

P1.1

Parameterization of Charge Modulation of Aerosol Scavenging with Varying Relative Humidity

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12. Aerosol-cloud-precipitation interactions and processing

Electric Charge Effects

14. Ice nuclei and cloud condensation nuclei

1. Basic cloud and precipitation physics

New simulations of electric charge effects on in-cloud scavenging rates include a range of relative humidities from 95% to 102%. The electrical effects and the phoretic effects can now be included when modeling the scavenging taking place at cloud boundaries that are electrically charged in the global circuit, where small parcels of entrained air cause evaporation at the interfaces with parcels of cloudy air. The electrical contribution to the scavenging rates at 100% RH are scaled by factors which for $RH > 100\%$ decrease from 1.0 to below 0.7 with increasing supersaturation, depending on particle and droplet radii and charges. For $RH < 100\%$ the scaling factors increase to about 1.1 and then decrease to below 0.4 for increasing subsaturation. The scaling factors are fitted to polynomials for rapid use in models.

P1.2

Analysis of Precipitation Characteristics based on Laser Optical Spectrometer Data in Tianjin Area

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Based on the data observed by laser optical spectrometer(DXC1), the raindrop spectrum characteristics of two precipitation cases at Tianjin are analyzed. The analysis results show that variation trends of precipitation from laser optical spectrometer and automatic weather station(AWS) are well consistent. But the total precipitation amount has difference. The value of laser optical spectrometer is larger than AWS. The raindrop spectrum has otherness during different precipitation period. The spectral width is more narrower at beginning and ending stage of precipitation. The average raindrop spectrum of two cases present multimodal distribution. The average particle diameter of convective precipitation is larger than stable precipitation. The ratio of small raindrop number concentration is lower during convective precipitation.

Key words : laser optical spectrometer, raindrop spectrum, precipitation, raindrop characteristic parameters

P1.3

Extreme deformation and breakup of drop suspended in a vertical wind tunnel in the presence of a horizontal electric field.

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3.

Presence of large raindrops in rainshaft region or below the melting band of freezing clouds is well-known. Breakup of these large drops in thunderstorms is one of the important mechanisms affecting the drop size distributions. In the present wind tunnel experiments, we have captured unique events of extreme elongation and the break-up of the water drops in the horizontal electric field (E_H) of 500 kVm^{-1} using high-speed photography.

During oscillations, elongated drop develops concavo-convex lens shape with a sharp-edged rim facing upward and breaks up into many droplets and a fine spray of droplets from sharp edges. In $E_H = 500 \text{ kVm}^{-1}$, the extreme length of elongation of the drop of 7 mm diameter was observed to be 19 mm as compared to 13 mm when $E_H = 0$. The total breakup process of drops of 7 mm diameter in $E_H = 500 \text{ kVm}^{-1}$ evolved in 57-93 ms, which required only 13-41 ms when $E_H = 0$. In the strong horizontal electric field, electrical forces and flattening of the drop may feedback each other and lead to extreme elongation. Although the total lifetime of drop reduces as compared to that in $E_H = 0$, the length of elongation of the drop increases with horizontal electric field. It is noteworthy that, no bag type of breakup of drops was observed when $E_H = 500 \text{ kVm}^{-1}$ which has been observed in $E_H = 0$. The significance of the results in modification of cloud microphysical processes and their electrification has been discussed.

P1.4

Buoyancy of warm convective clouds: the role of humidity

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1. Basic cloud and precipitation physics

Cloud buoyancy is proportional to the difference in density between the cloud and its environment. Buoyancy can be divided into three components: temperature difference (B_T), water vapor content difference (B_V), and liquid water loading (B_W). In this work, the relative importance of B_T and B_V will be described, for different environmental conditions and various clouds' sizes, using both theoretical calculations and numerical simulations of warm clouds.

Theoretical calculations of the buoyancy of warm convective clouds suggest that B_V plays a key role in shallow clouds and that many warm convective clouds are, in fact, colder than their environment and are driven solely by B_V . As the cloud size decreases, the B_V contribution increases. Results from single-cloud and cloud-field models will be presented to demonstrate how a drier environment (lower values of relative humidity near the clouds) drives higher B_V and lower B_T values. Moreover, we will show that the total CAPE as calculated using the temperature and humidity profiles is limited in predicting convection intensity and that the additional information gained by the difference between the buoyancy components can improve the prediction significantly.

P1.5

Moist vs. dry convection: Influence of cloud droplet growth and evaporation on turbulent flow

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12, 3

Clouds are turbulent. Turbulence drives entrainment and mixing in clouds which leads to strong fluctuations in e.g. aerosol concentration as well as in temperature, water vapor, and consequently supersaturation affecting cloud droplet activation, growth and decay (Siebert, 2006). The associated phase transition processes of water in turn feedback on the turbulent flow due to latent heat release (Malinowski et al., 2008).

Within our multiphase, turbulent reaction chamber which is called the Pi Chamber we investigate the influence of cloud droplet growth and evaporation on the turbulent environment. Turbulence is created via a temperature difference between the top and bottom surfaces inside the chamber, inducing turbulent Rayleigh-Bénard convection. Different gradients are set while the mean temperature stays constant. For each gradient steady-state turbulent cloud conditions are sustained for times of about eight hours to one day. Turbulence parameters are determined utilizing a sonic anemometer, a Lyman-alpha hygrometer and an array of thermistors measuring fast temperature fluctuations. Experiments are run for dry and moist conditions, i.e., with and without the presence of liquid droplets in order to determine differences in turbulence parameters. In the moist case, cloud droplets are continuously activating and growing as well as evaporating during the turbulent mixing releasing or absorbing latent heat which will feedback on the turbulent air motion. Additionally, the droplets themselves influence the turbulent flow (e.g., due to drag).

References

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P1.6

Scavenging of aerosol particles and minimum collection efficiency diameter during snow precipitation

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The scavenging of atmospheric aerosols by below-cloud scavenging during the rain or snow precipitation played an important role in removing of aerosols in the atmosphere. Because of the variety of frozen precipitation types and their physical properties, snow scavenging is a more complicated process compared with rain scavenging.

Scavenging gap or minimum collection efficiency diameter in scavenging process is the size where aerosols are not effectively removed by rain or snow hydrometeors. This is the size where the penetration of particles through the rain is maximized, and the collection efficiency minimized. Usually, the minimum collection efficiency diameter can be numerically calculated by differentiation of the collection efficiency.

In this study, the aerosol scavenging by snow precipitation is theoretically studied. The polydispersed lognormal size distribution is assumed.

Three types of collector (graupel, dendrite, and column) are considered and compared with each other. The change of polydisperse aerosol size distribution scavenged by snow is studied as a function of time. This study also obtained the minimum collection efficiency and the minimum collection efficiency diameter for polydispersed hydrometeor size distributions and their dependence on the precipitation intensity was investigated.

The results also showed that minimum collection efficiency diameters are smaller than the usual minimum collection efficiency diameter of water drop. For graupel hydrometers, the minimum collection efficiency diameter decreases as collector diameter increases. For minimum scavenging coefficient, the column collectors show the highest scavenging coefficient and the lowest in graupel collectors.

P1.7

Numerical simulations for cloud droplet diffusion processes with a newly modified triple-moment bulk cloud microphysics

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1 Basic cloud and precipitation physics

Observations demonstrate that the gamma function gives great fit to droplet spectra, so the gamma function with double-moment (mixing ratio of droplet water and droplet concentration) is normally used in bulk microphysics parameterization. However, the shape parameter of the gamma function does not change during the droplet diffusion process, which will lead to the spurious droplet spectrum broadening. To avoid such an abnormal broadening of the cloud droplet spectra, the gamma function with the change of the shape parameter should be considered in the droplet condensation and evaporation processes. We modified a triple-moment bulk cloud microphysics proposed by Clark (1971) and coupled into WRF model to investigate the cloud droplet condensation and evaporation and further compared with the simulation with a high resolution bin microphysics. Our results show that the modified triple-moment scheme can simulate the cloud droplet spectrum evolution consistently with the bin scheme. Such a triple-moment parameterization can restrain the broadening of droplet spectrum effectively compared with the double-moment scheme. Therefore, the current double-moment parameterization should be improved by adding the average radius as a new moment.

P1.8

Numerical investigation for the effects of the vertical wind shear on the cloud droplet spectra broadening at the lateral boundary of the cumulus clouds

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1

In order to investigate the impacts of the vertical wind shear on the cloud droplet spectra broadening at the lateral sides, we used the Weather Research and Forecasting (WRF) Model coupled with a newly developed aerosol-cloud interaction bin model with a high spectrum resolution (90 bins for aerosols, 160 bins for water drops) and a high spatial resolution (25m in vertical, 50m in horizontal). We run the Large Eddy Simulation (LES) case in the Tianhe supercomputer with more than 1000 CPUs. In our simulations, a new aerosol parameterization scheme has been proposed in order to investigate the secondary activation of cloud condensation nuclei (CCN) after cloud droplet evaporation. Unlike most of the current studies with the bin microphysics, the activated CCN will not be cleaned in this approach. This approach can also calculate the coalescence and the sedimentation of CCN. At the low lateral boundary of the leeward of the cloud, the secondary cloud droplet nucleation occurred. However, by analyzing the location of rain embryos, we found that the location rain embryos appear is higher than that of the cloud droplets produced by the secondary nucleation and the time of the rain embryos appear is earlier than that of lateral boundary entrainment driven by the single vortex circulation. Therefore, we believe that entrainment and inhomogeneous mixing did not play a major role in the formation of raindrop embryos.

P1.9

Analysis on the macro- and micro- characteristics of Cloud System Based on Airborne Particle Measuring System

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1

In this paper statistical analysis method is used to analyze cloud macroscopic meteorological parameters (temperature, dew point, relative humidity and cloud base high) and microscopic characteristics parameters (particle concentration, water content, arithmetic mean diameter and root mean square (RMS) diameter, mean cube root diameter, effective diameter, spectral type distribution parameters) based on datas from the airborne particle measuring system. The evolution characteristics of clouds and temporal and spatial distribution of microphysical parameters are studied. Results have shown that in winter in subtropical and southern trough, the confrontation of warm and cold air generated stable stratification of frontal cloud system, the cloud distribution from low to high were Fn, Sc, Ac. The mean cloud base height of low cloud, middle cloud and high cloud were 1285m, 3197m and 4596m; stratocumulus cloud particles arithmetic mean diameter is about 765 m on average, rain particles arithmetic mean diameter is about 252.86 m on average, cloud particle spectrum type distribution satisfies the spectrum Khrgian-Mazin, the correlation coefficient is up to 0.84.

Key words: cloud microphysical process, macroscopic meteorological parameter, microscopic characteristic parameters, cloud particle spectrum

P1.10

Raindrop Fall Velocity Deviations from the Terminal Velocities

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1. Basic cloud and precipitation physics

16. Measurement techniques (of cloud and precipitation properties) and uncertainties

Recent field studies showed that fall velocities of raindrops may deviate from the predicted terminal velocities. Motivated by the importance of accurate raindrop fall velocity information in various rainfall related applications (e.g. dual-polarization radar rainfall estimations), we investigated the fall velocity of raindrops using measurements from a number of different rainfall events. In our field measurements, we used a new optical-type disdrometer called the High-speed Optical Disdrometer (HOD) that we developed recently for precipitation microphysical observations. This instrument is capable of providing high-accuracy fall velocity measurements using sequential high-speed raindrop images. Our observations showed that both superterminal and subterminal raindrops may be present in a rainfall event. These observations along with the physical processes for the raindrop fall velocity deviations from the predicted terminal values will be presented. This material is based upon work supported by the National Science Foundation under Grants No. AGS-1144846 and AGS-1612681.

P1.11

Microphysical features of precipitation particles in melting layer by ground-based direct measurements

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It is important to estimate precipitation in the melting layer, which is well known as the bright band. Because frozen hydrometeor begin to melt as they fall through the 0°C level, and the surface of the ice particles become wet. It causes an increase in the radar reflectivity. In the melting layer, the precipitation phase changes as the solid/liquid hydrometeor distributions.

For the better understanding of microphysics in the melting layer, we have developed 'Ground-based Particle Images and Mass Measurement System (G-PIMMS)'. It can capture particle images by CCD cameras and measure particle weight by the electronic balance. Precipitation particles are classified as liquid particles (completely melted), partially/mostly melted particles, or solid (ice) particles on the basis of transparency and shape. The abundance ratio of solid/liquid particles and the averaged densities are calculated by the volume estimated from the image size and the weight obtained from the electric balance.

We carried out the intensive observation for the GPM/DPR ground validation at Mt. Zao during 2014-2015 winter season. G-PIMMSs were installed at two different altitudes on the hillside of Mt. Zao between two confronting Ka radar sites. We often experienced sleet or wet snow in early/late winter, and succeeded in observation of the melting layer. It was found that rain and snow, including sleet, were discriminated at approximately 1.5°C in wet-bulb temperature, and that the density of precipitation varied from 0.1 to 0.5 g/cm³ with wet-bulb temperature changing between 0°C and 2°C.

P1.12

Testing Lagrangian particle-based warm-rain microphysics scheme in a kinematic framework

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Basic cloud and precipitation physics

Aerosol-cloud-precipitation-interactions and processing

P1.13

How do collision and coalescence contribute to the activation of droplets?

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1, 12, 2, 3

The activation of droplets determines the number of particles within a cloud and therefore its microphysical properties. Diffusional growth is considered to be the primary source for activation. However, the coalescence of droplets is an additional process, enabling a droplet to grow beyond its critical radius for activation. This process is studied using a Lagrangian cloud model, which represents diffusional growth of wetted aerosols and droplets, as well as the collision and coalescence process, using individual particles that grow continuously within the whole simulated spectral range.

For the example of shallow trade wind cumuli, we analyze the spatial and spectral structure of collisional activation. The number of collisional activations increases linearly above cloud base. Droplets with dry aerosol radii larger than $1.0\ \mu\text{m}$ are exclusively activated by collisions (so-called giant and ultra-giant nuclei), but particles with dry aerosol radii larger than $0.1\ \mu\text{m}$ are already profiting from collisional activation. The combined contribution of diffusional and collisional growth to the activation of these sub-giant aerosols will be analyzed on the effect of the rapid production of precipitation embryos, as it is already known for giant and ultra-giant nuclei.

P1.14

Towards micro- and macrophysical parameterization of shallow convective clouds: From Large-Eddy Simulation to multi-UAV-based cloud sampling

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1. 2.3.16. 17.

The lack of adequate measurements of cloud dynamics and microphysics key parameters that regulate cloud formation has caused a divergence in the formulation of cloud models. Most cloud related studies, justify their lack of understanding of small-scale cloud-related physical processes because of insufficient simultaneous in-situ measurements. It is not only the precision of the instrument that matters, rather it is the way in which the sampling strategy is applied. As of yet, bringing together a sampling strategy for a field campaign using a swarm of unmanned aerial vehicles (UAVs) based on large-eddy simulation (LES) has not thoroughly been explored. This project (Skyscanner) which is a joint collaboration that involves a Multidisciplinary Team (including institutes specializing in aviation, robotics and atmospheric science), aims on bringing together novel shallow cumulus cloud sampling strategies using a swarm of UAVs based on Large-eddy simulation (LES). For this purpose, an extensive set of LES has been performed with the use of MesoNH-LES model. The simulations have been performed at three horizontal resolutions: 10 m, 25 m and 100 m. For each of these resolutions, four microphysics schemes have been tested with three horizontal wind speeds. The results reveal relationships between geometric properties, dynamics and microphysics of shallow convective clouds. The numerical experiments enabled bringing about a macroscopic model that quantifies the interrelationship between micro- and macrophysical properties of shallow convective clouds.

P1.15

EVOLUTION OF RAINDROP SIZE DISTRIBUTIONS DURING A STRATIFORM PRECIPITATION EVENT IN THE CITY OF LEON (SPAIN)

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1

During the sampling campaign carried out from July to the end of October 2015 in the city of León (Spain), an episode of light rain was recorded on 13 September with a duration of four hours and an accumulated precipitation of only 2.3 mm. Rainfall occurred softly and continuously, with a maximum rainfall intensity of 0.45 mm in 10 min. The raindrop size distribution was recorded every minute with a laser disdrometer Thies LPM (which registered drops with diameters between 0.125 and 8 mm in 20 channels).

Besides the meteorological and synoptic analysis of the day, a study on the evolution of precipitation has been made every minute, including rainfall intensity, amount of precipitation, raindrop mean size and the parameters of the gamma distribution. The eventual relationships between these variables and the meteorological parameters from a weather station have also been checked. This type of studies may be useful for the analysis of the scavenging of aerosol particles by rain.

P1.16

On the impact of internal fluctuations on growth of cloud droplets due to collision-coalescence: Numerical calculation of post-gel droplet size distribution.

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1.

The impact of internal fluctuations in cloud droplet growth is a matter of broad interest, since stochastic effects are one of the possible explanations of how cloud droplets cross the size-gap, and form the droplet embryos that trigger warm rain development in cumulus clouds. Most of theoretical studies in this topic rely on the use of the kinetic collection equation (KCE), or the stochastic simulation algorithm of Gillespie (SSA). However, the KCE is a deterministic equation with no stochastic fluctuations or correlations. On the other hand, the SSA, although it is stochastic, fails to reproduce adequately the large end of the droplet size distribution due to the huge number of realizations required. Therefore, the full stochastic description of cloud droplet growth must be obtained from the solution of the coalescence master equation. In this work, by using the coalescence master equation, the droplet size distribution is calculated when the droplet embryos forms, and the traditional calculations using KCE are no longer valid, since there is a transition in the system from a continuous distribution to a continuous distribution *plus* a massive droplet embryo (runaway droplet). The numerical calculations with the master equation show that after the formation of the massive droplet, the particle mass distribution splits into two parts: a continuum part whose behavior is described by the KCE equation, and a narrow peak with a mass comparable to the mass of the droplet embryo.

P1.17

On the observation of giant sea-salt aerosol size distributions over the SE Pacific during the 2008 VOCALS deployment

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1 2 12

Giant sea-salt aerosol particles (a type of GCCN) form an important part of the aerosol size distribution in marine boundary layers. Although such particles occur in relatively low concentrations (e.g. 1-1000 per liter of air with dry radius larger than 0.8 μm), they often contain about 90% of the total aerosol mass. As they are highly hygroscopic, they readily form large solute drops when caught by updrafts and moved into marine stratocumulus.

During the 2008 VOCAL deployment of the NSF/NCAR C-130 to the SE Pacific, an external impaction system, the Giant Nuclei Impactor (GNI) was used to expose polycarbonate microscope slides in the free airstream outside the aircraft fuselage. This allowed for the sampling of very large volumes of air, typically 100 liter or more per slide, depending on exposure time (about 10 seconds or more).

In this study we examine the variability of sea-salt size distributions in the VOCALS domain using analysis of more than 350 slides. Slides were analyzed in an optical microscope system, where the slides were humidified to 90% relative humidity, imaged digitally, subject to image analysis, such that size distributions with particles from 0.8 – 12 μm could be obtained. This massive data set is analyzed, and log-normal distributions are fitted. Although higher wind speeds are often thought to lead to more breaking waves, we find that size distributions show some wind speed dependence, but also that there is a very large variability for a given wind speed.

P1.18

Collision-coalescence rates estimated from in situ observations of marine stratocumulus

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Key areas:1,2,16

Warm rain formation is limited by a process bottleneck in the drop size regime where neither condensation nor collision-coalescence are particularly effective (roughly for drop diameter $20 < d < 50$ μm). In addition, direct *in situ* observation of the collision-coalescence process remains an unobtained goal. This study estimates collision-coalescence rates by applying a quasi-inverse method to microphysical observations in this "bottleneck regime." We use observations of the cloud top region in marine stratocumulus from the POST field campaign which took place off the coast of Monterey, California. It is found that the ability of a zero-dimensional collision-coalescence model to accurately reproduce observed drop size spectra depends strongly on the mode size of the spectrum such that larger mode size spectra are better represented by the model. Smaller mode size spectra require enhancement of collision-coalescence rates of up to a factor of 10^2 to reproduce observed spectra with a quiescent collision-coalescence kernel. A turbulent collision-coalescence kernel is also tested in the model to explore the direct role of turbulence in accelerating collision growth, but significant rate enhancements are still required for the smallest mode size spectra. These results indicate the importance of mixing and spatial heterogeneity in forming observed cloud drop size spectra, as also suggested by Pincus and Klein (2000). Finally, assumptions of the quasi-inverse method are tested to determine the sensitivity of results to observation averaging distance, closure parameters and neglect of other processes affecting the drop size spectrum (e.g. sedimentation).

P1.19

Characterizing microphysical precursor conditions for precipitation initiation in marine stratocumulus

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1,2

Although the classical model of how a population of cloud droplets grows to precipitation-sized drops through the condensation and coalescence processes is well accepted, it does not fully address the history of how nascent precipitation drops come about. Precipitation initiation is influenced by the properties of the cloud drop distribution and in bulk models is parameterized by autoconversion. Double-moment formulations of autoconversion rate generally weight cloud water content q_c more than cloud drop concentration N_c , and precipitation rate scalings derived from field campaigns suggest a dominance of thermodynamic over aerosol factors (e.g., h^3/N). However, the mechanisms that drive precipitation initiation in any given cloud are still uncertain. Specifically, which predominantly governs precipitation initiation, regions of anomalously large q_c or regions of anomalously small N_c ? This study explores the nature of precipitation onset precursor conditions within marine stratocumulus clouds. A large-eddy simulation model with size-resolving microphysics is applied to a case of marine stratocumulus over the eastern north Atlantic. Backward trajectories are calculated from the time-evolving LES flow fields to examine parcels containing embryonic precipitation drops back through time. A history of the droplets' drop size distribution (DSD) properties is then constructed to identify the precursor conditions of precipitation initiation.

P1.20

A new sedimentation scheme for double moment microphysics model: How to make it fast, interactive and avoid size sorting

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1. 17. Sedimentation . Modelling . Multi-moment microphysics .

We present a new sedimentation scheme for 2-moments microphysical models that mimics Eulerian or Lagrangian classical approaches with three major advantages. First, it is much faster and numerically efficient than classical Eulerian/Lagrangian methods and it is easy to implement. Second, it allows the microphysical processes to take into account the sedimenting particles during sedimentation; and vice versa. So that sedimentation and microphysical processes are computed at the same time. Third, it manages the sedimenting fluxes of the two moments together in order to avoid excessive size sorting, accordingly to a minimum and a maximum mean mass particle size observable in nature. This characteristic also allows much longer time step for the microphysics model with a satisfying precision, and insures conservation of both mass and number of hydrometeor particles, which is not the case in other sedimentation scheme presently in use. This novel approach paves the way toward the use of 2-moments microphysics schemes within operational numerical weather prediction (NWP) at global scale and climate models.

P1.21

The Eastern North Atlantic ARM site: a highly-instrumented surface remote sensing and in-situ measurement site for clouds and aerosols in the remote marine boundary layer

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2,12,13

In 2013, the US DOE Atmospheric Radiation Measurement (ARM) program started the Eastern North Atlantic (ENA) site to study clouds, aerosols and their interactions on Graciosa in the Azores. The ENA site was chosen to provide long-term measurements in a remote marine region dominated by marine boundary layer (MBL) clouds that are challenging to represent faithfully in climate models. The new ENA site was also the location of the 2009-2010 deployment of the ARM Mobile Facility, and the two datasets provide an unprecedented documentation of the remote MBL. Instrumentation is expected to be fully operational by summer 2016.

This poster provides a summary of the ENA measurements, together with examples of how the ENA and AMF measurements are being used to document cloud and aerosol variability, understand their interactions, and constrain models. Some key findings thus far indicate that: the NE Atlantic MBL is decoupled over 90% of the time, which limits the correlation between surface-observed CCN and cloud droplet concentration; approximately 50% of all clouds sampled produce virga or precipitation reaching the ground; cold air outbreaks result in very low aerosol concentrations, especially in winter; warm rain is susceptible to changes in the concentration of cloud condensation nuclei. The ENA data are freely available. During 2017 and 2018 several airborne deployments will take place to study key aspects of clouds, aerosols, meteorology and their interactions at the ENA site.

P1.22

Analytical solutions of the supersaturation equation for a warm cloud

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We derive approximate solutions of the supersaturation equation for a warm cloud which take into account the growth of the droplet radius. It is shown that the evolution of the droplet radius and supersaturation are governed by two time scales: one characterising the rate of change of the total amount of liquid water and water vapour above saturation and the other the rate of change of the droplet radius (or time scale characterising the return to equilibrium). When these two time scales are equal, the supersaturation and droplet growth equations can be non-dimensionalised such that solutions of the resulting dimensionless equations are independent of the vertical velocity, droplet number concentration, temperature and pressure; the dimensionless equations have only one degree of freedom, namely, the initial conditions. The analytical solutions that are obtained from these equations are only valid for small times but extend far enough to obtain reasonable estimates of the maximum supersaturation, s_{max} .

P2.1

Aerosol-cloud interactions in ultra clean layers (UCLs): idealized parcel model study with a detailed bin microphysics scheme

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Key area numbers: 2. Warm boundary layer clouds 12. Aerosol-cloud-precipitation-interactions and processing

Recent field campaigns over the eastern tropical/subtropical oceans are indicating major vertical stratification of aerosol and cloud droplet concentration such that measurements at the surface, even in very clean conditions, can be an order of magnitude higher than those at the level of the main cloud deck (e.g. VOCALS REx) in the marine boundary layers (MBL). This complicates the interpretation of near-surface ship and island-based estimates. The lowest concentrations ($<10 \text{ cm}^{-3}$ accumulation mode aerosol concentrations) often occur in so-called *ultra-clean layers* (UCLs) that reside beneath the trade inversion. UCLs appear to be ubiquitous in regions of subtropical mesoscale open cells, and were found to be common in regions dominated by trade cumulus during the 2015 Cloud System Evolution in the Trades (CSET) field program. Clouds forming on aerosols in the UCL were found to exhibit very low cloud droplet concentrations, making aerosol-cloud interactions in these layers an interesting and potentially important subject for cloud modeling. In this study, an idealized air parcel model with a detailed bin microphysics scheme is used to understand aerosol-cloud interactions in UCLs. In our model, aerosols are categorized by the dry size and the value κ (i.e. kappa; hygroscopicity parameter) as a 2-D distribution, and several cloud microphysical processes are explicitly simulated (i.e. sedimentation, condensation/evaporation and coalescence processes). The possible mechanisms for producing and maintaining low aerosol and cloud concentration within UCLs are explored and discussed.

P2.2

A Comparative Case Study for Cloud Droplet Spectrum of Shallow Maritime Cumuli in RICO with Numerical Simulation and Aircraft Observations

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The radiosonde profiles, radar data and aircraft data during the Rain in Cumulus over the Ocean (RICO) field experiment in the Caribbean Sea of the western Atlantic are collected and analyzed. Comparing the vertical velocity, liquid water content and the cloud droplet spectra, we found that raindrops initially appear at the height of the cloud at least 1 km. Numerical simulations for the evolution of cloud droplet spectra are not only useful to understand the microphysical and dynamical processes of the warm rain formation, but also helpful to establish more accurate cloud-to-rain conversion rate schemes in the bulk cloud microphysics parameterization. Such simulations require a cloud model with a high spatial and temporal resolution and a large bin number for cloud droplets and aerosols. Therefore, with the large eddy simulation (LES) module embedded in WRF model, we coupled with a newly developed aerosol-cloud bin model with a relatively high resolution. The simulated vertical velocity, liquid water content and cloud droplet spectra are consistent with those observed by the aircrafts. The simulated results also show that raindrops also initially appear above 1 km of the clouds.

P2.3

LANFEX (Local and Non-local Fog EXperiment); instrumenting a multi-site field campaign

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Met Office, Cardington, UK

7, 16

Fog, observation, instrumentation

LANFEX was a recent 19 month UK based field campaign set in a valley system in Shropshire and a shallow basin in Bedfordshire. The purpose was to better understand meteorological conditions which affect the formation and evolution of fog and to improve its prediction with numerical weather prediction models.

Instrumentation was deployed in regions of both homogeneous and heterogeneous terrain. In Shropshire, five key densely-instrumented, masted sites and eight satellite sites were equipped in a 15 km diameter circle, varying between valley and hill top sites. Instrumentation in Bedfordshire consisted of one permanent large field site at Cardington and four satellite sites in a 16 km diameter circle. These sites held over 200 individual instruments in Shropshire and over 100 in Bedfordshire. In addition to the continual measurements, extra equipment was deployed during key observing periods when forecasts indicated conditions of additional interest, including aerial measurements.

We describe the experimental set up, management and quality control analysis of the instrumentation and data. With over 300 instruments including newly developed fog spectrometers and dew deposition meters, this analysis presents a challenge, particularly when many locations are remote. The logistical challenge in selecting appropriate sites, then deploying, monitoring and maintaining equipment in the face of hostile weather conditions and curious animals is also discussed.

P2.4

Evaluating the Relationship of Volumetric Soil Moisture and Low-Level Cumulus Clouds during the CLASIC Field Campaign

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2, cloud and land-surface interaction, soil moisture

Using data collected on 3 flights of the NASA ER-2 and P-3 during the Cloud and Land Surface Interaction Campaign (CLASIC) on 11, 21, and 23 June 2007 over central Oklahoma, the relationship between soil moisture and various microphysical properties of low-level cumulus clouds are quantified. Measurements from the MODIS Airborne Simulator (MAS) and the Cloud Physics LIDAR installed on the NASA ER-2 were used to derive cloud properties such as cloud top height, cloud base height, optical thickness, effective radius, and cloud fraction, whereas the volumetric soil moisture was derived from a polarimetric scanning radiometer aboard the NASA P-3. In addition, the cloud properties are compared against Normalized Differential Vegetative Index derived from SeaWiFS. Data collected by the different aircraft and satellite were mapped onto a common 0.05° latitude by 0.05° longitude (approximately 26 km²) grid to investigate the relationships. Minimal correlation was found for quantities such as cloud base height, cloud optical depth, effective radius and cloud top height with soil moisture, even when accounting for variations in air and soil temperature. In an effort to capture the possible vertical transport of water vapor, an analysis was performed where low-level clouds are tracked to a point on the surface using wind profiles collected from rawinsondes. Cloud fraction was also calculated and yielded no apparent connection to volumetric soil moisture or vegetation water content.

P2.5

Droplet Concentration and Spectral Broadening in Southeast Pacific Stratocumulus Clouds

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16

Several airborne field experiments have been conducted to verify model descriptions of cloud droplet activation. Measurements of cloud condensation nuclei and updraft are inputs to the parcel model which predicts droplet concentrations and droplet size distributions (spectra). Experiments conducted within cumulus clouds have yielded the most robust agreement between model and observations. Investigations of stratocumulus clouds are more varied, in part because of the difficulty of gauging the effect of the entrainment mixing processes and drizzle on droplet concentrations. Airborne lidar is used here to supplement the approach used in prior studies of droplet activation in stratocumulus clouds.

A model verification study was conducted using data acquired during the southern hemispheric VAMOS Ocean Cloud Aerosol Land Study Regional Experiment. Consistency between observed and modeled droplet concentrations was achieved, but only after accounting for the effects of entrainment and drizzle on concentrations produced by droplet activation. Predicted spectral dispersions were 74 % of the measured dispersions following correction for instrument broadening, consistent with the conjecture that differential activation (at cloud base) and internal mixing - the processes simulated - are important drivers of true spectral broadening.

P2.6

A three-moment warm rain scheme for large-eddy simulation models of precipitating shallow clouds

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Key areas: 2, 3, and 'parameterization of cloud microphysical processes'

Two-moment bulk microphysical parameterizations are widely applied in atmospheric modeling, especially for large-eddy simulation of liquid (warm) boundary layer clouds. A disadvantage of these scheme is that the shape parameter of the raindrop size distribution has to be prescribed. This introduces considerable uncertainty into the simulations. Here we present a three-moment version of the Seifert-Beheng warm rain scheme which predicts besides mass and number densities also the second mass moment of the raindrop size distribution. Using the second mass moment, which is proportional to radar reflectivity, as a third prognostic variable, the scheme predicts all three parameters of a gamma distribution for raindrops.

We have derived consistent parameterization equations for all three moments for autoconversion and accretion as well as for sedimentation, selfcollection and evaporation of raindrops. These parameterizations include empirical assumptions regarding collision-coalescence efficiency as this is crucial for higher moments of the raindrop size distribution. Besides this complete set of analytic approximation we have also investigated the use of numerical approximations using rational functions (similar to the use of tables). This more technical approach allows in principle for a higher accuracy of the process parameterizations. We show that both approaches yield very similar results. Only collisional breakup is not yet explicitly parameterized and remains a challenge in the formulation of a warm rain three-moment bulk scheme.

We will present the derivation of the parameterization equations, detailed test and validation using a 1D model with spectral bin microphysics, and some first large-eddy simulations of precipitating shallow convection with the three-moment warm rain scheme.

P2.7

How does fog formation vary throughout a shallow valley network?

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Met Office, Cardington, UK

7

Fog is a notoriously difficult weather phenomenon to forecast, in part due to its tendency to be patchy over areas smaller than the grid scale of even the highest resolution operational forecasting model. In this talk results from the LANFEX field campaign will be presented. The ultimate aim of this project is to improve the accuracy of operational fog forecasts by combining observations and high-resolution modelling to better understand the process of radiation fog formation. It is hoped that this will lead to the development of better sub-grid scale parametrizations for fog formation in forecast models.

Surface heterogeneity is thought to influence the formation and extent of radiation fog. The observations being made in Shropshire, UK, during LANFEX comprise 5 main sites and 8 mini-sites distributed throughout a system of valleys of varying width and orientation. Sampled locations include main and side valleys, valley junctions, valley bottoms and ridge tops. This provides an excellent opportunity to study the effect of heterogeneity on radiation fog formation.

The instrumentation at all of these sites includes a method of determining whether fog is present, as well as observations of temperature, humidity, pressure, rainfall, and wind. These observations have been used to investigate systematic differences in the occurrence of fog over the LANFEX area, and to attempt to characterise the conditions at each site. The results of this investigation will be presented during this talk, including relationships between the surroundings of individual sites, and the frequency and timing of fog formation.

P2.9

Turbulent Mixing and Drizzle Formation in Stratocumulus Clouds

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2,1

The structure and microphysical properties of shallow stratocumulus clouds are determined through a composite of many processes. However, some key problems such as drizzle formation within narrow 300m cloud layers remain unresolved. The mechanism of drizzle formation in these clouds and the effect of turbulent mixing on this process are investigated using a Lagrangian-Eulerian model with spectral bin microphysics. The model contains ~2000 interacting parcels advected in a turbulence-like velocity field. In each parcel all microphysical processes are calculated and turbulent mixing between parcels is taken into account.

It was found that the first large drops form in air volumes closest to adiabatic and are characterized by high humidity, extended residence near cloud top, and maximum values of liquid water content (LWC). Mixing leads to broadening of droplet size distribution (DSD), yet the maximum collision rate is reached in adiabatic cloud volumes where the DSD width is smaller. Turbulent mixing was found to lead to an increase in drop size at cloud base, resulting in a more rapid formation of the largest drops in the ascending, nearly adiabatic cloud volumes.

Results show that on the one hand turbulent mixing inhibits the formation of the first large drops in the cloud by reducing maximum humidity values. On the other hand turbulent mixing is crucial for the creation of favorable background conditions in ascending air volumes, which enable droplets to reach large size and permit drizzle development through collisions during drop sedimentation.

P2.10

Large-Scale Meteorological Controls on Marine Boundary Layer Aerosol Variability over the North Atlantic

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2,14,12

While marine boundary layers (MBL) tend to be less polluted than their continental counterparts, understanding the sources and variability of aerosols in these environments is crucial. A cleaner background state tends to make clouds in the MBL particularly sensitive to aerosol perturbations through a wide range of microphysical and dynamical effects. The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) site in the Eastern North Atlantic (ENA), located within the Azores island chain, provides a comprehensive set of aerosol and cloud instrumentation to probe the surrounding MBL. We use two years' (2014 - 2015) worth of this data to determine dominant scales of variability in accumulation mode (diameter 100 nm - 1 micron) aerosol number concentration and their connection to relevant large-scale meteorological fields (e.g. wind speed and direction, temperature, surface pressure). Meteorological data are obtained from measurements on the island and ERA-Interim reanalysis. These observations reveal new relationships between synoptic conditions and variability in both aerosol number concentration and persistence in the atmosphere up through seasonal time scales in the North Atlantic region. We also explore possible meteorological mechanisms for why this variability is not always uniform within the accumulation mode size range. Synoptic controls on aerosol concentration and persistence in the MBL provide important context for aircraft-based field campaigns that are scheduled in 2017 and 2018 near the ENA site. These campaigns will focus on reducing uncertainty in MBL aerosol-cloud processes in this climatically important area.

P2.11

Improving A Cloud Parameterization with Satellite Observations

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(2)

The transition between stratocumulus and cumulus that occurs in the subtropical ocean basins has a strong effect on the radiative effect of clouds. Models struggle to reproduce the mean state of the subtropical boundary layer cloudiness. These struggles are related to the parameterized physics that represents turbulence and moist processes. One reason for the lack of progress made in the parameterization development community is the lack of sufficient data sets against which to compare the parameterizations. The common mode of evaluating model cloud parameterizations is through Single Column Model simulations (SCM) where a three dimensional model is run as a single column forced by large-scale tendencies. SCM's are often compared against high-resolution cloud models or scattered in-situ observations. This approach lacks the global representativeness provided by satellite data. Here we use weather reanalysis to run our unified parameterization of turbulence and moist processes as a SCM. The SCM is compared against detailed observations of cloud and precipitation from CloudSat, CALIPSO, and MODIS. Comparison is performed as a function of meteorological regime defined by the Estimated Inversion Strength (EIS), which is shown to have a strong control on the cloud cover and vertical structure. Sensitivity experiments are performed in which the parameterization physics is modified to best match the satellite observation across a broad range of meteorological regimes. This study demonstrates the important role that satellite observations can play directly in the parameterization development process providing a pathway to accelerate the improvement of parameterizations relative to the conventional approaches.

P2.12

Impacts of grid resolution on the maritime cumulus simulated by the stochastic Lagrangian cloud microphysical scheme.

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This study investigated impacts of grid resolution on shallow clouds simulated by a Lagrangian cloud microphysical scheme coupled with a large eddy simulation (LES) model. Even though the numerical simulation of clouds is very sensitive to the choice of the spatial resolution, less attention has been paid to the numerical convergence with respect to the grid size. In this study, a series of simulations on shallow maritime cumulus field was carried out to clarify the grid resolution required to obtain accurate results (i.e., to obtain the numerical convergence). The experimental setup was based on Barbados Oceanographic and Meteorological Experiment (BOMEX), which was originally proposed for a model inter-comparison. The horizontal (vertical) grid resolution was swept from 100 m (80m), which was the same as the BOMEX, to 6.25m (5m). The difference between Lagrangian and Eulerian cloud microphysical schemes was also investigated. Results of the experiments suggested that the grid convergence was achieved with the horizontal (vertical) grid resolution with 6.25 m (5m) in view of the cloud microphysical properties and surface precipitation.

1, 2, Lgrangian cloud microphysical scheme

P2.13

Scaling Analysis of Temperature and Liquid Water Content in the Marine Boundary Layer Clouds during POST

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We analyze scaling behavior of marine boundary layer (MBL) clouds using high-resolution temperature (T) and liquid water content (LWC) fluctuations from airborne measurements in the course of the Physics of Stratocumulus Top (POST) research campaign. As an extension of the past studies on the scale-invariant properties of MBL clouds, we study variability of scaling exponents with height.

The results confirm that both T and LWC in MBL have two distinct scaling regimes: one regime displays scale-invariant over a range from 1~5 m to at least 7 km, another goes from about 0.1~1 m to 1~5 m. For large scale regime ($r > 1 \sim 5$ m), the turbulence in MBL is multifractal, scale-break and scaling exponents clearly vary with height, especially in the cloud top region. For example, LWC spectral exponent β increases from 1.42 at cloud base to 1.58 at cloud top mixing sublayer (CTMSL), while scale-break decreases from ~5 m at cloud base to 0.8 m at CTMSL. The bifractal parameters (H_1, C_1) for LWC increase from (0.14, 0.02) at cloud base to (0.33, 0.10) at cloud top, while maintaining a statistically significant linear relationship $C_1 \approx 0.4H_1 - 0.04$ in MBL clouds. From near surface to cloud top (H_1, C_1) of T also increase with height, but above H_1 increases and C_1 decreases with height. The results suggest that existence of three different turbulence regimes- near the surface, in the middle of boundary layer and close to the cloud top should be distinguished.

P2.14

High-resolution LES simulations of stratocumulus clouds and their validation with in-situ data: focus on cloud top turbulence

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High-resolution LES simulations of marine stratocumulus were performed based of the T013 case from Physics of Stratocumulus Top research campaign. The aim was to understand the observed layered structure of the entrainment interfacial layer (EIL). EIL was found to be divided into two sub-layers that were stably stratified, turbulent, but substantially different in terms of dynamic and thermodynamic characterization. Analysis of production and transport of turbulent kinetic energy resulted in explanation of these differences. A better insight into details of stratocumulus cloud evolution was obtained with additional, non-standard analysis of the model results: model domain was sampled in the course of simulation along synthetic trajectories similar to research airplane track in the course of in-situ measurements. This approach allowed not only to better interpret the measurements and validate simulation results, but also to verify how the sampling method influenced the data set.

P2.15

The turbulent super-saturation field during the onset of shallow cumulus convection

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2 1 16

Helicopter-borne observations with the measurement payload ACTOS (Airborne Cloud Observation System) have been performed during the onset of shallow cumulus convection over a continental place. It was estimated that the patchy cloud fields have been developed roughly five minutes before the measurements. Cloud droplets have been measured with a Phase Doppler Interferometer, therefore, droplet diameter and concentration is available. Furthermore, the water vapor and temperature field have been measured closely collocated. From these readings, the turbulent water vapor saturation S has been derived with sub-meter resolution. The observations suggest that strong fluctuations of S with peaks up to several percent can exist during the onset of cumulus convection. Such peak values - significant higher compared to the quasi-steady state solution - are plausible if the reaction of the super-saturation field is slow compared to the turbulent time scale. Both time scales can be directly estimated based on observed variables. The observed high peaks in S have direct consequences for the activation process, which will be briefly discussed.

P2.16

Momentum transport in shallow convection

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2, 1, 3

The vertical transport of horizontal momentum by convection has an important impact on the general circulation of the atmosphere as well as on the life cycle and track of mid-latitude cyclones. So far it has mostly been studied for deep convection, whereas little is known about its properties and importance for shallow convection. In this study convective momentum transport by shallow convection is investigated by analysing both data from large-eddy simulations (LES) and simulations performed with the Integrated Forecasting System (IFS) of the European Centre for Medium-Range Weather Forecasts (ECMWF). Thereby the IFS is run in 3D mode as well as in a single column model (SCM) version. In addition, the central terms underlying the bulk mass-flux parametrisation of the IFS convection scheme are evaluated offline. The analysed cases exhibit shallow convective clouds developing within considerable low-level wind shear. Analysis of the momentum fluxes in the LES data reveals significant momentum transport by the convection in both cases, which is directed down-gradient despite substantial organization of the cloud field. A detailed inspection of the convection parametrisation reveals a very good representation of the underlying entrainment and detrainment rates and an appropriate representation of the convective mass and momentum fluxes. To deduce the correct values of mass-flux and in-cloud momentum at the cloud base for the parametrisation yet remains challenging.

P2.17

Factors leading to the deepening of the Stratocumulus marine boundary layer

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1, 2

The depth of the marine planetary boundary layer (PBL) is inferred from reanalysis data using measures of cloud top temperature (CTT), sea surface temperature (SST), and a parameterized lapse rate based on the temperature difference between cloud tops and the sea surface. An iterative sampling routine is developed to minimize bias in CTT associated with variable cloud amounts. This measure of PBL depth is created exclusively for stratocumulus decks in Eastern subtropical ocean basins.

A Lagrangian analysis is developed, following the flow within the PBL for 48 hours. The evolutions of over 60,000 individual PBL samples are observed for a wide variety of initial conditions sampled by satellites and reanalysis datasets. Climatologies of PBL depths and the rate of deepening in the PBL has been produced for eastern subtropical ocean basins. An early analysis suggests that reduced lower tropospheric stability, increased SST, increased 700mb temperature, and the absence of precipitation may all act independently to deepen the PBL. Additional mechanisms for PBL deepening are explored and tested.

P2.18

Simulating Feedbacks Between Stratocumulus Cloud Dynamics, Microphysics and Aerosols Over Large Scales.

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Key areas: 12,2,1

The response of a stratocumulus cloud deck to aerosols involves a complex interplay between cloud microphysics, precipitation, cold pool dynamical interactions between neighboring cells, cloud top entrainment and the boundary layer structure over larger scales. Such feedbacks are thought to be involved in, for example, the formation of Pockets of Open Cells (POCs), which represent a large albedo change relative to the closed cell regime. Mesoscale models with domains of order 1000km that are driven by meteorological analysis, allow realistic forcing and large scale interactions, in contrast to idealized LES simulations. However, some important questions remain about how such models represent stratocumulus. How important is the correct representation of aerosol number, cloud feedbacks upon aerosol, small-scale dynamical features such as narrow precipitating regions, sub-grid humidity, sub-grid updraft distribution, etc. to the accurate simulation of stratocumulus sheets?

Results will be shown from high resolution (<1 km) mesoscale simulations of overcast stratocumulus using a new multi-moment microphysics scheme coupled to the UK Met Office Unified Model. The new scheme represents the processing of aerosol by clouds, allowing examination of the feedbacks between cloud dynamics, microphysics and aerosol. Results will be presented highlighting the performance of the model compared to satellite and ship-borne measurements, along with results demonstrating the sensitivity to the aerosol concentration and the treatment of aerosol scavenging by cloud. We will use this case to explore cloud-aerosol evolution of stratocumulus through the use of the joint phase space of liquid water path and droplet concentration along Lagrangian trajectories.

P2.19

A hybrid Lagrangian-Eulerian numerical advection scheme developed for the simulations of cloud droplet diffusion growth

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keywords:cloud droplet spectrum broadening;Lagrangian advection scheme;

The cloud droplet spectrum broadening plays an important role in particle growth and the formation of precipitation. The calculation of particle spectrum growth is normally based on Eulerian advection schemes in current Eulerian models, which will lead to the spurious droplet spectrum broadening due to numerical diffusion. In order to overcome such a problem, we coupled one Lagrangian advection scheme into a 1.5D cloud-aerosol interaction bin model. In each cloud grid box, the cloud droplet growth will be simulated by the Lagrangian advection scheme with high resolution. However, the cloud droplet bins in each cloud grid box set for vertical and horizontal advection is less than those for cloud droplet growth simulations. The simulation results indicate that the new approach can greatly restrain the spurious broadening of cloud droplet spectra.

P2.20

Use of W-band Doppler spectra and in situ measurements to evaluate marine stratocumulus drizzle size distribution properties predicted by two large-eddy simulation codes with bin microphysics

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Key area: 2 (warm boundary layer clouds)

We use long-term measurements from a W-band Doppler radar during the CAP-MBL campaign to evaluate drizzle size distribution properties simulated by the DHARMA large-eddy simulation code with size resolved microphysics. Observations and MERRA reanalysis are used to derive specifications used for case study simulations. Gross deviations of DHARMA mean doppler velocity (MDV) statistics as a function of reflectivity (Z_e) motivate comparison with a second independent model, SAMEX. Relative to DHARMA, SAMEX produces substantially greater drizzle, at least in part owing to substantially lower droplet number concentrations, which we trace to substantially weaker vertical winds. Nonetheless, we find that spurious local minima in MDV(Z_e) are associated with unrealistically strong downdrafts in gaps of low Z_e in both DHARMA and SAMEX simulations, which could possibly be caused by inadequate resolution of cloud top dynamics. However, drizzle Doppler velocity spectral skewness (S) is more realistic in SAMEX than DHARMA simulations. Because individual simulations do not capture mesoscale variability associated with drizzle production, we use a four-member ensemble with low and high values of aerosol loading and liquid water path to demonstrate that simulated $S(Z_e)$ values are systematically more negative than observed, in DHARMA more so than in SAMEX simulations. To clarify errors in underlying drizzle particle size distribution (PSD) shape, we compare simulated PSD(Z_e) with those observed during the VOCALS and MASE campaigns. We also generate forward-simulated $S(Z_e)$ from in situ measurements for comparison with observations and simulations.

P2.21

The Impact of the Cloud Droplet Size Distribution Shape Parameter on Evaporation and Cloud Fraction

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2, 1, 13

Cloud microphysical parameterizations often use the gamma probability distribution function to describe the size distributions of cloud droplets and other hydrometeor species. The shape parameter that appears in this function describes, in part, the width of the size distribution. For cloud droplets, it is a parameter that is poorly constrained by observations. In this study, we conduct simulations of shallow cumulus clouds using RAMS and a two-moment, supersaturation allowing, bulk microphysics scheme that employs a cloud droplet shape parameter that is held constant in time and space. As the shape parameter is increased, the cloud fraction of the shallow cumulus field decreases. The percent decrease in the cloud fraction is as high as 25% for clean aerosol conditions. To determine the cause of the decrease, we systematically vary the value of the cloud droplet shape parameter that is used by the scheme to calculate the rate of each of the dominant microphysical processes in a series of sensitivity simulations. We find that the decrease in cloud fraction is linked most strongly to the value of the shape parameter used for evaporation due to a positive feedback process between the number of droplets evaporated and the evaporation rate. The large impact of the cloud droplet shape parameter on the cloud fraction and evaporation rates suggests that more work needs to be done to constrain the value of the cloud droplet shape parameter that is used by bulk microphysics schemes.

P3.1

A modified cumulus parameterization scheme and its applications in the simulation of heavy rainfall

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A cumulus parameterization scheme has been developed and modified according to the local weather features of East Asia, which can be used to forecast and simulate the heavy rainfall in the mesoscale model. Firstly, on the basis of synthetic analysis of organized convective precipitation located in Yangtze and Huaihe River basin during flood seasons from 1990 to 2010, the dynamic parameters that could reflect the environment of organized convective precipitation are diagnosed; Secondly, the dynamic parameters are operated to control conditions in order to develop and improve the Kain-Fritsch Eta cumulus scheme; Finally, the rainstorms occurred over Yangtze River valley and the south of China have been simulated with the Kain-Fritsch Eta cumulus scheme and the modified cumulus scheme respectively. The comparative simulated results show that the modified cumulus parameterization scheme could obviously improve the organized precipitation of our country.

Keywords: cumulus parameterization scheme Kain-Fritsch Eta

P3.2

The Use of Modern Information Technologies of Consolidation of Meteorological Information and of Machine Learning for Validation of the Numerical Model of Convective Cloud Intended for Operational Forecasting of Dangerous Convective Phenomena

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3, 17, numerical model validation, thunderstorm forecasting

The results of validation of 1.5 Eulerian convective cloud model which incorporates two in-cloud regions and the detailed description of microphysical processes (including 8 categories of cloud particles) are presented.

Consolidation technology is applied to develop the virtual environment for heterogeneous data extraction, transformation and loading to the relational database that contains the whole set of meteorological information about the state of the atmosphere at the place and at the time when a dangerous convective phenomenon is recorded. Data sources which are freely available via the Internet are used.

Series of numerical experiments using consolidated data as input and boundary conditions for the model runs have been provided. The results have allowed to develop special technology for transformation of real data of radiosonde measurements into the input data for the numerical model. Different methods of machine learning are used for classification of dangerous convective phenomena. Feature selection for thunderstorm forecasting based on invariant statistical tests is provided. The analysis of the received results is presented including estimation of their possible applicability in practice. Further prospects of classification of dangerous convective phenomena are considered.

P3.3

Excessive Forecasts of Precipitation produced by poorly-resolved convective plumes in a point-wise semi-Lagrangian model

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3.; 1.;

Modelling; Modeling; Unified Model; Cloud dynamics; Convection dynamics; moisture conservation; Grey Zone; Gray Zone; Tropical Meteorology; Spurious Precipitation

Accurate forecasts of location and timing of heavy precipitation are crucial for flood forecasting and other applications. For a number of years, forecasts of convection over the UK produced by the Met Office Unified Model (MetUM) at high-resolution have been subject to occasional spurious and excessive precipitation over a single catchment area. More recently, when the MetUM is run over the tropics, it is found that these excessive precipitation accumulations are a frequent occurrence.

In this paper, we present the investigation surrounding this issue and show that it is a problem due to the point-wise nature of the semi-Lagrangian transport scheme employed in the MetUM. This causes the moisture fields in the vicinity of poorly-resolved convective plumes to spuriously increase in mass. When convection is entirely parametrized there are no plumes. At high resolution the convective plumes are well resolved. Hence the problem is at its worse when convection is the most poorly-resolved.

Possible solutions to fixing the problem in the limited area model (LAM) are presented, including two different approaches to mass restoration in LAMs and discussion of a correction to the point-wise semi-Lagrangian scheme to approximate a volume-averaged scheme.

P3.4

The study of environmental conditions at the development of thunderstorms over Bulgaria

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The work is directed to test the ability of various thermodynamic characteristics, instability indices, and several in-cloud characteristics (maximum updraft velocity, liquid and ice water content and others) obtained by the simulation with 1D numerical cloud model to be used as an indicator of thunderstorms. Different thermodynamic parameters and instability indices are calculated using environmental conditions of 340 days (for four years during the period April–September) with precipitation, detected in eleven synoptic stations located in eastern Bulgaria. Statistical analysis will be performed to establish which of the studied characteristics are the best discriminator between the environmental conditions (instability, wind shears and moisture) at the formation and development of thunderstorms and ordinary precipitating convective clouds.

P3.5

Simulations of a squall line case from MC3E applying three different bin microphysics schemes

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3, 4

A squall line event on May 20, 2011, during the Midlatitude Continental Convective Clouds Experiment (MC3E) was simulated using three state-of-the-art bin microphysics schemes coupled with the Weather Research and Forecasting (WRF) model (www.wrf-model.org) in a three-dimensional quasi-idealized setup. Driven by the observed pre-storm sounding, all schemes simulated squall lines that compared quantitatively well against various observations. Specifically, this work studies the dynamic and thermodynamic structures of the simulated squall lines and the microphysical properties of the simulated stratiform region by analyzing results in the context of Rotunno-Klemp-Weisman (RKW) theory of squall line dynamics and using observations of 1) C-band radar reflectivities, 2) radar-derived vertical velocities, 3) low-level temperatures from Mesonet, 4) precipitation amounts and rates from Mesonet, and 5) hydrometeor size distributions from the Citation aircraft. The analysis and comparisons indicate that the different bin schemes simulated qualitatively similar domain-wide properties, but substantial differences were identified as the result of different mass-size relationships, hydrometeor terminal velocities, and particle shape assumptions applied by the different bin schemes. The sensitivities documented in this study suggest that bin ice microphysics schemes remain uncertain and should not be used blindly to provide benchmarks for other methodologies for ice microphysics parameterization such as bulk ice schemes. This is especially true in a dynamical model simulation where feedbacks between ice microphysics and cloud-scale dynamics can lead to significantly different solutions.

P3.6

Climatological study on the morphology and environmental properties of quasi-stationary convective clusters during the warm season in Japan

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The morphology and environmental properties of warm-season quasi-stationary convective clusters (QSCCs) in Japan were statistically investigated using operational weather radar and upper-air sounding data from May to October during 2005-2012. The environmental conditions for the development of QSCCs were described through a comparison with those for no-rain cases. With the use of an automated QSCC identification method, 4133 QSCCs were extracted over the Japanese major islands. It was found that QSCCs are typically meso- β -scale phenomena. The environmental analyses indicated that low-level moisture content controls the stability condition for the development of the QSCCs, and that the differences in the speed and directional shear of wind in the lower troposphere characterize the kinematic environments for QSCCs. The vertical shear also controls the shape of QSCCs: circular mode versus elliptical mode. An increased amount of the middle-level moisture was found for the QSCC environments, suggesting that atmospheric moistening is an important factor for the development of QSCCs. The precipitation intensity has a higher correlation with the convective instability, whereas the precipitation area with the shear intensity. A comparison between slower- and the faster-moving CCs indicated that the precipitation intensity of the slower-moving CCs is stronger. This feature is related to a higher convective instability for the slower-moving ones.

P3.7

Lifecycles of convective cloud morphology

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Areas: 3, 9

Keywords: convection, lifecycle, morphology, tropics, sevir, cbtram, tracking, africa

Convective clouds are fundamental to tropical weather and climate, playing important roles in the radiation budget, large scale circulations and hydrological cycle. Spatial scales of convection range from a few kilometres for individual plumes to thousands of kilometres for mesoscale systems. Relevant timescales range from minutes to seasons. In order to capture the full range of convective variability, high time-resolution observations are required across a large area.

In this study we use satellite observations from the geostationary SEVIRI instrument to quantify convective lifecycles. SEVIRI provides continuous, high time-resolution observations over Africa, Europe and the Atlantic Ocean. Unlike low earth orbit satellites, SEVIRI samples the entire lifecycle of individual clouds. We combine SEVIRI observations with the Cumulonimbus Tracking and Monitoring (Cb-TRAM) algorithm to identify and track convective cores across Sub-Saharan Africa and the southern Atlantic Ocean during 2007. We associate an anvil with each core by applying an image processing algorithm to SEVIRI brightness temperatures.

Tracked cores and their associated anvils are used to quantify spatial and temporal variability in various metrics of convective cloud lifecycles including the time and location of convective initiation and dissipation, degree of organization, cloud lifetime, cloud top height and the co-evolution of cores and anvils. The effects of orography, coasts, lakes and land surface types, on these properties are also considered. This is the first study to quantify lifecycles of individual tracked convective clouds across such a large area and period of time.

P3.8

The importance of multiple thermals in the production of ice and precipitation in COPE clouds

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The CONvective Precipitation Experiment (COPE) field campaign took place over the south west of England in the summer, 2013. The aim of COPE is to understand the microphysics and dynamics of convective clouds that produce heavy rainfall potentially leading to flash floods. In this poster, we will present WRF model results to show the importance of the interaction between the microphysics and dynamics for the development of ice and precipitation in the cumulus clouds. High-resolution WRF model runs were made for a potential flash flood case on 3 August where persistent rain occurred from small-scale convective clouds that continually formed and developed along a convergence line for a period of about 2 hours. A significant result that will be presented is the quantification of the extent to which the amount of precipitation from isolated cells was less than that from closely-packed cells.

P3.9

A mesoscale model intercomparison study of a mid-latitude event observed during the HYMEX campaign

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Within the framework of the international HyMeX program (HYdrological cycle in Mediterranean EXperiment), the MUSIC project (MULTiscale process Studies of Intense Convective precipitation events in Mediterranean) aims to a better understanding and modelling of intense convective precipitation events in Mediterranean in order to improve their forecast by Numerical Weather Prediction (NWP) scale models.

A mesoscale model intercomparison study is conducted based on a mid-latitude convective event IOP6 observed during the HyMeX campaign which took place in autumn 2012 in the Mediterranean basin. The results of the 3-D mesoscale models: WRF (Weather Research and Forecasting; Skamarock et al., 2008) or Clark-Hall (Clark et al., 1996), using a bulk microphysics scheme or the bin resolved microphysics scheme DESCAM (DEtailed SCAvenging Model) are compared with the HyMeX observations. Driven by the ECMWF analyses or global model forecasts, the models are indeed compared with the available aircraft and ground based observations during the IOP6: the airborne 95 GHz cloud radar RASTA, the in-situ microphysics probes, and two X-band radars... The robustness of mesoscale models in simulating convective systems at the cloud resolving scale has yet to be extensively evaluated. Hence, particular emphasis is put on the ability of simulations to capture the observed wide range of dynamical processes during a significant mid-latitude mesoscale convective event and to produce similar cloud fields and precipitation structures.

P3.10

Evolution of convective clouds initiated over mountains observed by Ka-band scanning Doppler radar and stereo photogrammetry

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6, 3

It is known that convective storms are frequently initiated over mountains in warm and humid environment. According to previous studies, shallow cumuli initiated over heated mountains develop into a deep convective storm. However, the transition process from shallow to deep convection is not well understood due to a lack of observation data. In order to elucidate this problem, we observed convective clouds initiated over mountains in Kanto, Japan on 18 August 2011 using a 35 GHz scanning Doppler radar and a pair of digital cameras. The first cloud observed over the mountains reached the 6 km level, while the maximum echo-top height was about 1 km lower than the cloud top. The maximum radar reflectivity in the cloud was about 10 dBZ found around the 2 to 3 km levels. The reason why the echo-top altitude was lower than the cloud-top height was considered to be due to the mixing with surrounding dry air. After such shallow cumuli appeared three times repeatedly, a deep convective cloud developed. These results are consistent with a "pre-conditioning" hypothesis, that shallow cumuli moisten midlevel air and produce favorable condition for development of deep convective storms.

P3.11

Hail cloud identification indexes based on Doppler radar data in Northwestern Fujian

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Based on Doppler radar data of 47 hail cloud processes by 28 meteorological stations from 2002 to 2014 in Northwestern Fujian, the formation and evolution of hail cloud are analyzed. Different profiles of radar echo are intercepted, and then the radar echo parameters of various development stages such as initial position, echo top height, strong echo top height, echo intensity, and VIL are analyzed, in order to conclude the structural characteristics of hail cloud. Combined with a case analysis of a typical supercell storm process, eventually 5 quantitative indexes for recognition of hail cloud in Northwestern Fujian by radar are reached as follow. (1) The initial echo and strong echo of hail cloud both appear above the height of 0 °C layer, and the strong echo area always locate in the upper part of cloud. (2) The average top height of strong echo greater than 45 dBz is higher than 7 km. (3) The average echo top height is higher than 12km. (4) The echo strength of strong echo area is no less than 55 dBz. (5) Strong echo of 45 dBz and VIL would generally rapidly rise before hail shooting, with a growth amount of 1.0 to 4.0 km for strong echo top height of 45 dBz, and a growth amount of 20 to 55 kg/m² for VIL.

P3.12

An Investigation of Relationships between Wind Shear and Microphysical Pathways Leading to Convective Rainfall

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3. convective clouds, 4. mixed-phase clouds, 1. basic cloud and precipitation physics

The CONvective Precipitation Experiment (COPE) was conducted in July-August 2013 in Southwest England. This field campaign was designed to document the dynamical and microphysical evolution of clouds and storms that may lead to heavy convective rainfall in that region in order to improve quantitative precipitation forecasting. Multiple cases of convective lines were studied with aircraft, radars (airborne and ground-based) as well as a wind profiler, ground-based aerosol system, and frequent soundings.

Two of the COPE cases on subsequent days produced up to 60 dBZ radar echoes with maximum storm top heights only 5 to 8 km MSL. The in situ microphysical data suggest different development of the warm rain process on these two days that later influenced ice processes. Although aerosol characteristics were similar on the two days, the environmental vertical wind shear was much stronger on one day.

High-resolution, 3D numerical simulations of the storms on the two days in their respective environments are used to investigate the potential impact of wind shear upon the microphysical pathways leading to convective rainfall.

P3.13

High-resolution numerical simulations of an unusual cloud formation

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1. On the 23rd December 2008, an unusual cloud formation was observed in the North Pacific (Ferlay et al., 2014). Satellite observations have revealed a large area of periodic cloud structures at the top of a frontal system located about 1000km offshore of Japan. From space radar (CPR) and lidar (CALIOP) measurements these structures look like cloud lobes oriented upward and well defined spatially: 20km across and 2-4 km deep on a distance of 800km. These apparently long-lived structures could modify the upper troposphere composition, a sensitive climate parameter. Some first analysis and idealized simulations suggest that this cloud structure results from a convective circulation driven by a radiative mechanism: the radiative exchange between the cloud top layers and the stratosphere would create local instabilities that eventually generate an organized convective circulation. The present study, based on high-resolution numerical simulations, aims to understand the processes that generate and maintain temporally these cloud structures. We perform real case simulations using RAMS initialized with ECMWF meteorological fields. We show how the frontal system is well represented in the simulations. The cloud top structures are not easily reproducible but some artificial forcing help to generate such cloud forms: for example, similar lobe structures are generated in the simulation with the introduction of a pocket of cold air at high altitude. Besides, the presence of a large jet creates important wind shear in the lobe's neighbourhood. We analyse here the possible competition and interaction between these two main cloud-generating mechanisms.

P3.14

Evaluation of the Microphysics of Precipitation with Multifrequency Radar Observations (EMPORIUM): a prospective study

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Several recent studies stressed the critical impact of rain drop size distribution (DSD) parameterization on the whole evolution of frontal systems simulated with cloud resolving models using two-moment microphysics schemes. For example, the latent heat release through evaporation depends heavily on the drop breakup efficiency and impacts the dynamics of the system and the total precipitation at the ground. The lack of observed profiles of the drop size distribution prevented further constraints on the parameterizations of the DSD and drop breakup.

A novel technique based on new observations from dual-frequency (35 and 94 GHz) profiling radars is able to provide profiles of binned DSD at very high vertical and temporal resolution for rain rates comprised between 1 and 30 mm/h. Such observations are unprecedented and can supply the necessary information to improve the simulations.

This prospective project will investigate on a case study how these observations can be used to improve the realism of the simulation of precipitation microphysics. This poster will present the DSD properties observed for the event chosen for this study: a squall line moving over Oklahoma and captured by the ARM radars at the SGP central facility on the 12 June 2011. Initial comparisons with a WRF simulation using a 2-moment microphysics scheme will be discussed.

P3.15

Stochastic Parameterisation of Deep Convection Based on the Plant and Craig Approach Applied to the Bechtold Scheme

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A stochastic parameterisation of deep convection based on equilibrium statistics is currently being developed at Recherche en Prévision Numérique Atmosphérique (RPN-A) to be used for ensemble prediction. The new parameterisation is based on Plant-Craig (PC) approach applied to the Bechtold deep convection scheme. In the original Bechtold scheme it is assumed that the population of subgrid-scale clouds consists of plumes of identical properties and therefore the calculations are performed for a single plume. In order to allow for plumes of different characteristics, such as cloud lifetime and radius at the cloud base, we introduced two principal modifications in the Bechtold scheme. First, the terms of mass exchange between the clouds and environment in the main closure equations of the new scheme are calculated as the weighted average over a spectrum of plumes. Second, the scheme is modified in order to maintain the presence of multiple plumes with random characteristics. The statistical properties and the sampling distribution are obtained from theoretical considerations following the PC approach. In this presentation we will examine the impact of the new stochastic deep-convection scheme on model performance in test integrations with a single column model and the full three dimensional atmospheric model.

(17, 3, 1)

P3.16

THE ROLE OF VERTICAL WIND SHEAR IN THE GREAT PYROCUMULUS OF COSTA DEL SOL (MÁLAGA, SPAIN) ON 30 AUGUST 2012

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3

The *Costa del Sol* (southern Spain) enjoys a Mediterranean climate, with dry summers but moderately high temperatures. It is separated from the mainland by a mountainous area, parallel to the coast. In situations of northwesterly flow, coming from the land or "terral" in the warm months, the downslope winds generate an environment with strong gusts of wind, high temperatures and low humidity which is very conducive to the generation of forest wildfires that spread to the coast at high speed.

Sometimes the *terral* is abruptly interrupted by easterly winds, caused by the westward propagation of a coastally trapped density current. If it occurs during a forest fire, its size or/and the direction may abruptly switch and create serious problems in fighting the fire. This was the case of the fire of August 30, 2012, whose great magnitude and long life can be explained by the large increase in vertical wind shear associated with the current density. The interaction of the pyrocumulus updraft and shear (an important factor in the convection organization) produced a steady pyrocumulonimbus with organized updrafts and downdrafts. It should also be highlighted the high lifting capacity of the pyrocumulus, that provided a mechanism for the transport of hot embers: twigs larger than 6 cm long and 1 cm in diameter were long-range transported, fuelling the spread of fire to distant areas. The associated downdraft gust front powered the fire front so that the fire-cumulus was not only a product of fire, but also feeder of fire.

P3.17

Drawing insights from a bin microphysical scheme to improve a bulk scheme in a simulation of a 3-dimensional squall line

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3.Convective clouds

Various microphysical source/sink processes such as ice crystals and water drop collisions can greatly impact numerical simulations of nearly all weather systems. The specific treatment of ice crystal and water drop size distributions, collection and conversions of various species, freezing of droplets, etc. all have consequences on the resulting cloud fields through myriad feedbacks. One such example is how the sensitivity of evaporation on the drop size distribution governs the cold pool formation and subsequent propagation in squall lines. More subtle, however, is that relatively small changes to the treatment of water shedding from partly melted graupel or what results from graupel and rain collisions contribute toward the final water drop distribution, often in unseen ways.

In this study, the specific treatment of water drop collection or shedding upon colliding with partly melted graupel was studied in a detailed size-bin-resolved microphysical model. These results were instrumental in adjusting various assumptions in the Thompson et al (2008) bulk microphysics scheme. Furthermore, with the advancement of computer speed, the bin scheme with nearly 500 prognostic variables was run in full three-dimensional long-lived squall line simulations with the Weather Research and Forecasting (WRF) model. Idealized and real case experiments are now feasible using these advanced schemes and are powerful tools to guide future developments in the simpler bulk schemes. Our research suggests that more sophisticated treatment of rimed snow and partly-melted graupel improves simulated squall line characteristics as compared to prior version of the bulk microphysics scheme.

P3.18

A pseudo-aerosol convective invigoration effect caused by meteorology

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Key area numbers: 3, 12

Numerous studies claim to show that increasing cloud condensation nuclei (CCN) or CCN proxies generally leads to convective updraft invigoration and deeper clouds through enhanced lofting and freezing of condensate in convective clouds with warm cloud bases. For example, this claim has been published using ARM Southern Great Plains (SGP) site measurements. However, perceived aerosol invigoration of deep convection through increases in cloud top height and temperature at this site is likely primarily caused by correlations between condensation nuclei (CN) concentration and meteorological factors such as convective available potential energy, vertical wind shear, and most importantly, level of neutral buoyancy. Relationships between aerosol concentrations and cloud tops when controlling for several meteorological factors and the diurnal cycle will be presented using 14+ years of data from the SGP site. Sensitivity to specific measurements is explored through comparison of CN, CCN, and aerosol optical depth, as well as cloud radar and satellite infrared cloud top estimates.

Statistical confidence is commonly overstated in published studies because of sampling autocorrelation, differences in the methods used to correlate aerosols and meteorology with cloud top heights, inclusion of shallow clouds, and omission of the most important meteorological factors affecting cloud top height. While increasing CCN may generally increase convective cloud top heights for warm cloud base systems, first order meteorological impacts need to be controlled for in a much better manner than has been done in numerous studies if this effect is to be properly isolated and quantified.

P3.19

Comparison of ice particle size distributions observed during MC3E in trailing stratiform outflow with NU-WRF simulations using diagnostic and prognostic droplet number concentrations

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Key area: 3

We evaluate the capability of NU-WRF simulations to reproduce ice mass size distributions observed in widespread precipitating stratiform outflow from deep convection on May 20th of the MC3E campaign. A baseline simulation using Morrison two-moment microphysics with hail and fixed droplet number concentration is found to reproduce a stratiform outflow region that is less widespread than was observed. Winds originating from updrafts identified using observed and forward-simulated specific differential phase above the melting level (see van Lier-Walqui et al. abstract on KDP columns) are used to track outflow for comparison of aircraft observations and simulations. Updrafts feeding the aircraft sampled outflow are estimated to have originated roughly 1.5° south and 0.5° west of the sampling location. Simulated ice particle size distributions at the 5.8 to 7.6-km level are found to concentrate mass at ~2–5 mm in maximum dimension, larger than ~0.5–1 mm observed. However, both observations and simulations exhibit coherent size distribution properties over wide areas, indicative of a correspondingly coherent set of microphysical processes operating on outflow ice, likely controlled largely by the combined effects of sedimentation and aggregation (see van Lier-Walqui et al. abstract re stratiform ice aggregation). To investigate whether prognostic droplet number concentrations improve simulated size distributions, we derive multi-modal aerosol size distribution profiles from ground-based and aircraft measurements. Although the prognostic aerosol lead to substantially increased droplet and ice number concentrations in simulated updrafts and outflow, respectively, outflow ice mass size distributions at the 5.8 to 7.6-km elevations are largely unchanged.

P3.20

Analysis of convective updraft characteristics: Comparing models and observations using KDP columns

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1, 3, 8, 16

Columns of positive specific differential phase (KDP) observed extending above the environmental melting layer act as indicators for the presence of deep convective updrafts, and here are compared to forward-simulated KDP columns and updrafts from NASA-Unified WRF simulations of a trailing-stratiform squall line observed on 20 May 2011 during the MC3E campaign. We present analysis of the organization and spatial statistics associated with these observed and simulated updraft features using nearest-neighbor statistics for objectively identified updrafts and KDP columns. We also assess fine-scale differences between simulations and observations through analysis of simulated updraft strengths as well as observed and simulated KDP column heights. These observations serve as a way to compare simulated and observed storm organization using a metric that is arguably more robust than radar reflectivity. We compare multiple microphysics schemes, including a size-resolved bin scheme.

P3.21

Application of High Speed Imaging (HSI) probe in the characterization of glaciated and mixed-phase conditions in deep convective clouds

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1, 3, 4, 8, 9, 14.

In May 2015, in-situ measurements in deep tropical convective clouds, was collected near Cayenne, French Guyana during the international HAIC-HIWC (High Altitude Ice Crystals - High Ice Water Content) field campaign. One of the objectives of the HAIC-HIWC campaign is characterization of mixed-phase and regions with high concentration of small ice crystals in Mesoscale Convective Systems. Under mixed phase conditions, the presence of ice crystals and droplets can result in significant uncertainties in the measurement of MVD and LWC. Ice crystals may be identified by shape using high-resolution imaging techniques which allow the potential separation of the phases and acquisition of size distribution for the individual phases (liquid droplets and ice crystals). For the HAIC-HIWC 2015 campaign, the National Research Council (NRC) Convair-580 research aircraft was jointly instrumented by NRC and Environment Canada with state-of-the-art of in-situ microphysics spectrometers including the IKP (isokinetic evaporator probe that gives reference values of TWC), and imaging probes like CPI, 2D-S, PIP, the Artium High Speed Imaging (HSI) probe, which is innovative new probe for imaging droplets and ice crystals.

The HSI probe utilizes a unique multi-beam illumination approach to control depth of field and minimize uncertainties in the sample area definition due to out-of-focus large particles. A description of this method and an evaluation of HSI response by means of comparisons with bulk microphysics and conventional 2D imaging instruments will be presented using the Convair HAIC-HIWC data collected in tropical convective clouds.

P3.22

Characterization of tropical convective cloud structure using an airborne G-band Radiometer and W-band cloud radar in the HIWC environment

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In May 2015, the National Research Council Canada (NRC) Convair-580 aircraft participated in the international High Altitude Ice Crystal (HAIC) – High Ice Water Content (HIWC) field campaign aimed at characterizing HIWC conditions. . The field operation was conducted from the base in Cayenne, French Guyana. In this campaign, the Convair-580 aircraft was jointly instrumented by NRC and Environment and Climate Change Canada (ECCC) with an array of state-of-the-art in-situ micro physics probes, an airborne G-band radiometer and remote sensing systems that included the NRC Airborne W and X-band (NAWX) radars.

In this study, we analyze the response of the sub-mm wavelength radiometer (GVR) operating at 183.31 ± 1 , 183.31 ± 3 , 183.31 ± 7 and 183.31 ± 14 GHz to the HIWC environment at flight altitude. The preliminary analysis of the GVR data shows that the 183.31 ± 7 and 183.31 ± 14 GHz frequencies are more sensitive to ICI conditions than the lower two frequencies. In this study, the measured GVR radiometer brightness temperatures are to be compared to those computed from radiative transfer simulations. This will ascertain the consistency of the measured radiometric data, given the availability of in situ measurements of cloud microphysical properties, surface properties, radar data that locates the cloud boundaries, thermal structure of the atmosphere and vertical distribution of water vapor. The study is also a necessary precursor to the more complex task of retrieving ice water content (IWC) and ice water path (IWP) using combined GVR and radar data.

P4.1

Analysis on the microphysical features of raindrop size distribution under different synoptic systems in mountainous area Fujian

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Microphysical parameters of raindrop size distribution got at Youxi from March to October 2014 were used to analyze microphysical characteristics of natural precipitations under different synoptic systems in mountainous area Fujian. When in small and moderate rain, there are large numbers of small raindrop contribute to the rainfall intensity mainly, low-speed raindrops and narrowest size-velocity spectrums under warm convergent zone or low-vortex shear, which contains cumulus and stratus-cumulus mixing precipitation (half and half). However, the size spectrums under low-vortex shear have broadest width and obvious double-peak or multi-peak structures. The under upper trough contains stratus-cumulus mixing precipitation mainly, which have moderate size spectrums, few low-speed raindrop numbers and wide distribution of high-speed drops within size-velocity spectrums. The subtropical high pressure zone precipitations that come from warm cumulus appear large numbers of high-speed drops. The precipitations under typhoon or intertropical convergence zone are more stable with single-peak size spectrums and centralized raindrops distribution. The correctional Gunn-Kinzer expression is used to fit the scale-velocity spectrums. It fits well at small raindrop part and has some deviations at medium and large raindrop part. The parameters μ and λ meet the linear function, and they both decrease with rainfall intensity increasing.

Key words: raindrop size distribution; synoptic system; cloud water resource; PASIVEL

P4.2

Investigation of Riming within Mixed-phase Stratiform Clouds Using Weather Research and Forecasting (WRF) Model

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4.

In this study, we investigated stratiform precipitation associated with an upper-level westerly trough and a cold front over northern China between 30 Apr and 1 May 2009. We employed the Weather Research and forecasting (WRF) model (version 3.4.1) to perform high-resolution numerical simulations of rainfall. We also conducted simulations with two microphysics schemes and sensitivity experiments without riming and changing cloud droplet number concentrations (CDNCs) to determine the effect of riming on cloud structure and precipitation. We then compared our results with CloudSat, Doppler radar and rain gauge observations. The comparison with the Doppler radar observations suggested that the WRF model was quite successful in capturing the timing and location of the stratiform precipitation region. Further comparisons with the CloudSat retrievals suggested that both microphysics schemes overestimated ice and liquid water contents. The sensitivity experiments without riming suggested that the presence or absence of riming significantly influenced precipitation distribution, but only slightly affected total accumulated precipitation. Without riming, updrafts were relatively weak and we primarily attributed the increased amounts of ice to rapid depositional growth. The results from the sensitivity experiments with CDNC values of 100, 250 and 1000 cm⁻³ suggested an increase or decrease in the CDNC can result in decreased riming intensity and delayed precipitation onset.

Keywords: riming; stratiform cloud; Weather Research and Forecasting model

P4.3

Investigation of Mass-Dimension Relationship Parameters Within a Surface of Equally Realizable Solutions

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Mass-dimension (m-D) relationships estimate particle mass from its maximum dimension. Such relationships are used to derive bulk microphysical properties such as total water content (TWC) and reflectivity (Z). The most common way of estimating a-b coefficients used in $m=aD^b$ relationships is to minimize the difference between TWC or Z derived from number distribution functions and that directly measured by a bulk probe or radar. These a and b values, however, may vary significantly based on meteorological conditions, particle habit, definition of particle maximum dimension, or probes used to obtain the data. Microphysical data collected by two-dimensional cloud and precipitation optical array probes (OAPs) installed on the NCAR C-130 during the Profiling of Winter Storms (PLOWs) experiment, and by the Meteorological Particle Spectrometer (MPS) deployed at the NCAR Marshall Field Site in Boulder, CO during the 2015-2016 winter months, are used with a novel approach to determine m-D relationships for winter storms. A surface of equally realizable a and b coefficients in (a,b) phase space are determined using a technique that minimizes the chi-squared difference between TWC or Z derived from the MPS or OAPs and that directly measured by a hot plate or radar, accepting all coefficients within some tolerance as equally realizable solutions. The surfaces of solutions for different days are compared to establish how meteorological conditions and spatial and temporal variability control the a-b coefficients. It's shown that using unique a-b coefficients in numerical modeling and remote retrieval schemes does not adequately represent the variability of cloud conditions.

P4.4

Diffusion processes in mixed-phase clouds involving direct particle interactions

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4. Mixed phase clouds (including Arctic/Antarctic stratus, mid-level clouds)

Clouds containing ice particles are important for the Earth-Atmosphere system. They modulate the radiation budget by a combination of albedo effect and greenhouse effect. In contrast to liquid water clouds, the radiative impact of clouds containing ice particles is still uncertain. Scattering and absorption highly depends on microphysical properties of ice crystals, e.g. size and shape. In addition, most precipitation forms via the ice phase. Thus, better understanding of ice processes is required.

A key process for determining shape and size of ice crystals is diffusional growth of ice particles and water droplets, especially inside mixed-phase clouds. Diffusion processes in mixed-phase clouds are highly uncertain; in addition they are usually highly simplified in cloud models, especially in bulk physics parameterisations. Generally, the direct interaction between cloud droplets and ice crystals is ignored; particles can only interact via their environmental conditions. Local effects as supply of supersaturation due to clusters of droplets around ice particles are usually not represented.

We present an approach to parameterize the direct interaction by diffusion of cloud particles (liquid and solid). This parameterization includes the local competition of ice particles and droplets for the water vapour, leading to the Wegener-Bergeron-Findeisen process. We consider the local steady-state solutions of the diffusion equation for water vapour for an ice particle as well as a droplet. These solutions are coupled together to obtain the desired interaction. We present the derivation of this bulk microphysics scheme and show some results of the scheme as implemented in a parcel model.

P4.5

Aerosol-cloud interactions over the Arctic using the Canadian atmospheric chemistry model GEM-MACH

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12, 14, 15

Aerosol-cloud interactions present large source of uncertainties in the atmospheric and climate models. Our role in NETCARE (**Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments**) project is to perform climate simulations over the Arctic using the Canadian atmospheric chemistry model GEM-MACH and assess the indirect radiative effects of aerosols. The coupling between meteorology and chemistry in GEM-MACH has been done recently. Aerosol-cloud interaction was made possible using advanced double-moment microphysics scheme in GEM.

Recently, several studies pointed out to the importance of knowledge of chemical composition and the origin of the air masses that impact the cloud formation. Our research should give further insight into quantifying the role of acidified aerosols in the evolution of ice clouds over the Arctic region.

Our main objective is to simulate the observed ice nuclei number concentration during the Amundsen campaign (summer 2014) and investigate correlation between ice nuclei and concentration of different aerosol particles. Additional approach is to use more physically based parameterization of ice nucleation implemented into existing microphysics scheme and try to find a better relationship to observations. In order to determine the right contact angle in new parameterizations, we have looked at aerosol acidity based on molar ratio criteria.

P4.6

Modeling the melting of graupel and hail in a bulk microphysics parameterization

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3,4

The melting rates of graupel and hail are decisive for the amount of ice reaching the ground, but the melting processes can also strongly affect the dynamics of convective and even frontal systems. For comparison of high-resolution simulations with remote-sensing observations like radar an explicit prediction of the melting of graupel and hail allows for a more accurate calculation of radar reflectivities. To develop an advanced melting scheme the fundamental properties of melting graupel and hail are revisited and parameterizations are compiled. Using those empirical relations in a spectral 1D iceshaft model lays the foundation on which the new bulk model is derived. To this end, several simplifications are necessary. For example, for a melting hail particle the internal conduction term, which in general depends on the actual temperature gradient between the ice core and the liquid surface, can be replaced by a simpler correction term considering only the thickness of the liquid layer. Shedding of melt water occurs during melting and affects the fall velocity of the melting particle and also the melting rate itself. A physically-based parameterization of shedding in a two-moment bulk scheme is suggested, but large uncertainties remain due to the complexity of the microphysical behavior of melting graupel and hail. Based on this study, we suggest a new parameterization of the melting processes of graupel and hail for use in two-moment bulk schemes, which has the important advantage that the amount of liquid water on melting graupel and hail is explicitly predicted. The new parameterization is applied in three-dimensional simulations of a hail storm and the impact of the new melting scheme is analyzed.

P4.7

Implementing ice microphysics to a large eddy simulation model coupled with sectional aerosol module

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4,12,14, large eddy simulation, ice microphysics

Large Eddy Simulation (LES) models can be used to study cloud dynamics in a fine grid. The used model is based on well-known UCLA-LES model (Stevens et al., J. Atmos. Sci., 56, 3963-3984, 1999) which has recently been coupled with a sectional aerosol microphysics module SALSA (Kokkola et al., Atmos. Chem. Phys., 8, 2469-2483, 2008). UCLA-LES-SALSA especially accounts for important aerosol-cloud interactions.

To this coupled version of LES-model we have implemented a sectional ice microphysics description. The included microphysical processes consist of formation, growth and removal of ice and snow particles. Ice particles are formed by homo- or heterogeneous nucleation. One of the growth mechanisms of ice particles and snow flakes is coagulation between all types of particles. Ice particles can also grow by condensation of water vapor. Autoconversion from ice particles to snow flakes is parameterized. The sedimentation of ice particles and snow fall is also included.

In the current model version the ice and snow particles are assumed to be spherical. Thus, a more detailed geometrical description is neglected as are different snow types. This has an effect on fall speeds, water condensation and optical properties which will be examined in future work. Likewise, the simulations of mixed-phase clouds will be compared with other model results found in the literature.

P4.8

Model simulations with COSMO-SPECS: Application of prognostic INP description for stratiform clouds

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4 Mixed phase clouds (including Arctic/Antarctic stratus, mid-level clouds)

In the range above about -38 °C ice formation in clouds typically is caused by heterogeneous freezing which means that a so-called ice nucleating particle (INP) is needed to trigger the primary freezing process. In the atmosphere, the most important INPs typically consist of biological or mineral material and are highly variable in type, time, and space. It is widely accepted that the immersion freezing process is the dominant freezing mode for most of the clouds in this temperature range. To avoid an overestimation of primary ice formation in modelling, the number of INP has to be treated prognostically. Two different prognostic approaches have been implemented into the coupled model system COSMO-SPECS which consists of the numerical weather prediction model COSMO and a spectral microphysical scheme for aerosol particles as well as for liquid and frozen hydrometeors.

Especially for long-living quasi-stationary clouds (e.g., arctic stratus) the interaction between the liquid and the ice phase via the gas phase (Wegener-Bergeron-Findeisen process) and the balance between ice particle sinks (sedimentation) and sources (primary ice formation e.g. by immersion freezing) determines the relative ice content as well as life time. This arises the question for the origin of the newly activated INPs (stochastic vs. deterministic approach, entrainment) and requires a detailed description of microphysics as well as dynamics.

Model studies of stratiform clouds will be shown.

P4.9

Comparison of large eddy simulation models for arctic clouds

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Key area numbers: 12, 14, 1

Stratocumulus clouds dominate the subtropical and polar oceans. Their dynamics is largely driven by radiative cooling from the cloud tops and turbulent transport of moisture and heat. The balance is delicate and even small changes in aerosol properties can eventually result in significant changes to cloud properties and lifetime. Large Eddy Simulation (LES) models are especially well suited for simulating the development of marine clouds in turbulent environment. The early LES models did not account for aerosol-cloud interactions at all and had relatively simple cloud microphysics, but the situation has now changed when the important role of aerosols is recognized. UCLA-LES-SALSA is one of the most developed models in terms of aerosol and cloud microphysics. It is based on a well-known large eddy simulation model UCLA-LES (Stevens et al., J. Atmos. Sci., 56, 3963-3984, 1999), which has been recently supplemented by an advanced sectional aerosol microphysics module SALSA (Kokkola et al., Atmos. Chem. Phys., 8, 2469-2483, 2008) and also cloud microphysics has been revised accordingly. The development work is currently focusing on ice microphysics. The effects of improved aerosol and cloud microphysics were examined by comparing different model versions while having the same boundary conditions representing arctic stratocumulus clouds. For these boundary conditions, the original UCLA-LES model with simple microphysics produced significantly thinner clouds than those produced by the more detailed UCLA-LES-SALSA model. This indicates that the difference is related to aerosol-cloud-radiation interactions.

P4.10

The Importance of Soil Dust for Mixed-phase Clouds in Global Climate Models

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Dust particles are an important driver of ice nucleation and glaciation in mixed-phase clouds. With that they influence precipitation and the hydrological cycle. Dust particles mostly originate from natural source regions, like deserts, and consist of different minerals, e.g. clay, feldspar, quartz. Soil dust particles, which originate from agricultural sites also consist of a small fraction of organic matter. It has been shown in different studies that this small fraction of organic matter influences the ice nucleating ability of the dust particles. Soil dusts have been found to be more efficient ice-nucleating particles (INPs) compared to mineral dusts. Currently global climate models do not consider a difference between soil dust and desert dust or the source of dust particles. Since soil dust is becoming increasingly important due to the increase of agricultural areas, we make a first attempt to quantify the importance of soil dust as an INP on a global scale in present and possible future conditions.

For our study we use a version of the global climate-aerosol model ECHAM6-HAM2, where it is possible to differentiate between soil dust and desert dust emissions. Furthermore, new parameterizations to describe the ice nucleation capability of desert and soil dusts are implemented. We present how the different parameterization schemes in combination with the dust type influence the freezing process and thus the properties of mixed-phase clouds, precipitation and their climate impact.

Areas: 4, 14

P4.11

Aircraft measurements of mixed-phase clouds versus cloud-resolving modeling studies in Northern China

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4

Ice crystal habits and growth processes in two mixed-phase clouds were observed simultaneously from three aircraft on April 18, 2009 and May 1, 2009 during the Beijing Cloud Experiment (BCE) and compared with the cloud microphysics and precipitation characteristics simulated by WRF model. The results show that both riming and aggregation processes played central roles in the broadening of particle size distributions, and these processes were more active in embedded convection regions than in stratiform regions. The broadening rates of particle size distributions in the embedded convection regions were larger than those in the stratiform clouds, as the aggregation and riming processes of ice particles in embedded convection regions were active.

Both in embedded convection and stratiform region the particle size distributions simulated and observed are not fully consistent, the simulated broadening rate of particle size distributions is smaller than observations. There is an uncertainty about for the particle size distributions parameters of cloud ice process in WRF model, especially at the growth and change of ice particle, so some improvement are needed.

P4.12

Formation and development of orographic mixed phase clouds in real cases

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4, 6, 17

Mixed-phase clouds (MPCs) describe clouds consisting of super-cooled liquid water droplets and ice-crystals. The coexistence of the three phases vapor, liquid and ice is thermodynamically unstable caused by a lower saturation pressure with respect to ice. Consequently MPCs are supposed to be short living. Nevertheless MPCs are frequently observed in complex orographic regions for several hours. To investigate the development and longevity of orographic MPCs model simulations with the regional climate model COSMO have been performed for the region around the Jungfraujoeh (JFJ) in the Alps. Measurement data provide suitable cases for analysing MPCs and show good agreement to model simulations with respect to meteorological data and cloud-microphysics. The development of MPC was analysed with a sufficiently large number of online trajectories.

Within two case-studies MPCs with different properties were simulated. One case consists of a MPC with a dominant water phase whereas in the second case ice crystals dominate. With online trajectories the development of the air parcels on their way to JFJ can be analysed. The development up to JFJ explains the difference in MPCs and why both can persist in orographic domain over hours. Even though the origin of air masses, temperature and synoptic conditions differ in the cases the orographic forced updrafts is a key factor in both cases. Theoretical consideration about the required ascent based on adiabatic behavior of air parcels could be confirmed along the trajectories. The applicability of theoretical considerations in real case-studies can help to interpret observations.

P4.13

An LES study on the role of ship induced ACI in mixed-phase stratocumulus

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4. Mixed phase clouds

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As the Arctic sea ice continues to melt under a warming climate, commercial shipping is projected to increase by the mid-century due to continuously ice-free passage ways north of the Arctic circle. An increase of CCN and perhaps IN concentrations due to container ships in such a pristine region may have impacts on the long-lived mixed-phase stratus clouds (MPSCs), which are detected in the Arctic almost all year around.

In this study we analyse aerosol-cloud interactions induced by ship exhaust in Arctic MPSCs. We assess their relative importance by contrasting the microphysical effects to changes in the cloud state induced by the variability in the environmental conditions, such as the surface forcing. Idealised LES simulations of the MPACE campaign (Verlinde et al. 2007, Klein et al. 2009) are performed with COSMO in which CCN, IN concentrations and surface fluxes are altered (together and individually). CCN and IN perturbations are chosen within the observed range of $50 - 1500 \text{ cm}^{-3}$ and $0.16 - 15 \text{ l}^{-1}$ respectively. The sensitivities to different combined and individual perturbations are quantified and compared.

Motivated by ship track observations in Arctic MPSCs (Christensen et al. 2014), we explore sensitivities of this microphysically unstable cloud type. In particular the in-cloud glaciation and riming effects, triggered by the aerosol perturbation, are discussed.

P4.14

The evolution and precipitation production of an orographic wintertime cloud with freezing drizzle

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6, 4

The presence of large amounts of super-cooled liquid water (SLW) in orographic clouds is often an indication that the precipitation process is not efficient, and poses a serious threat to aviation due to the potential for severe icing. In the region near Boise, Idaho, radiometer-observed SLW in wintertime clouds rarely (<5% of measurements) exceeds 0.5 mm. An atmospheric river event impacting the Pacific Northwest coast on 12 February 2014 brought moisture as far inland as Boise. During this event, SLW in excess of 1 mm was observed by a microwave radiometer near Boise. In this case, in situ measurements from the University of Wyoming King Air (UWKA) were also collected; however, this flight had to be cut short due to severe icing encountered by the UWKA aircraft.

This paper will present a suite of observations, including radiometer, sounding, snow gauge, and satellite data, to describe the overall evolution of this event. Measurements from a W-band cloud radar onboard the UWKA will be presented to investigate the precipitation production in this case, which indicated a mixed-phase scenario with freezing drizzle. A companion paper (French et al.) will present a detailed examination of the ice production processes in these mixed-phase clouds using the in situ probe data from the UWKA flight.

P4.15

Modelling of water stable isotope ratios in a 1.5D bin-resolved microphysics model

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During the past decades, the Arctic has warmed twice as fast as the global average, which state-of-the-art coupled ocean-atmosphere models fail to correctly simulate. The AC-AHC2 project aims to improve our understanding by quantifying the atmospheric moisture transport to the arctic and discriminating between local sources and long distance moisture transport. Water stable isotopes will be used as indicators and new measurements of precipitation and surface water vapour isotopic composition in north Greenland and Svalbard, will be compared with model output.

As a first step, the water stable isotopes will be added to the 1.5D bin-resolved microphysics Detailed Scavenging Model (DESCAM) and their evolution in a single precipitating cloud will be studied, before being introduced in DESCAM 3D and compared to meso- and global scale models.

P4.16

Ground based in situ measurements of arctic cloud microphysical and optical properties at Mount Zeppelin, Svalbard

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Climate simulations suggest that cloud feedback plays an important role in the arctic warming. Moreover, the high seasonal variability of arctic aerosol properties is expected to significantly impact the cloud properties during the winter-summer transition. Field measurements are needed for improved understanding and representation of cloud-aerosol interactions in climate models. Within the CLIMSLIP project (CLimate IMpacts of Short-Lived Pollutants and methane in the arctic), a two months (March-April 2012) ground-based cloud measurement campaign was performed at Mt Zeppelin station, Ny-Alesund, Svalbard. The experimental set-up comprised a wide variety of instruments. A CPI (Cloud Particle Imager) was used for the microphysical and morphological characterization of ice particles. Measurements of sized-resolved liquid cloud parameters were performed by the FSSP-100 (Forward Scattering Spectrometer Probe). The Nevzorov Probe measured the bulk properties of clouds. The Polar Nephelometer was used to assess the single scattering properties of an ensemble of cloud particles. This cloud instrumentation combined with the aerosol properties continuously measured at the station allowed us to study the variability of the microphysical and optical properties of low level Mixed Phase Clouds (MPC) as well as the aerosol-cloud interaction in the Arctic. Typical properties of MPC, snow precipitation and blowing snow will be presented. First results suggest that liquid water is ubiquitous in spring arctic low level clouds. Carbon monoxide measurements allow us to compare polluted with clean cases. The cloud-aerosol interactions processes which take place during the transport of polluted air masses from mid-latitude to the Arctic is thus assessed.

P4.17

Identification of super-cooled liquid layers in mixed-phase clouds based on cloud radar observations

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4. Clouds have an important role in climate and weather applications. Long-term Finnish Meteorological Institute (FMI) ceilometer network observations indicate that cloud cover over Finland varies between 45% and 90% depending on the season and location. The major fraction of clouds are ice or mixed-phase. Mixed-phase clouds contain super-cooled liquid layers, which can be maintained at the top of mixed-phase clouds for several hours; these layers are frequently observed at altitudes up to 6-8 km year-round with ceilometers. Super-cooled liquid layers can have significant radiative impacts, modify precipitation processes, cause rapid freezing onto surfaces, and thus, their detection and forecasting is necessary for industry (e.g. wind energy) and safety (e.g. aviation). However, freezing forecasting still remains uncertain and, in multi-layer situations, only the first liquid layer is usually detected by ceilometers. Cloud radar Doppler velocity profiles contain information that could allow significant improvements in the observational detection of super-cooled water layers in mixed phase clouds. In this project, an algorithm to identify super-cooled liquid layers based on cloud radar vertical Doppler velocity profiles was developed. Cloud radar observations collected at three inland locations in Finland are employed to investigate super-cooled liquid layer occurrence.

P4.18

Understanding microphysical controls on arctic stratus clouds: A comparison of high-resolution NWP models during the ASCOS field campaign

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Key subject area number: 4

Abstract

Mixed-phase arctic stratus clouds are a key component of the Arctic climate system. The macro- and microphysical properties of arctic stratus, and hence their radiative effects, are highly susceptible to changes in surface fluxes and aerosol concentrations. Satellite observations over recent decades show that sea-ice extent is in decline, and a big challenge for global climate models is to be able to predict the correct response of arctic clouds to the effects of sea-ice loss. Under sea-ice loss, aerosol concentrations and surface heat fluxes will increase, and it is not clear how arctic stratus layers will respond. Hence a resolution of the uncertainty surrounding aerosol-cloud-radiative feedbacks in the arctic is urgently needed.

Here we show results comparing the performance of three different high-resolution NWP models (the Met Office UM, WRF and COSMO) using a standardised protocol in the context of an arctic cloud case study from the ASCOS field campaign of 2008. The model simulations are used to help understand the microphysical controls governing the rapid dissipation of a stratus layer over sea-ice as seen in the remote sensing observations. These experiments will ultimately provide a platform for further sensitivity studies designed to explore cloud-radiative feedbacks in the absence of sea-ice.

P4.19

Response of mixed-phase boundary layer clouds with predominantly rapid or slow ice nucleation processes to cloud-top temperature trend

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Key area: 4 (mixed-phase clouds)

It has been argued on the basis of some laboratory data sets, observed mixed-phase cloud systems, and numerical modeling studies that weakly active or slowly consumed ice forming nuclei (IFN) could be important to natural cloud systems. It has also been argued on the basis of field measurements that ice nucleation under mixed-phase conditions appears to occur predominantly via a liquid-phase mechanism, requiring the presence of liquid droplets prior to substantial ice nucleation. Here we analyze the response of large-eddy simulations of mixed-phase cloud layers to IFN operating via a liquid-phase mode using assumptions that result in either slow or rapid depletion of IFN from the cloudy boundary layer. We use three case studies that do not exhibit riming or drizzle, based on SHEBA and ISDAC field campaign data, with stationary or cooling cloud-top temperature. With stationary cloud-top temperature, we find that steady ice crystal formation (a prominent feature in field observations) can result equally from either steady cloud-top entrainment of rapidly nucleated IFN or steady activation from a sufficiently large reservoir of slowly nucleated IFN. However, with cooling cloud top temperature, ice formation trend becomes unsteady in a manner that depends upon the slow or rapid process assumed. Regardless of cloud top temperature trend, ice nucleation mechanisms exhibit differing characteristic relationships of simulated ice crystal number concentration and ice mass mixing ratio, roughly consistent with those reported by Fan et al. (doi: 10.1002/2014GL060657).

P4.20

A model for a turbulent mixed-phase cloud

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Mixed-phase clouds play an important role in the correct determination of the Earth's radiative balance but are not as well understood as warm clouds. It has been known for some time that turbulence is important in generating and sustaining mixed-phase clouds and here we present a simple model of a turbulent mixed-phase cloud by coupling a simple adiabatic mixed-phase cloud model with a Lagrangian stochastic model for the vertical velocity. The statistical properties of the system are investigated for a range of typical values of the turbulence parameters (velocity variance, dissipation rate and decorrelation time scale) and cloud properties (droplet and ice particle number concentration, initial droplet and ice particle size, temperature). We demonstrate that this model can indeed generate and maintain both liquid water and ice and reproduces qualitatively many features of mixed-phase clouds. We show that the maximum droplet size scales well with the duration of the liquid phase of the cloud for a range of parameter values.

P4.21

Comparing model and measured ice crystal concentrations in orographic clouds during the INUPIAQ campaign

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As part of the Ice NUcleation Process Investigation and Quantification (INUPIAQ) project, two field campaigns were conducted in the winters of 2013 and 2014. Both campaigns included measurements of cloud micro-physical properties at the summit of Jungfrauoch in Switzerland (3580m asl), using a range of cloud probes. These probes measured significantly higher ice number concentrations in orographic clouds than observed in clouds at similar altitudes from aircraft.

This project assesses the high ice number concentrations observed by comparing in-situ measurements at Jungfrauoch with Weather Research and Forecast model (WRF) simulations over real terrain surrounding Jungfrauoch. During the 2014 field campaign the model simulations suggested ice concentrations of 3 orders of magnitude per litre less than the observed ice number concentration. Previous literature has proposed several processes for the high ice number concentrations in orographic clouds, including an increased ice nucleating particle (INP) concentration, secondary ice multiplication and the advection of surface ice or snow crystals into orographic clouds. Using the WRF simulations, we found the influence of these processes on the ice concentrations during the field campaign to be limited. We also assessed whether the inclusion of a surface flux of hoar crystals into WRF could account for the increased ice concentrations in the orographic clouds found at Jungfrauoch. By including a simple parameterisation based on the surface wind speed, the inclusion of the surface crystal flux provided a good agreement with the measurements at Jungfrauoch.

P5.1

Impact of nucleation rates on ice crystal number concentrations in cirrus clouds

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5.

Ice clouds in the tropopause region, so-called cirrus clouds are important regulators of Earth's energy budget. However, in contrast to liquid water clouds, the impact of cirrus clouds on radiation is quite unclear. Size and number concentration of ice particles

determine in first order the radiative effects. For the low temperature regime ($T < 235\text{K}$) we can assume that homogeneous freezing of solution droplets is the dominant formation pathway of ice crystals. This process is determined by a nucleation rate, which is very sensitive to environmental conditions (temperature and humidity), whereas the nature of the dissolved matter plays a negligible role. A standard formulation of the nucleation rate is available as a fit to experimental data; the logarithm of the nucleation rate can be expressed as a third order polynomial of the difference of water activities. Some issues appear with this representation. For analytical investigations (e.g. multiple scale asymptotics) this formulation is not very adequate. On the other hand, it is not really clear how details of nucleation rates affect ice crystal number concentrations in bulk parameterizations, i.e. how detailed the formulation of nucleation must be for physically meaningful results. We present new analytic fits for nucleation rates of homogeneous freezing of aqueous solution droplets for ice cloud research in the tropopause region and investigate the impact of different approximations of nucleation rates on ice crystal number concentrations in bulk model parameterizations. Our simulations suggest that for bulk parameterizations our simple formulation of the nucleation rate is a very good and much simpler approximation. This new formulation might be of interest for weather and climate models.

P5.2

Influence of soot number emissions on contrail cirrus life cycle and climate impact

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5, 13, 14

Contrail cirrus modify upper tropospheric cloudiness significantly. Aircraft soot emissions have a large impact on microphysical process rates of contrail cirrus. Our objective is to analyze the influence of reduced soot particle emissions, as expected from biofuels or lean combustion, on contrail cirrus properties, life cycle and climate impact.

Our study is based on a contrail cirrus parameterization, using a double moment microphysics scheme, within the ECHAM5 climate model. We perform idealized process studies prescribing constant initial ice crystal number concentrations and investigate life cycles of contrail cirrus clusters in different synoptic situations and flight levels.

In long-lived and large-scale ice supersaturated areas, sedimentation of ice crystals into subsaturated areas accounts for 25 to 45% of the overall ice crystal loss limiting the lifetime of contrail cirrus. At low ice crystal number concentrations, ice crystals grow initially faster, sedimentation is increased and, later in the life cycle, ice crystal number concentrations are earlier so low that deposition on ice crystals is limited by diffusional growth time scales. The influence of soot emission reductions is largest in large-scale ice supersaturated areas: A reduction in initial ice crystal number concentration by 80 % leads to an increase in ice particle loss due to sedimentation by about 15%. This means that on average, contrail cirrus lifetimes appear to be shorter by 3 to 4 hours, the mean optical depth is significantly reduced and the maxima of total extinction of short wave radiation are decreased by a factor of 2 to 2.5.

P5.3

Redistribution of water vapour and aerosol particles by cirrus clouds

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5, 12, 14

Heymsfield and Iaquinta (JAS, 2000) highlighted the importance of ice crystal sedimentation from cirrus clouds as the ice-crystal fall out may result in a redistribution of water vapour, aerosol and energy from upper to middle-tropospheric altitudes potentially leading to an altered radiative forcing.

An extensive data set of in-situ aerosol, cloud particle and H₂O measurements from the ML-CIRRUS 2014 campaign with the German research aircraft HALO allows for investigating the validity of the hypothesized redistribution and its potential consequences. We focus on three different cases: (i) cirrus clouds that were found in the outflow region of a synoptic scale warm conveyor belt (WCB) uplift (liquid origin), (ii) WCB outflow cirrus that were strongly influenced by Saharan dust particles, and (iii) cirrus clouds formed in-situ within a pristine ice nucleation environment.

We aim at answering the question whether the redistribution can be verified and quantified by airborne observations. The redistribution effect may depend on the ice particle size of the various cirrus cloud types (i-iii), the particles' sedimentation speed and the effectiveness of ice particle sublimation underneath the cloud level.

Additionally, we present sensitivity studies using the high resolution model EULAG and compare the output of idealized simulations with the results from the measurement data.

P5.4

Subvisible cirrus clouds - a dynamical systems approach

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Johannes Gutenberg University, Mainz, Germany

5, 14

Cirrus clouds occur very frequently in the tropopause region. A special class are subvisible cirrus clouds. The dominant pathway for these clouds is not known well. It is often assumed that heterogeneous nucleation at solid aerosol particles is the preferred mechanism although homogeneous freezing of aqueous solution droplets might be possible. For investigating subvisible cirrus clouds as formed by homogeneous freezing we develop a simple analytical cloud as a three dimensional set of ordinary differential equations, including relevant processes as ice nucleation, diffusional growth and sedimentation. The model is investigated using theory of dynamical systems. We found two different states for the long-term behaviour of subvisible cirrus clouds (attractor case and limit cycle scenario). The transition between the states constitutes a Hopf bifurcation and is determined by environmental conditions as vertical updraughts and temperature. In both cases, the microphysical properties of the simulated clouds agree reasonably well with simulations using a complex model, with former analytical studies and with observations of subvisible cirrus. Finally, the results indicate that homogeneous nucleation might be a possible formation pathway for subvisible cirrus clouds.

P5.5

Microphysical properties of cirrus clouds between 75N and 25S derived from extensive airborne in-situ observations

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5. Cirrus clouds

Numerous airborne field campaigns were performed in the last decades to record cirrus cloud microphysical properties. This is of importance for an improved certainty of climate predictions, which are affected by the poor understanding of the microphysical processes of ice clouds (IPCC, 2013).

Ideally, the observations should cover the complete cirrus parameter range and not be influenced by instrumental artifacts. However, some issues with respect to the measurements have arisen. In particular, concerns about the relative humidity in and around cirrus and the ice crystal numbers were under discussion. Too high ice supersaturations and ice number concentrations were often reported.

In this study, we compiled a large data set of cirrus clouds, sampled during eighteen field campaigns between 75N and 25S, representing measurements fulfilling the above mentioned requirements. The most recent were ATTREX (Global Hawk) and ML-CIRRUS and ACRIDICON (HALO). The observations include ice water content (IWC: 130 hours of observations), ice crystal numbers (Ni: 83 hours), ice crystal mean mass size (Ri: 83 hours) and relative humidity (RH_i) in- and outside of cirrus clouds (78 and 140 hours). We will present the parameters as PDFs versus temperature and derive medians and core ranges for each parameter. The new large data sets confirm the earlier results presented by Schiller et al. (JGR, 2008), Krämer et al. (ACP, 2009) and Luebke et al. (ACP, 2013), which are all based on much smaller datasets. Further, we will show the geographical and altitude distribution of IWC, Ni, Ri and RH_i.

P5.6

A Microphysics Guide to Cirrus Clouds - Part I: Cirrus Types

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5. Cirrus clouds

The microphysical and radiative properties of cirrus clouds still represent one of the largest sources of uncertainties in climate prediction (IPCC, 2013). Our study provides a guide to cirrus microphysics, which is compiled from an extensive set of model simulations (Krämer et al., 2015, ACPD). The model results are portrayed in the same parameter space as field measurements, i.e. in the Ice Water Content-Temperature (IWC-T) parameter space. We validate this cirrus analysis approach by evaluating cirrus data sets from seventeen aircraft campaigns, conducted in the last fifteen years, spending about 94 h in cirrus. Altogether, the approach of this study is to track cirrus IWC development with temperature by means of model simulations, compare with observations and then assign, to a certain degree, cirrus microphysics to the observations.

An important finding from our study is the classification of two types of cirrus: the first cirrus type is rather thin with lower IWCs and forms directly as ice (in-situ origin cirrus). The second type consists predominantly of thick cirrus originating from mixed phase clouds (i.e. via freezing of liquid droplets – liquid origin cirrus). In the European field campaigns, in-situ origin cirrus occur frequently at slow updrafts in low and high pressure systems, but also in conjunction with faster updrafts. Also, liquid origin cirrus mostly related to warm conveyor belts are found. In the US and tropical campaigns, thick liquid origin cirrus which are formed in large convective systems are detected more frequently.

P5.7

Cirrus clouds observations over the Amazon: Results from 3 lidar systems and radiosondings during the GoAmazon 2014/15 experiment

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5. Cirrus clouds , 9. Tropical clouds,

The Green Ocean Amazon experiment took place in Manaus-Brazil, a large metropolitan area within a pristine forest, from January 2014 to December 2015. It aimed to study the interaction of the Manaus pollution plume with the biogenic aerosols, and the effects on cloud and aerosol life cycles. In this paper, we investigate the characteristics of the cirrus clouds as measured by three lidar systems, which were operated in different experimental sites during GoAmazon2014/15. The first is a UV Raman lidar, which is running operationally since 2011 at site T0e (2.89°S 59.97°W) 30 km upwind of Manaus. The second is the Visible Micropulse Lidar (MPL) of the DOE/ARM mobile facility installed at site T3 (3.21°S; 60.59°W) 80 km downwind of Manaus and measuring polarized elastically backscattered light. The third was the mobile visible Raman lidar system from IPEN operated during IOP2 (from Aug to Oct 2014) at site T2 (3.13°S, 60.13°W), 5 km downwind of Manaus. An evaluation of cirrus clouds base and top altitudes, temperature, optical depth and extinction-to-backscattering ratio distributions will be presented. Finally, an instrument comparison will be given, based on data acquired simultaneously when the mobile lidar was brought to operate side by side with the other systems. We show the results from this intercomparison for the range-corrected raw signals, backscattering coefficient profiles and cloud properties, taking into account the different laser wavelengths, and instrumental characteristics.

P5.8

Satellite retrievals of the ice crystal number concentration

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5, 16, 13, 14

Recent assessments of the climate research community globally converge towards the conclusion that a better understanding of aerosol-cloud interactions is needed to further constrain current radiative forcing estimates. As a consequence, significant efforts have been made during the last decade to answer this question with regard to liquid clouds, but interactions between aerosols and ice clouds still remain poorly understood despite their high importance for long-wave forcing estimates. One important reason is the current lack of adequate satellite observations to perform such studies. Indeed, despite that the number of cloud particles is often viewed as one of the most important parameters to quantify aerosol-cloud interactions, there exists to date no space-borne product of the ice crystal number concentration (ICNC).

In this study, we present a novel product of ICNC retrievals from satellite observations, based on the liDAR-raDAR (DARDAR) operational algorithm. As a first step towards the validation of this product, we show comparisons to in-situ measurements from recent airborne campaigns. Good agreements are found in the overall variability of ICNC, despite a possible overestimation of its absolute value in our product at warm temperatures (greater than -40°C). Further analyses show that this overestimation can be explained by the misrepresentation of the small mode (ice crystals smaller than 100 microns) in current particle size distribution (PSD) parameterizations, which therefore need to be further improved. Finally, a climatology obtained from several years of ICNC retrievals is presented and analyzed.

P5.9

Hysteresis of ice cloud coverage in a climate model

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Large frequencies of supersaturation relative to ice are observed in the upper troposphere, with ice clouds forming at large ice supersaturations and persisting at ice saturation. This contrasts cloud parameterizations that infer ice cloud cover from relative humidity or water fluctuations in the same way as for warm clouds or simply shift ice cloud formation and dissipation to the same critical mixing ratio at fixed ice supersaturation.

We implement a non-equilibrium ice cloud cover in the ICON climate model based on a relative humidity scheme by leaving the purely diagnostic framework and introducing a prognostic ice cloud cover variable. Tendencies of the prognostic ice cloud cover are inferred from the PDF underlying the cloud scheme. We analyze the impact of this hysteresis behavior on the ice cloud properties and the upper tropospheric water budget and compare to simpler approaches like shifting the formation and dissipation threshold to grid mean ice supersaturation.

P5.10

Three-dimensional structure of ice supersaturation and cirrus clouds

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5. Cirrus Clouds

Ice supersaturation occurs quite frequently in the upper troposphere, either in cloud free air or even inside cirrus clouds, as we know from in situ measurements.

However, the spatial structure of these ice-supersaturated regions (ISSRs) is not known. From routine measurements on board commercial aircrafts (MOZAIC/IAGOS project, www.iagos.org) we can derive so-called pathlengths of ISSRs, indicated a one-dimensional extension of ISSRs. For investigating the three-dimensional structure of ISSRs, we would like to use meteorological analysis data from ERA interim project at European Centre for Medium-Range Forecasts (ECMWF).

Since it is not clear, how well ice supersaturation and cirrus clouds are represented in ERA interim data, we use data from the MOZAIC/IAGOS project in order to determine the quality in statistical comparison. In a first step, we investigate artificial pathlengths, i.e. simulated flight tracks through ISSRs as identified in ERA interim data, in comparison to pathlengths statistics as obtained from MOZAIC/IAGOS data (Gierens & Spichtinger, 2000; Spichtinger & Leschner, 2016). For detailed comparison, we investigate the pathlengths on a case study basis. Finally, we start to investigate the three dimensional ISSRs in the ERA interim data in more details. Since ERA is available for the time period since 1979, we additionally investigate annual and seasonal trends in pathlengths of ISSRs on solid statistical basis.

P5.11

Derivation of physical and optical properties of midlatitude cirrus ice crystals for a size-resolved cloud microphysics model

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¹NASA GISS, New York, NY, USA, ²University of Chicago, Chicago, IL, USA, ³Columbia University, New York, NY, USA, ⁴University of Illinois, Urbana-Champaign, IL, USA, ⁵Spec Inc., Boulder, CO, USA

Key areas: 5 (cirrus clouds), 13 (clouds and climate, radiative properties of cloud ice)

Single-crystal images collected in mid-latitude cirrus are analyzed to provide internally consistent ice physical and optical properties for a size-resolved cloud microphysics model, including single-particle mass, projected area, fall speed, capacitance shape factor, single-scattering albedo, and asymmetry parameter. Using measurements gathered during two flights through a widespread synoptic cirrus shield, bullet rosettes are found to be the dominant identifiable habit among ice crystals with maximum dimension (D_{\max}) greater than 100 μm . Properties are therefore derived for bullet rosettes based on measurements of arm lengths and widths, for aggregates of bullet rosettes, and for unclassified (irregular) crystals. Derived bullet rosette masses are substantially greater than reported in existing literature, whereas measured projected areas are similar or lesser, resulting in factors of 1.5-2 greater fall speeds, and, in the limit of large D_{\max} , near-infrared single-scattering albedo and asymmetry parameter (g) greater by ~ 0.2 and 0.05 , respectively. A model that includes commonly imaged side plane growth on bullet rosettes exhibits relatively little difference in microphysical and optical properties aside from increase in mid-visible g of ~ 0.05 primarily attributable to plate aspect ratio. In parcel simulations, ice size distribution and g are sensitive to assumed ice properties.

P5.12

Can detailed simulations reproduce general ice size distribution properties observed within a widespread mid-latitude synoptic cirrus deck?

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Key area: 5 (cirrus clouds)

To our knowledge, only two observation-based case studies have been prepared for 3D cirrus model intercomparison studies, one a thin cloud deck described by Yang et al. (doi:10.5194/gmd-5-829-2012) and the second a deep and widespread cloud deck investigated by Muhlbauer et al. (doi:10.1002/2014JD022570). Here we focus on the latter case. We compare observed particle size distribution (PSD) properties analyzed by Jackson et al. (doi:10.1002/2015JD023492) with results from large-eddy simulations with 100-m resolution and size-resolved microphysics. An ensemble of simulations is analyzed to consider sensitivity to initial water vapor field, large-scale forcings, ice crystal properties, and ice nucleation schemes. We evaluate the capability of each simulation to reproduce the general PSD properties of ice using multi-modal fits to observed and simulated size distributions following the method of Jackson and co-authors. In the coldest cloud tops, simulated ice PSDs come nearest to resembling observations when homogeneous aerosol freezing is not suppressed as a consequence of heterogeneous freezing. Within lower cloud regions, the assumption of low crystal effective densities produces ice that is larger than observed, and simulated PSD relative dispersion is systematically smaller than observed across the ensemble.

P6.1

Numerical study of a severe thunderstorm formed over Bulgaria

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3. Convective clouds (including cloud electrification)

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Numerical simulations of a severe thunderstorm formed over Western Bulgaria will be performed with the non-hydrostatic model MesoNH. Results for microphysical, dynamical and electrical evolution of the simulated storm will be validated with real data from radar, satellite and lightning detection measurements. The aim of our study is to propose appropriate parameterizations for the different cloud processes in the frame of the considered thundercloud case.

P6.2

Numerical investigation for a deep convection electrification and lightning with a 1.5D aerosol-cloud bin model

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3. Convective clouds (including cloud electrification)

In this paper, we used a 1.5-dimensional non-hydrostatic convective aerosol -cloud interaction bin model coupled with an improved 3-dimensional bi-directional stochastic discharging model to study the electrification and lightning processes for one deep convection case of CCOPE. The electrification schemes with two non-inductive charge separations (TAK and SP98) were adopted in our simulations. Not only were the number and mass concentrations of aerosols, including ice nuclei and cloud condensation nuclei, explicitly followed in all microphysical processes, but also the charge amounts for a pair of particles in their collision are determined. Our preliminary results show that two electrification schemes results in the same dipoles charge structure. Furthermore, the concentrations of ice nuclei and cloud condensation nuclei affect the electrification process because the large ice particle formation is highly related to ice crystal concentration and cloud droplet concentration.

P6.3

Cloud and Precipitation in the Brazil: The CHUVA Project

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key area numbers- 9,1,12,3

CHUVA meaning "rain" in Portuguese is a project designed to investigate a broad variety of tropical weather regimes, ranging from warm clouds in northeastern Brazil to Mesoscale Convective Complexes (MCC) in the border with Argentina, including, among other topics, the aerosol-cloud-precipitation interaction, the cloud electrification, the rainfall satellite estimation and the hydrometeor characteristics. CHUVA Project has conducted six field campaigns. The first two experiments, namely, Alcantara and Fortaleza in northeast Brazil, focused on warm clouds. The third campaign, which was conducted in Belem, was dedicated to tropical squall lines. The fourth and fifth campaign was in the southeastern and south of Brazil, a region with intense lightning activity and the sixth campaign was held in Manaus in the framework of the GoAmazon project. The aim of this presentation is to briefly describe the campaigns and highlight the following results: a) The two airplanes mission in GoAmazon, evaluating the aerosol effect in the cloud formation. Cloud inside the Manaus pollution plume, in the wet season, have mostly lower effective diameters and higher droplet number concentrations than in the background condition outside the plume. b) The lightning (LMA) and X POL observation observed during the Vale Campaign. The characteristics of the polarimetric variables as function of the lightning frequency and the life cycle of the thunderstorm from the first echo above the melting layer to the first CG. Finally a general view of all DSDs, measured using Joss disdrometer, for the 6 campaigns in the Gamma space

P6.4

Evaluation of the Lightning Potential Index in the COSMO-Model

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A modified version of the Lightning Potential Index (LPI) following Lynn and Yair (2010) and Yair et al. (2010) has been operationally implemented in the COSMO-model at DWD. This presentation presents the modified index and a longer-term evaluation study.

The LPI is designed for high-resolution convection-permitting cloud models using state-of-the-art bulk microphysical schemes and requires explicit simulation of riming processes within thunderstorms (graupel/hail physics). It is relatively simple (and thus computationally cheap) and diagnoses the 'intensity' of riming over a model grid column as an integral average of vertical updraft speed and the co-existence of supercooled liquid, graupel/hail and 'graupel/hail-embryos' such as cloud ice and snow. Other than that, there is no explicit parameterization of cloud electrification processes. We have added an additional buoyancy criterion to eliminate false alarms to the original LPI formulation and have re-tuned an updraft velocity threshold.

Despite its simplicity, a longer-term study with the operational COSMO-DE model (2.8 km grid spacing, graupel microphysics) in comparison with observations suggests that a simple linear relation between the modified LPI and the flash rate leads to a surprisingly good representation of the space-time distribution of flash rates from model forecasts. This is however intimately linked to the model's ability to realistically simulate deep convective clouds. Then, the correlation of the LPI to observed flashes is better than, for example, with the column integrated graupel content or the precipitation rate.

-Lynn and Yair, 2010, *Adv. Geosci.*, 23, 11-16

-Yair et al., 2010, *JGR*, 115, D04205, doi:10.1029/2008JD010868

P6.5

Explicit simulation of storm electrification processes in a mesoscale model and comparison to LMA observations taken during the HyMeX experiment.

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The Lightning Mapping Array (LMA) is a powerful 3D lightning flash detector that was operated during SOP1 of HyMeX in France during Fall 2012. In addition to the high resolution of the flash patterns by detection of thousands of VHF sources per flash, LMA data are very well suited for testing an electrification scheme like CELLS in the cloud resolving model MesoNH at kilometer scale resolution. The information carried by LMA data includes not only the count of the intra-cloud and cloud-to-ground flashes but also, the spatial extension and triggering altitude of the flashes and the polarity of the cloud volume where flashes propagate. The CELLS scheme computes the charge separation rate from the microphysics, the electric field and the flash characteristics.

The mesoscale model MesoNH was run for at least 5 HyMeX cases for which the cloud electrical activity was recorded by the LMA. MesoNH was configured in gridnesting mode (4 km and 1 km) with 50 levels and domain sizes of 192x192 and 384x384 grid points, respectively. Electrified storms lasting several hours are simulated by the CELLS module in real conditions thanks to the 3-hour Arome analyses of Météo-France.

The study presents simulations made with three different charge separation diagrams (Takahashi, Saunders et al. and Sanders and Peck) which basically represent a major uncertainty of the cloud charging processes. Detailed results concerning two case studies and a compilation of all simulated flash rates and characteristics will be given and compared to the HyMeX-LMA dataset.

P7.1

Mixing at the boundary between a turbulent cloud and non-turbulent environment.

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1)

Keywords: turbulent entrainment, shearless mixing layer, cloud-clear air interface

Three-dimensional direct numerical simulations which combine the Eulerian description of temperature, vapor content and velocity with a Lagrangian ensemble of cloud water droplets are used to study the turbulent entrainment and subsequent mixing of clear air with a cloudy air filament. The study is conducted in a shearless mixing layer setup, meaning the cloud is turbulent and the adjacent clear air is non-turbulent, with no initial relative velocity between the two. The cloud microphysical, thermodynamic, and turbulence properties are adjusted to realistic conditions at a cumulus cloud boundary. Fluid turbulence is driven in both cases solely by a buoyancy term which incorporates feedbacks from the temperature, vapor content and liquid water content fields, respectively. The buoyancy feedback leads initially to a downdraft motion at the cloudy-clear air interface. After about one large eddy turnover time cloud droplets entering an environment with low turbulence are more decelerated compared to the case with equal turbulence level. Due to evaporative cooling, downdrafts at the interface generate a shear layer and the resulting amplitude is greater for the shearless mixing case. Consequently, high-amplitude dissipation and local enstrophy events occur mostly in the mixing layer, i.e., right at the boundary of the turbulent cloud with its clear air environment. Cloud droplet sedimentation plays a major role in the initial evaporation process since particles are easily decoupled from the thermodynamic fields as soon as a cloud portion enters the dry air region.

P7.2

Theoretical investigation of mixing in warm clouds. Homogeneous mixing

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turbulent mixing, homogeneous mixing, drop size distributions

The evolution of monodisperse and polydisperse droplet size distributions (DSDs) during homogeneous mixing is analyzed. Universal analytical temporal dependencies of supersaturation and liquid water content, which depend on a sole non-dimensional parameter, are obtained for a monodisperse DSD. Also universal analytical equations for mixing diagram are obtained and analyzed in this case. The evolution of moments and moment-relation functions in the course of the homogeneous evaporation of polydisperse DSDs is analyzed using model of immovable parcel. It is shown that the classic conceptual scheme, according to which homogeneous mixing leads to a decrease in the droplet mass under constant droplet concentration, is valid only in cases of monodisperse or initially very narrow polydisperse DSDs. In cases of wide polydisperse DSDs, mixing and successive evaporation lead to a decrease of both mass and concentration such that the characteristic droplet sizes remain nearly constant. As this feature is typically associated with in-homogeneous mixing, we conclude that in cases of an initially wide DSD homogeneous mixing is nearly indistinguishable from in-homogeneous mixing.

P7.3

Theoretical analysis of mixing in liquid clouds: Inhomogeneous mixing

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1, 2,3,16, 17 The time dependent mixing between cloud and non-cloud volumes is analyzed using diffusion-evaporation model. Two types of initial droplet size distributions (DSD) are considered: monodisperse and polydisperse.

1. The evolution of microphysical variables in course of mixing are determined by two non-dimensional parameters: R , which is proportional to the ratio of the saturation deficit to the liquid water content in a cloud volume, and Da , which is equal to the ratio of the characteristic mixing time and phase relaxation time.

An analysis of the results within a wide range of parameters R and Da is presented. It is shown that mixing always starts as inhomogeneous and the mixing type can change during the mixing process. Mixing leads to the formation of a tail of small droplets and therefore to the DSD broadening. The duration of the mixing varies from several to one hundred phase relaxation times. At Da ranged from ~ 10 to ~ 500 , mixing is inhomogeneous, i.e. droplets experience different saturation deficit. This range is not included into the classical mixing diagrams.

2. Mixing diagrams depend on the DSD shape. If DSDs are wide, the value of effective radius can increase with time because of evaporation of smallest droplets. As a result the value $(r_e/r_{e_max})^3$ turns out to be larger than unity. If DSD is narrow $(r_e/r_{e_max})^3$ are less than unity. The mixing diagrams $(r_e/r_{e_max})^3$ vs cloud fraction are similar to the mixing diagrams characterizing homogeneous mixing, while mixing simulated by the model was obviously inhomogeneous.

P7.4

Examination of the bimodal droplet spectra observed during COPE

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The primary objective of the COncvective Precipitation Experiment (COPE) was to improve quantitative precipitation forecasts for summertime convection over SW England with a special emphasis on understanding microphysical processes that impact hydrometeor development. Observations from the University of Wyoming King Air research aircraft show occurrences of bimodal cloud droplet spectra, where there exist two distinct droplet size populations. The focus of this work is to describe the mechanism(s) responsible for development of bimodal spectra in COPE clouds. Observations are restricted to cloud penetrations devoid of precipitation where it is expected that only entrainment/mixing, secondary activation, or a combination of both would contribute to the bimodality of the cloud droplet spectra.

Here we present an analysis of several cases based on observations from in situ cloud microphysical probes. We examine several environmental factors to look for evidence of entrainment events within regions containing bimodal spectra. Correlations between the adiabaticity and concentration in each mode are examined. Mixing diagrams are employed in order to determine what type of mixing process is dominant. While some of these analyses indicate evidence of entrainment, others are less clear. The theoretical super-saturation a parcel would experience when neglecting the small mode and the updraft speed required to achieve various levels of super-saturation are also calculated. Initial results show evidence that secondary activation could potentially explain the observed bimodal spectra, however, further numerical modelling studies to determine the relative importance of secondary activation on the development of the bimodal droplet spectra observed during COPE will be required.

P7.5

The entrainment velocity in stratocumulus driven by radiative and evaporative cooling

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2 1 Stratocumulus Entrainment Turbulence

Stratocumulus entrainment remains a large source of uncertainty for weather and climate models. We investigate how radiative and evaporative cooling promote entrainment in direct numerical simulations of a cloud-top mixing layer configuration that mimics the stratocumulus top. Our analysis partitions the entrainment velocity into three contributions that are related to radiative cooling, evaporative cooling and diffusion. The diffusive contribution originates from not resolving all atmospheric scales (up to 1 mm), and artificially enhances the entrainment velocity. We estimate that it accounts for 20% of the total entrainment velocity for our highest resolution ($\Delta x = 14$ cm). For typical LES resolutions ($\Delta x \sim 5$ m) the diffusive contribution can dominate the entrainment velocity.

The radiative cooling contribution to the entrainment velocity decouples from the evaporative forcing and follows the same scalings as in the smoke cloud. On the other hand, the evaporative cooling contribution is proportional to the radiative contribution. The proportionality factor depends on the thermodynamic properties of the inversion, and on an efficiency that quantifies how effective evaporative cooling is on enhancing the entrainment velocity.

The introduction of the efficiency reveals a complex dependency of the entrainment velocity on the inversion properties. It shows that drying the free atmosphere can have a negligible effect, increase the entrainment velocity, or lead to cloud breaking, depending on the inversion properties. Curiously, each of these tendencies is separately predicted by the current parameterizations of the entrainment velocity, which can be reconciled by our analysis.

P7.6

Wind-shear effects in stratocumulus-top entrainment

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1, 2, 9

Cloud-top entrainment in the stratocumulus-topped boundary layer and its interaction with local processes remains a source of uncertainty in current atmospheric models. In this work, we investigate the interaction among evaporative cooling, radiative cooling, and vertical shear of horizontal wind. It has been argued that wind shear weakens the in-cloud turbulence caused by radiative cooling because wind shear enhances cloud-top mixing and thereby entrainment-warming and drying, which reduces the cloud-top cooling caused by longwave radiation. The dependence of these results on the extinction length of the radiation flux, however, remains unclear. At the same time, wind shear has been shown to enhance the in-cloud turbulence caused by evaporative cooling under conditions of buoyancy reversal. Under these conditions, evaporation leads to convective instability and hence turbulence, which in turn enhances evaporation. Alone, this positive feedback is too weak to affect the cloud-top dynamics. However, wind shear can act as a catalyst of this positive feedback, leading to entrainment rates comparable to measurement values. Nonetheless, in-cloud turbulence intensities are smaller than measured. In this work, we study the interaction of both evaporative and radiative cooling with wind shear. We focus on the cloud-top region, a region on the order of a few tens of meters. As a tool, we use direct numerical simulation, to remove the uncertainty associated with turbulence models. This approach allows us to calculate all the contributions to the entrainment-rate velocity: the turbulent flux, and the direct contributions from radiative cooling and evaporative cooling.

P7.7

A simple model for entrainment and mixing in growing deep cumulus updrafts

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It has long been established that entrainment is critical for moist deep convection, yet considerable uncertainty remains in how it is represented in convection parameterizations. Theoretical analytic expressions are derived for the evolution of a passive scalar, buoyancy, and vertical velocity within rising moist deep convective updrafts. These expressions are quantitatively consistent with idealized three-dimensional moist updraft numerical simulations initiated by applying warm bubbles of varying size in unsheared environments. In particular, the analytic expressions capture the decrease of buoyancy and vertical velocity as the environmental relative humidity is decreased, and show that the buoyancy becomes negative a few km above the level of free convection for the narrowest updrafts in a dry environment in agreement with the simulations. The analytic model also describes the sharp narrowing of updrafts below the height of maximum buoyancy seen in the simulations due to the inflow of environmental air required by mass continuity to balance upward acceleration of updraft air (i.e., dynamic entrainment). This flow sharpens horizontal gradients, thereby enhancing smaller-scale turbulent mixing. For narrow updrafts in dry environments, this enhanced mixing leads to a region of negative buoyancy below the level of maximum buoyancy, effectively cutting off the region of positive buoyancy within the updraft from the level of free convection below so that the updraft structure appears thermal- rather than plume-like. These results are encapsulated by a conceptual model that describes the behavior of growing moist deep convection, and particularly the occurrence of thermal- versus plume-like updrafts.

P7.8

Are LES model simulated cloud microphysical relationships consistent with in-situ measured ones for stratocumulus clouds?

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Large Eddy Simulation (LES) models are known as an appropriate tool for studying microphysical, dynamical and radiative properties, and their interactions in stratocumulus clouds. As a way to verify the reliability of the models, usually model simulated macro-physical properties were compared with observations. However, if model simulated microphysical properties are not consistent with observation, model results may not be fully trusted. In this study we examine how realistic LES model simulated stratocumulus cloud microphysical relationships are. To do that we select cloud microphysics data obtained from a flight through marine stratocumulus clouds during the Variability of the American Monsoon System Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx) and the observed cloud microphysical relationships are then compared with those simulated with two LES models: one is CIMMS (Cooperative Institute for Mesoscale Meteorological Studies) LES and the other is WRF (Weather Research and Forecasting Model) LES. Both models are 3 dimensional and bin microphysics schemes are used. Comparison between observation and LES models focuses on cloud microphysical relationships because they can reveal how well entrainment and mixing processes are treated in the models. Some preliminary results indicate that both models are reasonably good at simulating thermodynamic characteristics in stratocumulus clouds. Meanwhile, results of the mixing diagram analysis of cloud microphysical relationships are mixed: WRF LES model shows somewhat similar pattern to that from observation but CIMMS LES model results are different from observation. The question is what we can do with this much discrepancy. More detailed results will be discussed at the conference.

P7.9

Characteristics of cloud microphysical relationships in the clouds measured during the GoAmazon project and their implication on entrainment and mixing processes

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Cloud microphysical properties can be modulated by entrainment and mixing of clear air, and how this occurs critically determines colloidal stability (i.e., warm rain initiation) and optical properties of clouds. Our recent study showed predominant homogeneous mixing (HM) traits although relevant scale parameter analyses indicated dominance of inhomogeneous mixing (IM), for the marine stratocumulus clouds over the southeast Pacific. We speculated that entrainment and mixing at the cloud top may have been indeed inhomogeneous as the scale parameters suggested but the vertical circulation mixing in the cloud may have changed the cloud microphysical relationships to suggest HM at the altitudes of horizontal penetration. Meanwhile, continental stratocumulus clouds over the Southern Great Plains of the US showed even stronger HM traits. In this study we do similar analyses for the Amazonian clouds measured onboard the US DOE G-1 aircraft during the Green Ocean Amazon (GOAmazon) project. This project is unique in that different aerosol, thermodynamic and cloud microphysical properties for the dry and wet seasons were collected. Moreover, anthropogenic influence from Manaus, a city of two million population, can also be manifested. We specifically focus on highlighting the characteristic differences of cloud microphysical relationships between the dry and wet seasons and between polluted (Manaus plume affected) and clean conditions. Our aim is to reveal the implication on entrainment and mixing processes in these clouds generated under different aerosol and thermodynamic conditions.

P7.10

Local entrainment rates and anisotropy of entraining structures in laboratory analogues of cumulus and stratocumulus clouds.

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1, 2,3,16, laboratory studies

We investigate entrainment at the top of laboratory analogues of cumulus and stratocumulus clouds generated in a cloud chamber. The Particle Image Velocimetry technique, where cloud droplets serve as tracers, allows us to retrieve 2D velocity fields in a plane cut through a region of interest. Finding a cloud-clear air interface in the images and calculating a velocity field with respect to the interface, we are able to estimate local values of entrainment velocities. We report substantial small-scale variability of local entrainment/detrainment velocities. Integrated entrainment velocities in laboratory cumulus analogue are an order of magnitude greater than these in stratocumulus analogue. We notify differences in geometry of entraining structures in stratocumulus and cumulus analogues. Presence of stably-stratified, inversion-capping stratocumulus results in flattening the entraining eddies. This is in agreement with airborne measurements in the course of Physics of Stratocumulus Top (POST) research campaign, which document similar anisotropy of turbulence in stratocumulus top region. Using retrieved velocities, we quantify anisotropy of turbulence in both: stratocumulus and cumulus analogues and discuss the role of turbulence anisotropy in entrainment process.

P7.11

Effect of Entrainment-Mixing on Cloud Microphysics: A Study using In-situ Observations

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Entrainment and subsequent mixing of dry air significantly impacts the cloud droplet size distribution (DSD) that is important for cloud radiative properties and first rain drop formation. The entrainment and mixing mechanisms are investigated in this study using *in situ* observations in warm deep cumulus clouds over the Indian summer monsoon region. A Linear increase in the droplet number concentration (upto 0.6 km above cloud base) and the mean radius in the premonsoon cloud is observed, in contrast to the parabolic variation of mean radius and decrease in droplet number concentration above cloud base in the monsoon cloud. Mixing processes are discussed contrasting homogeneous and inhomogeneous mixing, and their effects on cloud droplet size distribution, number concentration and mean radius are addressed within the uncertainty of observations. Inhomogeneous type mixing is noted at cloud edges where dilution is significant and spectral width of DSD decreases. DSD suggests that largest droplets are typically formed in less diluted cloud cores where raindrops form. Strongly diluted cloud edges have relatively smaller droplets. The diluted parcel size is larger (100-200 m) for cloud edge parcels compared to the cloud core parcels (10-20 m). The origin of the entrained parcels in deep cumulus clouds is investigated with conserved thermodynamic diagrams. The analysis suggests that the entrained parcels originate from a level close to the observational level, in agreement with previous observations.

P7.12

Large-eddy simulation of the stratocumulus-topped boundary layer: a study of entrainment and anisotropic cloud-top turbulence

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Key area numbers: 2 and 1

Key words: Large-eddy simulation, stratocumulus, anisotropic turbulence, entrainment

New findings from the Physics of Stratocumulus Top (POST) field campaign indicate that the turbulence in the interfacial layer separating the cloud top and the free troposphere is anisotropic at scales larger than approximately 0.5 m. Motivated by these observations, we perform high-resolution large-eddy simulation (LES) to study details of small-scale processes in the cloud-top region. Using the 3D nonhydrostatic anelastic Eulerian/semi-Lagrangian (EULAG) model (<http://www2.mmm.ucar.edu/eulag/>), we perform series of simulations applying setups based on POST and DYCOMS-II observations as well as simulations of a smoke-like cloud with no evaporation/condensation (see http://www.atmos.washington.edu/~breth/GCSS/smoke/smoke_cloud_spec.html). While it is not yet feasible to resolve the smallest scales involved in the entrainment processes in LES studies of the stratocumulus-topped boundary layer (STBL), we find that the anisotropy of the observed turbulence can be mimicked by applying anisotropic computational grids, with higher vertical and coarser horizontal resolutions. This is because coarsening the horizontal resolution and refining the vertical resolution tends to dampen vertical fluctuations in the interfacial layer. Implications of these findings for LES modeling of the STBL in general and of cloud-top turbulence and entrainment in particular will be discussed at the conference.

P7.13

The role of updraft merging in the development of deep convection

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Recent numerical modeling studies have shown no significant correlation between initial properties like buoyancy and vertical velocity of cloudy parcels and their eventual detrainment height. This could suggest that the entrainment that these parcels experience is completely stochastic, and not related to their initial nature. However, it has been shown that cloudy parcels experience reduced entrainment rates and higher detrainment heights if they are part of a cloud with a large base size. It is also known from observations of cumulus convection that several small cumuli may unite to form a single cell, and that large updrafts may form from the merging of smaller updrafts. Most cumulus parameterizations assume that cumulus updrafts interact with other updrafts only indirectly via detrainment and cumulus induced subsidence. What has not been explored is the merging of updrafts, which would be a direct interaction. We use Large Eddy Simulation to look in detail at the updraft merging process. We use a combination of analysis techniques including Lagrangian Parcel Tracking to confirm that merging occurs in the development of deep convection. By examining the past history of parcel trajectories we can quantify the dynamic forces that cause cloudy updrafts to merge. In particular, it is known from numerical modeling that damping convective cold pools causes reduced updraft base sizes and less deep convection. We examine the hypothesis that cold pools encourage updraft merging by increasing convergence along their leading edges (gust fronts) and / or reducing the distances between updrafts.

P8.1

The simulation and mechanism analysis of '721' torrential rain in Beijing

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The reanalysis data from European Center for Medium-Range Weather Forecasts (ECMWF) and the infrared brightness temperature measurements of FY-2E from National Satellite Meteorological center were used for synoptic analysis of the extreme rainstorm on 21 July 2012 in Beijing. By assimilating the multi-source observations with the Local Analysis and Prediction System (LAPS), it was successfully simulated by the Weather Research and Forecasting (WRF) Model. The results showed that: the torrential rain occurred with the favorable multi-scale weather background, including the Hetao cyclone, the cold front, the configuration of upper and low-level jet and the typhoon 'Vicente'. The simulated results reproduced the time-space distribution characteristics in warm-sector precipitation and cold front precipitation stage, the development, propagation and organization of mesoscale convective systems. The mechanism analysis for warm-sector precipitation revealed: The convective cells were triggered by the terrain convergence line and moved along the Taihang Mountain with the southwesterly airflow. Due to vertical advection of potential vorticity and non-adiabatic heating, the propagation of cells were characterized by the back-propagation, which is the possible reason for the 'train effect' of convective activities. Meanwhile the dynamical uplift of surface cool pool and the downward momentum led to the coupling of vertical velocity centers in upper and lower levels, which played a key role in the enhanced and organized convections.

Key Words: torrential rain, numerical simulation, precipitation mechanism, back-propagation, train effect, downward momentum

P8.2

721-Beijing rainstorm process analysis caused by the Hetao cyclone development eastward shift

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Abstract : this paper diagnostic analysis the 721-Beijing rainstorm weather process caused by the Hetao cyclone development eastward shift, the results show that: Hetao cyclone is the major affected system of 721-Beijing rainstorm weather process, the 700 hPa strong cold air activities blocking the Hetao cyclone northward conventional path, forcing its eastward shift and directly affect the Hebei and Beijing. In the process of Hetao cyclones eastward shift, the warm heart barotropic cyclones change into baroclinic cyclone and strong development, its vapor, heat and High-low level jet stream coupling conditions significantly strengthened with the Hetao cyclone eastward shift, is the main reason of the precipitation increasing from west to east. Afternoon, warm front triggers the release of potential instability energy with the Hetao cyclones eastward shift, generated strong convective system, formed mesoscale convective complexes (mcc) in the Beijing area, make precipitation further strengthen, is the main reason of 721-Beijing rainstorm. The topographic Lifting increase the role of the precipitation in the southeast airflow, 721-Beijing rainstorm is caused by a variety of favorable factors superimposed.

Keyword: Hetao cyclone, Beijing, torrential rain, MCC

P8.3

Characteristics of Cloud Chart and Environment Field on a Heavy Rain in Shanxi Province in July 2011

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The characteristics of cloud chart and environment field on a heavy rain in Shanxi Province in July 2011 was analyzed. The results showed that: (1) This heavy rain occurred under the background of two trough and one ridge at 500 hPa, subtropical high stability, and an anticyclone at 200 hPa. High energy, high humidity, divergence at high and convergence at low, and strong ascending motion were the basic environment characteristic of initial generation of cloud cluster, but there is a great difference among dynamic and thermal structure, intensity, and mesoscale environment that lead to the development of cloud cluster a later period. Four area of heavy rain caused by different property of cloud, and there has a great difference between precipitation property and characteristics. (2) L Brand showed that disappear of cloud layer, lower of cloud top height, enlarge of humidity thickness, lower of congeal height, lower of 0°C layer, and disappear of temperature inversion layer were indication of forming of MCC. (3) Diagnosis physical quantity showed that there were main information of development of MCC: LLJ as narrows, a branch of jet was disappear, and NWJ high was weaken, NW at low was strengthen at the same time. Atmosphere instability was enlarge. Water vapor was enlarge suddenly, and air pressure was strengthen continually in warm area south of frontal surface. (4) Forced by humidity front, MCC formed by development of convective cloud cluster near humidity center since invasion of dry and cold air.

P8.4

Circulation induced by low level radiative cooling

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Studies of radiative convective equilibrium in idealised domains have shown that low level cooling is important in forcing the organisation of convection. This cooling, maximising at the top of the boundary layer, is thought to drive a divergent low level flow that both enhances subsidence in the non-convecting areas and transports moist static energy into convecting areas. A comprehensive interpretation of the role of low level radiative cooling in driving the organisation of convection is currently limited by a poor understanding of how low level radiative cooling, in particular in connection with a boundary layer flow, induces such a secondary circulation and which parameters influence its structure and strength.

In this study, we use bulk concepts and idealised large-eddy simulation to investigate to what extent radiative cooling in the lower atmosphere in non-convecting areas can induce a secondary circulation that is important in determining the structure in regions of deep convection. We explore which parameters determine the strength of the secondary circulation, and show that, e.g., the height of the cooling maximum and the gradient of cooling in the boundary layer are important to determine the structure of the flow.

P8.5

A Modeling Study of Parameterization Schemes for Depositional Growth of Ice Crystal: Four Rainfall Cases over Tropics and Midlatitudes

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Depositional growth of ice crystal, rainfall simulation, rain rate, cloud-resolving-model simulation

Four schemes that parameterize depositional growth of ice crystal are tested in the cloud-resolving mode simulations of four rainfall cases over tropics and midlatitudes in this study. The improvement of rain-rate simulation by Shen's scheme (2014) and associated physical process are studied through the comparison between the observations and simulations and the analysis of cloud and heat budgets. The simulations generally show overestimations of rain rate compared to the observations. The scheme developed by Zeng et al. (2008) could produce anomalous cloud ice and rainfall when ice nuclei concentration is high. Shen's scheme significantly cuts rain rate and cloud ice and produces the closest rain-rate simulation to the observation through the decrease in hydrometeor loss in response to the dramatic reduction in depositional growth of cloud ice from cloud water. Compared with the other schemes developed by Hsie et al. (1980), Krueger et al. (1995) and Zeng et al. (2008) with low and medium ice nuclei concentration, Shen's scheme also reveals the better rainfall simulation due to it enhances cloud ice and produces the infrared radiative warming in the upper troposphere, which weakens atmospheric cooling. The suppressed atmospheric cooling reduces the hydrometeor loss and thus rainfall through the decreases in collection of cloud water by rain, accretion of cloud water by graupel and conversion from cloud ice to snow.

P8.6

Effects of Large-Scale Forcing on Cloud Microphysical and Rainfall Responses to Radiation during the Landfall of Severe Tropical Storm Bilis (2006)

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Radiation , rainfall, large-scale forcing, net condensation, hydrometeor

The effects of large-scale forcing on cloud microphysical and rainfall responses to radiation were investigated by analyzing mean cloud budgets from sensitivity cloud-resolving model simulation data of severe tropical storm Bilis (2006) during its landfall. When imposed forcing had upward motions in the upper troposphere and weak downward motions near the surface on 15 July 2006, the removal of radiative effects of cloud water decreased hydrometeor loss and rainfall through the reduction in evaporation of rain in the presence of radiative effects of cloud ice but it increased hydrometeor loss and rainfall through the enhancement in melting of graupel in the absence of radiative effects of cloud ice. The removal of radiative effects of cloud ice enhanced rainfall via the strengthened net condensation regardless of radiative effects of cloud water. When imposed upward motions were extended to the lower troposphere on 16 July, the elimination of radiative effects of cloud water reduced rainfall via the suppressed net condensation regardless of radiative effects of cloud ice. The exclusion of radiative effects of cloud ice decreased hydrometeor loss and rainfall through the suppression in melting of cloud ice to cloud water and the enhancement in accretion of cloud water by graupel in the presence of radiative effects of cloud water, whereas it increased hydrometeor loss and rainfall through the enhancements in evaporation of rain and melting of cloud ice to cloud water in the absence of radiative effects of cloud water.

P8.7

Characteristics of wintertime snowfall for the last decade in the Yeongdong region of Korea

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The Yeongdong region has various meteorological phenomenon by virtue of complicated geographical characteristics with high Taebak and an adjacent East Sea to the east. The synoptic settings for the heavy snowfall in winter are the Siberian High extended to northern Japan along with the Low system passing by the southern Korean peninsula, which eventually results in the northeasterly or easterly flows in Yeongdong. The basic mechanism to initiate this snowfall around Yeongdong seems to be similar to that of lake-effect snowstorms around Great Lakes in Canada, and the United States, and also western Japan across the East Sea. Interestingly, snowfall appeared to begin in case of an air-sea temperature difference exceeding over 15°C. We also attempted to investigate temporal variations of water vapor, liquid water and snowfall using ground-based Global Navigation Satellite System measurements, Microwave radiometer, and radiosonde systems. The results show that low-level clouds exist below 2~3km thickness with cloud base less than 1km, where northeasterly and northerly winds are consistent. The analysis has been made along with the classification of 3 dominant synoptic patterns such as Low Crossing, Low Passing, and Stagnation types. The snowfall intensity of Low Crossing is lowest, when a sharp increase in water vapor is followed by an increase in precipitation with the remarkable time lag. Furthermore, we began to examine snow crystal habits using both digital and i-phone cameras since 2013. The snow crystal habits observed are mainly dendrite and dendrite combinations, consisting of 70 % of the entire snow crystals.

P8.8

Radar-derived structural characteristics and precipitation production of convection observed during the CONvective Precipitation Experiment (COPE)

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1,3,4,17

This study uses measurements from a polarimetric ground-based radar to investigate the microphysical properties of warm-based convection characterized by both warm rain and ice processes. Data were collected during the Convective Precipitation Experiment (COPE), which sampled convection in southwest England in July-August 2013. The primary data set used here is from the National Centre for Atmospheric Science (NCAS) dual-polarization X-band radar, which provided an extensive set of high-resolution observations of convection which were supplemented in many cases by airborne measurements from the University of Wyoming King Air research aircraft.

The convection observed during COPE produced radar reflectivity values of up to ~60 dBZ. Some of the deeper convective cells developed columns of positive ZDR values (commonly 1-3 dB) extending well above the environmental freezing level, with values of 1 dB extending up to 3.5 km above the freezing level in some cases. These ZDR signatures are characteristic of large liquid drops lofted in convective updrafts, and are indicative of a vigorous warm rain process early in the cell's life cycle. An automated technique to objectively identify cells developing ZDR columns was created in order to statistically quantify these cells' structural and microphysical characteristics. Based on this data set, statistical analyses will be presented summarizing the typical convective structure using the observed Z and ZDR signatures. Additionally, the statistical characteristics of the precipitation produced by this convection will be described, using rainfall estimates derived from the polarimetric signatures.

P8.9

Modeling of daytime convective development over land with COSMO-EULAG

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Dynamical core of the anelastic model EULAG (<http://www2.mmm.ucar.edu/eulag/>) has been implemented into COSMO weather prediction model (<http://www.cosmo-model.org/content/model/general/>). The motivation of employing EULAG to weather forecasting is two fold: i) the model has considerable advantages concerning conservation properties and ii) does not impose severe constraints on the maximal allowable steepness of the surface orography. In addition, EULAG features a high numerical robustness confirmed in number of benchmark tests.

To date the new prototype model COSMO-EULAG has been successfully tested in a number of idealized and realistic simulations. Current efforts are focused on accurate modeling of convective processes and further optimization of the prototype model. The main goal is to calibrate coupling between EULAG dynamical core and COSMO physical parameterizations to make the code suitable for resolving explicitly convective processes. The optimizations involve tuning of turbulence scheme, shallow convection parameterization, moist processes and other cloud processes.

The test simulation setup is based on observations of the diurnal cycle and convective development during rainy season in Amazonia. The focus is on the 6h period between the sunrise and early afternoon. A number of simulations have been performed for different parameterization of moist processes and for different resolutions (down to 100 m horizontal gridlength) and different subgrid-scale parameterizations. The simulations evaluate model's capabilities for modeling the transition from shallow to deep convection. The study involves also the comparison of COSMO-EULAG results with results of the standard compressible COSMO-Runge-Kutta model to test the suitability of an anelastic dynamical core for operational mesoscale high-resolution NWP.

P8.10

Evaluation of bulk microphysics schemes in simulated snow clouds in the Hokuriku district, Japan

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The Hokuriku district, which is located in the northern part of the central Japan, is one of heavy snowfall regions in the country. When a cold outbreak from the Eurasian Continent occurs, a large number of snow clouds are generated over the Sea of Japan. They are gaining strength as they head for the Hokuriku district. The resulting heavy snowfall makes enormous impacts on lifelines; the damage to electric power cables, the cancellation of flights and trains, traffic jams and so on. The reduction of the impacts requires the improvement of numerical weather prediction. The microphysics scheme in numerical models is one the most important factors in predicting accuracy precipitation. In this study, we evaluate bulk microphysics schemes in the Hokuriku snow clouds simulated by the WRF model, comparing the vertical profiles of hydrometeors predicted by each scheme with observations by videosondes, which are balloon-borne equipment that can measure sizes and electric charges of each precipitation particle in cloud. Large differences are found among the vertical profiles of hydrometeors simulated by each microphysics scheme. Some profiles are inconsistent with videosonde observations.

P8.11

The interaction between ice nuclei and deep convection in Southeast China

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The key area numbers are 12, 3, 4 and 14.

This study focuses on the vertical transport of aerosols by deep convection and the effect of aerosols as ice nuclei on the microphysical properties and precipitation of deep convection. Aerosols can facilitate ice formation through deposition nucleation, condensation freezing, contact freezing, and immersion freezing. We use the mesoscale WRF model with a double-moment microphysics scheme to simulate a deep convective system in Southeast China. It is found that, with strong updrafts in the convective core, aerosols are efficiently transported upwards to the 0 °C level and higher, where IN take effect and heterogeneous ice nucleation occurs. Contact freezing mainly occurs at warmer temperature (lower altitudes), and the other three ice nucleation modes occur at lower temperature (higher altitudes). The convective core region is more dominated by immersion freezing and homogeneous freezing, while the cloud anvil region with nearly no liquid droplets is more dominated by deposition nucleation and condensation freezing. When IN concentration is higher, ice can form at warmer temperature (lower altitudes), and the mixed-phase layer has more ice crystals but less liquid water. Snow increases as a result of the increased ice, while graupel is reduced slightly because of the lack of liquid droplets in the mixed-phase region. The area of cloud anvil is larger with more ice crystals. However, in the warm cloud region, the mixing ratio of liquid water shows no significant change. The effect of IN on deep convective precipitation is also very limited.

P8.12

Improved predictions of atmospheric icing in Norway

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17,1, 4,

Atmospheric icing is a major weather threat in many countries, including Norway. During the winter season 2013/2014 two major power lines in Southern Norway suffered severe damage due to ice loads exceeding their design values by two to three times. Better methods are needed to estimate the ice loads in order to build robust infrastructure. The Wind, Ice and Snow loads Impact on Infrastructure and the Natural Environment (WISLINE) project was initiated to address this problem and to explore how a changing climate may affect the ice loads in Norway.

Simulating supercooled droplets is essential when studying in-cloud icing. Currently, the microphysics scheme in the operational AROME numerical weather prediction model used at MET-Norway is based on physics similar to Lin et al. (1983). Several studies have shown that these schemes tend to produce too little supercooled water and tend to glaciate the clouds more often than observed. This also leads to excessive precipitation. The same studies have shown that the Thompson et al. (2008) and Morrison et al. (2009) scheme generates considerably better results.

The study will focus on improving the microphysics scheme in the AROME model, by making it more similar to the Thompson scheme. Both idealised and real simulations will be carried out. This will then be validated against observations, using both conventional and more advanced icing measurements. We will show first results from this investigation.

P8.13

On the effect of aerosols on orographic cloud and precipitation

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6. Orographic clouds

12. Aerosol-cloud-precipitation-interactions and processing

14. Ice nuclei and cloud condensation nuclei

The Weather Research Forecast (WRF) mesoscale model coupled with a detailed bin microphysics scheme is used to investigate the impact of aerosol particles serving as cloud condensation nuclei and ice nuclei on orographic clouds and precipitation. A mixed-phase orographic cloud developed under two scenarios of aerosol (a typical continental background and a relatively polluted urban condition) and ice nuclei over an idealized mountain is simulated. The results show that, when the initial aerosol condition is changed from the relatively clean case to the polluted scenario, more droplets are activated, leading to a delay in precipitation, but the precipitation amount over the terrain is increased by about 10%. A detailed analysis of the microphysical processes indicates that ice-phase particles play an important role in cloud development, and their contribution to precipitation becomes more important with increasing aerosol particle concentrations. The growth of ice-phase particles through riming and Wegener-Bergeron-Findeisen regime is more effective under more polluted conditions, mainly due to the increased number of droplets with a diameter of 10-30 μm . Sensitivity tests also show that a tenfold increase in the concentration of ice crystals formed from ice nucleation leads to about 7% increase in precipitation, and the sensitivity of the precipitation to changes in the concentration and size distribution of aerosol particles is becoming less pronounced when the concentration of ice crystals is also increased.

P8.14

Spatio-temporal characterization of warm convective cloud fields over Central Europe

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2. , 3.

Warm convective clouds are highly variable in space and time. Typical horizontal and vertical length scales of these clouds are roughly 1 km, and formation and dissipation of these clouds can occur very rapidly. This variability complicates a realistic representation in numerical models, and also introduces significant uncertainties in passive satellite retrievals.

While several satellite studies have already investigated typical spatial scales, we focus here in particular on the identification of temporal scales of warm convective clouds. For this purpose, we apply data from Meteosat SEVIRI with a repeat cycle of 5 minutes over Central Europe. The spatial auto-correlation function and the decorrelation time is determined for selected cases of convective cloud fields spanning an area of 50x100 km² and adopting both the Eulerian and the Lagrangian perspectives. The latter is based on cloud tracking using high-resolution cloud motion vectors. The budget in an Eulerian reference frame is nearly always dependent on an inherent, Lagrangian temporal change and an advective component, which can be described by the wind speed and the spatial decorrelation length.

We find a strong dependency of the Eulerian decorrelation time scales on the horizontal velocity of the cloud fields which is consistent with the expected behaviour for stationary ground-based measurements. In contrast, the decorrelation time in the Lagrangian frame is found to be relatively constant, having a mean value of about 30 minutes. Finally, we compare the spatio-temporal characteristics of high resolution modelled cloud fields and discuss the resolution dependency on these scales.

P8.15

Comparing the spatio-temporal variability of warm cumulus clouds from ICON-LES, COSMO-DE modelling and Meteosat observations

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2. Warm boundary layer clouds (Modelling)

Warm cumulus clouds show a high spatio-temporal variability which complicates a realistic representation in numerical models, and also introduces significant uncertainties in passive satellite retrievals. Thus intercomparisons between observations and high resolution models are essential in order to better understand these observational and model uncertainties.

Within the framework of the HD(CP)2 project, the innovative atmospheric model ICON-LES was developed. This model was successfully used for high resolution simulations covering Germany with a horizontal resolution of $150 \times 150 \text{ m}^2$. To evaluate this model and the benefit of its high spatial resolution, different simulations of cumulus cloud fields are compared to operational COSMO-DE model output with $2,8 \times 2,8 \text{ km}^2$ and Meteosat observations with $4 \times 6 \text{ km}^2$ spatial resolution. Further, the spatio-temporal characteristics of the simulated and observed cloud fields are compared and the resolution dependency of these scales is investigated.

We find a strong dependency of the spatio-temporal scales of warm cumulus cloud fields on the horizontal resolution. An additional coarse-graining of the high resolution ICON-LES data down to COSMO and Meteosat resolution shows a scale break at around 750 m. Despite the realistic simulation of cumulus cloud field structures, ICON-LES output shows some biases that are finally discussed.

P8.16

Aerosol-Cloud interactions in orographic wave clouds (ICE-L)

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4, 6, 12

Ice nucleation and cloud droplet freezing are two of the most poorly constrained cloud microphysical processes in the atmosphere. Orographic wave clouds at mid-tropospheric levels provide an ideal testbed to study these processes by combining aircraft measurements and numerical modeling. In the presented work we investigate wave clouds observed over the Rocky Mountains during the ICE-L campaign using the Unified Model. The thermodynamic and dynamic properties of the wave clouds are extremely well captured in the simulations, which allows us to focus on the representation of cloud and aerosol processes. Cloud microphysics are represented with the newly developed CASIM microphysical scheme, which accounts for aerosol processing and vertical transport. We evaluate the performance of different ice nucleation parameterizations in representing the measured microphysical evolution. This comparison provides important insights in our current understanding of cloud droplet freezing and ice nucleation.

The effects of atmospheric aerosol on the warm rain process: two case studies during the COncvective Precipitation Experiment (COPE) and numerical simulations

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We present in-situ observations of liquid convective cumulus clouds on the 18th (B788) and 25th (B789) July 2013 during the COncvective Precipitation Experiment (COPE) and simulation results from two numerical microphysics models, the Aerosol-Cloud-Precipitation Interactions Model (ACPIM) and the Kinematic Driver Model (KiDs). The purpose of this study is to determine the impact of aerosols on the warm rain process.

In-situ observations took place over the Southwest Peninsula of the UK, and included aerosol and cloud observations. The aerosol properties were distinctly different: the number concentration of small aerosols in B788 were triple that of B789. The cloud droplet effective radius (ER) of B788 was ~11 μ m at cloud top, while in contrast, for B789 it was up to ~19 μ m. NIMROD (operational precipitation network) radar data also showed the surface rain rate of B788 to be lower than that of B789. This agrees with the common observation that large number of small aerosols suppress warm rain.

In order to simulate and investigate the impact of aerosols on liquid clouds and warm rain processes, ACPIM (bin scheme parcel model) and KiDs (bin scheme column model) were employed. ACPIM showed a clear reduction of ER with large numbers of small aerosols. It also revealed the chemical properties of aerosols, ambient atmospheric environmental conditions and Giant CCN do not have a strong influence on the cloud structure or warm rain processes in this case. KiDs suggested a large number of small aerosols decreases the surface rain rate prolonging the lifetime of the clouds.

P8.18

Evaluating the role of precipitation-sized ice particles in the simulations of deep convection with a multi-moment four-category ice microphysics scheme

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8. WRF, MC3E, NTU microphysics scheme

The traditional ice microphysics parameterizations in cloud resolving models commonly predict three categories of frozen hydrometeors including cloud ice, snow, and graupel, and each with a fixed bulk density. Such treatments tend to produce large bias in simulated radar reflectivity associated with excessive precipitation-sized ice particles in the upper troposphere. A large portion of the discrepancies resulted from the assumption of fixed bulk density which led to biased sedimentation velocity and collection kernel. Also, for strong convections, a single category of graupel is insufficient to describe all together the hail-sized particles. Therefore, a hail category was added into the bulkwater microphysics scheme of National Taiwan University (NTU) which was coupled into the WRF (Weather Research and Forecasting) model version 3.5.1. The NTU scheme also included prognostic volume which allows flexible ice density. A squall line system on 20 May 2011 during the field campaign of Mid-latitude Continental Convective Clouds Experiment (MC3E) was selected for investigating the impact of these physical parameterizations on the simulation of deep convections. Preliminary validations against to ground-based radar observations depicted that the NTU scheme improved several major features, such as the vertical structure of radar reflectivity factor and updraft strength, of the simulated convective system. Further evaluations and mechanism analyses will be presented.

P8.19

Monitoring fog at Sofia Airport using GNSS tropospheric products and Sofia Stability Index

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7. Fog and fog layers

In this work we study fog formation, development and dissipation in Bulgaria by using surface synoptic observations and vertically Integrated Water Vapour (IWV) derived from Global Navigation Satellite Systems (GNSS). Selected are cases at Sofia Airport for the period 2011-2014, which include both short (< 24 h) and long (>25 h) fog episodes and different fog types.

The topography and climate peculiarities of Sofia high valley predispose the seasonal character of fog formation during anticyclonic conditions. The fog in Sofia appears mainly during the cold season, with the highest frequency of registrations during December and January. Clear and calm or nearly calm weather favours the formation of inversions and hence the fog formation. Usually, the maximum of fog registrations is at 06 GMT and minimum at 15 GMT. It should be noted that the fog registrations between 12 and 15 GMT are mainly during long duration fog events.

Fog formation/dissipation is often accompanied with IWV decrease/increase. The warm air advection at 850 hPa is detected in temporal variation of IWV during some fog cases. Sofia Stability Index (SSI) is computed using surface observation at 600 and 2300 m asl. The index gives additional information about the development and the dissipation of inversion layer which is of particular interest during the long duration event. Comparison of SSI and index computed with the WRF Numerical Weather Prediction model (SSI-W) is performed in addition.

P8.20

Cloud Characteristics over Beijing Revealed with IAP's Ka Band Doppler Radar

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A ka band Doppler radar with polarization ability has been continuously operating at the roof of IAP Building for about 3 years since 2013. The radar observation include vertical structure of reflectivity Z_e , radial velocity V , Doppler spectra, and depolarization, all are in resolution of 30m. The preliminary time resolution is 1/3 second. With this kind data we have used to derive the statistical characteristic of vertical distribution of cloud classified as high, middle, and low cloud as well as non-precipitating cloud and precipitating cloud, typical diurnal variation and seasonal variation. It has been shown that the quantitative typical values of different cloud types in northern China have obvious regional characters, depending on seasonal, main weather system, as well as surface situation.

Comparison with space-borne observation of Cloudsat/Calipso results is also made. Since Cloudsat/Calipso data have the ability of global average but limited local time only twice a day over same site, the space-borne observation and ground-based observation should be supplementary each other, thus result more satisfied cloud characteristics.

P8.21

Evaluation of cloud properties in Environment Canada's high-resolution NWP simulations with satellite-borne radar, lidar, and aircraft in-situ observations

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A sub-kilometer, nested numerical weather prediction (NWP) model with an inner-domain of (252 km)² and horizontal grid-spacing of 250m has been tested recently at Environment Canada (EC). It aims to improve the representation of atmospheric phenomenon on scales smaller than ~1 km. Therefore, it has the potential to improve the representation of cloud, and related, process which are often crucial for weather prediction. For this study, a tropical convective system, over Guyana (~4deg N) on 16-May-2015, was simulated. The timespan and location of the simulation included an overpass of A-Train satellites. Data from the W-band cloud radar on CloudSat, the cloud-aerosol lidar on CALIPSO, and the MODIS imaging spectroradiometer on Aqua were used to verify modelled cloud properties. The CFMIP Observation Simulator Package (COSP), which is capable of simulating some A-train products, was used to convert model-predicted variables to synthetic CloudSat and CALIPSO measurements. COSP represents an attempt to reconcile modelled clouds with remote observations; in this case radar reflectivity and lidar attenuated backscatter. In addition to A-train data, in situ observations of cloud properties were made from Canadian NRC Convair-580 and French SAFIRE Falcon-20 aircraft that flew along CloudSat's path and coincided at approximately the centre of the model's inner-domain. Both aircraft were equipped with a suite of remote sensing and cloud microphysical instruments. Further directions for using aircraft data together with COSP (i.e., A-Train data) to verify the NWP simulations will be discussed.

8, 9, 17 numerical weather predictions, mesoscale cloud systems, satellite validations

P8.22

Meteosat-based Characterization of the Initiation and Growth of Severe Convective Storms over Central Europe

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8,3

The initiation, the growth phase and the transition to the mature phase of severe convective storms over Central Europe is investigated for the years 2012 to 2014. Using data from the SEVIRI imaging radiometer aboard the geostationary Meteosat satellite, dynamical and microphysical properties of developing storms are collected and combined. Several satellite-based storm properties, e.g. cloud-top temperature, cloud-top cooling rate and cloud particle effective radius, are studied following storm tracks. In addition, the onset and magnitude of radar-based surface precipitation and their temporal changes in vicinity of the satellite-based storm tracks are considered.

The majority of studied storms show a distinct maximum in cloud-top cooling rate which times has been considered for synchronization. The cloud growth phase is divided into an initial updraft intensification period before the maximum cooling and a continued growth period afterwards. The two growth phases last half-an-hour on average which sums up to around one hour for the total convective growth processes on the spatial scales seen by Meteosat. We furthermore show that the maximum cloud-top cooling rates are connected with the properties of the resulting anvil clouds around 15 to 30~minutes later which show faster expansion and on average smaller particles for larger updrafts. We further discuss the predictive skill of satellite-based cloud-top properties in terms of strength of and changes in precipitation intensity.

P8.23

Dominant Cloud Microphysical Processes during the 2013 Southwest China Summer Floods

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8,6

The Sichuan Basin, with its complex terrain, is located east of the Tibetan Plateau, north of the Yunnan-Guizhou Plateau, south of the Qinling Heights, and is a key storm-prone region of China. An extreme precipitation event that occurred on 8-11 July 2013, led to widespread flooding and debris flows that caused considerable infrastructure damage and numerous fatalities. This event was simulated by the WRF Model, and the dominant cloud microphysical processes and budgets of this severe rainstorm was investigated. The preliminary results show that, the orders of magnitudes of the various hydrometeors' sources and sinks in the strong precipitation were larger than those in the weak precipitation, causing a difference in the intensity of precipitation. Both liquid-phase and ice-phase hydrometeors played important roles in the production of the torrential rainfall. There were two main microphysical source terms of rain water, accretion of cloud water by rain and melting of graupel to form rain. Meanwhile, there were two main paths through which rain water were generated: abundant water vapor condensed into cloud water, and on the one hand, accretion of cloud water by rain water formed rain water; on the other hand, accretion of cloud water by graupel increased graupel, which then melted to increase the amount of rain water. Besides, another path, "sublimation of water vapor to increase cloud ice-accretion of cloud ice by snow-accretion of snow by graupel-melting of graupel to form rain", also contributed to rain water's increase.

P8.24

Cloud microphysics simulation using multi-dimensional bin-microphysics model

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Multi-dimensional bin-microphysics model was developed to simulate cloud microphysical processes in detail. The model has three and five independent variables for representing physicochemical properties of liquid and solid hydrometeors, respectively. Each variable is discretized into a finite number of bins. The properties of droplets are expressed as the spectra of mass values of pure water and two types of aerosol in the bin space. For solid hydrometeors, aspect ratio and volume are also considered as constituent parameters of bin space to widely cover the diversity of ice particles in natural cloud. This model has been implemented into Japan Meteorological Agency Non-Hydrostatic Model (JMA-NHM).

The model performance was examined in a two-dimensional simulation of isolated convective cloud. In the simulation, a variety of ice particles were expressed as the spectra of aspect ratio and bulk density. In the initial stage of cloud evolution, the aspect ratio of ice particles became large around -6 °C and -23 °C layers representing columnar crystals but small around -15 °C representing planar crystals. As the cloud further developed, the contrast in aspect ratio became unclear due to mixing of different types of ice crystals. In updraft region, density of ice particles tends to be large up to several hundreds kg m^{-3} . Ice particles with small density such as tens kg m^{-3} appear outside of updraft. We plan to do more simulations to examine robustness of the model. The preliminary results will be presented.

P8.25

Numerical modelling of stable radiation fog

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7.

Forecasting fog remains a major problem for numerical weather prediction models due to the complex interaction between many physical processes. One challenge for numerical models is predicting the structure of the boundary-layer and its evolution during the life cycle of a fog event. It has been shown that the stability of the boundary-layer during the life cycle of fog often undergoes a transition from stable to weakly unstable. Consequently it is important to correctly predict the timing of this transition in order to provide an accurate simulation of the fog event. The UK Met Office Unified Model (MetUM) uses a boundary-layer scheme which has six stability regimes, so it is necessary to correctly transit through the appropriate regimes to provide the appropriate boundary-layer structure for fog development.

A case study from the recent local and non-local fog experiment, which has provided highly detailed observational data over an 18-month period, has been chosen due to its unusually long stable period. This event has been examined to understand the processes behind the suppression of the fog layer's vertical growth. In this case, something prevented the transition from a stable to weakly unstable boundary-layer. Simulations using the single column version of the MetUM forced by observations will be presented; including examining the sensitivity of the structure of the boundary-layer to the selection of the vegetation type and length, microphysics scheme and boundary layer scheme.

P9.1

Simulation of the tropical cyclone Dumile in Meso-NH : coupling between a 2-moment microphysics scheme, an aerosol scheme initialized with MACC analysis, and an explicit emission of sea salt

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The main issue in front of the cyclone threat is to forecast both the track, the intensity and the main consequences (wind, precipitation, storm surge and swell) associated to a tropical cyclone. The past decade has been marked by significant advances in numerical weather prediction of cyclones, which have greatly contributed to the steady decrease of forecast track errors. However, the intensity forecasting remains a major issue in scientific research. The key role of cloud microphysics and aerosols on the structure and intensity of tropical storms has been recently underlined.

A 2-moment microphysics scheme (LIMA ; Vié et al., 2015) is being coupled to an aerosol scheme (ORILAM ; Tulet et al., 2005) in the French mesoscale model Meso-NH. Aerosols are initialized by MACC analysis from ECMWF which also monitor the lateral boundary conditions of the aerosol fields (prognostic variables). A parameterization of the emission of sea salt aerosol is implemented as the main source of cloud condensation nuclei in the context of the South-West Indian Ocean.

A first evaluation of this aerosol-cloud-microphysics coupling will be done through a simulation of the tropical cyclone Dumile that passed next to La Réunion in January 2013. Available observations (CALIPSO, CLOUDSAT, TRMM and METEOSAT satellites, ground radar and observations from the Maïdo observatory and Météo-France ground stations) will be used to validate the simulation. The sensitivity of the system structure and intensity to the aerosol type and concentration will be analyzed.

P9.2

A characterization of cold pools in the West African Sahel

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9. Tropical clouds

Cold pools are integral components of squall-line mesoscale convective systems and the West African Monsoon, but are poorly represented in operational global models. Observations of thirty-eight cold pools made at Niamey during the 2006 AMMA (African Monsoon Multidisciplinary Analysis) campaign (1 June to 30 September 2006), are used to generate a seasonal characterization of cold-pool properties by quantifying related changes in surface meteorological variables. Cold pools were associated with temperature decreases of 2 to 14°C, pressure increases of 0 to 8 hPa and wind gusts of 3 to 22 m s⁻¹. Comparison with published values of similar variables from the Great Plains of the USA showed comparable differences. The leading part of most cold pools had decreased water vapour mixing ratios compared to the environment, with moister air, likely related to precipitation, approximately 30 minutes behind the gust front. A novel diagnostic used to quantify how consistent observed cold pool temperatures are with saturated or unsaturated descent from mid-levels (Fractional Evaporational Energy Deficit, FEED) shows that early-season cold pools are consistent with less saturated descents. Early season cold pools were relatively colder, windier and wetter, consistent with drier mid-levels, although this was only statistically significant for the change in moisture. Late season cold pools tended to decrease equivalent potential temperature from the pre-cold-pool value, whereas earlier in the season changes were smaller, with more increases. The role of cold pools may therefore change through the season, with early season cold-pools more able to feed subsequent convection.

P9.3

The Impact of Biomass Burning Aerosols on Convective Cloud over the Western Pacific Warm Pool

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12, 9, 14

Convective precipitation associated with the Madden-Julian Oscillation (MJO) is one of the important rainfall features over the Western Pacific Warm Pool (WPWP). Due to the pattern of circulation and a lack of local emission sources of anthropogenic aerosols, WPWP has long been considered a pristine area. However, over the past few decades, biomass burning frequently occurs in summertime over the Maritime Continent. Biomass burning aerosols driven by southwesterly monsoon are transported to WPWP. The number concentration of these biomass burning aerosols is about 60% of background aerosols of the region investigated in this study. These additional aerosols have a potential to act as cloud condensation nuclei (CCN) to alter convective clouds and precipitation in WPWP via aerosol indirect effects. Using the Weather Research and Forecasting (WRF) model with modified chemistry package (WRF-Chem) with and without biomass burning aerosols, we have investigated the aerosol-cloud interactions associated with the biomass burning aerosols. Biomass burning emission is from the Fire INventory (FINN) version 1.5 from NCAR. One MJO event in October 2006 will be discussed.

P9.4

Emergence of consistent reflectivity profile behavior in the tropics as observed by TRMM

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- 9. Tropical clouds
- 3. Convective clouds
- 1. Basic cloud and precipitation physics
- 17. Applications of cloud and precipitation physics

16 years of TRMM profile data for 6 different tropical regions (3 over land and 3 over ocean) were collected and sorted according to rain top height (RTH). For all regions, it is seen that on average, higher RTH results in higher near surface reflectivities (NSR). The monotonic increase in NSR with RTH is especially robust for convective profiles and to a lesser degree for stratiform profiles.

By sorting reflectivity slope (dBZ/km) profiles according to RTH, a clear separation to three RTH classes becomes apparent:

- i) cold rain: RTH typically above -20C height, where slope profiles converge to a single profile, with little dependence on RTH.
- ii) warm rain: RTH typically below 5C height, where slope profiles are strongly dependent on RTH and slope values increase with height.
- iii) mixed phase rain: show a gradual transition behavior between the two other classes.

Inter regional differences (such as land vs. ocean) are mainly expressed for convective type profiles, where increase in convection intensity is manifested in larger deviation of the profiles from their stratiform equivalents. For stratiform cold rain type, a convergence to a single unique slope profile is seen. The results here imply that average tropical stratiform and convective profiles can be fully parameterized based only on RTH and the convective cloud base height.

P9.5

The Effects of Sea-Spray on Deep Convective Cloud under strong wind conditions

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9, 12,15

The ocean- boundary-layer- deep convection coupling is the principal TC 'power generator". The sea-spray droplets flux produced near the ocean surface under high wind speeds constitutes an important component of the above coupling.

Shpund et al. (2011, 2012, 2014) showed that sea- spray affects dramatically the thermodynamics and microphysics of the hurricane boundary layer (HBL) and increases surface fluxes. It was shown also that at least 20% of the sea-spray mass ascends and penetrate deep convective clouds. In this study the sea-spray effects on deep convective clouds are investigated by coupling of the Lagrangian-Eulerian model (LEM) of the HBL with 1D and 2D high-resolution spectral bin microphysics cloud models. Drop size distributions in the LEM model calculated under strong wind are used in the cloud models (below cloud base) to simulate the continuous sea-spray being injected into deep convective cloud typical of a TC eyewall. It is shown that sea-spray ascending in cloud updrafts increases cloud intensity and cloud top height. Sea- spray increases ice mass content. At the same time, sea spray decreases droplet effective radius via mechanism of in-cloud nucleation. As a result, the deep convective clouds in the eye wall of hurricanes obey unique properties combining properties of maritime and continental clouds. The comparison of effective radii calculated in cloud models with available observed data indicates a good agreement.

The results obtained suggest that the main effect of sea-spray on hurricanes is the microphysical/dynamical effect leading to TC intensification.

P9.6

Sensitivity of precipitation to clouds over upwind ocean in the Hawaii Island

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9, 6

A fine resolution 10-year regional climate simulation over the entire Hawaii archipelago is being conducted at the National Center for Atmospheric Research (NCAR). Numerical sensitivity simulations of the Hawaii Rainband Project (HaRP, a field experiment from July to August in 1990) showed that the simulated precipitation properties are sensitive to initial and lateral boundary conditions, sea surface temperature (SST), land surface models, vertical resolution and cloud droplet concentration. One interesting question is how the clouds over upwind ocean that are advected to the islands impact the precipitation over land. It is hypothesized that 1) the advected shallow cumulus clouds provide existing condensate to accelerate the precipitation formation over the island; and 2) the precipitating shallow cumulus clouds over upwind ocean, through cold pool interactions, modify the thermodynamic structure of the air that is advected to the island and subsequently change the precipitation formation over the island. This study tries to quantitatively address this question by simulating a weeklong precipitation period in the Hawaii Island.

P9.7

Evaluating cloud processes in HadGEM-UKCA in preparation for CLARIFY

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12 Aerosol-cloud-precipitation-interactions and processing

15 Cloud and precipitation chemistry

14 Ice nuclei and cloud condensation nuclei

We present preliminary results for a study of the representation of aerosol-cloud interactions in HadGEM-UKCA. CLARIFY (CLOUD-Aerosol-Radiation Interactions and Forcing: Year 2016) is a concerted effort by the UK Met Office and the Universities of Exeter, Leeds, Manchester and Oxford to observe and simulate the extended stratocumulus clouds off the coast of Namibia during the biomass burning season. The heart of CLARIFY is an intensive flight campaign. Researchers working on CLARIFY will collaborate closely with their USA counterparts working on ORACLES and ONFIRE campaigns.

As part of CLARIFY, the University of Oxford will add new diagnostics to the HadGEM-UKCA model to better understand modelled aerosol-cloud interactions. These diagnostics include observation operators for near- and in-cloud aerosol (for comparison against observations) and detailed process budgets focussing on aerosol entrainment. HadGEM results will also be compared against a hierarchy of higher resolution models including large eddy simulations. In the present work we intend to show an evaluation of cloud droplet number and albedo.

Our overall objective is to identify potential structural errors in the way HadGEM-UKCA treats aerosol-cloud interactions and improve the model where possible. As well, we will assess the biomass burning aerosol's effects on clouds and the resulting radiative forcing.

P9.8

Convective invigoration in Indian monsoon a possibility ?

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The aerosol and cloud physics observations were carried out with the help of an instrumented aircraft during Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) and the cloud droplet size distribution in deep cumulus clouds were observed at several vertical levels, upto -15 °C to -22 °C over the continental region. The main focus of the experiment was to investigate rain formation under different aerosol conditions. Observations suggested that while warm rain is suppressed in the polluted monsoon clouds, there is increase in supercooled liquid, which is closely associated with the increase in subcloud CCN concentrations. It is noted that there is more graupel and aggregates at the tops of these convective clouds when subcloud aerosol number concentrations are high in the boundary layer and pristine conditions exist at elevated layers. It is hypothesized that there is suppression of rain in the lower part of clouds and enhanced mixed phase processes under high aerosol conditions. Observational evidence is substantiated by numerical simulations with bin microphysics simulations.

P9.9

Simulation of tropical cyclones response to aerosol type

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The structures of rainband and eyewall of tropical cyclones can be influenced by aerosols through their influences on cloud microphysical processes. In this study, Typhoon Soudelor (2015) was simulated using the NCAR Weather Research and Forecast model (WRF) model that coupled with the National Taiwan University (NTU) double-moment microphysical parameterization scheme. The NTU scheme allows full interactions between aerosols and clouds including aerosol activation and recycling. Different scenarios of aerosol types and spatial distributions were designed to test the aerosol impacts. We analyzed the results including not only the microphysics but also the dynamics responses during different development stage of Typhoon Soudelor (2015). Preliminary results showed that aerosols can affect not only the strength but also the track of Typhoon Soudelor (2015).

key words: aerosol-cloud interactions, tropical cyclone

P9.10

Physical basis for Cloud droplet spectral broadening in the downdraft zones

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1. Basic cloud and precipitation physics

Observations of monsoon convective clouds during Cloud Aerosol Interaction and Precipitation Enhancement EXperiment (CAIPEEX) conducted over Hyderabad, India are utilized to understand changes in the width of droplet spectra at various horizontal distances from the cloud core. It is observed that width of the droplet spectra broaden in the downdrafts region, while it narrows in the updrafts. The broadening of cloud spectra in the downdrafts takes place with increased droplet number concentration along both the small and large droplet size ranges. Investigation is carried out with a Direct Numerical Simulation (DNS) to investigate the cause of spectral broadening in the downdrafts. When in DNS, similar droplet spectra are observed in the updraft and downdraft zones as in the aircraft observations. DNS results could reproduce similar droplet spectra in the updraft and downdrafts while an undiluted cloud droplet spectrum is allowed to mix with the environmental dry air. The increased concentration of large droplets in the cloud downdrafts are due to gravitational settling while enhanced number concentration of smaller droplets are attributed to evaporation process. In the cloud updrafts, droplet spectra are narrow due to absence of large droplets which are strongly influenced by gravitational settling and contributed to downdraft region.

P9.11

The use of IAGOS BCP observations to evaluate satellite products developed for detecting areas of high ice water content.

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17, 2, 5

Penetration of regions of high ice water content (IWC) in tropical and sub-tropical convective cloud regions has been associated with engine damage and rollback events and is implicated in the loss of aircraft. The risks associated with aircraft encounters with high IWC regions are relatively well understood, the forecasting of such regions presents a challenge.

Several particle backscattering optical spectrometers have been installed on a fleet of commercial airliners as part of the IAGOS project and have been flown since 2011. The backscatter cloud probe (BCP) is mounted flush with the skin of the aircraft and measures the concentration and optical equivalent diameter of particles from 5 to 75 μm .

BCP data will be used to identify a number of events with high ice water content in convective cloud regions and the properties analysed. The periods identified will be compared to satellite products developed at the Met Office for detecting these areas of high ice water content and regions of strong convection. The feasibility of using the satellite products as an in-flight forecasting tool for commercial airline pilots to allow them to avoid areas of high IWC will be investigated.

Variations of Ice Microphysical Properties in Tropical MCS Using Cloud In-Situ Data and Corresponding Radar Reflectivity Profiles

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Mesoscale cloud systems (including severe storms)

Tropical clouds

Convective clouds (including cloud electrification)

Mesoscale convective systems (MCS) can last several hours or more and affect human societies in different ways. In order to predict and identify hazardous weather (e. g. in view of aviation safety) linked to MCS, numerical weather forecast and active/passive remote sensing products are currently the most useful tools. A major obstacle to increasing the accuracy of those tools is the fact that cumulonimbus clouds in MCS are composed of liquid droplets and ice hydrometeors (ice crystals); the latter have complex shapes based on diffusional growth, aggregation, and riming, which complicates the interpretation of remote sensing products and increases the uncertainties in numerical weather forecast. In this context, the study presented here investigates the properties of ice hydrometeors in MCS as a function of temperature and horizontal distance from the convective core. For this purpose, ice hydrometeor images, bulk TWC, and simultaneously measured radar reflectivity factors from three airborne campaigns in tropical MCS have been used. The underlying scope of producing these results is to improve the retrieval of MCS microphysical properties from satellite products and also improve cloud parameterizations in numerical weather prediction models.

P9.13

Analysis of high-resolution cloud-precipitation distribution over Tibetan Plateau

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Tibetan Plateau for its high and steep mountain range, Himalaya, Vast main plateau with complex terrain, surface situation plays important role in influencing its own climate and weather, east Asia even world climate, through its unique radiation distribution, hydrological cycle, and thermodynamic and dynamical functions. Among those significant factors, cloud and precipitation distribution in Tibetan Plateau are the factors influencing both radiation budget and water cycle, as well as surface ecological situation

To understand the cloud and precipitation distribution and its variability, we use the TRMM PR products with $0.1^{\circ} \times 0.1^{\circ}$ resolution combined with same resolution topography map, analyze the monthly average distribution during 2002-2012, the time period covers pre-Monsoon and Monsoon seasons in this region. With these long term high spatial resolution data, the cloud precipitation pattern and their parameters revealed with intensity, vertical structure, stratiform and convective, and extending from southern part of Himalaya mountain range to main Tibetan Plateau, and to eastern surrounding area, Sichuan basin. In this paper, the cloud and precipitation pattern with high resolution of $0.1^{\circ} \times 0.1^{\circ}$ will be shown and discussed.

P9.14

High-resolution simulations of aerosol impacts and ice-phase microphysics in convective clouds over the Amazon

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12 Aerosol-cloud-precipitation-interactions and processing

3 Convective clouds

9 Tropical clouds

Ice- and mixed-phase processes in convective clouds are highly uncertain, especially when considering aerosol effects on convective clouds. This has strong implications for estimates of the role of aerosol-cloud interactions in the climate system. The wide range of interacting microphysical processes are still poorly understood and often not sufficiently resolved in global climate models. We use cloud-resolving model simulations to directly investigate the microphysical processes controlling the evolution of deep convective clouds and their response to changes in aerosols. We have implemented the microphysical aerosol model HAM (currently used in the global climate model ECHAM) in WRF/chem. A detailed aerosol and cloud microphysical budget analysis provides insight into the relevant microphysical pathways controlling aerosol-cloud interaction, such as the activation of different types of aerosols and effects on hydrometeor partition, latent heating, fall speeds and convective updrafts. We focus on a case study over the central Amazon rainforest to investigate deep convection over a region with different aerosol types. We chose a time period during the GOAMAZON measurement campaign in 2014/2015, providing extensive ground-based observations, in-situ measurements and satellite analyses for the study region. The observational data is used to evaluate and constrain the aerosol and cloud microphysical processes in the simulations. The results underline the importance of an advanced understanding and representation of ice-phase microphysics to represent the effects of aerosol perturbations on convective clouds in models.

P9.15

Real case studies of the formation of cirrus clouds in the tropical tropopause layer with a mesoscale model

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5. Cirrus clouds

9. Tropical clouds

Cirrus clouds in the tropical tropopause layer (TTL) control dehydration of air masses entering the stratosphere and contribute to the local radiative heating. Despite their importance, there are still aspects of the formation of TTL cirrus that are not well understood. Especially, in convection-influenced environments, the interaction with deep convective clouds is not clear: do most of the clouds result from anvil evolution or overshooting ice, or is an important part of the ice clouds formed in situ in response to temperature perturbations associated with waves produced by the convection? In this presentation, we will address the question of TTL cirrus formation and origin using real case-studies in different environments.

The simulations are carried with the Weather Research and Forecast (WRF) model in a cloud-permitting mode. Different environments are chosen to span possible conditions of TTL cirrus formation: "convection-free" environment in the tropical Eastern Pacific, and convection-influenced environment in the Western and Central Pacific during boreal winter. The simulated cloud fields are validated with respect to remote-sensing observations from CALIOP instrument. For one of the cases, which takes place during the ATTREX (Airborn Tropical Tropopause Experiment) campaign, the modelled microphysical properties of the clouds are also compared with in situ aircraft observations. The in situ or convective origin of the clouds is examined for the different cases. Then, the cloud large-scale (area) and small-scale (microphysical) properties are discussed and contrasted, together with their radiative and dehydrating impacts on the TTL.

P9.16

Cloud Aerosol Interactions in Southern West African Stratocumulus

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Areas 12, 1

Climatologically during July-September southern West Africa is often affected by a diurnally varying layer of stratocumulus clouds. This stratocumulus cloud forms overnight, then during the day reduces in coverage and sometimes transitions to deeper precipitating convective clouds. Aerosols from natural and anthropogenic sources, including from the rapidly growing cities in the region, are expected to be involved in complex interactions with the stratocumulus. These interactions may affect the cloud brightness, lifetime and precipitation amount.

The Dynamics-aerosol-chemistry-cloud interactions in West Africa (DACCIWA) project will (among other objectives) investigate the coupling between aerosols, cloud and rainfall in this region. DACCIWA involves both modelling work and a field campaign during Northern Hemisphere summer 2016.

Here we present the first DACCIWA modelling results over West Africa from a new two-way fully coupled aerosol-cloud interaction model known as CASIM. CASIM is an in-development module for the Met Office Unified Model and includes the ability of cloud and precipitation processes to change the size distribution of aerosol in addition to the aerosol's ability to affect cloud. It is also possible to run CASIM in an idealised manner specifying initial aerosol distributions and the distributions advected in at the boundaries. This makes it ideal for investigating the sensitivity of southern West African stratocumulus to aerosol processes and changing emissions.

P9.17

Raindrop spectra observations in a coastal region of eastern Mexico

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1. Basic cloud and precipitation physics

The Central Coastal Plain of the Gulf of Mexico is a region with tropical wet climate that features annual wet and dry seasons. The main rainy season occurs from June to October, and is largely influenced by the presence of hurricanes. The secondary rainy season occurs in winter, when the passing of cold front masses through the region also produces some precipitation.

Ground-based measurements of rain microphysical characteristics were gathered at a site located about 2 km inland from the Gulf of Mexico (18.6°N, 95.1°W, 180 m a.s.l.). Data on raindrop size and fall velocity were measured with a PWS100 optical disdrometer (manufactured by Campbell Scientific, Inc.) during both rainy seasons. Analyses of the raindrop spectra show a multimodal behaviour, although some differences were found depending on the season. These may be attributable to the mesoscale system originating the precipitation episode. The implications of these results for understanding of rain evolution in the region will be discussed.

An ensemble approach using an optimization method to weighting convective parameterizations of the regional model BRAMS

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1, 2, 13, Cumulus parameterization

The physics ensemble-type cumulus parameterization scheme currently implemented in the model Brazilian developments on the regional Atmospheric Modelling System (BRAMS) consists of disturbances around the parameters associated with dynamic, static control and feedback. A methodology have been developed to generate a set of weights related with closure members to compute a best combination of them. As an inverse problem of parameter estimation, it was solved as an optimization problem for retrieving the weights using a metaheuristic algorithm. The method minimizes the objective function computed with the quadratic difference between BRAMS precipitation forecasts and observations obtained by merging remote sensing estimations with rain gauge observations and precipitation field estimated by the Tropical Rainfall Measuring Mission satellite, like a measure of the distance between the observed data and the model. BRAMS was run for 120h in advance to produce a set of 24-h accumulated precipitation forecasts for January 2008 and 2010 using the original ensemble mean and the ensemble weighted by the optimization method in a 20km model grid configuration. The algorithm had produced the best combination of the weights, resulting in heating and drying rates more realistically and consequently precipitation simulations closest to the observations. In addition, a better skill of the model to simulate meteorological variables was observed, as temperature near surface and sea level pressure, as closest to the observation as compared with the original ensemble mean.

P9.19

Seasonal aspects of cloud radiative heating in the upper troposphere lower stratosphere in the tropics

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The entry of tropospheric air into the stratosphere occurs mainly via the tropics either by the large scale ascent or convective pumping. The latter plays an important role in the upper troposphere lower stratosphere (UTLS) region, influencing vertical mass transport and the composition of the tropical tropopause layer. This is confirmed by both Eulerian and Lagrangian studies in the past. The cloud impact on the UTLS region also has a strong spatial and seasonal character as a result of seasonal movements of the ITCZ. For example, the variability in the UTLS is influenced by South Asian monsoon during boreal summer, while in winter, by the warm pool region.

Irrespective of the entry mechanism, it is important to understand what absolute and relative contributions different cloud types make in the UTLS region to the total radiative heating. Such assessment will eventually help to better understand and model troposphere-stratosphere exchange, as cloud radiative heating is one of the main drivers of circulation, especially in the TTL. In this context, we examine the seasonal aspects of cloud radiative heating in the tropical UTLS region using data from a suite of A-Train sensors (CloudSat, CALIPSO, AIRS, and MLS). We further investigate its possible connection to lower stratospheric dryness.

P9.20

Scanning Polarimetric Doppler Cloud Radar capability in characterizing the Tropical Clouds

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Study of tropical clouds vertical structure includes the three prominent tropical convection (viz Cumulus, cumulus-congests and cumulonimbus). Trimodal tropical clouds need to be understood on the basis of macro- and micro-physics besides to the contrasting dynamics. Wind variability associated with changing atmospheric conditions, especially during the transition from deep to shallow cloud system, will be an ideal case to explore the contrasting cloud dynamical features associated with the tropical cloud system (TCS). Polarimetric Scanning Ka-band radar observations over the Western Ghats region in India have been utilized in characterizing the tropical clouds. The cloud radar observations reveal the presence of variety of cloud types and they are characteristically different both intra and inter seasonally. The reason for the differences will be discussed by using the vertical profiles of cloud radar reflectivity, winds and polarimetric parameters. This work also utilizes the volume observations of scanning cloud radar to compute the kinematics associated with TCS using Velocity Azimuth Display (VAD)/Volume Velocity Processing (VVP).

P9.21

Impacts of mesoscale convective systems development on the distribution of precipitation over Costa Rica.

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Precipitation over Costa Rica is influenced by a wide variety of complex processes due to its location between the Caribbean Sea and the Eastern Tropical Pacific (ETPAC). Deep convection is well known to develop south of the east Pacific component of the ITCZ. The presence of the Western Hemisphere Warm Pool favors the development of mesoscale convective systems in the region. An objective analysis of satellite imagery based on area overlapping and an adaptive threshold method was implemented to identify the occurrence of mesoscale convective systems development in the ETPAC region and their correspondent duration. Precipitation data from a local rain gauges network was used to quantify rainfall linked with the identified events. The technique applied allows to determine the impact of the development of these systems on the spatial distribution and intensity of precipitation over the analyzed domain. A climatology of mesoscale convective activity (MCA) over the easternmost tropical Pacific was computed. Further analysis on the annual cycle and interannual variability of MCA reveals a strong link between MCA, the ITCZ and SST distribution.

P9.22

Numerical Simulation of Convective Cold Pools Observed during the DYNAMO Field Campaign

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The Dynamics of the Madden-Julian Oscillation (DYNAMO) field campaign took place in the equatorial Indian Ocean. It provided the observational analyses that we are using to study the shallow-to-deep convection transition accompanying the Madden-Julian Oscillation (MJO). We are particularly interested in the impact of cold pools on the MJO initiation through organizing the transfer of moisture from near the surface to above the boundary layer. We performed numerical simulations for the period from 1 October to 31 December 2011 of the DYNAMO experiment with a particular focus on the ability of the simulations to realistically capture convectively generated cold pools. We performed our numerical simulations using the System for Atmospheric Modeling (SAM) with a horizontal grid size of 1 km and a horizontal domain size of 256 km by 256 km. We are comparing the simulation results to surface (island and ship) observational data with particular focus on the cold pool statistics. We are studying how cold pool activity is related to large-scale fields, especially ones that can be predicted by a global climate model, and to convection organization.

P9.23

Aerosol cloud interaction in the West coast of India and Arabian sea during the drought year of 2015

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Cloud aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) in 2015 was conducted over the drought stricken parts of north Indian Peninsular region including the adjacent Arabian sea. The observations started during large scale subsidence and strong inversions that prevented any deep convection. Observations included the active and break monsoon periods during July 2015, where average rainfall was significantly reduced, aerosols were elevated, and thermodynamics favored local development of convection. For the first time co-located observations of cloud microphysics and chemistry of aerosols are carried out over this region on airborne platform. The cloud base CCN over the coastal and adjacent (100 km away from the coastline) areas and inland showed similar droplet number concentrations 400-600 cm⁻³. The droplet number concentrations got enhanced in the polluted environment in different types of clouds and at different elevations. The aircraft observations in the convection over the Arabian sea with mixed phase convective clouds, and inland with cumulus clouds and nimbostratus focusing on the diurnal cycle of convection and cloud properties are presented. The chemistry of aerosols inside the clouds with CVI inlets and subcloud layers were also carried out. Some interesting properties of CCN as revealed from the filter analysis will also be discussed.

P10.1

Characteristics of clouds at the northern edge of the Southern Ocean: A comparison between ground-based lidar and satellite observations

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10. Southern Ocean clouds

A UV Raman lidar with polarization capability was located at Cape Grim, Tasmania (41S, 140E) from July 2013 - February 2014. The data permit characterisation of clouds seen from the ground at the northern extreme of the Southern Ocean. The Southern Ocean has large sea surface temperature biases in climate models, which are believed to be due to incorrect cloud representations in the models which allow an incorrect amount of shortwave radiation to reach the ocean. Surface measurements have not yet been made in this region but are required to provide basic climatological parameters in order to validate models and evaluate satellite retrievals. We will present an overview of our Cape Grim lidar cloud detection algorithm and the climatology of various key parameters including cloud base height and cloud fraction. We will present results of the glaciation of thin clouds by aerosols at a range of temperatures over which heterogeneous freezing occurs. Using the Raman backscatter channel, we determine the cloud and aerosol backscatter and extinction and will use case studies to understand variations of these in terms of the synoptic-scale meteorology. We combine our ground-based observations with DARDAR satellite data products to determine where and why differences in observed cloud parameters occur.

P10.2

Regional differences in Antarctic Clouds and Aerosols – Part one Observations.

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4,10,14

The representation of clouds over the Antarctic and the surrounding oceans in numerical models is very poor and this has implications for the prediction of climate change, in the region and worldwide. Over the last five years a series of in-situ observations of Antarctic Clouds have been made using the British Antarctic Surveys instrumented Twin Otter aircraft. During the Antarctic summer of 2010 and 2011 measurements of clouds were made on both sides of the Antarctic Peninsula and in 2015 similar measurements were made over the eastern Weddell Sea close to Halley Station.

Here we contrast the clouds found on either side of the Antarctic Peninsula with the clouds over the eastern Weddell Sea. We expect that the differences found between the clouds in these two regions are due to the sources of Cloud Condensation Nuclei (CCN) and Ice Nuclei (IN). In particular it was found that the number of ice nuclei was very low over the Weddell Sea when compared to other regions. Tentative suggestions are made for the sources of both the IN and CCN.

P10.3

Characterization of clouds during ACSE 2014

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Boundary-layer structure and dynamics are intimately linked with both surface exchange processes and the properties of boundary-layer clouds, which in turn exert a strong control on the surface energy budget. Sea ice melt and formation are thus closely coupled with boundary layer clouds and turbulent exchange. Coordinated observations of boundary layer processes and cloud dynamics are sparse in over the Arctic Ocean. This holds especially for observations that extend over the entire ice melt season.

Measurements with surface-based remote-sensing instruments and radiosoundings were performed during the 3-month Arctic Clouds in Summer Experiment (ACSE) in the East Siberian Arctic Ocean during the summer and early autumn of 2014. We will present a detailed characterization of cloud type and occurrence as derived from the multi-sensor remote-sensing data set. Fog and liquid-phase stratus clouds were observed more frequently during summer, whereas mixed-phase clouds were more predominant during autumn.

P10.4

Mixed-phase Convective Clouds in the High-latitude Boundary Layer over Water: evaluation of convection parameterizations with LES simulations and observations

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4. Mixed-phase clouds

keywords: BL convection, cold-air outbreaks, grey zone, remote sensing, Barrow, LES, convection parameterization

Boundary-layer convection (BLC) commonly develops where cold air is advected over relatively warm water. Such convection falls within the 1-10 km resolution “grey zone”, and assumes a spectrum of scales, from fine linear features just off the land/ice edge to wider/deeper cloud streets and eventually open cells. Unlike the Sc/Cu BL clouds over subtropical oceans, these BL clouds are mixed-phase and produce rather heavy precipitation. BLC occurs rather frequently in autumn along the North Slope of Alaska (NSA), as cold air from the ice-covered Arctic ocean is advected over open coastal waters off Alaska. For more than a decade the U.S. Atmospheric Radiation Measurement (ARM) program has been operating a rich array of profiling and scanning radars, lidars and other sensors at the NSA, to document the vertical structure of the lower troposphere, as well as clouds and precipitation. We first summarize observations of a BLC episode at the ARM NSA site, including the mesoscale organization of precipitation, BL structure, and mean profiles and distributions of vertical air velocity, cloud liquid water and ice. Next, we use these data to validate a high resolution (<1 km) WRF simulation with parameterized BL processes but resolved convection. This WRF simulation is used in turn to evaluate how well deep/shallow convection parameterizations represent BL structure, clouds and precipitation in coarser resolution simulations, and to assess to what extent these schemes are scale-aware.

P10.5

Impact of the Convection on the Arctic Climate during Wintertime

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Role of convection on the Arctic climate during wintertime (December-January) is investigated. For this purpose, two versions of an atmospheric general circulation model (AGCM) that are different from each other only in their representation of convective cloud are employed. In one of the two versions, NCAR Community Model Version 5 (CAM5) with Unified convection (UNICON) scheme was conducted with observational sea surface temperature and sea ice concentration. UNICON is a process-based model of subgrid convective plumes and mesoscale organized flow without relying on any quasi-equilibrium assumptions such as Convective Available Potential Energy (CAPE) or Convective Inhibition (CIN) closures. The model simulates more realistic convective activity even in Arctic region as well as tropical and subtropical region.

CAM5-UNICON simulates more cloud fraction and more cloud liquid condensation than control run mainly due to increase of convective activity and the related detrainment cloud, which enhances long-wave cloud radiative forcing over the Arctic region during wintertime. Accordingly, in the climatology, CAM5-UNICON considerably reduces cold bias of control run at surface and upper layer. In term of Arctic amplification, CAM5-UNICON simulates more realistic warming trend since 2000. Our results suggest that the parameterization of convection is a crucial component of a GCM to correctly represent the Arctic climate.

P10.6

A case study evaluating Global Precipitation Measurement (GPM) observations of precipitation over the Southern Ocean

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An accurate representation of precipitation over the Southern Ocean is necessary to close the regional water and energy budgets. Satellite-based precipitation products remain to be verified for this region where the microphysical processes may be particularly unique given the strong winds, low cloud condensation nuclei (CCN) number concentrations and ubiquitous presence of supercooled liquid water. For example, Chubb et al. (2013) observed that the thermodynamic state of precipitation varied from glaciation to mixed phase to supercooled liquid drizzle across the span of hundreds of kilometres. Wang et al. (2015) found that CloudSat products underestimated the frequency of light precipitation when compared against surface observations made at Macquarie Island. The predominance of boundary layer clouds within the lowest kilometre makes the satellite observations even more challenging (Huang et al. 2012).

In-situ observations taken from the lightly instrumented Hydro Tasmania aircraft are presented for 30 August 2015. The aircraft operated to the south of Tasmania in a pristine Southern Ocean air mass far from any frontal passage. Shallow meso-scale convective cells were encountered (cloud top height of 1,280 m and cloud top temperature of -4.2°C) that were lightly precipitating. No observations of ice were recorded.

Both CloudSat and GPM precipitation products were made within a 30 min window during the mission. The structure, intensity and frequency of these satellite-based products are compared against the in-situ observations.

P10.7

In-situ observations of supercooled liquid water in a post-frontal environment over the Southern Ocean

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10, 4

Satellite observations reveal that low- and mid-level clouds in the cold-air side of the mid-latitude cyclones over the Southern Ocean (SO) are dominated by supercooled liquid water (SLW), which is poorly represented by climate models, leading to large solar radiation biases over this region (Bodas-Salcedo et al. 2016). In-situ observations that can be used to evaluate satellite products over this region, however, are lacking.

An effort has been made to provide coincident airborne measurements of cloud thermodynamics and microphysical properties over this measurement-sparse area, under the overpasses of A-Train satellites and Global Precipitation Measurement (GPM). A case (October 1, 2015) where SLW was recorded down to $\sim -13^{\circ}\text{C}$ within a post-frontal environment is presented. The winds were primarily south-westerly and varied between 15-25 m/s. The air mass is characterised by multi-layer, geometrically thin clouds (several hundred meters) at low (below $\sim 1.5\text{km}$) and mid (below $\sim 5\text{km}$) levels, with only light, sporadic precipitation being detected. The aircraft observations are employed to evaluate a set of satellite products, between which relatively large discrepancies in retrieved cloud properties are found (Huang et al. 2015).

This study provides a necessary reference for using spaceborne products to study clouds and precipitation over the remote SO. It also highlights the necessity of using a multi-sensor platform to better characterize the complexity of the SO cloud systems.

P10.8

Analyzing the dissipation of an Arctic mixed-phase cloud during the ASCOS field campaign

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4.

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Mixed-phase clouds are important contributors to the surface energy budget in the Arctic. These mixed-phase clouds can reflect solar radiation back to space and absorb long wave radiation from the surface, which can lead to either cooling or warming of the lower atmosphere. Because mixed-phase clouds contain supercooled liquid water and ice crystals at the same time these clouds are thermodynamically unstable and changes in droplet number concentration or ice number concentration can influence the life time of such a cloud. Several field campaigns in the past help to understand and improve the simulations of Arctic mixed-phase clouds and their impact on climate. This study focuses on the ASCOS (Arctic Summer Cloud Ocean Study) campaign. The ASCOS field campaign took place in 2008. It was an extensive field experiment and lasted over a month (Tjernström et al., 2012). Studies of the Arctic ocean and Arctic atmosphere were done during mid of August through beginning of September. Three weeks of extensive measurements near 87°N allow a look at the cloud development and the evolution of the boundary layer structure in the Arctic. The COSMO (Consortium for Small-scale Modelling) model is used in a semi-idealized LES (Large Eddy Simulation) setup. In a sensitivity study possible dissipation contributors such as CCN depletion, IN increase and dry-air advection are analyzed with a special focus on the boundary layer structure and the cloud microphysics.

P10.9

Impact of aerosol and meteorological conditions on the persistence of Arctic mixed-phase cloud

Shizuo Fu, Huiwen Xue
Peking University, Beijing, China

4 and 12

Arctic mixed-phase cloud (AMC) exerts a positive radiative forcing to the surface. Here, large eddy simulation (LES) coupled with detailed bin microphysics scheme for mixed-phase cloud is used to study the response of AMC to aerosol and meteorological conditions. Results show that cloud persistence occurs when ice crystal number concentration is low. Increasing ice crystal number concentration increases ice water path (IWP), but decreases liquid water path (LWP) and total water path. For example, increasing ice number concentration from 1 to 4 L⁻¹ can cause a 47% decrease in LWP. This is due to the competition for water vapor between liquid droplets and ice crystals. The significant decrease in LWP can result in weaker cloud top longwave cooling and hence even smaller LWP, which favors the dissipation of AMC. Besides the aerosol effect, meteorological conditions also affect the persistence of AMC. Increasing humidity in either boundary layer or free troposphere can lead to larger LWP, IWP and cloud thickness, which favor the persistence of AMC. In addition, increasing boundary layer humidity has much more significant impact on AMC than increasing free troposphere humidity. For example, an increase of 9% in boundary layer humidity can cause 63% increase in LWP while an increase of 20% in free troposphere humidity only causes 14% decrease in LWP.

P10.10

Regional differences in Antarctic Clouds and Aerosols - Part two Modelling

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4, 14, Mesoscale modelling

Antarctic clouds are known to be poorly represented in global and regional atmospheric models. They are responsible for shortwave and longwave biases affecting the simulated energy budget of the continent. They impact the ice mass balance through precipitation, and affect aircraft/ground operations. During the Antarctic summer of 2010 and 2011 in-situ measurements of clouds were made on either side of the Antarctic Peninsula using the British Antarctic Survey's instrumented Twin Otter aircraft. In summer 2015, similar measurements were made over the Weddell Sea, in the Halley Station region. The first two and the third campaign probed different environments respectively: the former group being more oceanic and the second more continental.

Using the Polar Weather Research & Forecasting (Polar WRF) model we investigate cloud formation in both Antarctic regions using different microphysical schemes implemented in WRF (v3.5.1), and compare with aircraft observations. We aim at understanding how the different microphysics schemes implemented in WRF compare with each other, and notably with the one which is used by the operational Antarctic Mesoscale Prediction System (AMPS), widely used in the field. Cloud condensation Nuclei (CCN) and Ice Nuclei (IN) parameterizations implemented in the microphysical schemes are almost exclusively based on mid-latitude measurements. We comment on the ability of current parameterizations to account for observations in both Antarctic regions, and discuss their effect on the simulated clouds.

Our ongoing work heads towards a new parameterization to be implemented and more generally to an improvement of Antarctic clouds microphysics modelling.

P10.11

The effects of microphysics on convection-permitting simulations of a Southern Ocean cyclone

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Too little supercooled liquid water in simulated coldair outbreaks may be a cause of the large radiative biases seen in climate models over the Southern Ocean. Using convection-permitting simulations of an entire Southern Ocean cyclone allows the cloud physics of these systems to be investigated, without the additional complexities that arise in global models. The dominant physical processes in the coldair-outflow region are riming, ice nucleation, diffusional growth and turbulent transport. We discuss the sensitivity of the simulations to the parametrization of these processes and evaluate the results against satellite-derived observations of liquid water path and top-of-atmosphere radiative fluxes.

P10.12

Lidar observations of the effect of gravity-wave activity on the properties of Polar Stratospheric Clouds

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We investigate the effect of gravity-wave activity (GWA) on the occurrence rate of different types of Polar Stratospheric Clouds (PSCs) over Esrange Space Centre, northern Sweden. The required information on both PSC occurrence and GWA has been obtained simultaneously and with a single instrument: the Esrange lidar. The backscatter ratio and the particle depolarization ratio are used to derive PSC type. Perturbations of the temperature profile are used to separate between low and high GWA conditions at our site downwind of the Scandinavian mountains.

It is found that PSCs observed during strong GWA are shifted towards higher altitudes and show an increased occurrence rate of ICE and NAT particles due to the wave-induced temperature decrease at PSC altitudes. Almost no

ICE and NAT PSCs are observed during low GWA conditions while MIX and STS PSCs are more abundant. GWA at Esrange is likely to be dominated by the Scandinavian mountains. Using a method to derive GWA based on modelled wind fields shows a less pronounced connection to PSC type occurrence.

P10.13

The Dry Ice Clouds of Summit, Greenland: A study of Properties and Characteristics

Claire Pettersen¹, Ralf Bennartz^{2,1}, Aronne Merrelli¹, Dave Turner³, Matthew Shupe⁴
¹*University of Wisconsin - Madison, Madison, Wisconsin, USA*, ²*Vanderbilt University, Nashville, Tennessee, USA*, ³*National Severe Storms Laboratory, Norman, Oklahoma, USA*, ⁴*NOAA Earth System Research Laboratory, Boulder, Colorado, USA*

1., 16., 5., 4.

ABSTRACT:

We have developed a method of identifying dry ice clouds and precipitation over the Greenland Ice Sheet (GIS). We define these "dry" ice clouds as those containing little to no cloud liquid water. Using differences in the spectral variation of the absorption and scattering properties of the cloud liquid water and ice in the microwave, we are able to isolate the occurrence of such clouds. This is achieved using microwave radiometer (MWR) observations from the Integrated Characterization of Energy, Clouds, Atmospheric State, and Precipitation at Summit (ICECAPS) in Greenland. Once identified, we use six years of co-located, multi-instrument data from ICECAPS to examine properties and characteristics of these clouds: When do they occur; do they have a seasonality? What are the physical properties of these clouds; are they deep or shallow; calm or turbulent? Where do these clouds come from? It is difficult to advect air over the GIS, so where do air masses that form ice clouds tend to originate? Though these dry ice cloud events are a small percentage of the overall cloud and precipitation at Summit, they contribute a disproportionately large amount to the mass deposited on the ice sheet. Additionally, better understanding of the physics of these ice clouds will help to improve current retrievals of atmospheric properties. These ice clouds are excellent test cases for radiative transfer studies as well. We intend to take advantage of the unique environment at Summit and the ICECAPS instrument suite to study these clouds.

P10.14

Southern Ocean Cloud - Radiation Interactions and their representation in the Australian regional forecast model as revealed by Research Vessel Investigator observations

Alain Protat

Australian Bureau of Meteorology, Melbourne, Victoria, Australia

10, 12

The Southern Ocean (SO) is a region of great importance to global and Australian climate and weather. Climate models are challenged by uncertainties in the simulation of SO clouds, aerosols, and surface fluxes. These biases produce large errors on the surface radiation budget and affect the location of sub-tropical jets, the simulation of anthropogenic indirect aerosol effects on climate, and the simulated global cloud feedbacks and carbon-cycle feedbacks on climate change. These model challenges can be traced to poor physical understanding of these processes. This lack of physical understanding can in turn be attributed to the unavailability of state-of-the-art observations of clouds, aerosols, precipitation, radiation and the air-sea interface, hindering our capability to conduct process studies. In March 2015 (9 days) and March 2016 (30 days), we collected detailed cloud, precipitation, aerosol, and surface radiation observations over the Southern Ocean as part of a sea trial of the Marine National Facility Research Vessel Investigator. In this talk we will describe the observations collected, the statistical cloud and radiative properties derived from those observations (cloud frequency of occurrence, cloud fraction, cloud thermodynamical phase) and we will compare these statistical cloud and radiation properties to those simulated by the Australian regional weather forecast model (ACCESS). From the first research voyage dataset, results show that the frequency of low clouds is largely underestimated and that of mid-level and high clouds is largely overestimated. Implications in terms of surface radiation budget errors will be quantified and discussed.

P10.15

Dissecting the role of various precipitation micro-physical processes in Arctic clouds using ICECAPS observations

Ralf Bennartz^{1,2}

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4. Mixed phase clouds (including Arctic/Antarctic stratus, mid-level clouds)

17. Applications of cloud and precipitation physics (required)

13. Clouds and climate (including radiative properties of clouds)

Constraining and quantifying the role of ice- and mixed-phase microphysical processes remains a challenge both in terms of process understanding and model parameterizations.

Our NSF-funded Integrated Characterization of Energy, Clouds, Atmospheric state, and Precipitation at Summit, Greenland (ICECAPS) experiment is located at 3200 m altitude on top of the Greenland Ice Sheet and has been operational since 2010. Because of its high and cold location it provides a unique opportunities to study ice- and mixed-phase microphysical processes.

In this presentation I will address the relative importance of riming, aggregation, and ice particle diffusional growth in high-latitude precipitation generation. I will compare observational results with model studies in order to understand the relevance of these processes in precipitation generation and their link to the large-scale environment.

The importance of different processes varies strongly between precipitation events and appears to be largely driven by integral properties of the atmosphere, which in turn are determined more by the large-scale flow than by microphysical details. If appropriate integral constraints can be identified, such constraints can be utilized to validate and narrow down uncertainties in cloud microphysical parameterizations.

P10.16

Evaluation of Arctic mixed-phase clouds simulated by a habit-prediction model

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Key area: 4

Key words: Habit prediction, Large Eddy Simulation

In this paper the ability of a habit-prediction cloud microphysical scheme is discussed for simulating Arctic mixed-phase boundary layer clouds. The scheme is the Spectral Ice Habit Prediction System (SHIPS, Hashino and Tripoli 2007, 2008, 2011a, 2011b), the ice module of the Advanced Microphysics Prediction System (AMPS). SHIPS predicts lengths of hexagonal crystals, growth of polycrystals, mass mixing ratios produced by microphysical processes, and circumscribing volumes based on growth history of ice particles. The cases chosen are from the Surface Heat Budget of the Arctic Ocean (SHEBA) and from the Mixed-Phase Arctic Cloud Experiment (MPACE). Previously, AMPS has been utilized for simulating the clouds with 2D settings to show that the immersion-freezing hypothesis can be a working mechanism to explain the discrepancy between observed IN and measured one (de Boer et al. 2010, 2013).

As a next step to prove the effectiveness of this modeling approach, we will implement 3D LES simulation and evaluate the predicted habits and size distributions mainly against ground-based lidar and cloud radar with reference to available in-situ observation. The lidar and radar backscattering signals will be calculated based on the predicted habit with a satellite data simulator. As shown by previous studies (van Diedenhoven et al. 2009 and Avramov et al. 2011), the lidar depolarization and Doppler velocity are especially effective for this purpose. The differences of predicted habit and signals between the two cases will be discussed in the presentation.

P11.1

Highly Active Ice Particle Production in Hokuriku Winter Snow Clouds - Videosonde and HYVIS Observations

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3, 1

One of the unsolved problems of cloud physics is the large difference in observed number density between ice crystals and ice nuclei. Hallett and Mossop (1974) proposed an ice multiplication process that is active only within a specific temperature range. However, many Hokuriku winter clouds have cloud bases that are colder than this active range while displaying the same degree of ice particle overrepresentation (Takahashi, 1993), indicating that it is produced by a different ice multiplication process.

To study ice particle production over a wide range of particle sizes, 20 conjoined Videosonde-HYVIS sondes were launched into Hokuriku winter snow clouds from Kashiwazaki, in December, 2012. Enormously high numbers of ice particles, as high as a few per cm³ were commonly observed in the clouds that developed during cold surge.

We observed two main types of small ice particles: beaded (composed of a chain of frozen drops) and threadlike. Both types increased in number density with increasing graupel number density. In addition, beaded ice particle number density increased with increasing cloud water content. Threadlike ice particle number density peaked just above the level of peak beaded particles and at the level where cloud water content rapidly dropped with increasing height.

We propose that both types of ice particles originate as rime branches on the graupel surface and are ejected during graupel-ice crystal (graupel) collisions. These newly formed ice particles play a vital role in both heavy snowfall and cloud electrification.

P11.2

Sensitivity of structure and polarimetric characteristic of a squall line to microphysical parameters

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8,12

A mid-latitude squall line in the area of Oklahoma is simulated. The intensity and structure of convective front and stratiform region to different microphysical parameters is studied. The role of time dependent freezing processes, conversion of graupel to hail during riming, the role of cold pool on the intensity of convective zone is analyzed. The effects of secondary ice nucleation caused by haze freezing at the upper atmosphere, secondary ice production during drop breakup during freezing, temperature dependence of sticking efficiency during ice-ice collisions on the stratiform area, size distributions of ice and polarimetric radar characteristics within melting layer are investigated in a set of 2D and 3D sensitivity experiments. An important role of squall line of spontaneous breakup of raindrops and snow in creation of realistic structure is demonstrated.

A relationship between polarimetric radar signatures and microphysical structure of squall line and the distribution of latent heat release is investigated. Relationships between microphysical structure at the upper and mid-troposphere levels and precipitation rate at the surface are analyzed.

P11.3

Laboratory studies of the rime-splintering process.

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University of Manchester, Manchester, UK

Experiments looking at the rime-splintering process were first conducted in the 70's with more recent experiments done in the 90's. These later experiments still relied on the same principle i.e counting ice crystals within a specified volume by eye and then relating these numbers to the riming rate. Thus parameterizations of the ice crystal production rate have been found. In this study we are aiming for a better characterization of the phenomenon by undertaking experiments utilizing modern electronic equipment and computer operated detectors, which are installed in the Manchester Ice Cloud chamber (MICC). In these experiments we create a supercooled cloud of drops within the chamber and allow the cloud drops to impact on a riming target. Ice multiplication by rime-splintering is observed in the experiments, and a dependence on the impact velocity is noted as in previous studies. In addition, the habits of the ice splinters is also evident from the experimental data, sometimes showing columnar shaped ice crystals and sometimes more amorphous shapes. The sensitivity of rime-splintering to other parameters in the experiments is investigated, with the aim of producing a more accurate parameterization of the process to be used in cloud models. The results of the analysis will be presented and summarized at the meeting.

P11.4

The role of submicron aerosol particles in the formation of high ice particle concentrations in mesoscale convective systems

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¹*Environment and Climate Change Canada, Toronto, Canada,* ²*National Research Council of Canada, Ottawa, Canada*

8, 14, 9 12 ice initiation, ice nuclei, mesoscale convective systems, ice concentration

Explanation of large difference between the measured concentration of ice nucleating particles (INP) and observed ice crystal number concentrations (ICNC) remains one of the long-standing problems in cloud physics. Secondary ice production has been suggested as the likely explanation of the discrepancy between the observed INP and the ICNC. More research in this direction is needed to confirm or to refute this hypothesis. The understating of the ice initiation mechanisms, which explains observed concentration of cloud ice particles, is important for improvement of numerical simulation of clouds in weather and climate models.

This study examines the effect of submicron aerosol particles on the microphysical properties of high ice water content (HIWC) cloud regions in mesoscale convective systems. The measurements were collected from the NRC Convair-580 during eleven flights operated out of Cayenne (French Guiana) in May 2015. It was found that the concentration of the submicron aerosol vertical profile correlates with the cloud droplet concentration. However, the predicted INP concentrations from the aerosol profiles are several orders of magnitude lower than the measured ice particle concentrations. The obtained results suggest that the concentration of the background aerosol particles cannot explain the measured concentration of ice crystals, and INP have a limited role in the ice initiation in the convective storms observed in Cayenne. One of the most likely explanations for the measured ice particle concentrations is the secondary ice production formed via e.g. the Hallett-Mossop (H-M) mechanism.

P11.5

Comparative study of very efficient ice nucleating particles in contact and immersion freezing mode

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14, 12, 4

Freezing of supercooled cloud droplets on collision with ice nucleating particle (INP) has been considered as one of the most effective heterogeneous freezing mechanisms. Potentially, it could play an important role in rapid glaciation of a mixed phase cloud especially if coupled with ice multiplication mechanism active at moderate supercooling temperatures. The necessary condition for such coupling would be, among others, the presence of very efficient INPs capable of inducing ice nucleation of the supercooled drizzle droplets in the temperature range of -5°C to -20°C. The accurate description of contact freezing in cloud models requires careful characterization of contact freezing probability for various types of IN particles and various temperature and humidity regimes.

In this contribution we give an overview of the experimental results of contact freezing experiments conducted in the past years with the individual supercooled water droplets suspended in an electrodynamic balance (EDB). The new results obtained with mineral dust aerosol preconditioned in cloud chamber AIDA are also given. We use CNT-based approach to analyze the temperature dependence of the contact freezing efficiency and show, that for very efficient contact INP- particles of potassium-reach feldspar, biological particles, and the mixtures of both, there is no enhancement of the contact freezing efficiency expressed as a surface density of ice active sites in the contact freezing mode.

P12.1

Characteristics of recent severe haze events in Korea and possible inadvertent weather modification

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The quantitative understanding of aerosol-cloud-precipitation interactions is still insufficient despite substantial amounts of previous efforts to solve this problem since it has inherent complexity. Probably we might need overwhelming aerosol forcings well beyond cloud and precipitation variabilities in order to identify and attribute its discernible effect on clouds and precipitation. Korea recently suffered from severe haze episodes that appear to be largely long-range transported from China, which could be made the best use of to evaluate the hypothesis of enhanced aerosols impacts on clouds and precipitation. A couple of severe hazes in January 2013 originated from eastern China were also observed in the mid-Korean peninsula. The cloud systems overlapped with aerosol plumes seemed to be modified such that drizzle-type light precipitation lasted longer within half a day than the operational weather forecast because precipitation might be extended at a less rate due to increases in number concentration of smaller cloud droplets as shown by a sensitivity test using the WRF model. This study shows a possible evidence of inadvertent weather modifications by enhanced aerosols. It also implies that Korea would be a better testbed to investigate aerosol impacts on weather.

P12.2

Numerical Simulation of Dust–Cloud Interactions Using a Regional Model

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Airborne mineral dust particles have potentially important influences on cloud and precipitation processes by playing the roles of ice nuclei (IN), which initiate cloud glaciation, or cloud condensation nuclei (CCN), which initiate cloud drop formation. On the other hand, dust can be removed from the atmosphere wet deposition processes such as nucleation/activation scavenging and collection scavenging. In-cloud dust particles not removed by wet scavenging may be modified chemically and then recycled back to the atmosphere after cloud dissipation. In order to understand these dust-cloud interactions, a dust emission module, which provides dust emission intensity and size distribution, was incorporated into the Weather Research and Forecasting model (WRF). Processes considered include dust activation, nucleation and collection by cloud particles, using the National Taiwan University (NTU) three-moment modal aerosol parameterization scheme. This aerosol scheme is coupled with the NTU two-moment cloud microphysical parameterization scheme and thus is suitable for simulating aerosol effect on clouds. A cold-front-leading dust storm event which caused “muddy rain” over northern Taiwan was simulated to demonstrate dust-cloud interactions. The simulations showed that dust particles tend to increase ice-phase hydrometeor contents and surface precipitation, mainly via the deposition nucleation process instead of the immersion freezing process. On the other hand, the cloud microphysical processes can significantly reduce atmospheric dust loading, mainly through the rainout instead of the washout processes.

keywords: dust-cloud interactions (key areas: 12, 14)

P12.3

From invigoration to suppression – the aerosol effect on warm convective clouds

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12. Aerosol-cloud-precipitation-interaction and processing

Cloud and rain formation are determined by both the thermodynamic potential and the aerosol properties. For a given thermodynamic conditions, an increase in aerosol loading creates a competition between the enhanced growth of clouds due to efficient and longer condensation that enables consumption of the available water vapor and the enhanced entrainment and water loading that suppress clouds' growth. Those competing effects dictate an optimal aerosol concentration for key macrophysical properties of the cloud (like total mass and rain yield). This optimal aerosol concentration depends on the thermodynamic conditions. Clouds that exhibit the optimal aerosol concentration with respect to rain yield (per given environmental conditions), show to have similar times to maximal cloud development and to maximal collection.

In this talk, numerical simulations of warm clouds will be presented. The scales of a single cloud up to a cloud field will be examined. The similarities and differences between the different scales and the additional thermodynamic feedbacks involved in the larger scale of the cloud field will be described.

P12.4

Ice in Clouds Experiment - Dust (ICE-D): In-situ aircraft measurements of cloud evolution

Richard Cotton
Met Office, Exeter, UK

12 14 ICE-D field campaign.

The Ice in Clouds Experiment - Dust (ICE-D) field campaign took place during July and August 2015, based at Praia, Cape Verde Islands. The main objective was to study the properties of Saharan desert dust primarily as ice nuclei, but also as cloud condensation nuclei, and the impact of these dust particles on cloud microphysical processes and precipitation formation in convective clouds.

The FAAM BAe-146 aircraft carried out in-situ measurements of the dust aerosol and cloud properties. On the ground at Praia, there was an extensive suite of aerosol measurements and a Doppler X-band radar which identified suitable cloud regions for aircraft sampling and provided coordinated observations of precipitation development.

Mineral dust with sources from the Saharan region have been identified as efficient ice nuclei in laboratory and field studies, but the effect on cloud evolution has not been measured. The Cape Verde area is near the source region where dust concentrations are large, and both dust events and cumulus clouds are frequently observed.

An overview of the broad range of measurement activities during the field campaign will be shown, followed by more detailed observations of in-situ aircraft-based aerosol, cloud particle and bulk-water during cloud evolution.

P12.5

Marine Boundary Layer Aerosol Variability: a Budget Approach

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(2, 12)

Marine boundary layer (MBL) aerosol plays a critical role in the climate system through cloud-aerosol interactions, and while the main sources and sinks of MBL aerosol are understood, the relative importance of these terms in determining the aerosol budget at different scales remains an open question. Using ship-based data gathered during the 2013 ARM MAGIC field campaign, aerosol variability is examined at a number of spatial and temporal scales. Key terms in the aerosol budget are estimated using observations of boundary layer properties, radar-inferred drizzle, and satellite-derived cloud top droplet number concentration, and their variability is compared with surface measurements of aerosol at seasonal, synoptic, and diurnal scales.

P12.6

Model simulations with COSMO-SPECS: New parameterizations of heterogeneous freezing modes

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4 , 12

Ice formation in clouds is essentially affected by freezing modes and ice nucleating particle types. As the formation of precipitation is often initiated via the ice phase these parameters determine in turn the resulting amounts of precipitation. Such correlations are investigated with the 3D cloud-resolving model COSMO-SPECS which provides a link between aerosol particles, cloud properties, and precipitation. It contains a spectral microphysical scheme for aerosols and hydrometeors including all processes proceeding during the development of clouds and precipitation. The description of ice formation includes new parameterizations of immersion, contact, and deposition freezing modes which are all particle-type dependant and based on the outcome of laboratory experiments. Simulated ice nucleating particle types are mineral dust (feldspar, illite, montmorillonite, and kaolinite) and biological particles (bacteria, plant debris, and pollen). Idealized test cases are investigated by using Weisman-Klemp profiles for the initial atmosphere. A convective cloud is initialized by a temperature disturbance of 2K in the centre of the model domain. Model simulations are performed to quantify the contribution of possible ice formation modes to ice formation and to study the sensitivity of cloud microphysics and precipitation amount to realistic variations of ice nucleating particle types and distributions. Preliminary results from model simulations confirm the dominance of the immersion freezing mode and of mineral dust as ice nucleating particles. The conditions where contact and deposition freezing on one hand and biological particles on the other hand might essentially contribute to ice formation will be investigated in further sensitivity studies.

P12.7

LACIS-T - A wind tunnel for investigating the Interactions between Cloud Microphysics and Turbulence

Jens Voigtländer¹, Dennis Niedermeier¹, Holger Siebert¹, Jörg Schumacher², Raymond A. Shaw³, Frank Stratmann¹

¹Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany, ²Ilmenau University of Technology, Ilmenau, Germany, ³Michigan Technological University, Houghton, USA

12, 1

To improve the fundamental and quantitative understanding of the interactions between cloud microphysical and turbulent processes we are currently building the first humid turbulent wind tunnel (LACIS-T). LACIS-T features well-defined turbulent and thermodynamic (temperature and relative humidity) conditions. It will allow for investigating cloud microphysical processes such as aerosol particle activation and cloud droplet freezing, under turbulent flow conditions, i.e., conditions similar to those encountered in the atmosphere and real clouds. It represents the logical continuation and extension of the cloud microphysics related investigations carried out at the Leipzig Aerosol Cloud Interaction Simulator (LACIS) under laminar flow conditions.

LACIS-T is a closed loop wind tunnel. The size of the measuring section is 0.8m*0.2m*2.0m, and flow velocities are in the order of 1.0 m/s.. The thermodynamic conditioning system design is based on our experience with the laminar device LACIS. In the measuring section, supersaturation is achieved by mixing of two saturated gas flows of different temperatures. Aerosol particles are injected and exposed to supersaturation directly within the mixing zone. Well-defined turbulence is generated by applying passive grids at the inlet stage. Characterization of the wind tunnel as well as particle measurements will be made by probes directly mounted in the gas flow of the measuring section, and from outside with optical detection methods. Computational fluid dynamics (CFD) simulations are carried out to define suitable experimental conditions and assist the interpretation of the experimental results. In this work, the experimental set-up and the fundamental operating principle of LACIS-T will be presented.

P12.8

Impacts of Aerosols Microphysics on Aerosol- Cloud-Interaction in a series of heavy haze-fog events

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Aerosol- Cloud-Interaction (ACI) has been established in China Unified Atmospheric Chemistry Environment (CUACE) which has been fully coupled into China New Generation Weather model GRAPES. In this GRAPES/CUACE modeling system, aerosols driven by emissions can be activated into the clouds and sub grid clouds in the Tests have showed that the ACI can improve the precipitation simulation by 33% Test Scoring.

Since the microphysics of aerosols are very important on ACI, sensitive tests have been done to analysis impacts of different aerosol microphysics on the size distributions and finally on the ACI, especially for nucleation and condensation of secondary aerosols. Through this study, the nucleation and condensation processes have been improved and tailored for the heavy polluted areas in China. Impacts on the thermal and humid states, and the haze and precipitation simulation have also been evaluated with the improvements.

P12.9

Spatial and temporal variations in aerosol properties in convection-permitting simulations in an idealised tropical marine domain

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High-resolution simulations in a general circulation model (Unified Model) with interactive aerosol microphysics (GLOMAP-mode scheme) are carried out to investigate the variation in concentrations of CCN occurring in the marine boundary layer. An idealised tropical domain designed to match approximately a single grid square of a climate model is set up with 1.5 km resolution, to focus on quantifying sub-grid scale variations in aerosol properties in a convection-permitting setting. Overall, CCN concentrations vary by a factor of 8, with sub-grid variations in the emission of sea-salt and DMS contributing to the overall CCN variance, the latter including a substantial contribution also from new particle formation in the free troposphere. In these simulations, coarse mode particles are almost exclusively sea-spray, with concentrations of such larger CCN varying by around a factor of 8, being influenced strongly by emissions variations from wind speed fluctuations. Concentrations of smaller CCN tend to have less variation, which may partly be due to them having a significant contribution from sulphate particles nucleated in the free troposphere, which are much less variable. These secondary particles are produced over timescales of several days following DMS oxidation and chemical and aerosol microphysical processing. The complex mix of sources and diverse community of processes involved makes sub-grid parameterization of the CCN variations difficult. However, the results presented here illustrate the limitations of predictions with large-scale models and the modelling approach used here shows promise for future studies aimed at better understanding aerosol-cloud interactions occurring at these fine spatial scales.

P12.10

In-cloud measurements highlighting the role of chemical composition in cloud droplet activation

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Key areas:14,1,2

The relationship between aerosol hygroscopicity and cloud droplet activation was studied at the Puijo measurement station in Kuopio, Finland, during the autumn 2014. Particle hygroscopicity under subsaturated conditions was measured using a hygroscopic tandem differential mobility analyzer. Typically, the measured growth factor distributions (GF-PDF) appeared bimodal, with clearly distinguishable peaks around 1.0–1.1 and 1.4–1.6. By using the GF-PDFs and particle concentrations measured separately for interstitial and total aerosol populations, the activation efficiencies within the two hygroscopicity modes were estimated.

According to the observations, the less hygroscopic particles remained almost non-activated while the more hygroscopic mode was present only in the cloud droplet residuals. This observation highlights the importance of chemical composition to cloud droplet activation. Highly variable portion of less hygroscopic particles have been reported in several studies and in many different locations during the last few decades. Due to the anthropogenic contribution, the less hygroscopic mode can be dominant at particle sizes up to 250 nm, which significantly decreases the fraction of available CCN.

By modifying the measured GF-PDFs, it was estimated, how the cloud droplet concentration would change if all the particles belonged to the more hygroscopic mode. This would eventually correspond a situation with typical aged, continental particle population being present in the atmosphere without any fresh anthropogenic influence. According to the simulations, the change in cloud droplet concentration varied up to 70 %, and depending on the initial particle concentrations, the absolute change could be up to hundreds of cloud droplets per cubic centimeter.

P12.11

Investigating the influence of water diffusion through aerosol particles on ice nucleation

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12, 14, 5

Recent studies have directly measured water diffusion coefficients for secondary organic aerosols (SOA) and found extremely low values under certain conditions. This study will use these findings, which take into account the variability in diffusion coefficients around the glass transition temperatures, to consider the effect this has on atmospheric processes, particularly focussing on ice nucleation.

Low values for water diffusion coefficients found in various SOA mixtures maybe influential with how aerosols interact in weather and climate models. These diffusion coefficients are inversely proportional to the timescales of diffusion, affecting the radial concentration gradient of water in the aerosol particles, in turn influencing the surface properties and interactions with humid air. These microphysical interactions with water vapour can consequently have an atmospheric effect, influencing precipitation processes, cloud lifetimes and optical properties.

Here we explore the effect that recently published water diffusion coefficients of particular SOA have upon ice nucleation. Our results are found using a cloud parcel model with bin microphysics. On first analysis, use of the diffusion coefficients for water - SOA mixtures has been seen to suppress ice nucleation in comparison to using the diffusion coefficient for pure water. The results of further investigation will be presented and discussed at the meeting.

P12.12

GIANT AEROSOLS OBSERVATIONS AND EFFECTS

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12. Aerosol-cloud-precipitation-interactions and processing

Aerosols affect the meteorological and climate system as well as health and transport in different ways. In particular, giant and ultragiant particles ($> 5 \mu\text{m}$ diameter) can act as Giant Cloud Condensation Nuclei (GCCN) and as Ice Nuclei (IN). Nevertheless, their distribution and impact in the atmosphere and climate is not well known, hence the observation and study on these particles is relevant. Therefore, the aim of this study is to investigate tropospheric aerosols and their effects.

The research carried out in this study focused, first, in exploiting the synergy of multi-wavelength Raman lidar and cloud radar to enlarge the size range in which aerosols can be characterized (from ultrafine to ultragiant particles).

Following, the effects of giant aerosols on the regional meteorology were explored by evaluating their effects on different atmospheric variables. Their influence on AOD (Aerosol Optical Depth), COD (Cloud Optical Depth), LWP (Liquid Water Path) and precipitation was evaluated. Notably, it revealed that giant aerosols affect the regional precipitation by enhancing the accumulated precipitation and the maximum rain rate.

P12.13

CEMBAI: Climate in Eastern Mediterranean Basin - Aerosol Impacts - presentation of the project

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12. Aerosol-cloud-precipitation-interactions and processing

13. Clouds and climate

14. Ice nuclei and cloud condensation nuclei

CEMBAI (Climate in Eastern Mediterranean Basin - Aerosol Impacts) focus is on aerosol-cloud interactions and impacts on the water cycle in the eastern Mediterranean region and their evolution in the near future. CEMBAI is part of a joint Cypriot-German-French scientific effort that is currently being deployed in synergy with the EU-FP7 BACCHUS project. CEMBAI aims at complementing the BACCHUS study by addressing specifically two scientific questions:

Identify with new observations and models which types of aerosol particles have a major impact on the water cycle in the eastern Mediterranean Basin. Stress will be put on the aerosol/cloud/precipitation interactions when ice phase is involved. The existence (or not) of a desertification feedback loop will also be addressed here.

(ii) Through modeling studies, investigate how precipitation regimes and wet deposition are likely to evolve in a changing climate. We will also investigate and apportion the respective impacts on the regional water cycle of changes in atmospheric circulation and atmospheric composition.

In this purpose, four French partners (LaMP, IPSL, OMP, LOA) and the Cyprus Institute will combine their expertise to run a field campaign in March 2017 to characterize from ground, airborne and remote sensing observations (ground and satellite) the aerosol particles capability to form droplets or ice crystal and initiate precipitation. Data will be used to improve models from cloud, to weather, to climate scale.

This poster will expose the experimental and modeling strategies of the CEMBAI proposal.

SCAVENGING OF AEROSOL PARTICLES BY RAIN IN LEÓN (SPAIN)

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In order to determine the scavenging of aerosol particles by raindrops, a sampling campaign was carried out from July to the end of October 2015 in the city of León (Spain). Precipitation and aerosols were monitored by means of a laser disdrometer Thies LPM (which registered raindrops between 0.125 and 8 mm in 20 channels) and an aerosol optical counter PCASP-X (registering particles with sizes between 0.1 and 10 μm in 31 discrete channels), respectively. At the same time, a weather station provided complementary data.

Regarding precipitation, different parameters have been determined: the intensity, the total cross sections of raindrops, the total volume swept out by falling drops, as well as the mean raindrop size. Gamma and lognormal distributions were used for characterising raindrop and aerosol size distributions, respectively. To evaluate the effect of rain on aerosols, the evolution of particle concentration before, during and after the precipitation events has been analysed. Furthermore, the scavenging coefficient (Λ) and the relationship between the different variables have also been studied. In order to know the behaviour of the scavenging in the Greenfield gap (between 0.3 and 1 μm), three different aerosol size intervals have been established including particles i) below 0.3 μm ; ii) between 0.3 and 1 μm and iii) above 1 μm . Preliminary results indicate a wash-out on the total mass of aerosols, also depending on the frontal passage.

P12.15

The Cloud System Evolution in the Trades (CSET) Study-A Showcase for Aerosol-Cloud-Precipitation Interactions

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12,2

The Cloud System Evolution in the Trades (CSET) study was designed to describe and explain the evolution of the boundary layer aerosol, cloud, and thermodynamic structures along trajectories within the north-Pacific trade-winds. The observational component of this study centered on 7 round-trips made by the NSF NCAR Gulfstream V (GV) between Sacramento, CA and Kona, Hawaii between 1 July and 15 August 2015. The CSET observing strategy used a Lagrangian approach to sample aerosol, cloud, and boundary layer properties upwind from the transition zone over the North Pacific and to resample these areas two days later. GFS forecast trajectories were used to plan the outbound flight and return flight plans two days later. Two key elements of the CSET observing system were the newly developed HIAPER Cloud Radar and the HIAPER Spectral Resolution Lidar, providing unprecedented characterizations of aerosol, cloud and precipitation structures. A full suite of probes on the aircraft were used for in situ measurements of aerosol, cloud, precipitation, and turbulence properties. A wide range of boundary layer structures and aerosol, cloud, and precipitation conditions were observed during CSET. The cloud systems sampled included solid stratocumulus infused with smoke from Canadian wildfires, mesoscale (10-20 km) cloud complexes, and patches of shallow cumuli in environments with accumulation mode aerosol concentrations of less than 50 cm⁻³. CSET will enable focused modeling studies of cloud system evolution and the role of aerosol-cloud-precipitation interactions in that evolution.

P12.16

Impacts of aerosol particle episodes on cloud physical properties and precipitation

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The broader Mediterranean basin is characterized by the presence of different types of aerosol particles of both natural and anthropogenic origin. The influence of the presence of highly increased dust-sea salt (DSS) aerosol concentrations under “episode” conditions on cloud formation is investigated in the present study. The episode occurred over the maritime Atlantic area west of La Coruna (Spain) on 6th February 2004 and is identified with an algorithm using satellite aerosol optical depth (AOD) and cloud condensation nuclei (CCN) observations. The 1.5D bin-resolved microphysics Detailed Scavenging Model (DESCAM) is employed to simulate the evolution of cloud physical properties, in particular its liquid and ice-phase water content (LWC and IWC respectively) and of the updraft/downdraft regime, for the cases of clouds formed under “episode” and “non-episode” conditions. The possible effect of aerosol episodes on precipitation produced by the clouds is also examined. The key effects of aerosol episodes, namely the increase of CCN and the enhanced atmospheric warming due to the absorption of solar radiation from aerosol particles, on cloud formation are being separately analyzed and compared.

P12.17

Analysis of Remote and Combustion Aerosol over the South East Pacific and its Links to Stratocumulus Cloud Droplet Size Distribution

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Because the nature and variability of aerosol effective as cloud condensation nuclei (CCN) impact cloud microphysical properties through cloud droplet number concentration (N_d), aerosol physiochemistry measurements from the NCAR C-130 aircraft during the VOCALS Regional Experiment were utilized to establish air mass characteristics and their CCN activity over the South East Pacific (SEP). The analysis reveals six distinct marine boundary layer (MBL) air masses associated with different stages of aging and processing of coastal combustion sources, clean South Pacific and heavy drizzling air. Derived MBL CCN also reveals a 1:1 relationship to N_d over the range of air mass characteristics observed once droplet concentrations are corrected for instrumental artifacts that tend to undercount N_d in polluted clouds.

In-cloud measurements also show a robust dependency of N_d with the empirical correction factor k^* utilized in cloud radiative transfer codes to account for droplet spectral properties. This relationship can be traced to aerosol size distributions below the clouds. Measurements for both clean marine and pollution influenced aerosol populations indicate that as they undergo cloud processing, reducing the number of CCN and N_d , their droplet mean radius (r_μ) increases while spectrum width (r_σ) is unaffected. The associated k^* increases, as it is roughly proportional to r_μ / r_σ . If this dependency is not accounted for, local forcing could be overestimated considerably in polluted clouds close to the Chilean coastline. Stratocumulus clouds further exhibited highest drizzle rates in the absence of typical pollution indicators as carbon monoxide mixing ratio and black carbon concentration.

P13.1

THE UPDATED EFFECTIVE RADIATIVE FORCING OF MAJOR ANTHROPOGENIC AEROSOLS AND THEIR EFFECTS ON GLOBAL CLIMATE AT PRESENT AND IN THE FUTURE

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12, aerosol effect, cloud, precipitation, effective radiative forcing

The effective radiative forcing (ERF), as newly defined in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5), of three anthropogenic aerosols and their comprehensive climatic effects were simulated and discussed, using an aerosol-climate coupled model. From 1850–2010, the total ERF of these anthropogenic aerosols was -2.49 W m^{-2} , of which the aerosol-radiation interactive ERF (ERF_{ari}) and aerosol-cloud interactive ERF (ERF_{aci}) were ~ -0.30 and -2.19 W m^{-2} , respectively. Sulfate was the largest contributor to the total ERF, with an ERF of -2.37 W m^{-2} . The ERF of black carbon and organic carbon were 0.12 and -0.31 W m^{-2} , respectively. From 1850–2010, anthropogenic aerosols brought about a decrease of $\sim 2.53 \text{ K}$ and $\sim 0.20 \text{ mm day}^{-1}$ in global annual mean surface temperature and precipitation, respectively. Surface cooling was most obvious over mid and high latitudes in the northern hemisphere (NH). Precipitation change was most pronounced near the equator, with decreased and increased rainfall to the north and south of the equator, respectively; this might be largely related to the enhanced Hadley Cell in the NH. Cloud cover were increased, especially in or near the source regions of anthropogenic aerosols. Experiments based on the Representative Concentration Pathway (RCP) 4.5 given in IPCC AR5 shows the dramatic decrease in three anthropogenic aerosols in 2100 will lead to an increase of $\sim 2.06 \text{ K}$ and 0.16 mm day^{-1} in global annual mean surface temperature and precipitation, respectively, compared with those in 2010.

P13.2

Sensitivity of Cloud Feedbacks to Turbulence Closure, Microphysics Scheme, and Grid Size in Cloud-Resolving RCE Simulations

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13,9,3

Radiative-Convective Equilibrium (RCE) simulations were performed using the System for Atmospheric Modeling (SAM). Dozens of simulations allowed for evaluation of turbulence closure schemes, microphysics (single-moment and double-moment schemes), grid spacing (0.5 km to 16 km), and SST (301 K and 305 K). The turbulence closure schemes tested included a closure that predicts the subgrid-scale turbulent kinetic energy (SGS-TKE) and the Simplified Higher-Order Closure (SHOC) parameterization.

Precipitable water and precipitation were most sensitive to SST. Cloud water path and ice water path were primarily sensitive to grid size and turbulence closure. Shortwave cloud radiative effect (CRE) values were larger in magnitude for SGS-TKE runs while SHOC runs had larger magnitude longwave CRE values. The simulated clouds are primarily upper-level cirrus. Net CREs were negative for single-moment SGS-TKE and positive for double-moment SHOC. Net CREs were positive for the abundant high-altitude cirrus and negative for the other cloud types. Cloud feedbacks were positive for single-moment SGS-TKE runs but negative for SHOC runs.

On average, warmer, single-moment and/or SHOC runs had more frequent strong updrafts. Heavier precipitation events were slightly more frequent in the double-moment runs. The higher SST SGS-TKE runs had more precipitation events at all intensities; however, higher SST SHOC runs had more light precipitation events and fewer heavy precipitation events.

P13.3

Validation of MODIS liquid water path for oceanic non-raining warm clouds and its implication on the vertical profile of cloud water content

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1. 2.

Liquid water path (LWP) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) is validated using the Advanced Microwave Scanning Radiometer-EOS (AMSRE) retrievals for global oceanic non-raining warm clouds, with focus on the vertically homogeneous (VH) model and adiabatically stratified (AS) model of liquid water content (LWC) profile used in MODIS retrieval. With respect to AMSRE-LWP that acts as ground truth under a series of constraints, the global average of MODIS-LWP_{VH} and MODIS-LWP_{AS} has a positive (11.8%) and negative (-6.8%) bias, respectively. Most of the oceanic warm clouds tend to have adiabatic origin and correspondingly form AS-like profiles, which could be well retained if drizzle is absent. Besides the presence of drizzle, cloud-top entrainment seems to be another cause that modifies the original LWC profiles to become VH-like, which is notable for the very low clouds that have rather small thickness. These factors jointly determine the appearance of LWC profile and in turn the spatial pattern of LWC profiles across global oceans, with AS-like profiles dominant in the areas where non-raining warm clouds occur very frequently in the form of stratocumulus. The optimal LWP of MODIS that is established using VH-optimal and AS-optimal ones agrees more consistently with AMSRE-LWP than either MODIS-LWP_{VH} or MODIS-LWP_{AS}. The bias is dramatically reduced to -1.0 g/m^2 (-1.3%), with correlation coefficient rising to 0.89. A combined usage of VH and AS model in the MODIS retrieval is found to be crucial for improving the LWP estimation for oceanic non-raining warm clouds.

P13.4

Implementing a two-moment bulk cloud microphysics scheme into TaiESM

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13, 12

Keywords: Cloud microphysics scheme, cloud macrophysics, aerosol-cloud interactions, global weather model, global climate model, satellite simulator

Abstract

Aerosol-cloud-radiation interactions in earth system models are often calculated via highly simplified parameterizations. Most of cloud microphysical schemes used in large-scale global weather and/or climate models are based on single-moment bulk cloud microphysics schemes and are still using the so-called saturation adjustment type of approach for determining large-scale condensate in the cloud macrophysics. In this study, we have implemented a two-moment bulk cloud microphysical scheme, CLR, (Chen and Liu, 2004; Cheng et al., 2007, 2010) into NCAR CESM and Taiwan Earth System Model (TaiESM). The unique feature of the parameterization is the detailed coupling of microphysical processes between cloud and aerosol schemes. Single column model simulations based on specific intensive observational periods and short-term prescribed sea surface temperature global simulations will be shown to reveal the impacts of such multi-moment and multi-class cloud microphysical scheme in the two earth system models. In addition to overall changes in climatological mean, both in-line COSP satellite simulator and off-line Joint-Simulator will be applied to understand and to validate the performance of global simulations as well as to evaluate model sensitivity with respect to various assumptions of cloud microphysical parameters in the macrophysics and microphysics schemes.

P13.5

Radiative impacts of cloud processed bimodal CCN spectra

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13, 12, 14, 2

Cloud droplet number concentrations (N_c) were related to bimodality in cloud condensation nuclei (CCN) spectra produced by cloud processing (Hudson et al., 2015). Cloud processing produces better CCN in the processed mode that more easily activate at low supersaturations (S). Therefore, CCN spectral shape influences cloud microphysics and, subsequently, cloud radiative properties and precipitation. We employ an adiabatic droplet growth model using bi- and monomodal CCN spectra with similar concentrations to observe spectral shape effects at various vertical velocities (W). At low W , typical of stratus clouds ($<70\text{cm/s}$), bimodal CCN spectra produced higher N_c and smaller mean diameters (MD) than monomodal CCN spectra. This resulted because improved CCN in bimodal spectra activated even at limited S from low W . Higher N_c increased competition for condensate reducing sizes which could reduce drizzle. At greater W , typical of cumulus clouds ($>70\text{cm/s}$), bimodal CCN spectra generated lower N_c and larger MD than monomodal CCN spectra. Here, competition diminishes as higher W does not limit S . Thus, bimodal CCN spectra potentially grow unabated which could increase drizzle. Nevertheless, more small droplets produced at low W subsequently produced greater cloud optical depths and greater cloud albedos. These cloud radiative property changes potentially impact climate because stratus clouds typically have lower W and cover vast areas of oceans. Stratus cloud susceptibility to spectral shape requires further investigation but may be regulated by CCN concentrations and cloud processing type. Hudson et al. (2015), JGRA, 120, 3436-3452.

P13.6

Seasonal trends in cloud vertical properties in the SE Asia region from IAGOS in situ observations

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17, 1,2,3,9

We present long-term in situ profile measurements of cloud microphysical properties over major cities in the SE Asia region compared with observations made over Europe. These are based on on-going measurements by the IAGOS commercial airline global climate observation fleet collected over a two year period over the cities of Taipei, Taiwan and its major industrial areas including New Taipei and Keelung, in the Taipei Basin. A subset of cloud microphysical profile properties provided by a miniature cloud particle spectrometer, part of instrumentation operated on the IAGOS Airbus fleet and operated by Lufthansa and China Airlines, were analysed. These included particle concentration, effective and median volume diameter, and extinction coefficients. These are used to highlight the seasonal variation in cloud properties from Spring, Summer, Fall and Winter as a function of height over the two cities. We compare and contrast these results with similar, extensive cloud profiles measured over the city of Frankfurt, Germany, where cloud observations covered temperature ranges from +20 to -20C and up to heights of approximately 10 km. The results are used to highlight and quantify the increasing responses seen in most vertical cloud properties due to changing boundary layer environments and ambient precursors across the seasons but particularly during Winter-time. We compare and contrast the results from the two cities and discuss the relative importance microphysical mechanisms involved and their potential importance for response to future changing regional climate-pollution scenarios.

P13.7

Climatic impact of marine organic aerosols as ice nuclei in the Arctic

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12,14,13,4

One of the projected changes in the Arctic environment with continued warming is an increase in the melting of sea ice in summer. In a pristine environment such as the Arctic where background aerosol concentration is particularly low, this may result in significant atmospheric aerosol burden changes, which can affect the radiative balance of Earth, and thus climate, both directly and indirectly as aerosol particles can act as ice nuclei (IN) and/or cloud condensation nuclei (CCN).

Since there is still much debate over the ice nucleating ability of various aerosol species, previous studies on changes in the Arctic have generally included a limited number of IN species. Recent measurement and modelling studies, however, have brought more credibility to the idea that marine organics can be a significant contributor of IN in remote marine regions. Thus we postulate that with the melting of Arctic sea ice leading to exposure of a larger ocean surface in summer in the future, marine organic aerosols can become an important IN source in the region. In this study, we examine the impact of marine organic INs on Arctic clouds in the present and future climate using the global aerosol-climate model ECHAM-HAM.

P13.8

Precipitation Differences in Boreal Summer Measured by DPR Ka- and Ku-Band

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The GPM Core Observatory satellite launched on February 27th, 2014, carrying advanced instruments, sets a new standard for precipitation measurements from space. In this study, the distributions of rain rate, frequency, storm top altitude, and vertical structure measured by DPR Ka- and Ku-band in boreal summer are investigated and the differences of those parameters from both bands are discussed. Comparing with mean rain rate derived from DPR, KaHS issues less than 0.7mm/h rain rate in the tropics whereas larger than 0.4mm/h extra-tropics. Meanwhile KaMS and Ku show larger than 0.6mm/h and 0.8mm/h in the tropics and mid-latitude, respectively. For storm top altitude (STA) in average, measurements from KaHS and KaMS produce 0.5km positive and 0.8km negative departures from DPR products, and almost the same STA generated by both Ku and DPR. The differences of liquid water content derived from KaHS, KaMS, Ku and DPR expose that KaHS produces 80 g/m² less than DPR in the tropics and 70 g/m² more in extra-tropics, while KaMS and Ku yield over 90 g/m² more than DPR in the tropics and mid-latitude. The similar situation shows in the differences of ice water content brought by KaHS, KaMS and Ku comparing with that by DPR. Our results also indicate that KaMS misses about 30% drizzles (rain rate less than 0.5mm/h) in the tropics and mid-latitude comparing with that measured by KaHS. For heavy precipitation (rain rate great than 10mm/h), KaHS leaves out about 10% of the rain type than measurements of KaMS, Ku and DPR.

P13.9

Radiative effects of inter-annually varying versus inter-annually invariant aerosol emissions from fires

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Open-burning fires play an important role in the Earth's climate system. In addition to contributing a substantial fraction of global emissions of carbon dioxide, they are also a major source of atmospheric aerosols such as black carbon, organic carbon, and sulphate. These "fire aerosols" can influence the climate via both direct and indirect radiative effects. In this study, we investigate these radiative effects using the Community Atmosphere Model version 5 (CAM5). Inter-annually varying emissions of fire aerosols exert a global mean net radiative effect of -1 W/m^2 , dominated by the cloud shortwave response. We find that if the inter-annual variability of emissions is ignored, the radiative effect of the fire aerosols can be substantially overestimated both globally and regionally. Hence we suggest that the inter-annual variability of fire aerosol emissions should be taken into consideration when designing climate modeling experiments.

P13.10

Observed relationship between cloud macrophysical properties and precipitation intensity

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17. Applications of cloud and precipitation physics (required)

In this study we analyze observational data to explore trends between cloud macrophysical properties (e.g., cloud water path, cloud thickness) and precipitation intensity. Multiple years (2006-2009) dataset of cloud and precipitation properties from the Moderate-resolution Imaging Spectroradiometer (MODIS)/Aqua, the Tropical Rain Measuring Mission (TRMM) and CloudSat satellites were used. Consistent with previous studies, we show a robust link between cloud water path (CWP) and rain rate (RR) for marine boundary layer clouds (cloud top temperature > 273 K). We extend the observed cloud regime and find significant trends also between deep mixed-phase clouds and their rain intensity. These connections can be described by a power law in the form of $RR \propto CWP^{Exp}$ with a varied Exponent that depends on the cloud's type, geographical region and season. Using theoretical consideration we express the rain exponent by means of level of adiabaticity and the characteristic drops terminal velocity. Such links can aid in better parameterization of rain properties in regional and global climate models. Moreover, they suggest a new measure for rain-rate using cloud properties retrieved by polar-orbiting climate satellites such as MODIS.

P13.11

Vertical Distributions and Seasonal Fluctuations from CALIOP: A Regional Aerosol-Cloud Interaction Analysis

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12,13,16

There are still many unknowns in regards to aerosols and clouds and their overall effect on the climate. By knowing the location and vertical distribution of aerosols in the atmosphere in relation to nearby clouds along with their seasonality, it will allow for a better understanding of aerosol-cloud-climate interactions. In order to study the intricate relationships between absorbing aerosols and clouds, an analysis is conducted using fourteen different regions that were chosen for observation based on fire count data from Aqua's MODIS satellite. This study uses CALIOP Level 2 Lidar Vertical Feature Mask (VFM) data for the years 2006-2015. The VFM data provides aerosol types in categories based on their optical properties, including those that are reflective, such as sulfur containing continental pollution, and those considered absorbing, such as dust and smoke. The CALIOP aerosol types under investigation in this study are clean marine, dust, polluted dust, clean continental, polluted continental, and smoke. In addition to aerosols, cloud types and their heights in the atmosphere will also be determined using the VFM data. The cloud types are low overcast (transparent), low overcast (opaque), transition stratocumulus, low, broken cumulus, altocumulus (transparent), altostratus (opaque), and cirrus (transparent). Gridded profiles were created based on the latitude and longitude of the regions. Each satellite pass through these regions was extracted and averaged over a nine year time period to create a climatological average of the dominant aerosol and cloud type, their maximum and average heights, and their seasonal fluctuations in the atmosphere.

P13.12

Large size and low number concentration cloud in mid and high latitudes

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The space-borne radar and lidar, CloudSat and CALIOP, found lots of clouds have significant radar echoes but low lidar returns above sea in mid and high latitudes even though there is no significant lidar attenuation. Some of their geometrical thickness is a few kilometers or greater. The radar-lidar analysis shows its particle radius is greater than 100 μm and number concentration is less than 10^4 num/m^3 . That is, the particle size and number concentration are larger and lower than those of usual clouds, respectively. We call it Large-Sparse cloud in this study. Data of the space-borne IR imager IIR and temperature profiles of ECMWF operational analysis also show an optical depth of Large-Sparse clouds is low because brightness temperature is the same as ground/cloud temperature below the Large-Sparse cloud. Thus, a Large-Sparse cloud is not detectable by IR and visible imagers, such as GOES and GMS.

The Large-Sparse cloud is unusual because the terminal velocity of such a large particle is tens cm/s and it will disappear immediately without updraft.

Previous studies carried out synergy observations of clouds by use of the ground-based lidar and radar in the Arctic; however, Large-Sparse clouds have not been measured. This is probably because these intensive observations are focused on clear sky precipitation, so called diamond dust, and a mixed phased cloud of which heights are below a few kilometers while a height of a Large-Sparse cloud is above a few kilometers.

We will show characteristics of Large-Sparse clouds in our presentation.

P13.13

Evaluation and Development of Cloud Microphysical Conversion Processes in the MIROC-SPRINTARS with A-Train Observations

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12. Aerosol-cloud-precipitation-interactions and processing

2. Warm boundary layer clouds

This study examines microphysical conversion processes in warm rain using a global aerosol climate model, MIROC-SPRINTARS, and the joint CloudSat/MODIS satellite observations. We apply the metric so-called precipitation susceptibility, which is defined as a change in rain rate for an increase in cloud droplet number concentration, to evaluate the aerosol-cloud-precipitation interaction. The results show that the model generally predicts a cloud-to-rain conversion process faster than the satellite observations. As suggested by recent studies, unrealistic light rain is also found in the model. The ratio of accretion to autoconversion is 1 or more orders of magnitude lower than previous observational studies implied, since the model diagnostically treats rainwater. We currently plan to apply a 2-moment prognostic precipitation scheme in the MIROC-SPRINTARS to overcome the above issues. The details of single-column tests will be shown in the presentation.

This study was supported by Grant-in-Aid for JSPS Research Fellows (15J05544), for Scientific Research (15K12190), and the Environment Research and Technology Development Fund (S-12-3) of the Ministry of the Environment, Japan.

P13.14

Uncertainty in the long-wave effective radiative forcing by aerosol-cloud interactions

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12, 13, 5

The radiative forcing by anthropogenic aerosols is highly uncertain. Some progress has been achieved recently in better quantifying the effective radiative forcing in the solar spectrum. However, the forcing in the terrestrial (long-wave) spectrum is virtually not constrained by observations. The effective radiative forcing involves thermodynamic and microphysical rapid adjustments of clouds. Only a few climate models that participated to the 5th Coupled Model Intercomparison Project parameterise microphysical effects of aerosols on ice clouds. In turn, all models include some representation of the thermodynamic adjustments. From an analysis of the CMIP5 models, this presentation shows that the magnitude of the forcing depends on the complexity of the parameterised effects, and is larger for the more sophisticated representations. In the terrestrial spectrum, adjustments are small unless microphysical effects are explicitly treated. Some observations-based constraints are shown to corroborate the forcing estimate in the solar spectrum. The talk will conclude by some suggestions concerning observations-based assessments of the effect in the terrestrial spectrum.

P13.15

On the relationships among cloud cover, mixed-phase partitioning, cloud feedback, and planetary albedo in GCMs

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¹*University of Washington, WA, USA*, ²*Yale University, CT, USA*, ³*Lawrence Livermore Laboratory, CA, USA*, ⁴*University of Leeds, Leeds, UK*

2,4,10,13

Increasing optical depth poleward of 45° is a robust response to warming in global climate models. Much of this cloud optical depth increase has been hypothesized to be due to transitions from ice-dominated to liquid-dominated mixed-phase cloud. In this study, the importance of liquid-ice partitioning for the optical depth feedback is quantified for several CMIP5 models. All models show a monotonic partitioning of ice and liquid as a function of temperature, but the temperature at which ice and liquid are equally mixed (T5050) varies by as much as 35K across models. Models that have a higher T5050 are found to have a smaller climatological liquid water path (LWP) and condensed water path, and experience a larger increase in LWP as the climate warms. Further, GCMs with a higher T5050 tend to have a greater mean-state cloud fraction. We know of no robust physical mechanism that can be invoked to explain the anti-correlation between the temperature at which supercooled liquid can remain unfrozen and cloud fraction in the climate mean state, especially because this anti-correlation extends through the subtropics. Liquid clouds have a higher albedo than ice clouds, so, all else being equal, models with more supercooled liquid water would also have a higher planetary albedo. The lower cloud fraction in these models compensates the higher cloud reflectivity and results in clouds that reflect a reasonable amount of shortwave radiation, but gives clouds that are too bright and too few.

P13.16

Interannual variations of cloud fraction and cloud types in the Atlantic Arctic from the end of the 19th century

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13, 3, 4

keywords: cloudiness, Arctic, cloud fraction, cloud types, surface observations

An analysis of cloud cover variability in the Atlantic part of the Arctic (the Norwegian, Barents and Kara Seas) based on long-term surface observations from Norwegian and Russian meteorological stations was carried out.

Total cloud fraction (TCF) had a maximum in the middle of the 20th century during the early 20th century warming (E20CW) and a minimum during the cooling of 1970s. TCF tend to increase in the last decades. However, values of TCF are still less in the present climate comparing to the E20CW according to the analyzed station data. The cold 1970s are characterized by high fraction of clear sky reports in the data sets. The occurrence of overcast conditions decreases while the occurrence of reports with broken clouds increases from the beginning of 1930s. These tendencies are revealed for all seasons but they are the most pronounced in autumn.

The analysis of the cloud types identified a pronounced increase of the convective cloud types (cumulonimbi and stratocumuli) and decrease of the stratiform cloud types (strati and nimbostrati) in the observational records from the middle of 1930s. These changes are the strongest over coastal and open-water stations. Over ice-band stations an increase of the occurrence of high-level cloudiness was revealed.

P13.17

Evaluations of microphysics in a global cloud system model using TRMM/AMSR-E and a satellite simulator.

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An evaluation and improvement of cloud properties and precipitations in the cloud system resolving model is important for the mesoscale and climate study. The satellite data are used for evaluations of cloud properties and precipitations in the cloud system resolving model because large coverage of space and time. The microwave channels on satellites are used to retrieve precipitation rates. Matsui et al. (2009) classified precipitation clouds and evaluated statistics in a cloud system model using 11 μm IR brightness and echo top height derived from Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR). In this study, we compare precipitation clouds in a global cloud system model using an active and a passive microwave satellite by a satellite simulator. We used the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) as passive microwave satellite data. We investigated how to change the precipitation cloud by precipitation indexes such as surface radar reflectivities and 19 GHz brightness temperatures over land and ocean. And we also investigate effects of local time on statics of precipitation clouds. We discuss uncertainties related to snow shape assumptions to simulate radiances and precipitation cloud statistic

P13.18

The longwave, shortwave and UV fluxes in the cloudy atmosphere: measurements and simulations using the onboard actinometrical complex of the aircraft-laboratory YAK-42D "ROSHYDROMET"

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13, 16

One of the tasks of the created in Russia, aircraft laboratory YAK-42D "ROSHYDROMET", is the study of the interaction between radiative fluxes and clouds over the territory of Russia and other regions of the Earth.

The on-Board actinometrical complex that allows to measure the downward and upward integrated fluxes of solar and thermal radiation as well as UV radiation is installed on the aircraft.

It consists of several instruments made by Kipp & Zonen company: pyranometers CMP-22 (for measuring the upward and downward solar fluxes), pyrgeometers CGR-4 (for measuring the upward and downward thermal fluxes) and the UVS-AB-T sensor (for measuring the downward UVA and UVB fluxes).

For analysis of the measurement results is developed high-precision model of the transport of atmospheric radiation based on methods of Monte Carlo for the photon scattering in the atmosphere, as well as Line-by-Line and K-distributions for taking in to account of molecular absorption.

At present these investigation are focused on the clarification of the relationship between cloud microphysics and radiation. In the report are considered preliminary data of fluxes of longwave, shortwave and UV radiation, obtained during the flights over European and Arctic territories of the Russian Federation.

Key words: actinometry, solar radiation, infrared radiative fluxes, cloud albedo, aircraft observations

P13.19

Impact of lidar data processing on the estimation of cloud radiative forcing

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13. Clouds and climate (including radiative properties of clouds)

The aerosol and cloud impact on climate change is evaluated in terms of enhancement or reduction of the radiative energy, or heat, available in the atmosphere and at the Earth's surface, from the surface (SFC) to the Top Of the Atmosphere (TOA) covering a spectral range from the UV (extraterrestrial shortwave solar radiation) to the far-IR (outgoing terrestrial longwave radiation). Systematic Lidar network measurements from permanent observational sites across the globe are available from the beginning of this current millennium. From the retrieved lidar atmospheric extinction profiles, inputted in the Fu-Liou-Gu (FLG) Radiative Transfer code, it is possible to evaluate the net radiative effect and heating rate of the different aerosol species and clouds. Nevertheless, the lidar instruments may use different techniques (elastic lidar, Raman lidar, multi-wavelength lidar, etc) that translate into uncertainty of the lidar extinction retrieval. The goal of this study is to assess, applying a MonteCarlo technique and the FLG Radiative Transfer model, the sensitivity in calculating the net radiative effect and heating rate of aerosols and clouds for the different lidar techniques, using both synthetic and real lidar data. This sensitivity study is the first step to implement an automatic algorithm to retrieve the net radiative forcing effect of aerosols and clouds from the long records of aerosol measurements available in the frame of EARLINET and MPLNET lidar networks.

P13.20

On the Potential Use of 3D Monte Carlo Radiative Transfer Models in Weather and Climate Models

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The Monte Carlo Independent Column Approximation (McICA) is used by several large-scale models to compute broadband radiative flux profiles. McICA generates stochastic subgrid-scale cloud columns that get used by the host radiative transfer (RT) model as it steps through spectral integration. To date, only two-stream approximations (TSAs) have been used with McICA, although any 1D solution of the RT equation could be used. For this study a 1D Monte Carlo (MC) solar RT algorithm replaced the TSA in McICA. This probably sounds odd given that MC solutions are usually presented as expensive benchmark-setters and unfit for operational use. But based on GCM experiments, the number of "photons" needed to limit MC sampling noise to "safe" levels is surprisingly small. Moreover, the MC model accommodates detailed scattering phase functions rather than just the asymmetry parameter. Moving forward, McICA's 1D cloud generator was replaced by a 3D stochastic cloud generator. This enables employment of a 3D MC RT model. It is shown that solar zenith angle θ_0 dependent biases due to the TSA's neglect of much scattering information and 3D cloud geometry are largely of the same sign. Cloud properties inferred from A-Train satellite data were partitioned into ~280 km domains and used to initialize the 3D cloud generator. Surface irradiance biases due to use of TSAs could average as much as -25 W m^{-2} near $\cos\theta_0 = 1$ and 10 W m^{-2} near $\cos\theta_0 = 0.2$. Initial tests using the new models in a GCM will be shown.

P13.21

Revised Cloud-Radiation Coupling for the COSMO-Model

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13; Coupling of cloud- and radiation schemes in atmospheric models

Clouds play an important role in the earth's radiation budget.

Now that today's atmospheric models

resolve ever finer cloud-scales and apply increasingly sophisticated microphysics schemes, the coupling of cloud- and radiation-schemes needs to be re-investigated.

This study presents our respective work for the COSMO-Model and results.

COSMO's standard radiation scheme takes grid-scale (microphysics) and subgrid-scale clouds (parameterized convection, RH-based cloud cover) into account.

Problems:

- Extinction coefficient β , single-scattering albedo ω and asymmetry parameter g of hydrometeors depend only on wavelength and LWC/IWC, hiding the dependency on particle shape and size distribution.
- Considers only cloud-water and cloud-ice. The species snow, graupel/hail and rain are neglected.

Our revisions:

a) Included grid-scale snow, graupel/hail, rain.

b) New parameterizations (fits) of β , ω , g as function of effective radius R_e , mean axis ratio A_R and LWC/IWC

to cover the required larger R_e -range (R_e and A_R consistent to microphysics from PSD assumptions therein).

c) Revised effective 'subgridscale variability' factor on LWC/IWC (currently 0.5).

Analysis suggests to increase this value for km-scale resolutions.

d) Subgrid-scale clouds: optical properties now also depend on R_e .

Revised LWC/IWC diagnostic.

Studies on surface radiation and two-meter-temperature of summer- and winter periods show larger sensitivities in summer.

a) and c) lead to increased cloud-radiation-interaction (e.g., reduced diurnal cycle in cloudy conditions). b) counteracts a) and c), d) provides new sensitive and uncertain tuning parameters.

Cloud-situation-dependent biases can be reduced, but a problem is that the 'rest' of the model is currently tuned to partially compensate 'the old' biases.

P13.22

Radiative-Convective Equilibrium to Evaluate AGCM Convective Parameterizations

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Clouds and climate; Tropical clouds; Applications of cloud and precipitation physics, Convective clouds, Radiative-convective equilibrium

Global radiative-convective equilibrium (RCE) setups in atmospheric general circulation models (AGCMs) are becoming increasingly useful for understanding model sensitivities, as well as diagnosing robust behaviors of cloud and precipitation processes. The role of convective parameterizations at high horizontal resolution and their impacts on clouds, circulation, and precipitation processes represent large uncertainties in current-generation AGCMs. As the statistical equilibrium in which radiative cooling is balanced by convective heating, RCE offers a *reduced complexity framework* to investigate such uncertainties.

In the age of increasing AGCM complexity (i.e., increased resolution, enhanced parameterizations, higher-order dynamics packages), the use of reduced complexity modeling for process studies remains crucial. This work presents a hierarchy of reduced complexity testbeds that have been used to explore sensitivities of model design choices at reduced computational expense. The role of convective parameterizations at high horizontal resolution and their impacts on clouds, circulation, and precipitation processes are explored as they represent large uncertainties in current-generation global models. Two versions of National Center for Atmospheric Research's Community Atmosphere Model (i.e., CAM5 and CAM6) are configured in non-rotating radiative-convective equilibrium to investigate organized convection and the scale-awareness of the underlying parameterizations.

P13.23

GCM cloud parameterization development from evaluation of large-eddy and SCM simulations using in situ observations and satellite retrievals of warm, boundary-layer clouds

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2, 13

Two low-cloud periods from the 19-month deployment of the ARM Mobile Facility at the Azores are simulated with the DHARMA LES and the GISS SCM. The cases are selected through a cluster analysis of ISCCP cloud-based weather states, so as to represent two low-cloud weather states that the GISS GCM severely underpredicts in that region and globally. The cases represent (1) shallow cumulus clouds occurring in a cold-air outbreak behind a cold front, and (2) stratocumulus clouds occurring when the region was dominated by a high-pressure system. The LES captures major structural differences between the two low-cloud fields, but there are unconstrained uncertainties in cloud microphysics and challenges in reproducing W-band Doppler radar moments. The SCM run on the vertical grid used for CMIP-5 runs of the GCM does a poor job of representing the shallow cumulus case and is unable to maintain an overcast deck in the stratocumulus case, providing some clues regarding problems with low-cloud representation in the GCM. SCM sensitivity tests with a finer vertical grid in the boundary layer show substantial improvement in the representation of cloud amount for both cases. GCM simulations with CMIP-5 versus finer vertical gridding in the boundary layer are compared with observations. The adoption of a two-moment cloud microphysics scheme in the GCM is also tested in this framework. The methodology followed in this study, with the process-based examination of different time and space scales in both models and observations, represents a prototype for GCM cloud parameterization improvements.

P14.1

A laboratory investigation of the ice nucleation efficiency of several types of mineral and soil dust

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14, 12, 5, mineral dust

Ice nucleation is an important pathway for cloud formation and initiation of precipitation in the atmosphere, thus affecting the Earth's hydrological cycle and energy and radiative balance. Mineral dust has long been known to efficiently act as ice nucleating particles (INP), primarily so due to its large size and morphology, and is commonly associated with the formation of cirrus clouds. Its importance as INP is increased by its ability to be subject to long-range transport after emission. While the ice nucleating ability of mineral dust increases with its size, there is also a strong dependence on its mineralogical composition, indicating a large and uncertain variability of the ice nucleation activity (INA) of mineral dust from various global sources.

Submicron size selected (monodisperse) mineral dust samples from several locations around the world are analysed in the Portable Ice Nucleation Chamber (PINC) in order to investigate the INA in the water sub- and super-saturated regimes to represent deposition nucleation and condensation freezing modes, respectively. Samples originate from a variety of locations, such as Antarctica, China, Iceland, Kyrgyzstan, the Mojave Desert and the Himalayas, and include mineral dust, volcanic sand and glaciological silt. The temperature range investigated is as low as 233K. Results will be analysed based on the ice nucleation active surface (INAS) density to compare efficiencies of these samples to previous parameterisations for dusts developed from laboratory and field studies.

P14.2

Parameterising Cloud Condensation Nuclei concentrations during HOPE

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Key Area: 14

Preferred: Poster presentation

An aerosol model was used to simulate the generation and transportation of aerosols over Germany during the HD(CP)2 Observational Prototype Experiment (HOPE) field campaign of 2013. The aerosol number concentrations and size distribution are evaluated against observations, which shows satisfactory agreement. From the modelled aerosol number concentrations, number concentrations of cloud condensation nuclei (CCN) were calculated as a function of vertical velocity using a comprehensive aerosol activation scheme which takes into account the influence of aerosol chemical and physical properties on CCN formation. There is a large amount of spatial variability in aerosol concentrations, however the resulting CCN concentrations vary significantly less over the domain. Temporal variability is large in both aerosols and CCN. A parameterisation of the CCN number concentrations is developed for use in models. The technique involves defining a number of best fit functions to capture the dependence of CCN on vertical velocity at different pressure levels. In this way, aerosol chemical and physical properties as well as thermodynamic conditions are taken into account in the new CCN parameterisation. The new parameterisation shows excellent agreement with the model derived CCN number concentrations over a large range of vertical velocities and pressure levels. This parameterisation may be used in other regions and time periods with a similar aerosol load, and furthermore, this technique demonstrated here may be employed in regions dominated by different aerosol species.

P14.3

Free tropospheric INP concentrations at the High Altitude Research Station Jungfraujoch

Larissa Lacher, Ulrike Lohmann, Zamin Kanji
ETH, Zurich, Switzerland

14.

Clouds containing ice play an important role in the Earth's system, but fundamental knowledge on their formation and further development is still missing. Only a tiny fraction of ambient aerosol particles are ice nucleating particles (INP) and continuous measurements in an environment relevant for ice and mixed-phase clouds are rare. We perform measurements with the Horizontal Ice Nucleation Chamber HINC at the High Altitude Research Station Jungfraujoch. The site provides free tropospheric conditions with seasonal influence from boundary layer air and is regularly affected by Sahara dust events. By measuring during different seasons of the year we address the question of an annual cycle of INP concentrations in the free troposphere. We sample aerosols at 242 K in the water subsaturated and supersaturated regime which is relevant for the formation of ice and mixed-phase cloud. Results from field campaigns in spring, winter and summer are compared during free tropospheric conditions. The concentrations range from almost zero to more than 100 INP l^{-1} with highest concentrations during Sahara dust events and an event with influence of marine air. With the exception of these special sampling events, average INP concentrations are around 10 l^{-1} with the highest concentrations during spring. With the continuation of these measurements we have a longer time series of INP concentrations and a better understanding of their evolution in the free troposphere.

P14.4

CCN measurements at the Princess Elisabeth Antarctica Research Station

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14, 12

Atmospheric aerosol measurements were conducted at the Princess Elisabeth Antarctica Research Station during three Antarctic summers from December 2013 to February 2016. The total particle number concentration (N_{total}) and the Cloud Condensation Nuclei number concentration (N_{CCN}) were determined using a Condensation Particle Counter and a CCN counter, respectively. N_{CCN} was measured for supersaturations between 0.1 and 0.7 %. N_{total} generally ranged from as low as 100 $\#/cm^3$ up to 1000 $\#/cm^3$. During particle formation events N_{total} up to 7000 $\#/cm^3$ were observed. For the above mentioned range of supersaturations N_{CCN} varied between some ten to 500 $\#/cm^3$. Particle number size distributions were measured between 90 nm and 7 μm using an Optical Particle Counter. By applying the κ -Köhler-Theory (Petters and Kreidenweis, 2007) the hygroscopicity parameter κ was calculated for 0.1 % supersaturation ($\kappa_{0.1}$). For this supersaturation, critical diameters were found to be in the range of 100 to 130 nm, and $\kappa_{0.1}$ values range from 0.6 to 1. Hence the aerosol particles seem to consist of mainly hygroscopic material (e.g. sulfate) rather than organic compounds. The high hygroscopicity in the Antarctic region agrees well with global simulations (Pringle et al., 2010) and other field studies (e.g. Asmi et al., 2010). Back trajectories will be used to obtain information about air mass origins and possible correlations to N_{CCN} , N_{total} and κ .

Petters and Kreidenweis (2007), Atmos. Chem. Phys., 7, 1961-1971, 2007

Pringle et al. (2010), Atmos. Chem. Phys., 10, 5241-5255, 2010

Asmi et al. (2010), Atmos. Chem. Phys., 10, 4253-4271, 2010

P14.5

What influences CCN properties in central Europe?

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At the TROPOS field station Melpitz (Germany), aerosol and CCN properties are measured, which are regionally representative for central Europe. A 3-year dataset (August 2012 to July 2015) of continuous CCN size spectra measurements, for particle sizes between 25 and 300 nm at 5 different supersaturation (SS) levels (0.1, 0.2, 0.3, 0.5, 0.7%) has been analysed. The derived particle hygroscopicity (κ -value) and the number of CCN at a certain SS (N_{CCN}) were examined as a function of the large scale weather situation using a backward trajectory cluster analysis leading to 15 distinct weather clusters (cl 0 to cl 14).

A significant difference in CCN ability is found between very stable winter weather conditions (cl 0 & 7, high PM_{10}), and unstable spring / autumn weather situations (cl 1, low/very low PM_{10}). The ratio of N_{CCN} to N_{tot} at a supersaturation of 0.7% is 0.65 (cl 0) vs. 0.35 (cl 1) and N_{CCN} to N_{tot} for a supersaturation of 0.1% is 0.3 (cl 0) vs. 0.05 (cl 1). For cl 0 the air mass is stagnating for several days, the mass concentration is increasing and by the same time CCN ability increases as well, most probably due to the enrichment of soluble material on the pre-existing particles. In case of cl 1 the boundary layer is well mixed and consequently a lower PM_{10} load is observed. However almost the same N_{tot} was found, most probably due to new particle formation and thereby particles yet too small to act as CCN.

P14.6

Particle Hygroscopicity of Organics in the Supercooled Temperature Range Down to Minus 10°C

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14, 12

An unique data set concerning the hygroscopic growth of supercooled droplets grown on inorganic and organic seed particles at temperature down to minus 10°C will be presented. Seed particles consisting of either sodium chloride, levoglucosan, and 3 dicarboxylic acids (malonic, citric, glutaric acid) were investigated. The substances were atomized from aqueous solution, resulting droplets dried and the remaining particles were size-selected applying a Differential Mobility Analyzer (DMA). The resulting monodisperse aerosol flow was either humidified or directly imbedded into a preconditioned sheath air flow at the inlet section of the laminar flow tube Leipzig Aerosol Cloud Interaction Simulator (LACIS-mobile). Depending on the set wall temperature of LACIS-mobile the particles were grown hygroscopically at temperatures down to minus 10°C. The size of the grown particles was determined applying the TROPOS in-house developed White-light Optical Particle Spectrometer (WOPS), and the effective relative humidity (RH) inside LACIS-mobile was calibrated using ammonium sulfate particles.

Effective hygroscopicity parameters for the investigated compounds were determined for temperatures below 0°C up to a maximum RH of 99% and compared to values from existing Köhler models. For all substances a good agreement between predicted and measured supercooled hygroscopicity was found. The deviation in growth for different temperatures is small, however for the deliquescence RH of the sodium chloride particles, distinct temperature dependence was observed. In case of the supercooled organic particles no glassy phase state, and growth as model-predicted was observed. Deliquescence was not observed for the investigated organic particles.

P14.7

An approximation for freezing temperature of water droplets: homogeneous nucleation and immersion mode heterogeneous ice nucleation

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14. Ice nuclei and cloud condensation nuclei;

Based on the well-known formulae of classical nucleation theory (CNT), the temperature $T_{nc}=1$ at which the mean number of critical embryos inside a droplet is unity is derived and proposed as a new approximation for homogeneous freezing temperature of water droplets. Without consideration of time dependence of the ice nucleation process and the stochastic individual differences among drops, the approximation $T_{nc}=1$ is able to reproduce the dependence of homogeneous freezing temperature on drop size and water activity of aqueous drops observed in a wide range of experimental studies. We use the $T_{nc}=1$ approximation to argue that the distribution of homogeneous freezing temperatures observed in the experiments may largely be explained by the spread in the size distribution of droplets used in the particular experiment.

Then, the approximation $T_{nc}=1$ is applied to study the freezing temperature of immersion mode heterogeneous ice nucleation. Immersion freezing occurs when ice nucleates on ice nucleating particles (INPs) immersed in the supercooled water, and the ice nucleation ability of INPs depends on the surface area and contact angle (θ) of the particles. The approximation $T_{nc}=1$ of the immersion freezing is then considered as the temperature at which the mean number of critical embryos on the total INPs surface inside the drop is unity. Here, based on the proposed approximation $T_{nc}=1$, the ice nucleation ability parameter $f(\theta)$ of various atmospherically relevant INPs are derived and compared. The application of $T_{nc}=1$ in the cloud parameterization will also be discussed here.

P14.8

The influence of particle generation on the immersion freezing behavior of different kinds of combustion ashes

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14, 12

The freezing behavior of combustion ash particles has rarely been investigated in the past. A recent study by Umo et al. (2015) shows that bottom ashes (i.e., ash remaining on the ground after combustion) from wood and coal burning, as well as fly ash (i.e., ash being emitted together with flue gases into the atmosphere) from coal burning contain particles which are able to catalyze freezing in the immersion mode. As coal combustion still fuels the biggest proportion of electric power production worldwide and biomass burning contributes significantly to the global aerosol loading, further data is needed to better assess the ice nucleating efficiency of ash particles.

The here presented study focuses not only on differences in the immersion freezing behavior of several kinds of bottom and fly ashes but also on the effect of particle generation. For this, particles were generated either by aerosolization of dry sample material, or by atomization of ash-water suspensions, and then led into the Leipzig Aerosol Cloud Interaction Simulator (LACIS, Hartmann et al., 2011). Whereas the immersion freezing behavior of bottom ashes from wood burning was not affected by the particle generation method, it depended on the type of particle generation for bottom and fly ash from brown coal. Furthermore, it was found that the common practice of treating prepared suspensions in an ultrasonic bath to avoid an aggregation of particles led to an enhanced ice nucleation activity.

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Umo et al.: ACP, 15, 5195-5210, 2015

P14.9

Ice Nuclei Measurements over Mountain and Coastal site along West Coast of India

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14 16

Deposition mode ice nuclei measurement over two stations along west coast of India the first one at a Mountain site (17.92 N, 73.65 E, ~1500m amsl) and the second one at Sea level (18.62 N, 72.87 E, 0m amsl) are reported here. The aerosol samples collected on filter paper have been processed in a thermal gradient diffusion chamber to get the ice nuclei concentration. The maximum ice nuclei count is found to be 1.8 lit^{-1} for Mountain site and 1.5 lit^{-1} for costal station when sample is exposed to ice supersaturation (SSi) varying from 15 to 32%. The average value of ice nuclei count over a period of one week is found to be higher over Mountain site 0.77 lit^{-1} in comparison to costal site where it is 0.25 lit^{-1} . Ice nuclei count is very high when the airmass is coming from Arabian Desert over the mountain site.

SEM-EDX analysis show the presence of sea salt particles Na, Cl over both stations along with some other elements like Si, Al, Mn, Zr etc. Presence of Si and Al indicate dominances of mineral aerosols.

P14.10

Could prediction of atmospheric dust help better modelling of heterogeneous cloud glaciation?

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14. Ice nuclei and cloud condensation nuclei

Ice nucleation (IN) in cold clouds is generally not yet satisfactory represented in atmospheric models. Research shows that mineral dust significantly contributes to cloud ice nucleation. Particle residues in cloud ice crystals collected by numerous aircraft sampling in the upper tropopause of regions distant from desert sources shows that dust particles dominate over other known ice nuclei. Measurements also show that there is a significant correlation between IN concentrations and the concentrations of coarser dust aerosol at given temperatures and moistures.

Due to dominant role of dust, several parameterizations has been recently developed to parameterize immersion and deposition IN in the presence of dust. Based on these achievements, we have developed a forecasting system based on an atmosphere-dust model, capable to predict occurrence of cold clouds generated by dust. The model have been thoroughly validated model against available observations. The CNR-IMAA Potenza lidar and cloud radar data have been used to explore the model capability to represent vertical features of the cloud and dust vertical profiles. Furthermore, the MSG-SEVIRI satellite data on ice water path have been utilized to examine the accuracy of the simulated horizontal distribution of cold clouds formed due to dust. Based on the encouraging verification scores obtained, an operational prediction of ice clouds nucleated by dust has been introduced in the Serbian Hydrometeorological Service as a publicly available product.

P14.11

Long-term Measurements of Ice Nuclei Concentration at Cape Verde

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PM₁₀ filter samples collected at Cape Verde atmospheric observatory (CVAO; 16,848°N, 24.871°W) are analyzed for number concentrations of ice nucleating particle (IN) in the immersion mode. The samples are collected on a tower 30m above the sea level, representing the subtropical marine boundary layer. Besides marine sources, aerosol transported from the Saharan desert, the Sahel zone and SW Europe contribute to the PM₁₀ particle composition at CVAO (Fomba et al., 2014). Using the drop freezing technique described in Conen et al. (2012) the IN concentration above -16°C is determined.

Measured IN concentration are examined in relation to the large scale wind direction using backward trajectories, to season, meteorological features, PM₁₀ mass and chemical bulk composition. An example result of this analysis: contrary to the widespread assumption that wind-blown dust is the main source for IN, we do not observe an association of IN concentration at temperatures above -16°C with desert dusts, in accordance to Bigg and Miles (1964). Highest IN concentrations are found in autumn coming from a NNE direction, pointing to SW Europe as source region. Additional correlations e.g. to anthropogenic or biological tracers are discussed.

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Bigg and Miles: The Results of Large-Scale Measurements of Natural Ice Nuclei, *J. Atmos. Sci.*, 21, 396-403, 1964.

Conen et al.: Atmospheric ice nucleators active ≥ -12 °C can be quantified on PM₁₀ filters, *Atmos. Meas. Tech.*, 5, 321-327, 2012.

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P14.12

A chamber study on the impact of organic components on warm and cold cloud formation

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- 1. Basic cloud and precipitation physics
- 14. Ice nuclei and cloud condensation nuclei

keywords: cloud chamber, cloud formation

abstract:

Cloud droplet formation by condensation of water vapour on cloud condensation nuclei has been studied for many years. The process is relatively well understood for non-volatile particles, however, particles suitable to act as condensation nuclei varies widely in volatility and may therefore be semi-volatile or volatile. In theory, co-condensation of organic vapours and water vapour increases cloud particle numbers. As an air parcel rises and cools, organic vapours become increasingly saturated and condense onto particles on their way to become activated as cloud particles. This, in turn, facilitates uptake of more water.

Since experimental proof of the effects of co-condensation is missing, the CCN-Vol experiments aim at investigating this process further. The experiments are carried out in the Manchester Ice Cloud Chamber (MICC) coupled to the Manchester Aerosol Chamber (MAC). With this unique setup, specified aerosol can be injected into MICC to study cloud formation in a broad temperature range from -50°C to room temperature. The laboratory study shall investigate the influence of organic vapours on the activation of secondary organic aerosol in warm clouds and the ability of secondary organic aerosol particles to act as ice nuclei in cold and mixed phase clouds.

Here, we will show (preliminary) results of the two CCN-Vol experiments, aiming at quantifying the impacts of organic components on warm and cold cloud formation.

P14.13

Deposition ice nucleation: Can the FHH adsorption nucleation theory shed light on the temperature dependence of critical supersaturations?

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14, 5, 4, 12, 13

A wealth of laboratory data has been collected over the years on the ice nucleation efficiencies of different types of water insoluble particles. The data are often classified based on so called nucleation site densities, but deeper theoretical understanding of the ice nucleation process is mostly lacking. One of the unexplained features seen in the experiments is the temperature dependence of the critical supersaturation of deposition mode ice nucleation: at lower temperatures (e.g. below 225 K, depending on particle composition and size), the critical supersaturation usually increases with decreasing temperature, whereas at higher temperatures (e.g. above 240 K), the dependence is vice versa. We have applied the new FHH adsorption theory of heterogeneous nucleation to examine the deposition nucleation efficiency of sodium montmorillonite particles. The basic idea of the theory is to use a combination of the FHH adsorption theory and the Kelvin relation, and to calculate the critical supersaturation of adsorbed clusters (in this case ice clusters) having a known contact angle with the underlying surface. We find that the theory predicts both the critical supersaturations and their temperature dependences quite well for 100 – 800 nm sodium montmorillonite particles at low temperatures. However, the theory does not predict the inverted temperature dependence at $T > 235$ K. We suggest that at these high temperatures, the adsorbed clusters are in fact in the liquid phase, and the measured critical supersaturations manifest the freezing of these clusters, which would explain the strange temperature dependence.

P14.14

Evaluation of the immersion freezing behaviors of dust collected in northwest Greenland

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14, 4, 12

It is thought that immersion freezing is an essential process for forming ice crystals in mixed-phase clouds and subsequent ice-induced precipitation. It has long been known that mineral dusts are the most dominant types of ice nucleating particles that can trigger cloud glaciation under conditions at temperatures between about -36°C and -15°C. So far, much of the focus on the global distribution of dust sources has centered on arid/semi-arid regions in low and mid latitudes (e.g., desert areas in central China and/or North Africa). However, recent studies have indicated that significant dust storms can also occur on proglacial floodplains in high latitudes, such as Greenland, Alaska, Patagonia and Iceland. This fact leads to speculation that dust emissions from high-latitudes may occasionally influence heterogeneous ice nucleation in Arctic mixed-phase clouds. Thus, it is probably important to understand the ice nucleation properties of dusts emitted from high latitudes, as well as low/mid latitudes, under mixed-phase cloud conditions. In this presentation, we will introduce a cryogenic refrigerator applied to freezing test (CRAFT) system designed to investigate the ice nucleation properties of particles immersed in supercooled water over a wide temperature range (about -30°C to 0°C) and then report preliminary results of freezing experiments with dusts collected in northwest Greenland.

P14.15

An introduction to the BACCHUS INP Database and a review of the geographical distribution of INP measurements

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Key area numbers: 14, 4

The geographical distribution of Ice Nucleating Particle (INP) observations is limited. Historical measurements have concentrated in the European and North American continents with few recent measurements over the oceans or in the southern hemisphere. Meanwhile, the modelling of INP has been evolving from simple parameterisations to those based on aerosol real world observations. Future observations of INP need to be targeted to fulfil the requirements of modellers for wider data verification. For Cloud Condensation Nuclei, the link between modellers and observational scientists is provided by the ACTRIS network and database, but for INP, no equivalent facility exists. One of the main aims of the EU FP7 Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding (BACCHUS) project is to create a database to link INP observers and modellers. Presented is an overview of the structure of the new BACCHUS INP database and a summary of the data contributed to the database to date, highlighting regions that are lacking in data sets. Finally, comparisons of observational data with their measurement conditions and location are made. This new database will significantly streamline the process of matching modellers with the data they require.

P14.16

Closure between CCN and Cloud Droplet Concentrations for Warm Clouds in Western Japan

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14, 12, 2

We carried out measurements of aerosol and cloud microphysical structures using an instrumented aircraft (B200T) over Shikoku district, Japan in the summers of 2008, 2009 and 2010.

The number concentrations of CCN activated at $SSw=1\%$ and aerosol particles larger than $0.1 \mu m$ showed a good correlation. Estimated hygroscopicity of the atmospheric aerosols was on the order of 0.1.

Air masses originated from the Pacific Ocean region did not come from a distance so much because of low wind speeds due to gentle pressure gradients. Therefore the maritime air masses we observed were very much influenced by pollution from Japan and big cities and industrial areas in the East Asia.

Typical maximum cloud droplet number concentrations near cloud bases were $300\sim 1,500 \text{ cm}^{-3}$. The ratio of cloud droplet number concentration and CCN number concentration activated at $SSw=1.0\%$ increased with decreasing the CCN number concentration and increasing updraft velocity.

The estimated maximum SSw near cloud bases ranged from $0.2 \sim 1.0\%$ and also increased with decreasing CCN number concentration and increasing updraft velocity.

P14.17

CCN activation characteristics in the presence of biomass burning plumes

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12.

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The observations conducted during the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX 2011) over Mahabubnagar (16° 41' N, 77° 56' E), a semi-arid, rain shadow region in peninsular India, involving aircraft measurements and ground based instruments are presented. The surface CCN number concentrations are three times higher than that of the cloud base measurements at different super saturations as illustrated in an earlier study Varghese et al., (2015). New particle formation and growth events have been observed and were found to be more often on days with convective mixing and they did not contribute significantly to the CCN. In the present study, case studies of two flights from the experiment are used to link the activation properties with the observed cloud microphysics of cloud systems one on the coastline and other one inland. The vertical profile of aerosols showed the dominance of Aitken mode particles at elevated layers and their activation to CCN. Observations in the fresh biomass burning plumes showed high CCN activation ratio at 0.4% supersaturation. The activation diameters in the coastal and inland cases were found to be less than 90 nm at 0.4% supersaturation at cloud base and above, while the ground level activation diameter was approximately 60 nm at 0.6% supersaturation. The convective clouds with mixed phase were observed with vigorous convection organization was also noted in the vicinity. It is showed that convective lifting of biomass aerosols in this area contribute to dominant fine mode aerosols at elevated layers.

P14.18

Seasonal variations of aerosol, CCN, IN concentrations from ground-based observations at Tsukuba, Japan

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14

In order to characterize the abilities of atmospheric aerosols to act as cloud condensation nuclei (CCN) and ice nuclei (IN), we have conducted the ground-based monitoring observations since March 2012 at Tsukuba (36.06°N, 140.13°E), by using a CCN counter (CCNC), continuous-flow-diffusion-type IN counter (INC), scanning mobility particle sizer (SMPS), optical particle counter (OPC), and aerodynamic particle spectrometer (APS). The atmospheric aerosol particles are drawn with a blower from outside the building through the 10-um cut inlet and the piping penetrated the roof (ground height:11 m), and then supplied to each instrument through the stainless steel and conductive tubing to isokinetically sample the aerosol particles from the flow in the piping.

Number concentrations of aerosol particles larger than 0.01, 0.3, and 1.0 um in diameter over the monitoring periods were monthly averaged to investigate the correlation with the CCN and IN concentrations. Seasonal variations of the critical diameters and hygroscopicity of CCN in each water supersaturation (0.1-1%) and the activation spectrum of IN (-10 to -35°C) are discussed in the paper.

P14.19

Comparative study of ice nucleating efficiency of K-feldspar in immersion, deposition and contact freezing modes

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14

One of the main challenges in understanding the evolution of Earth's climate resides in the understanding the role of ice nucleation on the development of tropospheric clouds as well as its initiation. K-feldspar is known to be a very active ice nucleating particle and this study focuses on the characterization of its activity in two heterogeneous nucleation modes, immersion and deposition freezing. We use a newly built humidity-controlled cold stage allowing the simultaneous observation of up to 2000 identical 0.6-nanoliter droplets containing suspension of mineral dust particles. The droplets are first cooled down to observe immersion freezing, the obtained ice crystals are then evaporated and finally, the residual particles are exposed to the water vapor supersaturated with respect to ice. Furthermore, we compare our data with the results of contact freezing experiments conducted in the electrodynamic trap and show that we can describe all observed features of ice nucleation within a single approach based on the CNT-parameterization. Based on the electron microscopy analysis of the residual particles, we discuss the possible relationship between the ice nucleation properties of feldspar and its microstructure. Finally, we discuss the atmospheric implications of our experimental results.

P14.20

Measurements of Aerosol hygroscopicity in a tropical site influenced by pristine and anthropogenic polluted air masses

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14

The Amazon region is particularly susceptible to changes in number-diameter distributions of atmospheric aerosols, corresponding to a regime of cloud properties that is highly sensitive to aerosol microphysics. This natural regime, different from other continental areas, is disrupted by anthropogenic pollution from large and growing urban centers. The main objective of the Green Ocean Amazon (GoAmazon2014/15) campaign was to study the interaction of the pollution plume with the biogenic aerosols, and the effects on cloud and aerosol life cycles. The experiment took place around Manaus-Brazil from January 2014 to December 2015. In this paper we compare the particle hygroscopicity obtained from measurements of size-resolved cloud condensation nuclei performed at three ground sites. Site T3 was about 70km downwind from Manaus experiencing urban polluted and background conditions; site T2 was just across the river running alongside Manaus and CCN measurements were performed only from Aug14 to Feb15; and T0, at the Amazon Tall Tower Observatory (ATTO), is a pristine site about 200km upwind from Manaus. Our results show a lower hygroscopicity under polluted conditions than under clean conditions (0.09 and 0.14 for SS% 0.15). At the clean site, it was possible to identify peaks of sea salt particles with organic coating, while small particles seems to be pure organic. The activation fraction and hygroscopicity will be compared and discussed as a function of particle size.

P14.21

Understanding ice nucleation by desert dust: Feldspar composition is important

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(14, 12, 13) Without the presence of particles capable of nucleating ice water can super cool to below -38°C, which is important in cloud formation processes¹. Desert dusts provide a major source of these Ice Nucleating Particles (INPs). A large emphasis of research has been based around the most common mineral in desert dusts, the clays, however new insight suggests the mineral feldspar may be more vital in determining ice formation in the atmosphere². Feldspar is a complex mineral group with varying composition and structure. Here we present a survey of different compositional feldspars along with their ice nucleating efficiency. We find that feldspars rich in calcium are the least active where as those high in potassium are the most active. Sodium-feldspars can have a wide range of activities which are comparable to that of potassium-feldspar and calcium-feldspar. Chemical effects were seen when leaving samples in suspension, with their activity decreasing with time. Overall, this work confirms that potassium feldspars are extremely effective at nucleating ice, but the ice nucleating activity of feldspars in general is diverse.

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P14.22

Immersion freezing ice nucleation ability of atmospheric aerosol particles: an experimental study on asian dust and local dust

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14

The activation processes of atmospheric aerosol particles functioning as cloud condensation nuclei (CCN) and ice nuclei (IN), which determine an initial droplet size distribution and number concentration of ice crystals, are very important. Although some mechanisms of heterogeneous ice nucleation in atmospheric clouds have been investigated using numerical model, our knowledge is still not sufficient.

Aeolian mineral dust is well known to be one of the most efficient aerosol particle is capable to initiate ice formation. During the period from May 26th to June 2nd 2014, asian dust (kosa) was observed in Kanto District. The aerosol data including CCN and IN measurements obtained from our monitoring site at the MRI showed the number concentration of particles larger than 0.5 microns tended to be increasing until the end of May. A series of immersion freezing experiments was carried out using MRI dynamic cloud chamber (Tajiri et al. 2013) during the asian dust period. The activated fraction of atmospheric aerosol particles as ice nuclei in the temperature ranges below -20°C was measured to be the highest ($>10^{-3}$) in the case on June 1st, though we founded out the ice nucleation onset temperature at around -15°C in all 4 cases. The Ice nucleation active surface site (INAS) density derived from the experiment on June 1st in comparison with surrogates of mineral dust was comparable high. In additionally, we also investigated the case of local dust storm occurred on 3rd March 2013.

P14.23

Density Functional Calculations of Thermodynamic Characteristics of Droplets on Small Solid Charged and Uncharged Nuclei

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14. Ice nuclei and cloud condensation nuclei

1. Basic cloud and precipitation physics

Direct calculations of thermodynamic characteristics of a nonuniform droplet formed on uncharged or charged small nucleus in supersaturated vapor have been presented. The calculations are based on the gradient density functional theory (DFT) with the Carnahan-Starling-Lennard-Jones model for the bulk liquid and vapor phases and interfaces. The condensation nucleus is impenetrable for condensate and has been characterized by an attractive short-range molecular potential and the long-range electric Coulomb potential. The dielectric permittivities of the droplet-vapor systems have been taken [1] for polar and nonpolar fluids as known functions of the local condensate density and droplet temperature. The appearance of the capillary, electrostatic and molecular forces in the specific cases of water and argon ion-induced and heterogeneous nucleation [2,3] has been considered in detail. The chemical potential per condensate molecule and the work of droplet formation as a function of the droplet size have been computed.

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P14.24

Activity of different proteinaceous ice nucleating particles

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14, 12

keywords: ice nucleation, biological particles, proteins

A variety of microorganisms (bacteria, fungi, lichen) from land produce protein structures, which act as a template for ice nucleation (Szyrmer and Zawadzki, 1997). Also marine sources of ice nucleating particles (INPs) came in focus. The spatio-temporal distribution of INPs from microorganisms is still not well known. However, a prevalent contemporary interpretation of the observed onset of atmospheric ice nucleation ($T > -20^{\circ}\text{C}$) is due to the existence of ice-nucleation active biological particles.

In this study we compare the ice nucleation activity of different proteinaceous particles produced by bacteria and fungi. For bacteria we investigate (i) cells and fragments of *Pseudomonas syringae* from commercially available SnomaxTM and (ii) purified ice-nucleation-active proteins from atmospheric isolates where a truncated version of proteins had been produced. We also analyzed freeze-dried leaves (Schnell and Vali, 1976) where we assume that proteinaceous particles are responsible for the ice nucleation activity.

Immersion freezing experiments are performed at the Leipzig Aerosol Cloud Interaction Simulator and using a cold stage. We attempt to describe the activity of a single proteinaceous ice nucleating particle (Hartmann et al., 2013) in order to achieve direct comparability. Further, the results are compared with complex system such as soil dust.

The objectives of this study are to clarify potential differences in the ice nucleation potential of proteinaceous particles and to draw conclusions concerning the need to differentiate them for modelling purposes.

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P14.25

The new INKA instruments for laboratory and field measurements of ice nucleating particles

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14, 4, 5, The Fifth International Ice Nucleation Workshop (FIN)

Ice nucleating particles (INPs), a minor fraction of the atmospheric aerosol, are the only source for primary ice formation in most tropospheric cloud systems and thereby have important impacts on the aerosol-cloud-climate interactions and the precipitation initiation. The atmospheric INP number concentration can either be inferred from laboratory measurements of the ice nucleation activity of certain aerosol types, or can directly be measured in the atmosphere with mobile INP instruments. We have constructed and built two new continuous flow diffusion chambers (CFDC) called INKA (Ice Nucleation Instrument of the KARlsruhe Institut of Technology), one for laboratory ice nucleation studies, the other for atmospheric INP measurements. The INKA instruments are built in collaboration with the Colorado State University (CSU) with basically the same cylindrical design as the CSU-CFDC. Both versions can be operated to a temperature of about -60°C.

During the Fifth International Ice Nucleation Workshop FIN-2 hosted at the KIT AIDA facility in March 2015, the laboratory INKA version was operated for the first time. In this contribution we will show and discuss the INKA ice nucleation results for various aerosol types in comparison to the CSU-CFDC and the AIDA results. We will also discuss the performance, and if possible, first measurements of the mobile INKA version which is expected to become operational within the next few months.

Acknowledgements: The valuable contributions of the FIN organizers, their institutions, and the FIN-1 Workshop science team are gratefully acknowledged.

P14.26

Results from the FIN-2 formal intercomparison of ice nucleation measurement methods

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P15.1

Modeling of the volcanic convection and acid precipitation of the Piton de La Fournaise during the April 2007 eruption

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p { margin-bottom: 0.25cm; direction: ltr; color: rgb(0, 0, 0); line-height: 120%; orphans: 2; widows: 2; }p.western { font-family: "Times New Roman",serif; font-size: 10pt; }p.cjk { font-family: "Times New Roman",serif; font-size: 10pt; }p.cjl { font-family: "Times New Roman",serif; font-size: 10pt; }p.ctl { font-family: "Times New Roman",serif; font-size: 10pt; }**3. , 2., volcanic clouds**

The Reunion Island experienced its biggest eruption of Piton de la Fournaise volcano during April 2007. Known as the eruption of the century, this event degassed more than 230 kt of SO₂ and formed a large SO₂ and aerosols plume over the Indian Ocean. This event was successfully modeled with mesoscale chemical MesoNH model coupled with the lava flux model ForeFire. Three types of convection interacted in the same area. First, from the crater, where a strong injection of water occurred, heat and SO₂ were released to a 2 km of thick layer in the atmosphere. Second, from the lava, sensible heat fluxes associated with the flow generated strong convection with a formation of a precipitating cloud that reached up to 8 km altitude. Third, from the entrance of lava into the sea leading to an intense release of water into the atmosphere, a convective cloud formed that reached the tropopause. Strong acidity was modeled in the raindrops due to the presence of hydrochloric and sulfuric acids. Sensitivity modeling studies have been made on different key parameters such as heat and water fluxes to show interactions and the positive feedbacks of these different types of convection on cloud formation and acid precipitation.

P15.2

Chemical Composition of Fog Water in the Winter Season in Nanjing: Observational Study

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Abstract: Fog water samples during several heavy fog events were collected at Nanjing University of Information Science and Technology (NUIST) in the winter of 2007 and 2013. Fog droplets were collected in three separate droplet size ranges (4~16 μm 、16~22 μm 、>22 μm) in 2013. Composition characteristics of the fog water, the correlation of ions in each stages and the relationship between ion concentrations and gaseous pollutants or microphysics were considered. The results showed the pH mostly resided in acidic range. In fog water samples of 2007, the average SO_4^{2-} concentration was the highest among water-soluble anions, followed by Cl^- and NO_3^- . The average concentration of heavy metal elements Ca, K, Na, Mg, Al and Zn were much higher than that of Cu, Ni, Pb, Cd and Cr. The concentration of metal elements in fog water was high at the initial fog stage, then decreased with the fog development, but increased significantly after sunrise during the peak traffic period. By comparing fog water and rain water, we found the air pollution in fog areas was higher than on rainy days. In samples of 2013, The small drop fraction had significantly high concentrations of the major ions (NH_4^+ , NO_3^- , SO_4^{2-}), lower pH values and higher EC values than the large drop fraction. The data showed concentrations of the species was higher at night. Due to the differences in contribution of pollution sources, soluble components varied greatly in different fog events. Also, the ionic composition had a significant relationship with microphysical properties and pollutant gases.

P15.3

Numerical simulation of cloud chemistry using bin microphysical scheme

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15.

Bin microphysical scheme has been developed to simulate the absorption/desorption of different gases through the surface of the water drops and the chemical reactions occur inside the water drops. Because the pH of the solution strongly depends on the size of the water drops, the bin scheme allows us to simulate the chemical reactions more correctly. This study focuses on the sulfate formation inside of water drops. 2D kinematic model is applied to describe the cloud chemistry in stratocumulus at maritime and continental CCN concentrations. The microphysical scheme involves the formation of water drops on sulfate particles; diffusional growth of water drops and the collision coalescence of liquid drops. The chemistry scheme describe the absorption of CO₂, SO₂, H₂O₂, O₃ and NH₃ gases, furthermore sulfate formation due to oxidation by O₃ and H₂O₂ inside of the water drops is also calculated.

keywords: Stratocumulus, absorption, chemical reactions in water drops

P15.4

Characterizing the Chemical Properties of Individual Metal-containing Particles in the Atmosphere of Nanjing by Single Particle Mass Spectrometry (SPAMS)

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Abstract.

An atmospheric measurement campaign took place in the August and September of 2014 to characterize the chemical composition of particles at an industrial zone in Nanjing, China, using a single particle aerosol mass spectrometry (SPAMS, Hexin Co., Guangzhou, China). The metal elements including Fe, Pb, V, Cu, Zn, Mn, Ca, Al, Mg, Si, Na and K were detected in the particles. Fe-rich components are the most abundant particles, accounting for 72.2% of the total aerosols. The second important metal particles are Pb-rich particles, which account for 14.21% of the total metal containing particles. The number fraction of other metallic particles, including Cu-rich, V-rich, Zn-rich and Mn-rich particles, were less than 10%. Dust particles could be divided into three subtypes (Dust-Ca, Dust-Al(Mg) and Dust-Si), and were mainly distributed in coarse mode. Na-rich particles class, including NaK and NaRich subtype particles, accounted for 7.02% of the total particles analyzed. The obtained information on the mixing state and the temporal variation of the emission of metal-containing particles can be useful to reveal the point sources and to develop an understanding on the origin and evolution processes of atmospheric aerosols.

Keywords:

Metal-containing particles; Single particle analysis; Source; Mixing state; SPAMS; Steel mill

P15.5

SPACCIM modelling of the non-radical aqueous-phase chemistry of organic compounds in clouds and deliquesced aerosols

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15, 12

Clouds and deliquesced particles are a complex reactive multiphase environment with simultaneously occurring chemical transformations. Besides well-known radical oxidations, aqueous-phase non-radical reactions of important organic compounds are currently a key scientific subject. These reactions can represent a potential pathway contributing to the aqSOA formation and processing. To improve the limited understanding of non-radical aqueous-phase chemical processes, detailed studies were performed with the SPectral Aerosol Cloud Chemistry Interaction Model (SPACCIM) and a newly developed reaction module. This module was coupled to the MCMv3.2/CAPRAM4.0a mechanism with 21328 multiphase processes and contains 121 additional reactions of organic compounds. Firstly, non-radical oxidations by $\text{H}_2\text{O}_2/\text{O}_3$ and non-oxidative processes including oligomerisations and NH_4^+ -catalysed reactions were considered. SPACCIM simulations were performed for different environmental conditions using a non-permanent cloud scenario. Sensitivity studies are performed to study the importance of the different non-radical reaction pathways on aqSOA. The model analyses are focused on organic multiphase reactions and particularly the role of non-radical pathways compared to radical oxidations under cloud and deliquesced particle conditions.

The investigations showed that non-radical oxidations can play an important role in the aqueous organic oxidation besides key radical oxidants. Particularly under cloud conditions, O_3 is important for soluble unsaturated organic compounds such as methacrylic acid contributing with 82% to the aqueous oxidation flux. H_2O_2 is an important oxidant particularly for substituted organic acids in both clouds and deliquesced particles. Moreover, the studies imply that oligomer formation and the further oxidations in cloud entrainment/detrainment zones might be potentially important for the aqSOA formation.

P15.6

WRF Modelling of ozone transport over the West Pacific Warm Pool

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9. Tropical clouds

The CAST campaign, along with sister campaigns CONTRAST and ATTREX, was an aircraft and field campaign based in Guam and Manus Island, Papua New Guinea between January and March 2014. The field campaign in Manus Island consisted of ground measurements and ozonesonde launches. One of the observations from the ozonesonde data was a low-ozone event in the tropical tropopause layer on 21 - 23 February, which was traced to the outflow from a marine convective system that pumped ozone-deficient air into the tropopause region. This air was advected by an easterly jet over Manus Island, where it was measured by the ozonesondes.

This low-ozone event has prompted further investigation using the Weather Research and Forecasting (WRF) model. The model has been run for the period between 17 - 23 February to investigate its ability to reproduce the conditions that produced the low-ozone event. The model output was compared with the ground measurements and ozonesonde measurements from Manus, and tracers were used to understand how efficient the convective systems are at lifting air from the surface or lower troposphere into the tropopause. Furthermore, the sensitivity of particular physics options to the experiment was investigated. Future work will be focused on finding other instances of the low-ozone phenomenon in the tropopause layer in order to determine their typical frequency, size and longevity.

P15.7

Hygroscopic parameterization of multi - scale aerosol during summer in the Mount Huang,China

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Aerosol hygroscopic parameter κ observed in July, 2014, and the aerosol ionic components observed in July, 2011 were utilized to analyze the hygroscopic parameter of multi - scale aerosol particles during summer in the Mount Huang, then established a parameterization scheme of hygroscopic parameter in the region. The results show: the sampling site is mainly affected by southwest, southeast and northern air masses. During the Mount Huang summer, κ values between 0.1 and 0.42, and first increase then decrease. The campaign's average size distribution of κ values shows two distinct modes: a highly hygroscopic mode ($0.15\mu\text{m} < D_p < 1\mu\text{m}$) with κ greater than 0.3, a less hygroscopic mode ($D_p < 0.15\mu\text{m}$, $D_p > 1\mu\text{m}$) with κ smaller than 0.2. when southwest wind dominates, κ values in Aitken nuclei mode and accumulation mode is larger than the other two air masses background; when under the control of southeast wind, κ values in Coarse mode is larger. κ value is highly positive correlated with mass fractions of NH_4^+ and SO_4^{2-} for all sampled particles. Parameterization of hygroscopic parameter κ is established by the multi - scale chemical components, and the equation is . The parameterization can predict κ of multi - scale aerosol particles well, and the predictive value is within the range of 30% deviation.

P15.8

Cloud condensation nuclei (CCN)-activation behaviour of atmospheric black carbon particles and acquisition of coating in fog

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7. Fog and Fog layers

Black carbon (BC) is emitted during the combustion of fossil and biogenic fuels and affects the Earth's climate via both aerosol-radiation and aerosol-cloud interactions.

Mostly because BC particles undergo various modifications during their aging, their cloud condensation nuclei (CCN) activity at different times is highly uncertain. Often emitted as non-hygroscopic bare BC, BC particles can acquire hygroscopic coatings by condensation or coagulation of organic and inorganic materials. This makes them more CCN active.

While clouds mainly form above the planetary boundary layer, where the great majority of BC-containing particles are already aged, the presence of fog at low altitudes enables potential interactions with BC at any aging level. However, the conditions for activation in fog are different because of low supersaturations compared to clouds.

During a field campaign in the city of Zurich, we used a total and an interstitial inlet to sample air into a single particle soot photometer (SP2), two scanning mobility particle sizers (SMPS) and a cloud condensation nuclei counter (CCNC). We investigated the droplet activation behavior of BC-containing and BC-free particles in fog conditions and determined the influence of fog processing on the acquisition of coatings. The choice of the measurement site gave us the opportunity to measure both aged and freshly emitted BC particles in fog and non-fog conditions. An aerosol chemical speciation monitor (ACSM) ran in parallel in order to get information on the chemical composition of the total aerosol.

P15.9

15 years of in-situ measurements of upper tropospheric humidity and ice-supersaturated regions by the MOZAIC programme

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5. Cirrus clouds

The European Research Infrastructure IAGOS (In-service Aircraft for a Global Observing System, www.iahgos.org) operates a global-scale monitoring system for atmospheric trace gases, aerosols and clouds by using the existing provisions of the global air transport system. The infrastructure collects regular in-situ observations in the extra-tropical upper troposphere/lowermost stratosphere (UTLS) over mid-latitudes at high spatial resolution and provides long-term observations of atmospheric chemical composition since 1994. The longest time series are 20 years of temperature, H₂O and O₃, and 15 years of CO. Upper tropospheric humidity (UTH) was in the focus of the observations from the beginning because water vapour is a major parameter in weather prediction and climate research. However, the spatial distribution of UTH and particularly properties of ice-supersaturated regions in the UTLS are still not well understood, although they are indispensable prerequisites for understanding cirrus cloud and contrail occurrence.

After the reanalysis of UTH data from 1994 to 2009, this extensive and unique data set has been examined by criteria of continuity, homogeneity and quantity of data coverage, to identify global regions suitable for UTH climatology and trend analyses. For one of the identified target regions over the North Atlantic we will present time series and climatologies of, e.g., relative humidity with respect to ice, temperature, and absolute humidity for the upper troposphere, the tropopause region and the lowermost stratosphere. Different data sets selected according to geographic and atmospheric dynamics criteria and different tropopause definitions are compared to demonstrate the robustness of the obtained results.

P15.10

Role of bacteria in atmospheric chemistry: Biodegradation rates determination in cloud water, from experimentation to modelisation.

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Abstract

Clouds are multiphase systems in which dissolved organic matter is subjected to multiple chemical transformations. It has been recently shown that metabolically active microorganisms are present within cloud water and are able to interact with carbon compounds and reactive oxygenated species.

The aim of this project was to determine biodegradation rates to implement an atmospheric chemistry model (M2C2).

In order to study the contribution of microbes in cloud water in comparison to radical chemistry, artificial cloud solutions, containing the substrate studied (formate, acetate, formaldehyde and hydrogen peroxide) at various concentrations, were incubated with microorganisms at 17°C and at 5°C. The purpose of these experiments was to determine the kinetic parameters of the Michaelis-Menten model, parameters obtained via a linearization of the experimental data through the Eisenthal-Cornish and Bowden representation.

The biodegradation rates were determined and values obtained are approximately 10^{-17} mol.s⁻¹.cell⁻¹. These rates were then compared with those obtained by radical chemistry process with values from the literature and from modelling. It appears that the rates are in the same order of magnitude and that the microbial contribution prevails at night. Regarding the case of hydrogen peroxide, previous studies carried out with natural cloud samples revealed that the biodegradation rate is about the same order of magnitude as the photochemical process.

Results show that microorganisms have the ability to change the carbon budget in the aqueous phase of cloud and also to interact with oxidant species through their anti oxidative stress metabolism, and could revolutionize atmospheric chemistry.

P15.11

Rainwater chemistry in Central Amazonia during GoAmazon2014/5

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(15,12) Rainwater is a net result of the interaction between clouds and atmospheric chemistry. Chemical species are incorporated in rain droplets in two ways: 1) by the ingestion of CCN in the droplet formation process, and 2) by the scavenging of species below the cloud base. It is the consolidation of a broad set of processes in the cloud-aerosol-gases interaction. Precipitation samples were obtained using a wet-only automated rainwater collector during the IOP-2 (Aug-Nov/2015) on a daily basis. Operated sites were EMBRAPA and Manacapuru (MCP). During the dry season both sites were subject to large-scale biomass burning but only MCP could be reached by the Manaus plume. Preliminary sample analysis includes pH, conductivity. Major ion concentrations are being obtained by Ionic Chromatography and further results will be shown at the workshop. Preliminary results show a broad range of pH values in both sites but values were typically acid. Minimum (maximum) observed pH was 3.5 (6.5) but median pH was 3.7. Actually the pH = 6.5 was due to a single event but observed in both sites. Once that this strong acidity was measured in both sites it becomes clear the dominance of the influence of large-scale biomass burning, overcoming the Manaus plume influence. Conductivity in samples ranged from 11.2(11.7) μS to 31.1 (99) μS at EMBRAPA (T3). A slight negative linear relationship was observed between conductivity and pH. As a whole, the strong influence of large-scale biomass burning dominates the composition of rainwater instead of the Manaus plume.

P15.12

Antarctic Observations of Bio-Fluorescent Aerosol

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10, 14 Bio-fluorescent aerosol characteristics and dynamics were recorded at the Clean Air Sector Laboratory (CASLab), part of British Antarctic Survey's Halley VI Research Station in Antarctica. CASLAB is approximately 1 km from Halley and is 20-30 m above sea level on the Brunt ice shelf and located near the Weddell Sea coast (75°34'59"S, 26°10'0"W). The location is mainly flat, with snow covered surrounding areas, and the nearest rock formation is 200 km away. As part of the NERC funded MAC (Microphysics of Antarctic Clouds) aircraft campaign, surface based measurements of aerosol size distribution and composition were made at CASLAB where a single particle multi-waveband UVLIF spectrometer was located. Measurements have been used to quantify and constrain potential bio-fluorescent cloud condensation and ice nuclei concentrations, and to identify source regions for these aerosols that may influence clouds in the Southern Ocean. Average diurnal bioaerosol concentrations showed very little variation during the period November and December 2015 with median concentrations approximately 1 L-1 ranging up to several L-1. A higher concentration bioaerosol event was observed with average concentrations up to several L-1 with peak concentrations up to 10 L-1. Bio-fluorescent particle sizes typically peaked in the sub micron range but also showed an enhancement at approximately 2 µm. A statistical cluster analysis was applied to the data and used to interpret the background levels and bioaerosol event in greater detail and to discuss possible source attribution of these aerosols.

P15.13

Wet removal of black carbon aerosols controlled by their cloud condensation nuclei activity

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14, 15

Wet removal is a major process to remove aerosol particles from the atmosphere. The removal efficiency is considered to depend on processes including aerosol activation to cloud droplet and conversion of cloud water to rain water (warm rain wet removal). In numerical model calculations it is generally assumed that a selection of aerosols to be removed is controlled by their cloud condensation nuclei (CCN) activity (critical supersaturation, S_c). However, it has never been tested by direct observations thus far, due to lack of methodology. Here we present a new observational approach, where black carbon (BC) aerosols are used as a particle tracer for the removal process. In the urban atmosphere of Tokyo, Japan, we conducted simultaneous measurements of BC both in air and in rainwater. We show that the number size distribution of BC in rainwater was larger than that in the surface air just before precipitation, demonstrating higher removal efficiency for particles with larger size. This size dependence was successfully explained by the measured mixing states (or S_c) of BC particles in the air and an assumed maximum supersaturation that the particles would have experienced during rain events. The observational results indicate that wet removal of aerosol particles is primarily controlled by their CCN activity. On average, aerosol particles with S_c larger than 0.22 % were likely transported upward without being removed by precipitation. Thus the simultaneous observation of BC in air and in rainwater provides data for assessing model schemes related to wet removal of aerosols.

P15.14

Observational study of the cloud condensation nuclei (CCN) activity in the North China Plain

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In my talk, I will present a study of the size-resolved activation ratio of aerosol based on a series of field campaigns between 2009 and 2015 in the North China Plain which is one of the most polluted regions in China. Aerosol activation properties under the conditions of high aerosol loading will be described using statistical results and closure study of CCN. Aerosol physical and chemical properties are investigated as well as the size-resolved activation ratio of aerosol. The impacts of new particle formation events on aerosol activation properties will be discussed. These results will be used to develop a proper parameterization scheme of aerosol activation in the highly polluted atmosphere such as eastern China. At last, the results of aerosol hygroscopicity derived from sub-saturated measurements like HTDMA or $f(RH)$ and supersaturated measurements of CCN counter will be compared and discussed.

P15.15

Multiphase chemistry modelling using the regional model COSMO-MUSCAT: Results for the field campaign HCCT-2010.

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15. Cloud and precipitation chemistry: 3d regional modelling, multiphase chemistry, aerosol-cloud interactions

To treat detailed cloud chemistry in COSMO-MUSCAT [Wolke et al., 2012], the model was enhanced by a description of aqueous-phase chemical processes. To investigate the 3-D cloud processing as well as to demonstrate the general 3-D applicability of the detailed aqueous-phase chemistry of C3.0RED [Deguillaume et al., 2010], the enhanced model was applied for real 3-D case studies simulating two selected time periods of the HCCT-2010 field campaign. For the prevailing south-westerly wind directions, the airflow roughly passes three different measurement sites before, during and after the cloud phase. Measurements of the aerosol-cloud processing were only performed under suitable flow conditions [Tilgner et al., 2014].

Firstly, the model performance with respect to the meteorological fields and selected gas-phase concentrations was evaluated by a comprehensive comparison with available observations. Overall, the main characteristics of the compared species and the airflow at Mt. Schmücke are modelled quite well. For the investigations of cloud chemical processes, simulations with C3.0RED, with a simple inorganic, and without aqueous-phase chemistry are compared with each other and with measured data. The comparison of C3.0RED with a simpler mechanism showed differences in e.g. in the modelled multiphase HO_x budget and pH values. The difference in pH leads consequently to different regimes for e.g. the S(IV)-oxidation and organic partitioning.

Wolke et al. (2012), *Atmos. Environ.*, 53, 110-130.

Deguillaume et al. (2010), *J. Atmos. Chem.*, 64, 1-35.

Tilgner et al. (2014), *Atmos. Chem. Phys.* 14, 9105-9128.

P16.1

Improving the retrieval of particle size spectra and liquid water content from optical spectrometer measurements using a Monte Carlo inversion method

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Key area numbers : 16 ; 4

Keywords : spectrometer measurements, mie theory, particle size distributions, monte carlo method

Light scattering spectrometers rely on the Mie scattering theory deducing particle sizes from light intensity measurements. As a matter of fact, the relationship between the scattering cross section and the particle size is nonlinear, implying oscillations, when the particle size is of the same order of magnitude as the wavelength of the used laser light. Consequently, the probes' particle size distributions (PSD) show strong fluctuations, with almost empty bins next to bins with high counts of particles.

In this work, the differences between true cloud PSD and the corresponding response of the cloud droplet probe (CDP) optical spectrometer is explored, with Mie simulations. Besides the pattern of the spectra, it is shown that liquid water contents (LWC) are underestimated by at least 10% and up to 30% for small LWC values, when using raw CDP data. The error in median volume diameter (MVD) is less variable and can reach 15%.

In order to improve the retrieval of both the size spectrum and derived bulk parameters, an approach based on the Monte-Carlo method is presented and tested. Compared to regularization algorithms, the proposed method avoids negative values and is more flexible. The size distributions retrieved with this method show very good agreement with the given initial (true) particle spectrum as compared to the corresponding inaccurate CDP measured PSD. Consequently, the retrieval of LWC and MVD is noticeably improved.

P16.2

Mass retrieval for ice crystals from particle images and ice water content measurements: a numerical optimization approach

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This study focuses on building a statistical model of crystals' mass as a function of their size, environmental temperature and crystal microphysical history in order to describe variations of the microphysical properties of ice crystals in high ice water content (IWC) regions of convective clouds. The primary objective is to retrieve the mass of crystals sorted by size from 2D images using a numerical optimization approach.

The problem is formulated as an inverse problem in which the mass of crystals is assumed constant over a size class and is computed for each size class from IWC and particle size distribution (PSD) measurements by minimizing an objective function. First, the method is applied on 3D synthetic crystal populations in order to evaluate the influence of data noise (2D projections of randomly oriented 3D crystals and discretization of the PSD into size classes) and to set up a regularization strategy. Subsequently the method is validated using datasets of in-situ measurements collected during two airborne field campaigns held in Darwin (2014) and Cayenne (2015) in the frame of the High Altitude Ice Clouds (HAIC) / High Ice Water Content (HIWC) projects. The large quantity of data available as well as the diversity of environmental conditions met during these campaigns allow comparison of IWC values derived from the computed mass solutions with measured IWC values and preliminary assessment of the influence of temperature and dynamical parameters on crystals' masses.

P16.3

Characterization of response time behavior on the Fast-2D optical array probe detector board

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Two-dimensional optical array probes are frequently used for characterizing large cloud particles and precipitation. It is well established that the effective sample volume and general performance of these instruments depends on the response time characteristics of their detection system. Slower detection electronics are more likely to miss small particles, thus skewing the assumed sample volume of the probe and particle concentration estimates.

We have performed a thorough laboratory and electro-optic investigation of the time response characteristics on the DMT Fast-2D detector board used in NCAR's optical array probes. This analysis has been specially designed to account for all components in the detection chain, from optical input to digitization. In this process we have determined that there are two independent response terms in the detection chain. The first is a high speed electronic response with an exponential time constant less than 50 ns. The currently unexplained second term is a slow decay function that does not appear to be exponential. This slow term results in an effective response time between 50 and 150 ns depending on its amplitude. This variability in response characteristics results in concentration uncertainty in excess of 20% in the smallest size bin 25 μm bin for airspeeds near 150 m/s. The concentration uncertainty from this effect decreases as particle size increases. The presence of the second, slow response term, implies that there are still additional factors that need to be considered when designing next generation 2D detection systems.

P16.4

Study of droplet activation in thin liquid clouds using ground-based Raman lidar and ancillary remote sensors

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16, 12

The study of droplet activation is strongly needed to evaluate and improve the ability of numerical models to forecast clouds and their microphysical properties, as well as to better quantify the aerosol-cloud interactions in global climate models. This study needs an accurate estimation of optical and microphysical properties of clouds and aerosols close to the cloud boundaries, that can be achieved using ground-based remote sensing techniques.

In this work, a methodology for the experimental investigation of droplet activation, using a ground-based Raman lidar, a cloud Doppler radar and a microwave radiometer operational at CNR-IMAA Atmospheric Observatory (CIAO), is presented. The methodology is applied to optically thin liquid clouds with a broken horizontal structure. Taking advantage of the discontinuous structure of these clouds, the variability of optical properties in the transition from cloudy regions to cloudless regions close to the cloud boundaries allows to estimate the cloud properties, such as their geometrical and optical depth, the temperature of cloud base and cloud top, the cloud liquid water path, as well as the type, the source and the microphysical properties of aerosols in cloud-free regions close to the cloud boundaries. Statistics enable the identification of threshold values for the optical properties, allowing the discrimination between clouds and cloudless regions.

P16.5

Cloud cover estimation based on ceilometer measurements: a comparison with visual observations

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Standard ceilometers are being used at airports to assist in the take-off and landing maneuvers, as they provide an accurate measurement of the cloud base height (CBH) over the site. In this study, we analyze the use of the temporal averaging of ceilometer data (i.e., a measured CBH means that there is an occurrence of cloud overhead) as an estimator of cloud cover (CC). Indeed, although standard ceilometers only see in the zenithal direction, clouds usually move, so a temporal averaging of occurrence measurements must be an approximation of the areal extension of clouds. Eight years (2007-2014) of ceilometer measurements at a site in Girona (Spain) are combined with the corresponding human observations of cloudiness at two nearby sites to carry out this research. Sky images taken by a camera complement the suitable information. The comparison of CC values is performed at daily and monthly basis. Overall, there is an underestimation of around 20% in relative terms of the ceilometer when compared to visual observations, with a minimum and maximum during winter and summer, respectively. Part of the disagreement may be a result of the limited vertical range (7.5 km) of the ceilometer used in this research. Additional discussion is held on the optimal averaging time of ceilometer occurrence measurements to approximate instantaneous human observations. Despite the differences and limitations, results of this study could be of interest to extend long-term traditional measurements of CC as the number of human observers at meteorological stations tends to decrease.

P16.6

Finnish Meteorological Institute - Aerosol Cloud Interaction Tube (FMI - ACIT), parameters for proper operation and first results.

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16. Measurement techniques (of cloud and precipitation properties) and uncertainties, 14. Ice nuclei and cloud condensation nuclei

Properties of clouds and their formation processes are poorly understood. Finnish Meteorological Institute - Aerosol Cloud Interaction Tube (FMI - ACIT) is a multi-purpose instrument for investigating atmospherically relevant interactions between aerosol particles and water vapour under defined laboratory conditions.

FMI - ACIT combines principles of a laminar flow diffusion chamber and design of a laminar flow tube. It consists of three main parts: a saturator, a preheater and a condenser. Optical Particle Sizer Spectrometer (3330 OPS, TSI Inc., USA) which detects particles in the range 0.3-10 μm , was used as a counting system.

For the parametrization of FMI - ACIT, particles of ammonium sulfate were used to derive the relation among FMI - ACIT setting parameters. Monodisperse particles in the size range of 10 to 300 nm were introduced through an aerosol inlet into preheater. Different saturation ratios in the range of 0.1 to 0.9% were obtained by using different temperatures gradients between saturator and condenser. The particle critical diameter D_{50} from activated fraction curves and the hygroscopic growth were obtained and compared to theoretical predictions of CFD model and Köhler theory.

P16.7

Calculation of polarimetric radar fields using the output of a bin microphysics scheme

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16,1

Keywords: polarimetric radar, bin microphysics

The calculation of the polarimetric radar parameters (ZDR, LDR, KDP, etc.) and the related polarimetric radar fields gives a good opportunity for the comparison of the simulated and real clouds. The derivation of the polarimetric parameters from the model output allows more comprehensive case studies and testing of the cloud microphysics schemes. In this study a new method was developed to calculate the polarimetric radar parameters and to simulate the polarimetric radar fields by using the output of a detailed microphysical scheme. In this scheme four different types of hydrometeor (ice crystals, water drops, snowflakes and graupel particles) were divided into 36 size categories. Further prognostic variables, as the melting fraction for the graupel particles and snowflakes, furthermore the riming fractions of snowflakes allow a more sophisticated evaluation of the polarimetric radar parameters. Laboratory observation data about the oscillating water drops is applied for the calculation of the ZDR parameter of water drops. The numerical method developed in this study is applied to calculate the polarimetric radar data by using the model output in the case orographic clouds and squall line.

P16.8

A droplet generator system for calibrating and evaluating the performance of airborne cloud particle probes.

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Recent studies demonstrate the importance of precisely positioning and accurately sizing test particles within the sample volume of airborne forward scattering droplet measurement probes for the purpose of both calibrating and evaluating the performance of these probes in the laboratory. Optical and beam alignment, beam inhomogeneities, and electronic response can all effect how an instrument responds when challenged with a droplet of a given size. Further, many of these characteristics can be instrument specific. Therefore, The University of Wyoming (UW) designed a lab-based system for calibration and response evaluation of its airborne forward scattering droplet probes (FSSPs and CDP).

The system is similar to that described by Lance et al. (2010), consisting of a piezoelectric droplet generator inserted into a sheath flow that accelerates droplets to velocities of around 40 m/s. The droplets then enter the probe sample volume. The response of the probe is recorded and compared against an independent estimate of droplet diameter.

Accurate and repeatable positioning of droplets within the sample volume is achieved through a two-stage micro-positioner, allowing for investigations relating the droplet location within the sample volume to probe response. A positioning rod is used to adjust the size of the generated drops by increasing/decreasing the dwell time droplets remain within the sheath flow. Preliminary results from performance evaluation of the UW Cloud Droplet Probe are presented. Future efforts will expand the system's capabilities for operation with optical array probes.

P16.9

Interpretation of airborne CASPOL measurements using methods developed in the CLOUD chamber

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16, 4, 5

CLOUD, CASPOL, classification, small ice, polarisation

It is thought that cirrus clouds have a warming influence on the atmosphere. The presence of small (<50 µm) ice crystals in cirrus can complicate matters leading to a net cooling feedback on climate. Additionally, in mixed phase clouds, detection and quantification of small ice particles continue to pose a challenge for classification and derivation of Ice Water Content (IWC). Remote sensing techniques of cloud water and ice particles continue to require in-situ airborne measurements for validation.

It was shown in previous studies that it is possible to classify such particles by their unique polarisation signature. The Cloud Aerosol Spectrometer with Polarisation (CASPOL) allows a semi-quantitative derivation of the spherical and aspherical fractions of particles. In this study we combine single, particle-by-particle, polarisation measurements with path averaged depolarisation measurements from chamber experiments at the European Organisation for Nuclear Research (CERN) to improve determination of particle specific polarisation response. We then use this comparison to implement a laboratory developed discrimination method for CASPOL airborne measurements collected as part of the Aerosol-Cloud-Coupling-and-Climate-Interactions-in-the-Arctic (ACCACIA) and the Cirrus-Coupled-Cloud-Radiation-Experiment (CIRCCREX) field campaigns.

Results from homogeneously mixed chamber experiments showed good agreement between single particle polarisation and path averaged "remote" depolarisation measurements. However, contributions from larger particles (>50 µm), can lead to discrepancies. Analysis of the aircraft cloud data showed that CASPOL derived aspherical fraction periods in cirrus clouds agreed with image shape analysis collected using a high resolution CCD imaging spectrometer (3-View Cloud Particle Imager, 3V -CPI).

P16.10

The complexity of variational retrieval of liquid cloud properties

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Warm clouds, consisting of liquid droplets only, are assumed to be the simplest cloud type to be observed. However, the retrieved liquid water content (LWC) and droplet effective radius (REF) may differ significantly among different ground-based remote sensing retrieval methods. Uncertainties may arise from retrieval assumptions but also from measurement biases.

Here, we will present the results of a 1D-Var retrieval method, the Integrated Profiling Technique (IPT), which combines groundbased microwave radiometer (MWR), cloud radar and a priori information to derive profiles of temperature, humidity, LWC and REF. In contrast to other commonly used cloud radar-MWR-methods, which are based on simple relations to retrieve LWC and REF, the IPT provides physically consistent profiles implying that the measurements can be reproduced from the retrieved profiles within their assumed errors.

We will test the IPT performance using synthetic observations. Knowing the true atmospheric profiles, we can simulate what the instruments would observe. In this way, we can test how the retrieval behaves under ideal conditions and can also analyse the complex interplay of prior, measurement and forward model uncertainties in the retrieval. In the "real world", it is likely that measurements are prone to have (unknown) biases. Furthermore, the forward model with its assumptions, e.g. the assumed droplet size distribution, might not be appropriate. We will also assess how such discrepancies affect the retrieved cloud property profiles.

In addition, the results will also be set into context to other commonly used cloud radar - MWR cloud retrieval algorithms.

P16.11

Investigating a New Disdrometer Sampling Method to Reduce Measurement Variability

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16, 17

A new method of sampling for precipitation events was developed to reduce errors associated with the idiosyncrasies of the conventional, temporal based, method. Using data from a Joanneum two-dimensional video disdrometer near Charleston, SC (USA), several rain events were divided into samples containing a uniform number of drops (the new method) as well as standard samples (of uniform temporal duration). Bulk quantities including rain rate, radar reflectivity factor, liquid water content, and mass weighted mean diameter were found for each sample type. This new sampling methodology is implemented in order to minimize the influence of samples with few drop arrivals from having disproportionate impact on estimating bulk rainfall properties. Uniform drop-number sampling of precipitation events is expected to produce less scattered Z-R relationships compared to those derived from conventional sampling. The alternative sampling method presented here, although unsuitable for direct use by weather RADAR, offers new insights into the use of disdrometers in measuring bulk quantities and determining Z-R relationships.

P16.12

An observation system for detection of local severe snowstorm causing snow-related disaster

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16 (key area). The uncertainty of the quantitative precipitation estimation for the solid precipitation from the observation of a weather radar is large in the current state due to various assumption such as the constant snow crystal types and the constant size distribution. It is needed that the algorithm to estimate the distribution of the solid precipitation intensity at the surface using the relation between equivalent radar reflectivity and precipitation intensity for some solid precipitation types, such as graupel and aggregates. In order to accurately estimate for solid precipitation within the observation range of a weather radar, we have been developing the observation system for local severe snowfall at Niigata prefecture, a heavy snowfall area in Japan. This observation network system is composed of X-band polarimetric Doppler radar installed on the roof of Snow and Ice Research Center and six ground observation sites established within the observation range of the weather radar. The ground observation sites are installed with an active and passive remote sensing and in situ instruments. This system can measure the precipitation intensity and precipitation particle type at the ground observation sites and can estimate the exact precipitation intensity within the view of the weather radar using the measured information of precipitation particles by the ground observations. The overview of the observation system for severe snowfall, and the preliminary results will be presented in the presentation.

P16.13

Quantitative Estimation of Contribution of Raindrop flux to total precipitation intensity in Mixed Phase Precipitation from Optical Disdrometer Data

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16. rain and snow mixed, melting layer, optical disdrometer. We propose a method to calculate the contribution of raindrop flux to total precipitation intensity, F_R , in mixed phase precipitation from size and fall speed distribution obtained by optical disdrometer. F_R ranges from 0 (for solid precipitation) to 1 (for rain) according to the degree of melting of precipitation in the melting layer. The total liquid water in precipitation consists of raindrops and melt water bound in snowflakes. This liquid water fraction to total precipitation intensity, F_L , can be derived from F_R using empirical relationship in Misumi *et al.* (2014). We applied our method to the observation data obtained by OTT PARSIVEL installed in the Falling Snow Observatory at Nagaoka, Japan. Using time series of F_R , we could extract the mixed phase precipitation events objectively and classify them into several types of mixed phase precipitation events, for example, the events in which the precipitation turned from rain to dry snow (R-S event) and from dry snow to rain (S-R event). The air temperature dependence of F_R was different for each event. For example, the temperatures at $F_R=0.5$ ranged 0.5~2(°C) for R-S events and 0~1(°C) for S-R events. On the other hand, in comparison of F_L with wet bulb temperature, most of events showed steep change of F_L from 0 to 0.8~1 in the narrow range of wet bulb temperature in 0~0.5(°C). Our method provides important information for cloud and radar meteorology of melting layer via bulk parameters, F_R and F_L .

P16.14

Fast open path IR hygrometer for airborne application – feasibility study

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16

Water vapor measurements taken from airborne platforms in lower atmosphere aiming at resolving fine details in turbulent motion require fast sensors. Large gradients of humidity were observed in regions where air parcels of different character mix (e.g. at cloud edges). Fast response (< 10 ms) detectors are necessary to achieve the desired spatial resolution (< 1 m). Open path optoelectronic system based on the absorption in near infrared by water vapor molecules was designed as a proof of concept of a fast airborne hygrometer and was tested measuring the humidity fluctuations in atmospheric boundary layer.

Concentration of water vapor molecules is derived from the attenuation of laser beam passing twice along ~25cm path in open flow. Wavelength corresponding to selected H₂O absorption line (namely 1364.6896 nm) is used to ensure selectivity and highest sensitivity (1015 cm⁻³) of the instrument. Tunable diode laser stabilization in the absorption peak is provided by dedicated unit with reference cell.

Two different strategies of signal acquisition were developed making use of continuous and modulated illumination respectively. The first measures absorption directly, the latter involves digital lock-in algorithm to reduce noise. Test measurements have proven the advantage of the second approach, which is, however, computationally demanding for high-rate signal sampling (200 kHz). Results were compared with other instruments (including dew point hygrometer, ultraviolet KH-20 hygrometer). Satisfactory operation of the prototype was verified within the up to output data frequency of $f = 200$ Hz.

P16.15

Rainfall characteristics in central London: a cross sensor, high temporal resolution analysis

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16.

Keywords: ceilometer, radar, backscatter, gauge

Energy balance and hydrological models must simulate the physical processes across small areas (~1-100 ha) and timescales (<~ 1 min) to account for the spatial heterogeneity within urban areas at scales of hundreds of metres. Common input data sources include climate model outputs (10-100 km; 1-3 hour), rainfall radar products (1 km; 15 min) and single mechanical rain gauges (point; ~ 15 min).

Minimum required resolutions of 1 km and ~1 minute were identified for a 100 ha catchment (Berne et al., 2004), and modelled latent heat fluxes were found to be sensitive to temporally aggregated precipitation data (Ward et al., in prep). Rainfall data for sub-kilometre areas at fine time resolution are not available using existing data sources, and a basis for downscaling is therefore needed.

This work addresses the issue using measurements from a network of ceilometers and rain gauges in central London over three years (2012-2014). Gauge data are used to identify the approximate timing of a rainfall event and to quantify the accumulated rainfall. Near-surface backscatter intensity is then used to identify the rain pulses within the event, and the accumulation is downscaled to 1-minute resolution. The speed and spatial extent of advancing rainfall events are estimated by tracking them across the ceilometers.

The resulting rainfall event durations are substantially different from those obtained from 1-minute gauge data, and are comparable to those calculated using radar measurements at timescales longer than ~10 min. Estimated speeds are broadly consistent with reference measurements.

P16.16

Compararison Study between Ultrasonic and Laser Snow Depth Meter over Daegwallyeong Site during 2011-2014

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For the improvement of understanding on practical use of cloud seeding experiments technology for snow enhancement and cloud-precipitation (snowfall), we need to obtain more precise snow depth measurement. We compared the observation data of Ultrasonic with Laser snow depth meter at Cloud Physics Observatory (CPO) in Daegwallyeong during 2011-2014. The correlation coefficient (R^2) of snow depth meters shows 0.7. The correlation coefficient was lower because of cases that observed about 5 cm to difference between snow depth meters. Snowfall of laser meter guesses 10% larger than that of Ultrasonic meter.

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Documenting variability of ice mass-dimensional properties during winter storms in Finland

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Our focus is on understanding microphysical processes and their evolution during winter storms. We have observed that snow microphysics can change within storms, and the changes could happen on temporal scale of several minutes. To characterize the microphysics of winter precipitation we have implemented a procedure to retrieve mass-dimensional (m-D) properties of ice particles. To ensure minute-scale changes in retrieved m-D properties are meaningful, a comprehensive error analysis and consistency study was performed.

In this study the main instrument is a video disdrometer, Particle Imaging Package (PIP), developed by NASA. It is a successor of Snowflake Video Imager (SVI, Newman et al. 2009) with capability to measure fall velocity as well as shape characteristics of free falling hydrometeors. M-D relation is retrieved by utilizing the general hydrodynamic theory (Böhm, 1989, Szyrmer and Zawadzki 2010, Huang et al. 2015). As PIP is scanning the particles only on single observation plane, the errors in measured quantities in respect to the true irregular shaped 3D- particles and orientation are addressed (Hogan et al. 2012, Wood et al. 2013).

We show results of m-D changes of ice particles during aggregation, riming and also the time periods, when distinguishable multiple particle types are present indicating e.g. ice multiplication processes. For consistency the computed liquid equivalent accumulation is compared with gauge measurements, and the accumulated snow volume to optically measured snow depth, and by linking the confirmed m-D relation with radar observations, we can study the vertical structure of precipitation changing during the event.

P16.18

Discriminating between liquid and ice particles measured in mixed phase cloud during the INUPIAQ campaign

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16, 4, 6

As part of the Ice Nucleation Process Investigation and Quantification (INUPIAQ) project, two field campaigns were conducted in the winters of 2013 and 2014. Both campaigns included measurements of cloud micro-physical properties at the summit of Jungfrauoch in Switzerland (3580m asl), using various cloud probes, including the Two-Dimensional Stereo Hydrometeor Spectrometer (2D-S), the Cloud Particle Imager 3V (CPI-3V) and the Cloud Aerosol Spectrometer with Depolarization (CASPOL). The first two of these probes measured significantly higher ice number concentrations than those observed in clouds at similar altitudes from aircraft.

One of the major issues in measuring properties of mixed-phase clouds is determining the phase of the particles measured by the cloud probes. Several studies have undertaken laboratory experiments to assess the shape of cloud particles using depolarisation ratios between their scattered light and their polarised scattered light and show promise. Hence, using the depolarised light scattered by particle by particle data recorded by the CASPOL probe during the INUPIAQ campaign, we attempt to assess whether depolarisation ratio can be used to discriminate between concentrations of droplets and ice crystals. Using the resulting findings, we compare the CASPOL ice concentrations with the 2D-S and CPI-3V ice concentrations to assess if a better representation of ice concentrations can be found using the depolarisation data. A summary of these results will be presented at the meeting.

P16.19

Providing the better methods to estimate snowfall rate by using laser disdrometers

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Simultaneous observation of snowfall using some precipitation gauges such as optical disdrometers and a accumulated snow weight gauge using an electric balance, and snow particles observation equipment using a USB microscope were carried out to provide a better method to estimate a snow rate accurately as part of the SPICE (Solid Precipitation Intercomparison Experiment) campaign at Rikubetsu in Hokkaido in the northern part of Japan, in 2014/2015 winter. This study attempts to provide better methods to measure amount of solid precipitation accurately by comparison of the data of optical disdrometers which measures sizes and fall velocities of all precipitation particles passing through the laser beam. At first stage, the amounts of snowfall were estimated by sum of the mass of each snow particles, which was decided by a function consisting two parameter of size and fall velocity, which derived from the relationship between size and mass reported in previous works. These estimated amounts of snowfall were more correct to compare with other indirect methods except the cases when the particles mainly smaller than 1mm observed at lower temperature. The new snow particles observation equipments were developed to record precipitating particles every 30 seconds fallen on a USB microscope from below to know the relationship between snowfall particle shape and particle size distribution. At second stage the relationships was used to correct the function of two parameter of size and fall velocity used in the first stage.

P16.20

Variability of Local Droplet Size Distributions in Marine and Arctic Stratocumulus Clouds Observed with Airborne Digital Holography

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16, 2, 4

Traditional airborne cloud droplet probes sample a single droplet at a time, requiring a long averaging distance of typically order tens of meters of in-cloud flight path to get a statistically significant size distribution. Holographic cloud droplet probes, namely HOLODEC and HALOHolo, each record a local 3-dimensional sample volume of about $1 \times 1 \times 13 \text{ cm}^3$ within which the size, shape and 3-d position of each droplet are measured. This allows each holographic probe to estimate size distributions with ~ 10 cm averaging scales, closer to the scale on which cloud droplets interact. In summer 2015, HOLODEC and a Cloud Droplet Probe (CDP) measured marine cumulus and stratocumulus during the field project Cloud System Evolution in the Trades (CSET) between California and Hawaii both flying aboard the US NSF/NCAR G-V HIAPER aircraft. In spring 2014, the HALOHolo Instrument, also with a CDP instrument, flew aboard the Alfred Wegener Institute DC-3 Polar 6 aircraft measuring supercooled liquid arctic stratocumulus clouds. HOLODEC and HALOHolo obtain a size distribution at 3 and 6 Hz, respectively or, considering the different aircraft speeds, about every 50 and 10 meters, respectively. Averaged over the same time scale (usually one 1 Hz), the holographic and CDP instruments show excellent agreement in the estimated size distribution. The local size distributions in some cases reveal pronounced variability in the size distribution, even between adjacent holograms and within the typical instrument averaging length. For example, the size distribution can change from mono-modal to bi-modal from hologram to hologram.

P16.21

Improvements in Optical Array Probe Characterization: Laboratory and Simulation Results

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Keywords: Optical Array Probes, 2DS

Here we present an update on the status of new characterization techniques for Optical Array Probes (2DS, 2D-128, 2DC, CIP, etc.). The effectiveness of the SPEC OAP processing software is demonstrated by comparison to a known standard with mono-dispersed and poly-dispersed simulated data sets. Using these computer generated data sets we will demonstrate that a non-linear sizing bias is evident for all particles, even after applying a correction factor for out of focus images with large Poisson Spots. Due to this effect, small particles may be oversized by as much as 50% on average, though the issue is less pronounced for very large particles. To account for this oversizing of droplets we present a size dependent correction factor that can be applied during post processing to augment the depth of field (DOF) resizing tables described by Korolev et al. 2007. A detailed comparison of the oversizing issue will also be presented for OAP probes with different resolutions.

Additionally, new laboratory efforts to quantify sizing uncertainty in OAP instruments at simulated flight speed will be presented. We have designed a new transparent high speed spinning disk (capable of simulated air speeds of 100-200 m/sec) with opaque reticle features to simulate the typical size regime of cloud particles. This instrument provides the unique ability to compare the time response, and imaging resolution of different OAP probes. Here we present our initial findings with this apparatus, and compare results to validate computer generated simulated data sets.

P16.22

Uncertainties in historical precipitation and wind time series over Russia and their influence on reanalysis data

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16

The link between identified shifts in precipitation/wind station time series and reanalysis data over Russia is discussed.

During the XX century over Russia, there were some significant changes in measurement procedures of precipitation and wind data. Shifts in time series follow the periods of active measurement procedure modifications. Objective homogeneity tests (the standard normal homogeneity test (Alexandersson, 1986), the Buishand range test (Buishand, 1982) and the Pettitt test (Pettitt, 1979)) show inhomogeneities in precipitation/wind station data over Russia during 1936-2010.

The empirical model for precipitation gauge data correction (The Voeikov Main Geophysical Observatory monthly datasets – MGO datasets; Golubev, 2000; Bogdanova, 2008) provides more accurate precipitation sum values, but not avoids all expected shifts. The model uses wind data for correction procedures, so it could generate additional residual uncertainties in corrected time series.

Through wind data assimilation, the shifts and residual uncertainties in time series could be identified not only in bias-corrected precipitation data (MGO dataset), but also in reanalysis datasets, which start early 1970. Uncertainties and inhomogeneities in station time series obstruct reanalysis validation, especially for precipitation, wind and wind- depended parameters.

The research focuses on influence of measurement changes in Russia on reanalysis precipitation and wind data.

Keywords: precipitation, wind, measurement uncertainties, homogeneity, reanalysis

P16.23

Improved Algorithms for Radar Remote Sensing of Snowfall Rate Using Dual Polarization C Band Radar

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16. Many operational snowfall rate algorithms for weather radars rely on simple relationships between equivalent radar reflectivity factor (Z_e) and snowfall rate (S). Developing better methods is challenging because of a lack of accurate snowfall data (due mainly to wind effects) and the difficulty associated with characterization of scattering properties of snow particles. Estimates of S can be improved by use of dual polarization (DP) radar. In this paper, development and testing of new snowfall retrieval algorithms using DP C-band radar using snowfall data collected with an automatic Geonor gauge used as a Double Fence International Reference gauge will be discussed. The data were collected at the Centre for Atmospheric Research Experiments (CARE) site located in Southern Ontario, Canada during the 2012-2013 winter period as part the World Meteorological Organization Solid Precipitation Intercomparison Experiment project. The radar is located 32 km south of the CARE site. The scan strategy employed for this study was a 10-minute cycle which included one high quality dual polarization scan. Comparisons of 10-minute averaged data showed that inclusion of polarimetric radar parameters such as Differential Phase (ϕ_{dp}) and Specific ϕ_{dp} (K_{dp}) in addition to Z_e significantly improves the retrieval algorithm.

P16.24

ADVANCED OPTICAL PACKAGE FOR ESTIMATING OF CLOUD COVER AND STRUCTURE

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16

While massively observed visually, cloud cover and altitudinal structure needs also to be quantified using precise automatic instrumental measurements. Major disadvantages of the most of common cloud-cameras are associated with their complicated design and post-processing inaccuracy. Typically, it result in the uncertainties of up to 30% in the camera-based estimates of cloud cover. We developed new generation package for cloud cover estimating. It provides much more accurate estimates and also allows for measuring additional characteristics.

New post-processing algorithm, developed for the designed package, is based on the synthetic controlling index, namely the "grayness index". It allowed for the development of a technique for the detection and suppression of the background sunburn effect. This makes it possible to increase the reliability of the detection of the optically thin clouds and to significantly increase the accuracy of cloud cover estimation. Root mean square errors for the package decreased down to about 5%.

New algorithm is focused on the accurate determination of the clouds in the presence of sun disk and on the accounting for the state of the sky image. For solving these problems, the algorithm uses several machine learning techniques along with some other sky images processing methods.

New cloud-camera has already been tested on board during several sea missions in 2014-2016 years. We will demonstrate results of the field measurements and will discuss some still remaining problems and the potential of the further developments of the package and post-processing.

P16.25

Vertical profile of fog microphysics measurements : a case study.

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The occurrence and development of fogs result from the non-linear interaction of competing processes and the forecasting of their life cycle still remains a challenging issue. Previous field campaigns have shown that fogs microphysics near the ground exhibit large differences and various evolutions during their life cycle. To better understand relationships between the different processes and to validate numerical simulations it is necessary however to document the vertical profile of the fog microphysics.

A CDP (Cloud Droplet Spectrometer) from DMT has been modified to allow measurements of the droplet size distribution in fog layers with a tethered balloon. This instrumental set-up has been used during the winter 2013-2014 in the South-East of France. To validate the vertical profiles provided by the balloon-borne CDP, a mast was equipped with instruments at 2 altitude levels with another CDP at 24 m and a Fog Monitor FM100 at 42 m.

The instrumental set-up deployed during this campaign is presented. Data collected during a fog event that occurred during the night of 5-6 March 2014 are analysed. We show that microphysical properties such as droplet number concentration, LWC and effective diameter, exhibit different time evolution during the fog life cycle depending on the altitude level. Droplet size distributions are also investigated. They reveal sharp variations along the vertical close to the top of the fog layer. In addition it is shown that their shape at the top follows time evolution typical of the droplet growth by condensation.

P16.26

Comparative analysis of lab-grown ice crystals by Cryo-Scanning Electron Microscopy

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We present Cryo-SEM images and 3D surface measurements of ice crystals grown in two distinct laboratory settings: 1) Ice crystals nucleated and grown in-situ within the TCNJ Hitachi SU5000 VP-SEM, and 2) ice crystals grown within a low temperature chamber at atmospheric pressure and then transferred to the SEM for imaging. Ice crystals have been imaged and analyzed for a range of temperatures and saturation conditions, and originating from several nucleation modes. Several recent SEM studies have demonstrated ubiquitous mesoscopic roughness on ice surfaces, relying primarily on in-situ nucleation and growth of ice crystals on a chilled surface within the chamber of an environmental SEM, filled with a pure water-vapor environment. The in-situ SEM experiments deviate markedly from typical cloud conditions by 1) the presence of an electron beam during nucleation and growth, 2) presence of a large substrate, and 3) absence of air pressure in the environment. This raises questions about how pertinent the in-situ roughness results are for atmospheric ice. The current comparative tests provide evidence that mesoscopic surface roughness is still observed for crystals grown within in the freezer chamber under a full atmosphere and without presence of an electron beam. Similar patterns of microscale roughness are detected on the crystals from the distinct experimental settings, with characteristic topographies present on basal and prism faces. Despite similarities, significant differences in microscale and particle-scale morphologies are also measured. Strongly divergent textures are described for ice particles exposed to sublimation compared to actively growing or un-sublimated crystals.

P16.27

Potential of Higher Moments of the Radar Doppler Spectrum for Studying Ice Clouds

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More observations of ice clouds are required to fill gaps in understanding of microphysical properties and processes. However, in situ observations by aircraft are costly and cannot provide long term observations which are required for a deeper understanding of the processes. Ground based remote sensing observations have the potential to fill this gap, but their observations do not contain sufficient information to unambiguously constrain ice cloud properties which leads to high uncertainties. For vertically pointing cloud radars, usually only reflectivity and mean Doppler velocity are used for retrievals; some studies proposed also the use of Doppler spectrum width. In this study, it is investigated whether additional information can be obtained by exploiting also higher moments of the Doppler spectrum such as skewness and kurtosis together with the slope of the Doppler peak. For this, observations of pure ice clouds from the Indirect and Semi-Direct Aerosol Campaign (ISDAC) in Alaska 2008 are analyzed. Using the ISDAC data set, an Optimal Estimation based retrieval is set up based on synthetic and real radar observations. The passive and active microwave radiative transfer model (PAMTRA) is used as a forward model together with the Self-Similar Rayleigh-Gans approximation for estimation of the scattering properties. The state vector of the retrieval consists of the parameters required to simulate the radar Doppler spectrum and describes particle mass, cross section area, particle size distribution, and kinematic conditions such as turbulence and vertical air motion.

P16.28

Quantifying uncertainty in forward scattering probes due to non-sphericity of atmospheric ice crystals

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Current in-situ airborne probes (e.g., forward scattering spectrometer probes (FSSP)) that measure the sizes of ice crystals smaller than 50 micrometers are based on the concept that the measured intensity of light scattered by a particle in the forward and/or backward direction can be converted to particle size. The relationship between particle size and scattered light used in forward scattering probes is based on Mie theory, which assumes the refractive index of particle is known and all particles are spherical. Not only are small crystals not spherical, but also there are a wide variety of non-spherical shapes. Although it is well known that the scattering properties of non-spherical ice crystals differ from those of spherical shapes, the impacts of non-sphericity on derived in-situ particle size distributions are unknown. Thus, precise relationships between the intensity of scattered light by a particle and its size and shape are required, as based on accurate calculations of scattering properties of crystals. In this study, scattering properties (i.e., angular dependence of scattered light) of ice crystals smaller than 50 micrometers are calculated at a wavelength of 0.55 micrometer using a numerically exact method (i.e., the discrete dipole approximation). For these calculations, hexagonal ice crystals with varying aspect ratios ($AR=length/width$, $AR=0.1, 0.25, 0.5, 1.0, 2.0, \text{ and } 4.0$) are used to represent the shapes of natural small ice crystals. Implications for the sizing of ice crystals by forward scattering probes are discussed.

P16.29

Recalibration of CAS probe during time periods with large droplet concentrations: Results from RACORO

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An extended-term, statistical characterization of continental, boundary layer, liquid water clouds was obtained by the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Twin Otter aircraft during the Routine AAF CLOWD Optical Radiative Observations (RACORO) campaign from 22 January to 30 June 2009 in the vicinity of the Southern Great Plains (SGP) ARM Climate Research Facility (ACRF) in Lamont, Oklahoma. The Twin Otter was equipped with a Gerber probe measuring bulk liquid water content (LWC) and a Cloud and Aerosol Spectrometer (CAS) and Forward Scattering Spectrometer Probe (FSSP) measuring cloud droplet size distributions (SD).

Discrepancies between the bulk LWC and that derived from integrating the CAS and FSSP SDs were noted. In this study, the hypothesis that the qualifier diode is saturated by background light for time periods with droplet concentrations above some threshold, N_o , is tested. If such a saturation occurred, the baseline of the detectors would drift, so that the pulse heights of detected particles would reach their maximum levels before reaching the maximum channel boundaries, meaning the size of the particles and hence the LWC would be underestimated.

Here, the CAS and FSSP are recalibrated by estimating the change in particle diameter and baseline shift as function of measured number concentration (N_m) that provides the best match between the Gerber LWC and that estimated from SDs. Results suggest that this saturation is partly but not totally, responsible for the difference between LWCs. Implications for the calculation of bulk microphysical parameters from the FSSP and CAS SDs are discussed.

P17.1

Effect Verification and Analysis for Artificial Precipitation Enhancement of Stratiform Cloud by Rocket in Dalian

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Effect verification for artificial precipitation enhancement is a complex scientific issue, limited by complexity of research object, research capacity, instrument and so on. After years of experiments and applications, judging indicators of artificial precipitation enhancement by rocket and technical schemes for various clouds are established for Dalian area, providing foundation for effect verification for artificial precipitation enhancement by rocket afterwards. With the use of raindrop spectrometer, the preparation for this project was implemented in early 2015. This paper accesses the effect verification and analysis for artificial precipitation enhancement for a stratiform cloud precipitation event, which occurred over Dalian area on April 12, 2015, by using statistical and physical verification methods. The results reveal that relative rain enhancement rate increases by 49% ($\alpha < 0.01$) in 30-50 minutes after catalyzing the operational clouds and reaches the maximum rainfall rate by calculating rainfall amount per minute of observational and fitted values in operation and contrast area. Moreover, significant improvement exhibits in physical effects in terms of radar echo intensity and area of target cloud, precipitation duration and variation characteristics of raindrop spectra in fitting clouds.

P17.2

Research on the use of radar products in artificial precipitation effect assessment

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In this paper, Doppler weather radar products (echo top height monitoring, echo area and echo intensity data) are used in the analysis before and after the artificial rainfall operations. The results showed that: large-scale weather systems caused the precipitation echo long time to maintain a wide range, the relevant parameters of clouds are significant changes in the operation took place, the intensity field and velocity field echo characteristics with mixed precipitation, and rainfall catalysis stage performance is remarkable, real-time monitoring of Doppler radar is an effective means to carry out artificial precipitation effect assessment.

Keywords: artificial rainfall; impact assessment; Doppler radar

P17.3

Cloud Seedability Study Using WRF Model Outputs to Drive a One-Dimensional Cloud Model

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In this research, a novel dual-model system, one-dimensional stratiform cold cloud model (1DSC) coupled to Weather Research and Forecast (WRF) model (WRF-1DSC for short), was employed to investigate the effects of cloud seeding by silver iodide (AgI) on rain enhancement. Driven by changing environmental conditions extracted from the WRF model, WRF-1DSC could be used to assess the cloud seeding effects quantitatively. The employment of WRF-1DSC, in place of a one-dimensional two-moment cloud seeding model applied to a three-dimensional mesoscale cloud-resolving model, was found to result in massive reduction of computational resources. Numerical experiments with WRF-1DSC were conducted for a real stratiform precipitation event observed on 4-5 July 2004, in Northeast China. A good agreement between the observed and modeled cloud system ensured the ability of WRF-1DSC to simulate the observed precipitation process efficiently. Sensitivity tests were performed with different seeding times, locations, and amounts. Experimental results showed that the optimum seeding effect could be achieved through proper seeding at locations of maximum cloud water content when the updraft was strong. The optimum seeding effect was found to increase by 5.61% when the cloud was seeded at 5.5km above ground level around 2300 UTC 4 July 2004, with the maximum AgI mixing ratio equaling 15 ng/kg. On the other hand, for an overseeded cloud, a significant reduction occurred in the accumulated precipitation. This research demonstrates the potential of WRF-1DSC in determining the optimal AgI seeding strategy in practical operations of precipitation enhancement.

Keywords: cloud seeding, WRF, cloud model

P17.4

Second-order potential vorticity in moist atmosphere and its application in the diagnosis of heavy precipitation

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PV gradient, second-order inhomogeneity, heavy rainfall

In this paper, a PV-gradient related parameter-the second-order potential vorticity (SPV) is generalized into a non-uniformly saturated atmosphere to involve the PV-gradient into precipitation diagnosis, assuming that PV gradient is more capable of describing the whole structure of the air mass boundaries than other single element gradients. The newly derived second-order moist potential vorticity (SMPV) is defined as the dot product of vorticity vector and three-dimensional gradient of generalized potential vorticity (GPV). A heavy-rainfall case study shows that GPV is mainly a coupling of static stability and vertical vorticity, while SMPV contains static stability, vorticity enstrophy and their vertically inhomogeneity. Due to these information, both GPV and SMPV show strong anomalies over the precipitation region, by reflecting the cyclonic shear and large vertical variations of temperature and humidity in the lower troposphere. However, GPV also appears strong, wide anomalies out of the precipitation region while SMPV does not. In addition, due to the vertical gradient of vorticity enstrophy and static stability contained in SMPV, it also has a reflection on the invasion of cold, dry air in the near-surface layer, which is seen to be a triggering mechanism of the strong precipitation. This indicates that SMPV perform better than GPV in detecting heavy rainfall. A long time-series analyses over China further verify a steady performance of SMPV on diagnosing precipitation, which means SMPV may be used as a precipitation indicator as well as GPV in the future.

P17.5

Using geochemical analysis of rain samples and satellite images in order to investigate cloud seeding efficiency

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Glaciogenic cloud seeding with Silver Iodide (AgI) has been done around the world since the 1950's. However, the debate regarding its efficiency and rain enhancement is still ongoing. Currently, a randomized cloud seeding experiment is conducted in Israel (Israel-4). As part of this experiment we collect rain and cloud samples in the northern part of Israel (the seeding target area). Using geochemical analysis of the rain water and statistical tools, we can successfully identify different air masses arriving to Israel with different aerosol types and loads. Since different air masses vary in their seeding potential, our research examines the seeding effect on different air masses. Until now, (the second year of the experiment), the largest effect on clouds happened during times of marine air mass, as manifested by significantly larger ice content during seeded than non-seeded times for a given cloud-top temperature. This is in agreement with the expectation that ice nuclei (IN) concentration in this air mass is low, and hence an additional IN should have a pronounced effect. Seeding clouds under high concentrations of desert dust did not cause higher ice content (compare to non-seeded times) and hence did not affected these clouds. This is because of the high IN concentration in these air masses.

It is important to mention, that this is the first time that chemical analysis of rain samples combined with cloud top properties are conducted as part of a randomized cloud seeding experiment. This approach provides useful information regarding the efficiency of cloud seeding.

P17.6

Cloud Response after Precipitation Enhancement Operation

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Using method of contrast cloud and radar tracking target cloud, on September 28, 2014 Shandong ground precipitation enhancement test results are analyzed. Relations between the radar response and the rainfall after the precipitation enhancement operation are discussed. The results indicate that cloud top of the target cloud began to rise after seeding 13 min. target cloud began to strengthen after seeding 19 min, target cloud VIL increased from 2.5 kg/m^2 to 3 kg/m^2 after seeding 25 min. 10 min precipitation that target cloud passed three rainfall stations has the same increasing trend. From the time and location analysis these changes associated with the rockets precipitation enhancement operation.

P17.7

Analysis On Characteristics of Radar Echoes and Conditions for Precipitation Enhancement in Gutian of Fujian

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The cloud echo characteristic and indexes of precipitation enhancement in experiment area Gutian are analyzed with the weather pattern, based on Doppler radar data during April and June in 2008-2012. The results show that : the chief weather systems influence Gutian include low vortex shear, warm convergent zone, upper trough and continental high ; the precipitation mainly come from stratus-cumulus mixed clouds, the next are cumuliform clouds; there are obvious differences in cloud echo characteristic and precipitation features by weather systems; the structure of stratus-cumulus mixed clouds can provide advantages of rainfall ; the strong echo area $S_{>25dBz}$ (echo intensity larger than 25dBz) of mixed clouds are obviously larger than that of cumuliform clouds, while the average echo height and the echo top of mixed clouds are both lower ; the vertical liquid water in cumuliform clouds is much more than in mixed clouds ; the depth of negative temperature layer of mixed clouds and cumuliform clouds both exceed 2km ; the maximum echo intensity, the strong echo area $S_{>25dBz}$ and the depth of negative temperature layer of mixed clouds all correspond well to the regional mean daily rainfall. The indexes of precipitation enhancement in Gutian are: the echo intensity larger than 25dBz, $S_{>25dBz}$ larger than 400 km², the echo higher than 5.5km, the depth of negative temperature layer larger than 1.5km, the vertical integrated liquid water more than 1 kg/m².

P17.8

Simulation of an orographic cloud airborne seeding case using a bin microphysics scheme

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6, 4

A detailed bin (spectral) microphysical scheme implemented in the Weather Research and Forecasting (WRF) model is used to study the processes, mechanisms and effects of silver iodide (AgI) seeding on wintertime orographic clouds associated with an airborne seeding case in western Idaho. An atmospheric river event was observed and seeded for a short period on 12 February 2014. Cloud radar/lidar observations and in-situ measurements from the University of Wyoming King Air (UWKA) were collected and presented by companion papers (Tessendorf et al. and French et al.). The seeding aircraft released 1.23 kg of AgI within 12 minutes before the mission was aborted due to severe icing. A WRF Large-Eddy Simulation (LES) of this case using the AgI cloud seeding parameterization coupled with the Thompson bulk microphysics scheme (Xue et al., 2013) showed that very high liquid water contents persist throughout the 5-hour simulation period and 12 minutes of airborne seeding enhanced precipitation in the target area. Due to the nature of the bulk microphysics scheme, the detailed evolution of the hydrometer size distribution as measured by the UWKA could not be simulated in that study. Therefore, a bin microphysics scheme coupling the same AgI cloud seeding parameterization is used to simulate this case to better understand the processes associated with the natural and the seeded clouds. Comparisons between model results and observations, and between bin and bulk results will be presented.

P17.9

Observation and study of macro and micro physical responses in cold cloud catalytic

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1,12,17

P17.10

Examination of Potential Changes in Orographic Precipitation and Snowpack over the Western United States in a Future Climate from a High Resolution 10 year CONUS Simulation using WRF

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The NCAR Water System program strives to improve the full representation of the water cycle in both regional and global models. Our previous high-resolution simulations using the WRF model over the Rocky Mountains revealed that proper spatial and temporal depiction of snowfall adequate for water resource and climate change purposes can be achieved with the appropriate choice of model grid spacing (< 6 km horizontal) and parameterizations. In order to investigate regional differences between the Rockies and other major mountain barriers and to study climate change impacts over other regions of the contiguous U.S. (CONUS), we have expanded our prior CO Headwaters modeling study to encompass most of North America at a horizontal grid spacing of 4 km. A domain expansion provides the opportunity to assess changes in orographic precipitation across different mountain ranges in the western USA, as well as the very dominant role of convection in the eastern half of the USA. The model was forced on the boundaries by the ERA-Interim re-analysis for 10 years from 2000 – 2010 for the current climate and a Pseudo Global warming simulation using mean monthly CMIP5 ensemble mean temperature, humidity, winds, and geopotential perturbations applied to the ERA-Interim current climate forcing to simulation conditions from 2090 – 2100. This study will present the distribution of orographic snowfall and snowpack over the major mountain ranges of the western U.S. as well as the likely impacts of GHG warming and moistening.

The modern climatology of Northern Eurasia tornadoes

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keywords: tornado, funnel clouds, supercell, waterspout, climatology of tornado

There have been significant changes in global and regional climate, especially in Northern Eurasia, over the last 30 years. The warmest decades throughout the whole era of instrumental observations were accompanied with an increase of cumulonimbi occurrence and intensity of convective precipitation. On the other hand, also because of the digital revolution, there has been a qualitative leap in obtaining and disseminating information about rare weather events (like tornadoes). In recent years, a set of new climatologies of tornadoes was presented for many European countries but not for fUSSR territory.

In this study, we present the modern climatology of tornadoes and waterspouts in Northern Eurasia, based on different sources, including historical and scientific literary sources and surveys, weather reports, newspaper stories, eyewitnesses reports, satellite data (for tornado traces) and so on. Partly, these tornado cases are collected in European Severe Weather Database. Around 2,000 tornadoes and waterspouts were found in fUSSR countries since XII century till the year of 2015. It was found that June and July are the most favorable months and the afternoon is the most favorable time for tornadoes in fUSSR. Waterspouts (mainly above the Black Sea) are more common in August. The most severe tornadoes are associated with cold fronts or such mesoscale structures as supercells. Typical values of diagnostic severe weather indices (like CAPE, SRH, SWEAT, K-index etc.) were assessed for fUSSR tornadoes based on ERA-Interim data.

P17.12

Cloud physical response of cloud seeding based on radar observation

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Key subject area: 17, Applications of cloud and precipitation physics

The change of macro and micro cloud physical properties may lead to the change of precipitation or hail dropping on the ground, which can be made through cloud seeding thereby increasing or decreasing the precipitation and preventing the hail disaster. It has been developed a new method of time series comparison and analysis based on five radar observational variables including the maximum reflectivity, the height of echo top, the echo volume, the vertical integral liquid water content and the precipitation flux. It is applied to compare and analyze the variation of difference between the seeded units (target units) and unseeded units (control units), which are similar to the target units, and find out the physical evidence that cloud seeding makes macro and micro cloud physical properties changed. By analyzing radar observation cases of rain enhancement, hail suppression and rain reduction, the evidence of effectiveness of cloud seeding is provided.

P17.13

An analysis of the impact of ground-based glaciogenic seeding on winter orographic clouds at Daegwallyeong during 2013-2015

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The purpose of this study was to investigate the impact of ground-based glaciogenic seeding on orographic clouds in the Daegwallyeong area from 2013 to 2015. The experiments were conducted by releasing silver iodide (AgI) under following conditions: surface temperature below - 4C, wind direction between 45 and 130. Numerical simulations were carried out by using the WRF model with AgI point-source module which predicted dispersion fields of AgI particles. The results indicated that the dispersion of AgI particles tended to move along the prevailing wind direction and the target orographic clouds contained sufficient supercooled liquid water. To validate the seeding effects, the observation data from SNPS, FM-120 and MPS as well as PARSIVEL disdrometer were analyzed. Aitken nuclei mode (30-100 nm) particle concentration has a tendency of increased during the seeding period in the seeding region. The increased concentration of small ice particles below 1 mm in the target region suggests enhanced precipitation during SEED period possibly due to the seeding impact.

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P17.14

Probabilistic Quantitative Precipitation Forecast of Different Type Typhoons in Taiwan

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Typhoon forecast techniques, particularly for mesoscale convective features, are critical to rainfall forecast and disaster management. To consider the influence of topographical lifting on the typhoon circulation, a typhoon rainfall climatology model had been developed and used in real-time operation practice. However, the mesoscale convective features could not be captured well in the typhoon rainfall climatology model. An ensemble meteorological modeling system has been developed after the Morakot (2009) disaster. This system is one-way coupled with a hydrological model to predict typhoon rainfall and flood responses in a mountainous watershed. In addition, the ensemble meteorological model framework includes perturbations of the initial conditions, data analysis methods, and physical parameterizations. Conversely, to quantify the uncertainty of the ensemble precipitation forecast, the probabilistic quantitative precipitation forecast (PQPF) is developed. In this study, the reliability diagram, relative operating characteristic, Brier score, and ranked probability score are used to verify the probabilistic rainfall forecast. The PQPFs of different type Typhoons affecting Taiwan, including the tracks, intensities, sizes, and motion speeds, are compared by the probabilistic verifications. As a result, the PQPF of the typhoon with smaller radius during 2011–2014 is usually overestimated for high probability value. Because the track uncertainty of the northward typhoon is more significant, the averaged error of PQPF for the northward typhoon is larger than the westward typhoon. The different motion speeds of typhoon cause a west-east dipole pattern of the error distribution in Taiwan. However, the influence of typhoon intensity on the PQPF is non-significant in this ensemble system.

P17.15

Silver Iodide Ice Nucleus Observations On and Over the Medicine Bow Range, Wyoming

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14, 16, 6, 12

Measurements of silver iodide (AgI) ice nuclei on and over the Medicine Bow Mountain Range of Wyoming, USA, with acoustic ice nucleus counters are examined to assess dispersion of ground-based AgI plumes, in the context of the recently-completed Wyoming Weather Modification Pilot Project (WWMPP), a randomized crossover statistical experiment. Ground-based observations are compared with more limited airborne observations, revealing that plume meander over the complex terrain is considerable and highly variable. Implications for the randomized statistical experiment (RSE) are discussed. One AINC was deployed near the WWMPP Medicine Bow target gauges; and measurements collected during most experimental units of the first three winter seasons of the project. The AINC was operated whether the Medicine Bow Range or the other range in the RSE, the Sierra Madre Range, was actually seeded, affording some indication as to whether cross-contamination occurred. A second AINC was flown above the range during an intensive operations period later in the project and measurements of plumes from single and multiple ground-based ice nucleus generators obtained in westerly flow to further elucidate the plume behavior.

S1.1

Large Eddy Simulations of the impact of shear-driven turbulence on snow growth

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keywords: Orographic clouds, Mixed-phase clouds

Houze and Medina (2004) and Medina and Houze (2015) hypothesize that small-scale cellular overturning motions and associated turbulence within a stably stratified elevated shear layer upwind of blocking terrain enhance hydrometeor growth. Another observational study, by Geerts et al. (2011), hypothesizes that turbulence in the shear-driven boundary layer over mountains may contribute to snow growth when strong winds produce a deep BL and the cloud base is near or below mountain top level. The observational studies mentioned above can only speculate that turbulence enhances hydrometeor growth, because they lack detailed cloud-microphysical chain-of-events evidence to demonstrate the significance of this process. The objective of this paper is to examine whether shear-induced overturning in stable blocked flow over a mountain, as well as PBL turbulence, enhance hydrometeor growth in a mixed-phase cloud by means of idealized WRF large eddy simulations (LES). The LES framework is required because vertical exchanges implied by BL parameterizations do not communicate with the cloud microphysics in a model. We show that both KH billows in the free troposphere and PBL turbulence enhance snow growth, and that this mechanism is adequately captured with a 100 m LES resolution.

S1.2

Omitted turbulent mechanism leading to preferential concentration in clouds

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1,2

Many studies attribute the evolution of droplet size distribution in warm convective clouds to enhancement of collision-coalescence by turbulence (see e.g. review by Grabowski&Wang [1]). One of the phenomena in which turbulence manifests its influence on droplet spatial distribution is preferential concentration. Majority of research about preferential concentration focus on the statistical analysis though. Such approach obscures some dynamical effects important for better understanding cloud microphysics. One of them is droplets response to presence of vortex tubes considered the smallest elements of turbulence. In this study we examine motion of inertial, heavy droplets in theoretical models of such tubes aligned at arbitrary angle to the direction of gravity. Both analytical calculations and numerical simulations demonstrate characteristic features of droplet motion in plane perpendicular to the vortex axis, such as gathering in regions attributed to equilibrium points, limit cycles or stable, periodic orbits. Conditions of existence of such regions are calculated analytically and illustrated by numerical simulations. Additional simulations of motion of polydisperse droplets in vortex tubes illustrate preferential concentration (occurring also for small Stokes numbers) , size sorting effects as well as increasing relative velocity of droplets. The model is also used to explain cloud holes phenomenon – holes observed in otherwise homogeneous cloud droplet field [2]. [1] Grabowski, W.W., Wang, L.-P. (2013) *Annu. Rev. Fluid Mech.* 45:293-324 [2] Haitao Xu et. al. (2012) Turbulence induced “cloud holes” in the mountaintop clouds at Schneefernerhaus research station, poster at ICCP-2012, Leipzig, Germany

S1.3

Turbulence enhancement of cloud droplet collisions: how does the droplet size distribution evolve in turbulent clouds?

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Key area number: 1,2,3,9

As a major feature in warm cumulus clouds, turbulence has long been postulated to accelerate the droplet collision-coalescence process to shorten the time for warm rain initiation. In both stochastic models and direct numerical simulation (DNS) experiments, significant turbulent enhancement of the geometric collision kernel has been observed. However, the inclusion of hydrodynamic effects, which affect the collision efficiency, are relatively rare in DNS studies. As a result, there are few definitive results on the evolution of droplet size distribution (DSD) in warm cumulus clouds from DNS experiments.

We developed a DNS model to simulate the droplet collision-coalescence process inside adiabatic cloud cores where turbulence is assumed homogeneous and isotropic. The model explicitly resolves the droplet disturbance flow by applying the Stokes flow solution around the droplet using an improved superposition method proposed by Wang et al. (2005). In this presentation, the evolution of the DSD for different turbulence intensities will be shown. The results for cases with and without turbulence and hydrodynamic effects will be compared.

S1.4

Drop-droplet collisions observed with holography in a vertical laminar flow

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16., 1.

Collision and coalescence are important processes in cloud evolution and rain formation. Parametrizations of these processes in clouds models are based on very few laboratory measurements made since the 1970s complemented by recent numerical investigations. In past experiments, the most widely used collision parameter, collision efficiency, was obtained indirectly after making assumptions about flow and particle parameters.

Here we establish proof of concept that we are able to measure collision efficiency directly using holography, in contrast to experiments found in the literature, and that we can simultaneously characterize the particles and flow without the need for additional measurement techniques.

For this purpose we used in-line holography in the Mainz vertical wind tunnel to investigate individual collisions between small rain drops (ca. 550--770 μm) levitated in a vertical laminar stream of cloud droplets (20--70 μm) moving with the drop terminal velocity of about 3 m/s. Recording holographic images made with a high speed camera allowed us to determine drop and droplets positions in three dimensions along with their sizes. To find collisions, we tracked the droplets and then looked for tracks leading to collisions and near-collisions. In a data series length of around 50 s we found 106 collisions. In addition to collisions, we can estimate how laminar and uniform the flow is, drop and droplets terminal and relative velocities, droplet size distributions as well as droplet number concentrations.

S1.5

Retrieval of binned rain drop size distributions profiles from multi-frequency radar observations: potential for fingerprinting rain microphysics processes

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16. Measurement techniques (of cloud and precipitation properties) and uncertainties

A novel technique based on Ka-W-band dual-wavelength Doppler spectra has been developed for the retrieval of profiles of binned rain drop size distributions (DSD).

This technique is now mature and is applied to a dataset of 180 hours of light to moderate rain observed with the ARM mobile facility in Finland during the summer 2014. The overall performance of the technique will be described from comparison with other observations from ground base measurements of DSD or independent measurements of the rain profile available during this campaign.

Finally, this presentation will show the potential of these observations for fingerprinting rain microphysical processes like evaporation, accretion or drop break-up on some case studies. Such observations are essential since latent heat release depends on these microphysical processes and drives the evolution of precipitating systems.

S1.6

Use of 3D-printed analogues to investigate the fall speed and orientation of natural ice particles

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University of Reading, Reading, UK

1,5,16

The fall speed of ice particles in clouds has a strong impact on climate, but its parameterisation remains uncertain. Meanwhile, the orientation of the ice particles controls optical phenomena like arcs and halos, and are key to interpreting dual-polarisation remote-sensing data of ice clouds. Both of these effects are controlled by the air flow around the falling ice particle.

One way to study this process is to try and observe falling ice particles in snowfalls at the ground, and characterising their velocity, orientation, diameter, mass and area. Making such observations in practice is extremely challenging.

An alternative approach is to make use of “analogues” - realistic models of natural ice particles which can be used in a laboratory environment to simulate the aerodynamics of real ice particles falling through the atmosphere. In this work, we have exploited the recent advancement of 3D printing technology to produce realistic analogues of pristine crystals, aggregates and graupel and explore their aerodynamics.

This presentation will show some of the first results from these experiments. For example, we have discovered that the orientation needed to produce the rare Lowitz arc cannot be produced by regular hexagonal plate crystals, and in fact is a property of scalene ice crystals where two opposite sides of the basal facet are longer than the other four. We have also begun computing drag coefficients of realistic ice particles and comparing these to parameterisations used in models.

S1.7

Effective terminal velocity as a measure for the coupling between cloud microphysics and dynamics

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1. Basic cloud and precipitation physics Or 12. Aerosol-cloud-precipitation-interactions and processing

Abstract

Investigation of aerosol effects on clouds becomes challenging once the coupling between hydrometeor size distribution and cloud dynamics is considered.

We suggest that the mean terminal velocity weighted by mass, defined here as the Effective Terminal Velocity (ETV), is a measure that captures the way by which microphysical processes determine the mobility of water and ice within the cloud.

The term Effective Terminal Velocity is used to emphasize the fact that it represents a fundamental property of the cloud. For the same initial water mass and air velocity field, the predicted vertical water-mass distribution will be completely different for clean and polluted clouds as captured by their ETV. Moreover, for a given cloud's volume element, ETV is the velocity of the element's water mass center of gravity. Therefore, the sum of ETV (always negative) and the air's updraft represents the vertical movement of the center of gravity and allows exact calculations of water fluxes.

S1.8

Cumulus precipitation and the development of the boundary layer

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12 and 2

This study investigates the effect of shallow cumulus precipitation on the growth of the boundary layer using a large eddy simulation model and bin microphysics. A precipitating shallow cumulus case from the Rain in Cumulus over the Ocean (RICO) experiment is studied. It is found that increasing aerosols can significantly reduce the precipitation rate. Therefore, the precipitating simulation (with less aerosol) and the non-precipitating simulation (with more aerosol) are compared. In the non-precipitating case, the inversion layer height proportionally increases with time, which is consistent with previous studies. However, the precipitating case has lower inversion layer height (about 120 m on average) and lower cloud top height (about 200 m on average). This indicates that the precipitating case is associated with slower development of the boundary layer. The reason is that precipitation removes liquid water from cloud top, leading to less cloud-top evaporation and cooling, and therefore weaker cloud-top entrainment. The growth of the boundary layer is therefore slowed down. On the other hand, in the layer below cloud base, the precipitating case has more turbulent kinetic energy due to the stronger downdrafts and updrafts induced by precipitation. However, the stronger turbulence in the lower layer in the precipitating case does not contribute much to the growth of the boundary layer. It is the weaker cloud-top entrainment that dominates the slower growth of the precipitating shallow cumulus boundary layer.

S1.9

Homogeneous nucleation in supercooled cloud droplets

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1 2 4

Water droplets in some clouds can supercool to temperatures where homogeneous ice nucleation becomes the dominant freezing mechanism. In many cloud resolving and mesoscale models, it is assumed that homogeneous ice nucleation in water droplets only occurs below some threshold temperature, often set at -40°C . However, it is well known that there is a finite rate of nucleation at warmer temperatures. In this study we use a parcel model with detailed microphysics to show that cloud properties can be sensitive to homogeneous ice nucleation to temperatures warmer than -33°C . Accounting for the small concentration of ice crystal produced homogeneously at warmer temperatures is important because these crystals have time to grow and influence the evolution of a cloud. Thus, homogeneous ice nucleation may be more important for cloud development, precipitation rates, and key cloud radiative parameters than is often assumed. Furthermore, we show that cloud development is particularly sensitive to the temperature dependence of the nucleation rate. With this in mind we have conducted new experiments in an attempt to further constrain the nucleation rate. The temperature dependence of the measured nucleation rate is significantly higher than many of the older data sets, but consistent with several of the newer measurements. However, we also note that there is a dearth of measurements at nucleation rates less than about $10^5 \text{ cm}^{-3} \text{ s}^{-1}$, but nucleation rates as small as $1 \text{ cm}^{-3} \text{ s}^{-1}$ may produce important quantities of ice in clouds; hence there is a need for new measurements.

S1.10

Supercooled Cloud Tunnel Studies on the Growth Conditions of Branched Planar Snow Crystals: The Influence of Crystal Growth Time

Tsuneya Takahashi

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1

4

How does liquid-water content (LWC) and temperature affect the growth of branched snow crystals? To address this issue, we carried out experiments with the finer-scale temperature resolution of 0.1°C using a vertical supercooled cloud tunnel in which a single snow crystal could be freely suspended and continuously grown in front of the observer (Takahashi 2014). It was shown that the crystal habits are divided mainly by temperature: sector above -12.5°C , then broad-branch, then stellar, dendrite, and fern; then the pattern reverses, with dendrite, stellar, broad-branch, and finally sector below -16.1°C . Between -13.3° and -14.5°C , the side-branch density increases with LWC. The cloud droplets contribute not only to the development of sidebranches but also to the increase in crystal thickness. The crystal diameter and mass show a maximum at -15.0°C , at which a stellar crystal, but no ferns, grows.

However, only for a snow-crystal growth time of 10 min those experiments were run between -12° and -16.5°C . Here, we made experiments for growth time of 5 and 20 min to see how the above findings hold under more natural conditions. The boundaries between the basic branched habits were kept at the growth time of 20 min when a fern and a dendrite have at least three crystal branches that each contain eight or more and four or more side branches, respectively. How growth parameters such as mass, dimensions, and fall velocity depend on temperature, LWC and growth time will be discussed.

S1.11

The effectiveness of spectral bin schemes in simulating ice cloud particle size distributions and their variability

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1, 16, 3, 8

In this study, a mesoscale convective system (MCS) sampled on 20 May 2011 during the Mid-latitude Continental Convective Clouds Experiment is simulated using the Weather Research and Forecasting (WRF) model with 3 different spectral bin microphysics schemes. The simulated ice cloud particle size distributions (PSDs) and their variability are compared against those measured in-situ using Two-Dimensional Cloud Probe, Cloud Imaging Probe and High Volume Precipitation Spectrometer on University of North Dakota Citation aircraft in the trailing stratiform region behind the MCS.

The observed and simulated PSDs are fit to gamma distribution functions with three parameters: intercept (N_0), slope (λ) and shape (μ). The observed and simulated PSDs are quantified using ellipsoids in the parameter phase space (N_0 , λ , μ) to represent volumes of equally realizable solutions. Under this framework, the PSD and its dependence on the environmental conditions are compared between the three bin schemes and the in-situ observations. Significant differences in PSDs are found among the three bin schemes and between the simulation and observation. Various microphysical process rates, such as nucleation, diffusional growth, aggregational growth, and melting, are output and compared for the different schemes. Assumptions about the particle properties (such as mass/terminal velocity-dimensional relations, etc.) and representations of microphysical processes in different bin schemes are investigated to explain the differences between models and in-situ observations.

S1.12

The effect of ice particles growth rates in convective clouds

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1. Basic cloud and precipitation physics

5. Cirrus clouds

3. Convective clouds

The cirrus region of tropical thunderstorms has been shown to consist of linear chains of aggregated plates and columns. These ice particles interact with the vapour field by either growing in the rising turrets or slowly evaporating as dry environmental air mixes into the cloud. The rate at which the ice particles either grow or evaporate depends on their shape or capacitance, which researchers have parametrized to be linearly dependent on the maximum size of the ice particles. Here we revisit this assumption, using observations from field data to constrain the ice particle shape and perform detailed calculations of the shape factors / capacitances of these different chain aggregates. We show that previously derived shape factors for aggregates overestimate those of chain aggregates by a factor of 2 to 4.

The implication here is that, with the new shape factors, the ice particle should grow slower in the supersaturated regions of the clouds, but also evaporate more slowly in the subsaturated regions. The new shape factors are tested within the Weather Research and Forecast model (WRF) and applied to case studies from the ACTIVE / TWP-ICE field campaign, which studied a regular deep convective cloud known to the locals as "Hector". Here differences are seen in the rate of development, life cycle and vertical structure of the simulated clouds. These results will be summarised and put into context at the meeting.

S1.13

Simulations of Radar Reflectivity Factors at 94GHz: Ice Crystal Approximation with Oblate Spheroids

Emmanuel Fontaine¹, Delphine Leroy¹, Alfons Schwarzenboeck¹, Pierre Coutris¹, Julien Delanoë², Alain Protat³, Fabien Dezitter⁴, Alice Calmels⁴, Walter Strapp⁵, Lyle Lilie⁶
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Mesoscale cloud systems (including severe storms)

Tropical clouds

Convective clouds (including cloud electrification)

This study explores the potential of simulating cloud radar reflectivity factors (RRF) at 94GHz from a combination of cloud particle 2D images from optical array probes and bulk condensed water content, simultaneously measured during the first aircraft field campaign of the High Altitude Ice Crystals (HAIC) / High Ice Water Content (HIWC) international project performed out of Darwin in 2014. Within these simulations, ice crystals are approximated by oblate spheroids without a priori assumptions on mass-size relationships of ice crystals. The method allows calculating time dependent ranges of radar reflectivity factors deduced for given size distributions of hydrometeors, averaged over 5 seconds. Ice hydrometeor size distributions and shapes (flattening parameter for oblate spheroids) are deduced from 2D images, and are subsequently used to constrain the ice particle density (thereby matching simulated and corresponding measured radar reflectivity factors). Finally, uncertainties in oblate spheroid approximations are studied in order to demonstrate some limitations of this method.

S1.14

Measurements of vapor growth and sublimation of individually levitated ice particles below -30°C

Marcus Hanson, Alfred Moyle, Jerry Harrington
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1,5, Ice physics

The physics and evolution of cirrus and other cold clouds are dependent on the physics of ice particle mass growth from the vapor. Mass growth rates of ice crystals in clouds are known to influence cloud properties such as particle size distribution, phase partitioning, and glaciation timescale. Crystal growth rates are determined by a temperature-dependent critical supersaturation. Growth occurs only when the supersaturation over the ice surface in question is large enough with respect to the critical supersaturation of the surface.

By using a laboratory technique that electrostatically levitates individual ice particles in a stable diffusive environment, ice mass growth can be achieved without potential biases from either conductive heat transfer or vapor shadowing due to the presence of a substrate. In addition, the diffusion chamber is designed to remove any surfaces that could serve as competing vapor sinks.

Particles were grown at several different supersaturations at temperatures below -30°C. Growth is always limited by surface kinetics and the resulting data allow us to calculate the critical supersaturations and deposition coefficients at these temperatures.

The upper part of the diffusion chamber is sub-saturated and this feature allows for successive cycles of growth and sublimation. Data on both vapor growth and sublimation processes will be presented.

S1.15

Developing an advanced categorization scheme for autoconversion using new observables from ground based observations.

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16)

Autoconversion describes the mass transfer rate from cloud droplets to embryonic-drizzle particles. It is crucial process part of the atmospheric water cycle and plays an important role for short and long wave cloud radiative forcing in our climate system.

Since autoconversion is a sub-grid-scale process, several parameterizations have been proposed for numerical models but their evaluation remains difficult due to the lack of direct observations.

Here, we focus on new criteria to detect drizzle onset within clouds based on higher Doppler spectra moments (as opposed to the "standard" moments reflectivity, mean Doppler velocity and Doppler spectrum width) obtained from the MIRA cloud radar at JOYCE (Jülich Observatory for Cloud Evolution) and from the synergy of various instruments present.

Among the higher moments, the skewness of the radar Doppler spectrum is able to detect the onset of drizzle formation in the cloud. The new method has been tested on individual cases at JOYCE and areas of drizzle formation within the cloud have been retrieved. We propose that this new method can provide additional observational constraints for autoconversion parametrization in numerical models.

Moreover, two additional studies have been performed. First, simulations of the observations using a Doppler spectra radar forward model have been developed to provide a microphysical interpretation of the measurements. Second, IQ raw cloud radar data have been analyzed to evaluate the accuracy of higher moments estimates and their sensitivity to basic radar parameter settings (number of FFT points in the radar Doppler spectrum and number of spectral averages).

S1.16

Wind tunnel studies on formation and growth processes of atmospheric ice particles

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1.

Latest results of the experiments on the most important ice particle formation and growth processes, heterogeneous nucleation and riming, carried out at the Mainz vertical wind tunnel will be presented. The tunnel air was cooled down to -25 °C, therefore several types of microphysical processes typical for mixed phase clouds could be investigated. The hydrometeors were levitated in the vertical air stream simulating their fall in free atmosphere at terminal velocities.

In a first series of experiments immersion freezing of water droplets with diameters of 700 micron containing ice nucleating particles (INP) was investigated. A second series of measurements was addressed to contact freezing: INP were injected upstream of freely floating supercooled water droplets; as soon as the INP collided with the droplet the freezing was initiated. From the wind tunnel measurements immersion and/or contact freezing properties of different INP were characterized, mainly focusing on the temperature, INP concentration, and specific surface area dependences of the freezing processes. Furthermore, a direct comparison of immersion and contact freezing of atmospherically relevant INP (e.g., mineral dust, or biological particles) was provided.

In a third series of experiments riming of graupel was studied. Frozen drops were floated in the wind tunnel and grew by accretion of tiny supercooled water droplets injected into the air flow. Growth rates and collection kernels of graupel of different sizes were experimentally derived. The effect of turbulence on the graupel growth was also investigated, utilizing distinct levels of turbulence kinetic energy in the wind tunnel air flow.

S1.17

Does the shape of the assumed raindrop size distribution matter in convection?

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1, 3, 8

Rain Drop Distribution, gamma distribution, modeling

Two-moment (2M) microphysical parameterization schemes, which typically predict both number concentration and mixing ratio, still require some *a priori* description of the shape of the size distribution, which is held constant throughout the simulation. This study employs the Regional Atmospheric Modeling System (RAMS) to simulate a variety of idealized organized convection, varying only the shape parameter of the assumed gamma distribution of rain. The results show that as the drop size distribution becomes narrower, the amount of accumulated liquid precipitation decreases dramatically (up to nearly 500% lower), especially in supercellular convection. Additionally, the characteristics of the mid-level updraft and mid-level condensate change with changing shape parameter, due to the subsequent impacts of this change on the ice phase physics. It appears that this is due to non-linear feedbacks including changing evaporation and differences in the behavior of collision-coalescence. The decreasing precipitation with increasing narrowness holds consistent with observations of continental convection. This work shows that the shape parameter should be considered when modeling convective events, especially when investigating accumulated rainfall. Because of this, more progress towards ubiquitous triple-moment schemes and hybrid 2M schemes which predict the shape parameter must be made if we are to improve precipitation predictions.

S1.18

Exploring the diabatic role of ice microphysical processes in two North Atlantic summer cyclones

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Key area numbers: 8, 4, 1

Keywords: Latent heating, diabatic processes

Abstract:

Numerical simulations are performed with the Weather Research and Forecasting model to elucidate the diabatic effects of ice phase microphysical processes on the dynamics of two slow moving summer cyclones that affected the UK during the summer of 2012. The first case is representative of a typical mid-latitude storm for the time of year, whilst the second case is unusually deep. Sensitivity tests are performed with 5 km horizontal grid spacing and at lead-times between 1-2 days using three different microphysics schemes, one of which is a new scheme whose development was informed by the latest in-situ observations of mid-latitude weather systems. The effects of latent heating and cooling associated with deposition growth, sublimation and melting of ice are assessed in terms of the impact on both the synoptic scale and the frontal scale. The results show that, of these diabatic processes, deposition growth was the most important in both cases, affecting the depth and position of each of the low pressure systems and influencing the spatial distribution of the frontal precipitation. Cooling associated with sublimation and melting also played a role in determining the cyclone depth, but mainly in the more intense cyclone case. We also explore the effects of ice crystal habit and secondary ice production in our simulations, based on insight from in-situ observations.

S1.19

Cloud Droplet Growth and Drizzle Formation in a Turbulent Laboratory Cloud

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1, 12, 16

We have developed a turbulent cloud chamber (the Pi Chamber, volume 3.14 m^3) that is uniquely suited to addressing aerosol-cloud-drizzle interactions. It is capable of pressures ranging from sea level to ≈ 100 mbar, and can sustain temperatures of $+40$ to -55 °C. More importantly, we can establish a temperature gradient between the floor and ceiling inducing Rayleigh-Bénard convection and a turbulent environment. The mixing cloud which forms when the boundaries are wet has a constant forcing so that the dynamics are fixed and the cloud can persist for long times (hours to days). We can thus explore how the microphysical properties respond to aerosol input, and the relative roles of growth by condensation and collision-coalescence.

Clouds that form under strong temperature gradients can achieve liquid water contents above approximately 1 g/m^3 and the droplet size distributions under these conditions exhibit a pronounced large-drop tail reminiscent of drizzle formation. Indeed, computations with a bin model suggest that it is very difficult to explain this tail theoretically without accounting for collision-coalescence. This opens the door for controlled, laboratory studies of aerosol-cloud-drizzle interactions. Our initial results show that the cloud droplet effective radius and concentration respond quickly to changes in the aerosol number concentration. Furthermore, if the aerosol in the chamber are not replenished as droplets are removed from sedimentation and collisions with the walls, the fraction of large droplets (> 40 micron diameter) increases, leading to a rapid collapse of the cloud.

S2.1

Shallow Marine Cloud Droplet Distributions: In-Situ Field Campaign Observations and Model Parameterization Comparison

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2,1,3,9,16 Numerous field campaigns in the last decade have measured shallow marine clouds including RICO, VOCALS, DOMEX, ICE-T, PACDEX, HIPPO, and CSET. Here, we compare in-situ observations of shallow marine cloud droplet distributions observed with single particle spectrometers such as FSSP and CDP. Differences in cloud droplet distributions can be attributed to conditions associated with geographic location, as well as dynamical, entrainment, aerosol, thermodynamic and instrumentation differences. For example, DOMEX has some orographic influence due to the proximity of an island, and CSET in the Pacific appears overall “cleaner” than RICO in the Caribbean. Also, as instrumentation improves, the number of droplet bins and count rates increase, artificially modifying the shape of the large and small tails in the droplet distribution. These aspects are taken into consideration with an eye toward robust differences between projects associated with explainable phenomenon. A key aspect of this work is understanding how and how well various models and microphysics schemes represent cloud droplet distributions (e.g. gamma distributions), and how we can use new observations to verify assumptions currently used in microphysics parameterizations to improve model representations of cloud droplet spectra. We find that using a double moment scheme for the cloud water category (including both cloud number concentration and liquid water content) is vital for capturing the shape of the droplet distribution, and our analysis supports the presence of a relationship between the μ and λ shape and slope parameters of a gamma distribution fit to cloud droplet distributions.

S2.2

Design and evaluation of a large-eddy simulator with a novel description of aerosol-cloud interactions using a sectional framework

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12, 2, 3

Aerosol cloud interactions (ACI) in marine stratocumulus clouds comprise an essential, yet still rather poorly understood subject in terms of the Earth's climate. Although conceptually simple archetypes of ACI and the related radiative effects have long been recognized, the reality is more obscure because of a range of feedbacks in both microphysics and dynamics. One such feedback mechanism is related to cloud processing and wet removal of aerosol particles, which may alter the properties of the aerosol population and eventually clouds themselves. Here, a new cloud resolving modelling system with an innovative approach to describe aerosols and clouds in a sectional framework is presented and evaluated.

The developed model is based on the UCLALES Large-Eddy Simulation model. It is coupled with an extended version of the SALSA module, which contains fully interacting sectional descriptions for aerosols, clouds and precipitating particles. The strategy for the layout of the cloud droplet bins emphasizes the tracking of size resolved aerosol particle properties both in- and outside of clouds. This makes the coupled UCLALES-SALSA an ideal system for studying the wet removal of aerosols and the associated feedbacks.

The new model is applied to simulate well characterized marine stratocumulus cases based on the VOCALS-REx campaign. The ability of the UCLALES-SALSA to reproduce mechanisms for the removal of aerosol particles through activation and collection scavenging of interstitial aerosols is demonstrated. The properties of the simulated clouds and the boundary-layer are compared with aircraft observations from the VOCALS-REx datasets.

S2.3

Drizzle and non-drizzle cloud regimes observed over the northwestern Pacific in summer: Aerosol-cloud-precipitation interactions

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12 2

Summertime low-altitude clouds over the northwestern Pacific play an important role for Earth's radiation budget. In this paper, we report the first systematic aircraft measurements of cloud microphysical properties and aerosols over the most western part of north Pacific made in July 2013 during the Aerosol Radiative Forcing in East Asia (AF2013S) experiment. Two distinct cloud regimes were observed, namely with and without drizzle (D and non-D regimes, respectively). The D regime is characterized by low concentrations of both cloud droplets (Nc) and accumulation mode aerosols (Na). Drizzle likely removes aerosols within the marine boundary layer by wet deposition. Reduced Na (therefore low Nc) is favorable for more precipitation, leading to a positive feedback. In contrast, the non-D regime is characterized by both high Na and Nc that tend to inhibit precipitation. A cloud thickness is generally thicker for the D regime clouds and it is speculated that vertical development of clouds may trigger precipitation that causes a transition from non-D to D regime. Another distinct difference between the two regimes is vertical structure. The cloud liquid water contents (CLWC) generally increase monotonically with altitude for the non-D regime, while those of D regime show more heterogeneous layering vertical structures. Although cloud thickness is greater for the D regime, reduced CLWC results in cloud liquid water path similar to those of the non-D regime. These results indicate that precipitation likely exerts an influence on the structure of the boundary layer and cloud dynamics.

S2.4

Identifying Meteorological Controls on Open and Closed Mesoscale Cellular Convection as Associated with Marine Cold Air Outbreaks

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10, 13, 2

We conducted an examination of time-varying meteorological conditions associated with satellite-determined open and closed mesoscale cellular convection (MCC) to illustrate the influence of marine cold air outbreaks (MCAO) on cloud development and to expand our understanding of open and closed cloud formation. Cold air from polar regions moving across warmer waters (i.e. particularly in the mid-latitudes) initially drives the formation of low marine clouds, especially open MCC. Such outbreaks may also influence the transition from open to closed MCC. Thermodynamic variables from ERA-Interim Reanalysis are assessed for each pre-identified MCC cloud (using identifications from Wood and Hartmann, 2006). Additionally, Lagrangian trajectory analysis (Eastman and Wood, 2016) is applied to these MCC Identifications to illustrate the dynamical evolution of open and closed MCC. The behaviors of open and closed MCC are contrasted to improve developmental knowledge and understand the influence of MCAO. Results from this may improve the parameterization of cloudiness and reduce shortwave bias in cyclonic cold fronts (i.e. MCAO) as well as advance the simulation of marine low clouds.

S2.5

Modulation of stratocumulus to cumulus transition by rain

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key area numbers: 2, 12

The stratocumulus to cumulus transition (SCT) is associated with a warming sea surface temperature westward of cold ocean waters, formation of boundary layer decoupling, appearance of penetrative cumulus, and then gradual dissipation of the stratocumulus. The typical time scale for the SCT is about three days, and the system enters the cumulus regime sometime thereafter. In addition, the time scale of the transition is thought to be largely determined by the lower tropospheric stability in the stratocumulus state. In this study, the modification of the rate of the SCT due to rain is investigated with three-day Lagrangian large eddy simulations. Our model includes a two-moment bin-emulating microphysics scheme coupled with prognostic aerosol number concentration. When aerosol loading is large, the SCT follows a typical scenario; penetrative cumulus appears during the second and third nights. When aerosol loading is small, drizzle forms in the second night, which triggers an early transition. When aerosol is intermediate, two counteracting effects come into play: (i) the microphysical suppression of drizzle by the aerosol and (ii) the resultant boundary layer deepening, which enhances cloud depth, cloud water and drizzle. The net effect is a delay in the transition to the third night, and a more cumulus-like structure. At this intermediate aerosol loading, local penetrative cumulus can now reach more significant depth, transporting surface moisture into the clouds and creating locally strong rainfall. Thus modulation of the rate of the SCT time due to rain is significant.

S2.6

Ultra-clean Layers and Low Albedo Clouds in the Marine Boundary Layer

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12, 2

During the recent Cloud System Evolution in the Trades (CSET) field program, a common feature of the decoupled subtropical marine boundary layer (MBL) is the presence of ultra-clean layers (UCLs), here defined as horizontally extensive layers with extremely low accumulation mode aerosol concentrations ($<10 \text{ cm}^{-3}$) and frequently as low as $0.1\text{-}1 \text{ cm}^{-3}$. UCLs form in the upper part of the decoupled MBL above the transition layer at the top of the surface mixed layer. Clouds within UCLs are frequently horizontally extensive layers with some of the lowest droplet concentrations found in the troposphere (typically $1\text{-}10 \text{ cm}^{-3}$). They typically have low liquid water contents ($0.01\text{-}0.1 \text{ g/kg}$), and display a range of thicknesses from $<100 \text{ m}$ to several hundred meters. Geostationary satellites indicate that the albedos of these extensive UCL clouds to be $0.1\text{-}0.2$, giving them a "grey" appearance when viewed from space. Most of these layers do not fully attenuate lidars, indicating low optical thickness.

The range of aerosol and cloud droplet concentrations in UCL clouds is approximately an order of magnitude below levels typically assumed in modeled MBL clouds. The mechanisms for producing and maintaining UCLs and the clouds within them will be explored in this work. Simple parcel modeling indicates that droplets in UCL clouds can grow predominantly via condensational growth, with collision-coalescence unlikely to be important for shaping the droplet size distribution in most cases. This challenges the conventional wisdom that collision-coalescence growth is necessary to grow liquid droplets to radii larger than about 20 microns.

S2.7

Turbulent enhancement of collision-coalescence processes in large-eddy simulations of trade wind cumulus clouds

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2,3

In-cloud turbulence leads to an increase of the collision frequency of drops. In recent years several semi-empirical models have been suggested to quantify the effect of turbulence on the collision kernel. Such models are mostly based on direct numerical simulations (DNS) at moderate Taylor-microscale Reynolds number and any application to atmospheric flows comes with additional assumptions to extrapolate the DNS results to high Reynolds numbers. We compare the two semi-empirical collision kernels of Ayala-Wang and Onishi and discuss their different behavior at high Reynolds number. We find that both kernels show distinctly different behaviour for the drop sizes relevant for either autoconversion or accretion and selfcollection of rain drops. While the Ayala-Wang kernel predicts an increase of the collision frequency for almost all drops at high Reynolds numbers, the Onishi kernel shows a different and more complex behavior. Autoconversion decreases slowly, while the collisions related to accretion and selfcollection of rain increase in frequency. To apply those collection kernels in a large-eddy simulation model we derive the corresponding two-moment bulk schemes and test them with bin-resolved reference solutions. We find that the accuracy of the bulk scheme is sufficient to reproduce that different behavior of both turbulent collision kernels. This allows us to perform large-eddy simulations using either the Ayala-Wang or Onishi kernel, and to investigate how the different collision kernels affect the evolution of a trade wind cumulus cloud field, the on-set of precipitation and the area-averaged rain rates. We find that both collision kernels lead to a significant effect on the evolution of the cloud field and enhance the development of precipitation.

S2.8

Relationship Between Turbulence and Drizzle Onset and Growth in Low-level Continental and Marine Stratiform Clouds Using ARM Observations

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Key areas: 2, 12, 16

Drizzle is ubiquitous in low-level stratiform clouds. Several numerical studies and field experiments have provided supporting evidence on the dominant role of liquid water path in drizzle growth and of an aerosol role in drizzle suppression. However, it remains unclear if and to what extent turbulence influences the production and development of drizzle in low-level stratiform clouds. Here, we use observations from the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) program to investigate the relationship between turbulence and drizzle. A large dataset of continental and maritime stratocumulus clouds is identified. Using synergy between ground-based aerosol observing systems and active and passive remote-sensing instruments, time series of LWP, cloud condensation nuclei (CCN) number concentration (NCCN), cloud base drizzle rate (RCB), and eddy dissipation rate (EDR) are derived. This dataset is conditionally sampled with respect to LWP and NCCN, and for each subset within a specific range of LWP and NCCN values, several additional parameters are estimated to provide information on drizzle onset, drizzle growth and in-cloud turbulence. In particular, the profiling cloud radar Doppler spectra dataset is used to estimate the radar Doppler spectrum skewness, a particularly sensitive parameter in the early detection of drizzle onset. Drizzle growth is evaluated using the drizzle rate estimated at the cloud base. All of these new parameters are utilized to investigate the level of turbulence in low stratiform clouds and its relationship to drizzle onset and growth.

S2.9

Giant aerosols vs turbulent collision enhancement in marine stratocumuli.

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key area numbers: 1, 12

The Giant cloud condensation nuclei (GCCN) are large aerosol particles which, despite their low concentrations, might accelerate formation of precipitation.

We revisit the question of relative importance of GCCN versus turbulence for formation of precipitation in marine stratocumuli. The problem is studied using a two dimensional LES simulation. Cloud microphysics is modelled with a Lagrangian super-droplet method proposed by Shima et al (2009). The initial GCCN spectrum used is based on observations of large sea-salt particles generated by breaking waves. Turbulence is taken into account by using the coalescence kernel proposed by Onishi et al (2015).

Simulations are performed for different aerosol concentrations (pristine and polluted cases) and for different values of kinetic energy dissipation rate and Taylor-microscale Reynolds number. The last two parameters control the turbulent enhancement of collision efficiencies.

Precipitation onset time is compared across simulations, as well as the total amount of precipitation and dry and wet radii spectra. Special attention is given to the evaporation of GCCN-based drops in downdraft regions.

S2.10

Turbulence-microphysics feedbacks in LES of marine stratocumulus

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Key areas:1,2

- Microphysics is coupled to turbulence in a large-eddy simulation model by introducing a turbulent collision-coalescence kernel that depends on local TKE dissipation rate.
- Simulations are performed for 3 case studies with and without turbulent collision-coalescence turned on for marine stratocumulus derived from flights during the POST field campaign which took place off the coast of Monterey, California. These cases span a range of mean cloud-top drizzle rates $\langle R_{CT} \rangle$: non-drizzling (RF 17, $\langle R_{CT} \rangle \sim 0.4$ mm day), moderately drizzling (RF 14, $\langle R_{CT} \rangle \sim 1.7$ mm day), and heavily drizzling (RF 7, $\langle R_{CT} \rangle \sim 2.5$ mm day).
- Preliminary results indicate feedback of microphysical processes on the structure of turbulence in all 3 cases. Turbulent kernel simulations show a similar mean cloud-top dissipation rate but much higher maximum rates relative to the control (quiescent kernel) simulations. For example, the 99th percentile of the dissipation rate PDF is 50-60% greater in preliminary turbulent kernel simulations versus control simulations.
 - The relatively small change in mean dissipation rate values coupled with the shift to higher extreme values in the turbulent kernel simulations indicates a more intermittent dissipation rate distribution.
- Changes in the PDF of R_{CT} are also evident. All turbulent collision-coalescence cases show an increase of about a factor of 2 in the 99th percentile of cloud-top drizzle rate.
- The mechanisms driving the observed microphysics-turbulence feedback will be explored as well as implications for precipitation formation.

S2.11

Marine stratocumulus: Variability in Precipitation Rate Caused by Variability in Giant Sea-Salt Size Distributions (GCCN)

Jorgen Jensen, Alison Nugent
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1 2 12

Giant sea-salt aerosol particles (GCCN) are an important part of the atmospheric aerosol population in the boundary layer air that occur as part of the major marine stratocumulus regions. Just as small sub-micrometer aerosol variability may give rise to variability in cloud properties (Twomey, 1977; Albrecht, 1979), there is significant variability in the size distributions of GCCN over the ocean, in part due to generally more wave breaking generating GCCN at higher wind speeds.

In this study we use several hundred measurements of GCCN size distributions from the 2008 VOCALS project off the coast of Chile as input to an adiabatic parcel model with condensation and coalescence. The object is to determine the range of rainfall rates (drizzle rates) that can be explained by (i) a constant small aerosol size distribution and constant cloud depth, but (ii) with the observed variability in GCCN.

The total GCCN aerosol loading ranged from 1 to 25 $\mu\text{g}/\text{m}^3$, with observed seasalt GCCN having dry radii from 0.8 – 12 μm . We calculate the rainfall production in clouds of 300, 400 and 500 m depth. The critical result is that for deep marine stratocumulus (500 m), the observed GCCN variability leads to a range of rainfall rates from 0.5 to 10 mm/hr. Thus natural GCCN variability may lead to a factor 20 difference in rainfall rates. This is a very large range, demonstrating that seasalt GCCN size distributions and their effect on rainfall should be predicted in large scale and climate models.

S2.12

Recirculation and growth of raindrops in simulated shallow cumulus

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2, 1

Despite the ever increasing grid resolution, understanding precipitation remains one of the major challenges in numerical weather prediction as well as climate modeling. In this study, we investigate the growth process of raindrops and the role of recirculation of raindrops for the formation of precipitation in shallow cumulus. Two related cases of fields of lightly precipitating shallow cumulus are simulated using Large-Eddy Simulation combined with a Lagrangian drop model for raindrop growth and a cloud tracking algorithm. Statistics from the Lagrangian drop model yield that most raindrops leave the cloud laterally and then evaporate in the subsaturated cloud environmental air. Only 1 % to 3 % of the raindrops contribute to surface precipitation. Among this subsample of raindrops that contribute to surface precipitation two growth regimes are identified: those raindrops that are dominated by accretional growth from cloud water, and those raindrops that are dominated by selfcollection among raindrops. The mean cloud properties alone are not decisive for the growth of an individual raindrop but the in-cloud variability is crucial. Recirculation of raindrops is found to be common in shallow cumulus, especially for those raindrops that contribute to surface precipitation. The fraction of surface precipitation that is attributed to recirculating raindrops differs from cloud to cloud but can be larger than 50 %. This implies that simple conceptual models of raindrop growth that neglect the effect of recirculation disregard a substantial portion of raindrop growth in shallow cumulus.

S2.13

Stratocumulus precipitation from long-resident droplets

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1 2 12 Stratocumulus Lagrangian

We explore the hypothesis whether droplets that remain long periods at cloud top can initiate stratocumulus precipitation. Long-resident droplets grow well above the average due to the combined action of collisions and radiative cooling. In order to investigate long-resident droplets we follow the trajectory of one billion cloud droplets in direct numerical simulations with well-resolved turbulence at cloud top. The simulated droplet size distribution (DSD) agrees with the measurements from the VERDI campaign.

We observe that 0.2% of the droplets escape the large-scale cloud convective movements, probably driven by small-scale turbulence. These droplets become memoryless, in the sense that the probability of leaving the cloud top asymptotes to a constant value. As a result, they can remain at cloud top for considerably longer times than droplets that are attached to convective eddies.

In order to show that long-resident droplets can be relevant for rain formation, we have modified the stochastic coalescence equation by adding a simple turbulent-mixing term that produces long-resident droplets. Growth due to radiative cooling is also considered. The resulting equation is integrated following the classical Berry and Reinhardt algorithm. The so-calculated DSDs agree with previous observations for reasonable values of the mixing and radiative parameters. Contrary to the original equation, the solution of the modified equation is stationary and independent of the initial conditions. This suggests that than the distribution of aerosols (which determines the initial condition in the model) might be less relevant for stratocumulus precipitation than turbulence and radiative cooling.

S2.14

Drizzle Production in Stratocumulus-topped Boundary Layers

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2. Warm boundary layer clouds

Marine stratocumulus clouds frequently produce light precipitation in the form of drizzle. The drizzle precipitation rate at the cloud base (R_{CB}) scales well with h^3/N_c , where h is the cloud thickness and N_c is the number concentration. However considerable variability is observed between the different proposed experimental fits. Several other factors can affect the drizzle microphysical properties (i.e., characteristic size, shape of the size distribution, drizzle rate intensity) at the cloud base. These factors include the profile of cloud liquid water content, cloud effective radius, air motion and turbulence intensity. Here, synergistic observations from the US Department of Energy Atmospheric Radiation Measurement (ARM) program Eastern North Atlantic (ENA) site located on Graciosa Island in the Azores are used in conjunction with a 1-D steady state microphysical model to investigate the role of these factors. This is accomplished by focusing both on the analysis of the drizzle properties at the cloud base but also and on impact of drizzle particles in the vertical profiles of the radar observables. The R_{CB} and other drizzle properties are retrieved using a radar-lidar algorithm. A new retrieval method is used to estimate the eddy dissipation rate in the cloud layer and surface-based aerosol number concentration measurements are used to describe N_c . Preliminary results that indicate how the profiles of radar observations can be used to investigate the roles of the different factors responsible for the variability in R_{CB} will be shown.

S2.15

The microscale dynamics of warm fog layer in the Ganges Valley

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7

Fog

The ground based observations conducted during the warm fog formation and dissipation in the Ganges Valley area is illustrated from micrometeorological observations and Large Eddy Simulations. Micrometeorological observations include the eddy covariance flux measurements, four components of radiation, soil heat flux, and other weather parameters on a 20 m tower. All components of surface energy budget during the fog events and non-fog events illustrate the important role of radiative cooling in the fog free conditions and warming in the fog conditions. Results showed a significant impact from longwave radiation and the modification of near surface warming through constant interactions from a dynamic fog layer. Stratification is disturbed by the formation of fog layer and a mixed layer develops, where the energy exchanges are determined purely by the longwave radiation emitted by the fog layer. Turbulence characteristics and flow structures during the fog event will be illustrated.

S2.16

The effect of aerosol on radiation fog life-cycle

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7,12

Radiation fog is formed during the night under clear skies when emission of long wave radiation cools the surface and air above it. After formation, the development of fog is further influenced by longwave cooling at the top of the fog layer, and microphysical processes through droplet activation and sedimentation. After sunrise, the fog is dissipated due heating of the surface and the air above it.

To explore how aerosols are affecting radiation fog properties and lifetime, we have used a Large Eddy Model with explicit representation of aerosol particles and aerosol-fog droplet interactions. Our results show that the fog droplet concentration increases with increasing aerosol concentration. In the early stages of fog formation the radiative cooling at the top of the fog controls the maximum water supersaturation and droplet formation in a similar manner than the updraft velocity does at the base of a cloud. The liquid water content in the fog is mainly determined by the droplet concentration as large droplets are efficiently removed through sedimentation. Thus, with increasing aerosol particle concentration, the more numerous, but smaller fog droplets increase the fog's optical depth and thereby delay the fog dissipation after sunrise, because the surface warms more slowly. This effect is further enhanced if turbulence inside the fog leads to secondary activation of droplets. Overall, the radiation fog dissipation in polluted conditions can be delayed up to hours when compared to clean conditions.

S2.17

An overview of the LANFEX, (Local and Non-local Fog EXperiment) observational campaign.

Amanda Kerr-Munslow, Jeremy Price, Siân Lane, Bernard Claxton, Simon Osborne
Met Office, Cardington, UK

7. Fog, observation, modelling

Radiation fog is a high impact weather type which remains difficult to forecast accurately, the complex local and non-local processes which impact the timing and location of fog formation are not well understood.

LANFEX was a recent 19 month UK based field campaign set in a heterogeneous valley system in Shropshire and a shallow more homogeneous basin in Bedfordshire, between September 2014 and April 2016. The purpose was to better understand meteorological conditions which affect the formation and evolution of fog and to improve its prediction with numerical weather prediction models. The campaign comprised 13 sites within a 15 km diameter circle in Shropshire, varying between valley and hill top sites, and 5 sites within a much flatter region in Bedfordshire. The six main sites were equipped with comprehensive instrumentation including flux towers, ceilometers, LiDARs, nephelometers, aerosol spectrometers, and dewmeters. Fifteen sites were equipped with newly developed fog spectrometers for measuring droplet size distributions and the liquid water content of fog. Sites were chosen to sample contrasting terrain types - particularly with regard to valley geometry and site elevation.

The campaign involved collaboration between observation and numerical modelling groups from the Met Office, NCAS and the Universities of Leeds, Manchester and East Anglia, led by Met Research Unit, Cardington.

The campaign is described, together with initial results and an overview of the interesting cases observed.

S2.18

Improving high-resolution fog simulations using LANFEX observations

Ian Boutle, Adrian Lock, Jeremy Price
Met Office, Exeter, UK

7

The Local and Non-local Fog Experiment (LANFEX) is an 18 month field campaign designed to provide intensive observations of fog at two contrasting sites in the UK - one with relatively simple, flat terrain, and the other with more complex terrain and valley systems. This paper will discuss kilometer and sub-kilometer scale modelling of some LANFEX intensive observation periods, identifying the key processes affecting fog evolution. Reasons why accurate numerical weather prediction of fog is such a challenging problem, and potential improvements to model parametrizations will be discussed. It will be shown that aerosol-fog interactions and the correct prediction of the cloud droplet number is crucially important in the simulation of fog evolution. An unrealistic choice of how to represent cloud droplet number can lead to the model forming well-mixed, optically thick fog very quickly, while optically thin fog exists in a stable boundary layer in reality.

S2.19

Elucidating the processes responsible for radiation fog formation during the LANFEX fog campaign.

Jeremy Price

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Key area: 7

This work presents initial findings from the recent LANFEX observational campaign (2014-2016) which studied fog formation in both complex and homogeneous terrain, with a view to improving numerical weather prediction of fog. Thirteen sites were deployed in the region of complex terrain (Shropshire, UK) and five sites in the more homogeneous region (Bedfordshire, UK). Data from sites in the region of complex terrain have shown systematic differences in conditions around and after the evening transition, some of which have implications for the formation of radiation fog. Data of turbulence, temperature and humidity, dew deposition and fog formation have been examined and their relative importance on fog formation is assessed and presented. In particular, initial results indicate that turbulence must lie below certain thresholds for stably stratified radiation fog to form and develop, and that turbulence may control the balance between heat and moisture fluxes from above, and dew deposition at the surface, all of which affect the likely hood of fog formation.

S2.20

Mid boundary layer humidity pockets as the formation mechanism of small warm clouds

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A ground-based field campaign was conducted during the summer of 2011 near the coast of Israel for studying warm clouds. Many days of sparse cloud fields were observed, containing very small clouds (10s-100s m) with low liquid water path (< 10s g/m²), small effective radius (few microns) and short lifetimes (minutes). During the campaign, we documented cloud formation in days that were predicted to be cloud free by standard forecast methods and often their bases were much lower than the calculated LCL. A detailed theoretical model that was developed and tuned to resolve the growth of haze particles into cloud droplets was used to examine the formation and characteristics of such clouds. It revealed that such clouds can form only when the convective motion is driven by a perturbation in the relative humidity in the middle of the boundary layer, rather than temperature perturbations near the surface, as commonly considered. Such mechanism is likely to be a common one in atmospheric conditions of hot and humid boundary layer capped by a strong inversion layer.

S2.21

How shallow convection in drier subsiding atmospheres supports deeper trade-wind layers and more precipitation

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2,1,9,3

Observations at a typical trade-wind location (Barbados) indicate that the main difference in low-level cloudiness between seasons is associated with cloudiness near the trade-inversion. The dry Winter regime, characterized by moderate subsidence, is marked by deeper trade-wind cumuli with more outflow near cloud tops, compared to the more humid Summer with mean rising motion. Cloudiness near cloud base instead is remarkably insensitive to seasonal changes in the large-scale state. Here we use large-eddy simulation to explore the controls on these seasonal changes of cloudiness.

We find that the mean trade-wind layer depth is largely influenced by the development of single deeper cumulus clouds with tops exceeding 4 km, which diminish the inversion structure. This explains why, in the presence of deep convection, the average cumulus cloud in Summer is smaller. In Winter, a number of factors act together to maintain a deep trade-wind layer that is still capped by an inversion: larger longwave cooling and both stronger subsidence and surface winds.

How a (combined) perturbation of wind speed, subsidence and free-tropospheric humidity affects the propensity of shallow convection to aggregate and deepen determines much of the response of the trade-wind structure and cloudiness. Despite strong variability in trade-wind layer structures, cloud radiative effects vary relatively little, with cloud albedos ranging from 4.9-6.3%. Contrastingly, surface precipitation varies more strongly, between 0.4-1.6 mmd^{-1} . The moisture content of a layer strongly affects its precipitation efficiency. Because drier layers cannot as efficiently balance surface evaporation by subsidence drying, they need to precipitate more.

S2.22

Impacts of cloud microphysical schemes on precipitation of shallow warm clouds

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12

The impacts of cloud microphysical schemes on the sensitivity of precipitation of shallow warm clouds to cloud condensation nuclei (CCN) were investigated by numerical experiments. The kinematic driver model (KiD) developed by Shipway and Hill (2012) was used to conduct comparative numerical experiments by changing only the cloud microphysical schemes under the different CCN condition. Two types of cloud microphysical scheme were used in this study: the two-moment bulk scheme which is based on Seifert and Beheng (2006) with slight modifications by Seiki and Nakajima (2014) and the two-moment spectral bin microphysical scheme developed by Kuba and Fujiyoshi (2006). The results showed the simulations using the two-moment bulk scheme led to later start and small amount of precipitation compared with that using bin microphysical schemes. Those results agreed with previous studies using large-eddy simulations (van Zanten et al. 2011; Sato et al. 2015). This showed that the KiD which ignores feedbacks from microphysical processes to dynamics can estimate the impacts of cloud microphysical schemes on the precipitation of shallow warm clouds. The simplicity of the kinematic driver model enables us to investigate the detail mechanism related with the differences between the two schemes. Additionally the results showed that the sensitivity of precipitation to CCN number was larger (increase in CCN number largely decreased the precipitation) in the simulations using the two-moment bulk scheme. In this study, auto-conversion rate and accretion rate of generation of rain drops, and the droplet size distributions were compared in detail between two microphysical schemes.

S2.23

Overlap statistics of shallow boundary layer clouds: Comparing ground-based observations with large-eddy simulations.

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2. Warm boundary layer clouds

13. Clouds and climate (including radiative properties of clouds)

High-resolution ground-based measurements are used to assess the realism of fine-scale numerical simulations of shallow cumulus cloud fields. The overlap statistics of cumuli as produced by large-eddy simulations (LES) are confronted with Cloudnet data sets at the Jülich Observatory for Cloud Evolution. The Cloudnet pixel is small enough to detect cumuliform cloud overlap. Cloud fraction masks are derived for five different cases, using gridded time-height data sets at various temporal and vertical resolutions. The overlap ratio (R), i.e., the ratio between cloud fraction by volume and by area, is studied as a function of the vertical resolution. Good agreement is found between R derived from observations and simulations. An inverse linear function is found to best describe the observed overlap behavior, confirming previous LES results. Simulated and observed decorrelation lengths are smaller (~300 m) than previously reported (>1 km). A similar diurnal variation in the overlap efficiency is found in observations and simulations.

S2.24

Attaining Low Horizontal Variability of Effective Radius in Stratocumulus Clouds

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1, 2

Effective radius is one of the most common microphysical parameters of cloud physics and remote sensing. Many studies have shown directly or indirectly that effective radius in both cumulus and stratocumulus clouds is characterized by low variability in the horizontal direction. This feature is surprising, given the great variability of liquid water content (LWC) in the same areas. The formation of spatial distribution of effective radius in stratocumulus clouds is investigated using a spectral bin microphysics Lagrangian-Eulerian model of stratocumulus clouds. The model consists of ~2000 adjacent parcels moving in a turbulence-like field, with observed correlation properties. The parcels interact through sedimentation and turbulent mixing.

We demonstrate that in stratocumulus clouds large effective radius may be the result of several different processes. At cloud top, mixing leads to broadening of droplet size distribution and the formation of a tail of small droplets. It is shown that when cloud parcels mix with inversion air the effective radius remains almost unchanged, despite a significant decrease in LWC. When initially droplet-free parcels entrain the cloud, the effective radius rapidly reaches a value close to that of neighboring cloud parcels, while the LWC remains much lower. These properties indicate that the model simulates inhomogeneous mixing. Since it was found that the effective radius is only slightly affected by turbulent mixing, adiabatic parcels ascending from cloud base establish the reference values of the effective radius for each altitude. This result stresses the importance of adiabatic processes in cloud microphysics.

S3.1

The microphysics and kinematics of a potential flash flood on 3 August 2013 during COPE

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3, 4, 17. Flash floods.

Measurements made during the COncvective Precipitation Experiment are being used in conjunction with high-resolution models to determine the interactions between the kinematics and microphysics that are so important for the development of heavy precipitation leading to flash flooding. The measurements were made with two aircraft (University of Wyoming King Air and UK BAe 146), a mobile radar, a network of permanent radars and ground-based aerosol instruments. The mobile radar is a dual-polarisation Doppler X-band radar that made PPIs with a volume return time of about 5 minutes. 1-min output of 400-m resolution WRF runs and a detailed microphysics model were used to help interpret the observations. A description will be presented of the development of the convective clouds along the convergence line on 3 August, 2013. Heavy precipitation was produced that persisted for several hours in some locations because each cloud followed a rather similar track. Although, there was no river catchment or town adversely affected, it was a similar situation to the Boscastle flash flood. The most intense rain was possibly not as persistent. Observations and model results of the details of the convective clouds, precipitation and cloud interactions will be presented. This is the first combined modelling and observational study of such a cloud system in the UK. The interaction between the kinematics and microphysics is key to the development of the precipitation particles, the large reflectivity values and the persistence of the precipitation.

S3.2

Ice formation in convective clouds over southwest England

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Convective clouds. Mixed-phase clouds.

We present cloud microphysics observations of cumulus measured over the Southwest Peninsula of the UK on 03 August 2013 during the COncvective Precipitation Experiment (COPE). In the early afternoon, two lines of cumulus clouds formed along convergence lines aligned with the peninsula. The lines became longer and broader during the afternoon as new cells emerged and stratiform regions formed downwind of the convective cells.

Predicted ice nuclei (IN) concentrations were calculated by inputting boundary layer aerosol measurements into several bulk and composition-specific parameterisations. The maximum IN concentrations predicted at cloud tops of -15 °C were a few per litre. In contrast, ice concentrations up to 350 L⁻¹ were measured in the mature stratiform regions, suggesting one or more secondary ice production mechanisms were active.

Detailed sampling focused on an isolated liquid cloud that glaciated as it matured. In the initial cell, we observed drizzle concentrations up to ~20 L⁻¹ and frozen drizzle concentrations up to a few per litre. As new cells emerged in and around the cloud, ice concentrations developed that were up to two orders of magnitude higher than the predicted IN concentrations, and the cloud glaciated over a period of 12 - 15 minutes. Almost all of the first ice particles observed were frozen drops, while vapour-grown ice crystals were dominant in the latter stages. We discuss possible ice multiplication mechanisms including their interactions with the warm rain process, and the importance of freezing drizzle for the formation of precipitation.

S3.3

Microphysical Structure of Elevated Convection in Winter Cyclones

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3. Convective clouds (including cloud electrification)

The comma-head region of continental winter cyclones often consists of differing precipitation substructures, including elevated convection. As opposed to stratiform regions, elevated convective cells and their microphysical properties have not been well sampled in past studies of wintertime precipitation. Understanding the microphysics of elevated convective cells is essential to improving future winter storm forecasts. Here we present analyses of the microphysical structure of elevated convection within the comma-head region of winter cyclones over the United States, using data obtained by the Wyoming Cloud Radar (WCR) and various microphysical probes mounted on the NSF/NCAR C-130 on 24 November 2009 and 9 December 2009 during the Profiling of Winter Storms field campaign. Convective cells were identified visually from radar images using the WCR data and with utilization of Contoured Frequency by Altitude (CFAD) diagrams. Separate analysis of the microphysical structures of these cells was performed for active updrafts (Doppler velocities greater than 0 m/s), downdrafts (Doppler velocities less than -2 m/s), and regions with no active convection (Doppler velocities between 0 and -2 m/s), where the regions are divided assuming approximate crystal fall velocities of 1 m/s. Additional stratification of the dataset by sample distance below cloud top was also performed. For the thirty-six convective cells identified on the two dates, microphysical parameters such as median mass diameter, ice water content, liquid water content, and number concentration of ice crystals showed statistically significant differences between these three categories.

S3.4

Microphysical implications of convection, turbulence, generating cells and other fine scale structures within a cyclone along the U.S. Northeast Coast: a first look at high resolution HIAPER Cloud Radar Observations

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3, 4, 16

S3.5

The microphysical properties and radiative consequences of frozen droplets in the upper regions of convective storms

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1, 3, 4

Homogeneous freezing of cloud droplets is a source of small ice particles in the upper regions of convective storms. These frozen droplets are often found as low-density aggregates which may have enhanced aggregation due to electrical forces in the storms. This study looks at the proportion of aggregated versus un-aggregated frozen droplets in the upper regions of different storms using airborne data collected in situ during the Deep Convective Clouds and Chemistry experiment (DC3). The conditions (such as location in the cloud and environmental conditions such as humidity and temperature) favoring the two types of hydrometeors are examined. The radiative consequences of the presence of aggregated versus un-aggregated frozen droplets are determined using a radiative transfer code to determine how the radiative heating at the tops of the ice clouds varies depending on crystal type (i.e., aggregated versus un-aggregated frozen droplets). In addition, differences in backscatter intensity and polarization at the two wavelengths of the CALIOP lidar are computed to aid future efforts at developing climatologies of the different crystal types from the CALIPSO data. It is hypothesized that some upper storm regions exhibit similar radiative characteristics as dilute warm clouds because they consist primarily of frozen cloud droplets of similar sizes and concentrations (per unit mass of air) as found in lower warm clouds. In regions where aggregation occurs, less scattering is expected.

S3.6

Graupel and hail properties retrieval in supercells thunderstorms from airborne multifrequency radar and radiometer observations

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Due to the large natural variability of its microphysical properties (size, shape, density), the characterisation of solid precipitation is a longstanding problem. In particular, since in-situ observations are unavailable in severe convective systems, innovative remote sensing retrievals are needed to extend our understanding of such systems.

This study presents a flexible novel technique able to retrieve the density, mass and effective diameter of graupel and hail in severe convection through the combination of multiple airborne remote sensing instruments (radars and microwave radiometers).

A case study using measurements from 4-frequency radars and 4-frequency radiometers on-board the NASA ER-2 high altitude aircraft describes the retrieved solid precipitation properties within two supercells observed on the 23rd May 2014 over North-Carolina during the IPHEX campaign. The retrieval shows a good agreement with hydrometeors classification from ground based polarimetric radars observations and large hail reports on the ground.

A key finding of this study is that multiple scattering due to large ice hydrometeors is important at radar frequencies above the X-band and must be taken into account in order to interpret the observations.

S3.7

How are changes in warm phase microphysics reflected in deep convective clouds?

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12. Aerosol-cloud-precipitation-interactions and processing

The aerosol invigoration effect on convective clouds describes a chain of events that starts with the impact of enhanced aerosol amount on the initial cloud droplets size distribution and ends with various results on the macro scale, like deeper and bigger clouds. In the case of deep convective clouds with warm base, the warm processes serve as the initial and boundary conditions for the mixed and cold-phase parts and therefore the aerosol impact on the warm processes affects the whole cloud.

The weather research and forecasting model with spectral bin microphysics (WRF-SBM) is used to simulate a deep convective system over the Marshall Islands, during the Kwajalein Experiment (KWAJEX). Three levels of aerosol loading were simulated with concentrations of 100, 500 and 2000 cm^{-3} . The polluted simulation showed an increase in the total cloud mass, enlarged cloud fraction in the middle and upper troposphere, intensified precipitation, as well as stronger updrafts.

In this work we try to gain a process level understanding of such aerosol effects with a focus on how the coupling between the warm microphysical processes and the cloud dynamics affect deep convective clouds' properties.

S3.8

Aerosol-cloud interaction signal in a meteorological ensemble of convective precipitation from COPE

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12, 3

Theoretical considerations of idealized cloud systems suggest a profound impact of aerosols changes on cloud dynamics and precipitation amounts and pattern. However, observations of aerosol impacts on precipitation in daily weather remain elusive. Part of the difficulty to observe changes in precipitation patterns or amounts to different aerosol concentrations is related to the co-variability of atmospheric conditions and aerosols in the real atmosphere. To address this issue we conducted high-resolution (1km and 500 m horizontal resolution) ensemble simulations of convective clouds observed over the southwest peninsula of the UK during COPE with a variety of aerosol profiles applied to a meteorological ensemble. We have compared the model simulations to observational data from the COPE campaign including 3D radar data and aircraft measurements. Properties used for the investigation of the cloud-precipitation system in these simulations were precipitation rate, precipitation amount, cell size, number and lifetime and cloud depth. The approach allowed us to evaluate whether there was any statistically significant signal of changes due to perturbations in the aerosol conditions or whether the variability in the cloud-precipitation system is dominated by the initial condition perturbations.

S3.9

Storm Transport of Dust from the Boundary Layer to Upper Troposphere

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12, 1, 3, 8, 9

Storms play a fundamental role in transporting dust and other aerosols between the boundary layer and the upper troposphere. The vertical redistribution of dust has important implications for upper tropospheric heating, cirrus cloud formation, long-range transport and ocean fertilization. However, the efficiency of this process, defined as the ratio of aerosols detrained in the upper troposphere to those ingested by the storm, is not well understood. Furthermore, it is not clear how this transport efficiency varies in different storm systems. Cloud resolving model simulations using the Regional Atmospheric Modeling System (RAMS) have been conducted of Tropical Storm Debby, a winter extratropical cyclone developing over the Pacific NW and isolated deep tropical continental convection in order to evaluate how efficiently these storms transport dust to the upper troposphere. RAMS has a prognostic aerosol scheme in which dust is activated based on the environmental conditions, tracked within different hydrometeor species, and returned to the atmosphere following sublimation and evaporation. The microphysical processes impacting the dust transport have been tracked in these three simulations, and the dust fields compared to passive tracers that are not microphysically active, in order to determine which processes have the greatest impact on the dust transport efficiency. The model results will be compared with in-situ measurements and satellite observations where possible. The dust transport efficiency as a function of different storm types, as well as the processes responsible for the loss of dust on its pathway to the upper troposphere, will be presented.

S3.10

Toward a PDF representation of deep convection: the importance and parameterization of hydrometeor transport

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3; convection parameterization

Rising plumes that form convective clouds often carry rain, snow, and hail within them. This vertical transport of hydrometeors is important because it prolongs their growth stage and changes the resulting precipitation intensity and amount. Yet, the process is not accounted for in most convection parameterizations in coarse-grid models that do not explicitly resolve convective updrafts or spatial cloud structure. Guided by high-resolution simulations of continental and tropical deep convection, we develop a parameterization for the convective vertical transport of hydrometeors based on statistical distributions of vertical velocity and mixing ratios of precipitating species.

We begin by demonstrating that an adequate representation of precipitating storms is not possible without an accurate description of rain, snow, and graupel transport by infrequent vigorous upwards and downdrafts. Results indicate frequent counter gradient vertical transport that cannot be modeled under a traditional eddy-diffusivity approximation. Next, it is shown that realistic hydrometeor fluxes can be obtained by sampling joint distributions of vertical velocity and hydrometeor mass mixing ratios into quadrants separated by their respective mean values, and then scaling the quadrant mean fluxes to account for within-quadrant correlations between vertical velocity and the microphysics. The origins of and ways to quantify these correlations are discussed. The proposed algorithm is then tailored toward assumed probability density function schemes, which provide marginal but not joint distributions of the needed variables. Finally, we evaluate the newly developed scheme diagnostically, using output from high-resolution simulations, and in an interactive setting of a single column model.

S3.11

Center-of-gravity vs. mass phase space - an efficient approach for analyzing interactions and key processes in cloud fields

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3. Convective clouds

12. Aerosol-cloud-precipitation-interactions and processing

1. Basic cloud and precipitation physics

2. Warm boundary layer clouds

A new analysis approach for large eddy simulations (LES) of cloud fields is proposed. Based on insights gained from 3D cloud tracking trajectories, the center-of-gravity vs. mass (CvM) phase space is used to span the entire range of cloud evolution pathways for a given cloud field, while maintaining a clear partition to the different stages during cloud lifetimes (i.e. growing, precipitating, dissipating). Additionally, CvM space can be used for analysis of various cloud fields properties such as: level of adiabaticity, amount and types of interactions between clouds, surface precipitation yield, and preferred dissipation pathways.

We demonstrate how the CvM phase space enables efficient and comprehensive comparison between simulations. Specifically, profound aerosol effects seen in the CvM space for warm cumulus cloud simulations are shown and linked to their underlying physical processes. Although useful for all cloud types, CvM phase space is especially beneficial for convective cloud fields which display a large spread in the CvM phase space. Finally, the possibility of comparing numerical simulations and observations using the CvM space is discussed.

S3.12

Controls on the Characteristics of Convective Clouds Associated with Sea Breeze Circulations

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3, 12, 1

About half of the world's population lives along coastlines where sea breeze circulations are often daily phenomena. These circulations promote the development of convective clouds and precipitation that propagates inland during the daytime. Due to their ubiquity, much research has been devoted to understanding these circulations and their associated convection. In modeling studies, the sensitivity of sea breeze convection to various environmental and geophysical factors has usually been tested by changing just one or two variables at a time, making it difficult to assess the importance of any given factor under all possible conditions. In this modeling study, we work to alleviate this problem by combining cloud resolving simulations of sea breeze convection under a wide range of thermodynamic, land surface, and aerosol conditions with statistical emulation methods in order to assess the sensitivity of the convective characteristics, such as precipitation production, inland propagation distance, and convective strength, to each factor under all conditions tested. The statistical emulation methods allow us to test thousands of combinations of factors, many more than would be possible by running simulations alone due to their large computational cost. In general it is found that thermodynamic conditions are more important than the aerosol characteristics for determining convective characteristics. Regimes are identified in which a subset of factors exert the most control over the convection characteristics and the dominant physical processes in each regime are described. Implications for the forecasting of these systems are also discussed.

S3.13

Assessing Clausius-Clapeyron scaling of moist convection over land within an idealized convection-resolving modeling framework

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3, 17

Climate models suggest that climate change may imply an increase in heavy precipitation events, in some regions even despite reductions in mean precipitation amounts. The hydrological cycle is expected to undergo an intensification driven by the increase of the saturation vapor pressure with temperature of approximately 7%/K leading together with near-constant values of relative humidity to a non-linear increase of the specific humidity with temperature. Several studies indicate that hourly precipitation extremes can even exceed expectations from the Clausius-Clapeyron equation. We study the processes leading to heavy precipitation events during episodes of mid-latitude diurnal convection over land with an idealized convection-resolving modeling framework. We generate a wide range of convective states within this framework, covering changes in atmospheric temperature, lapse-rate and soil moisture content. The resulting response of the diurnal convection and associated cloud and precipitation development is then analyzed. As expected from water-vapor scaling we find an increase of heavy precipitation in accordance with Clausius-Clapeyron scaling for the case of homogeneous warming. Moreover, clouds increasingly organize into larger clusters and become more efficient in converting the atmospheric water vapor into precipitation. However, if the warming is associated with a stabilization of the atmosphere, as is projected by many climate models, the highest percentiles of the precipitation distribution exceed Clausius-Clapeyron scaling. This can be explained by a shift to very localized, intense convective events. A decrease of soil moisture in contrast reduces precipitation amounts over all intensities and leads to the development of very localized precipitation patches.

S3.14

Dynamical Influences on Cold Pool Development

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8. Mesoscale cloud systems (including severe storms)

3. Convective clouds (including cloud electrification)

This work focuses on the development of surface-based cold pools in mesoscale convective systems (MCSs). The microphysical influences on cold pool development have been well studied, and the roles played by evaporation and melting are obviously important. Less studied are dynamical influences such as entrainment and vertical mass transport, which can modify the thermodynamical properties within MCSs, and can thus modulate microphysical rates. Consider, for example, air within a developing cold pool that has very high (nearly saturated) relative humidity; rainwater evaporation rates will be small in this case no matter what kind of microphysical scheme is considered. In contrast, if this air has a history of descent from mid-levels where water-vapor content is lower, it will likely be subsaturated and could lead to higher evaporation rates.

As an example, idealized simulations of a well-observed squall line from Oklahoma are integrated with a large number of Lagrangian parcels and passive tracers. Among a large set of sensitivity tests, the simulations that best match observations have drier cold pools containing air with a history of entrainment and descent from mid-levels. We further show that these dynamical processes are difficult to capture with present-day "cloud permitting" resolution of order 3 km.

S4.1

Microphysical cloud properties and cloud probes' benchmark during the Pallas Cloud Experiments (PaCE).

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4. Mixed phase clouds (including Arctic/Antarctic stratus, mid-level clouds), 14. Ice nuclei and cloud condensation nuclei, 16. Measurement techniques (of cloud and precipitation properties) and uncertainties

Interactions between clouds and aerosols are associated with some of the largest uncertainties in predictions of climate change. We made continuous, semi-long term, ground based, in-situ cloud measurements during the last three intensive Pallas Cloud Experiments (PaCE) in years 2012, 2013 and 2015. The campaigns were focusing on cloud and aerosols physico - chemical properties and their interactions. The measurements were conducted in Finnish sub-Arctic region at Sammaltunturi station (67°58'N, 24°07'E, 560 m a.s.l.), the part of Pallas Sodankyla - Global Atmosphere Watch (GAW) programme.

We made a detailed analysis of all measured cloud microphysical properties and how they were influenced by meteorology. Also we mutually compared and benchmarked performance of three cloud probes: the Cloud, Aerosol and Precipitation Spectrometer probe (CAPS), the Cloud Droplet Probe (CDP) and the Forward Scattering Spectrometer Probe (FSSP-100), all three made by DMT, Boulder, CO, USA.

S4.2

Liquid water content and effective radius retrievals in mixed-phase cloud layers from Cloud radar data based on the forward modeling

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Cloud liquid water content (LWC) and effective radius (RE) in mixed phase cloud layers were retrieved from CloudSat data based on the forward modeling for a weakly convective and a widespread stratus cloud. Within the mixed-phase cloud layers, liquid-phase fractions needed to be assumed in the data retrieval process, and the existing linear (p_1) and two exponential (p_2 and p_3) functions, which estimate the liquid-phase fraction as a function of subfreezing temperature (from -20°C to 0°C), were tested. Function p_2 and p_3 performed better than p_1 in retrieving the LWC and RE in the convective cloud and the stratus cloud by compared with airplane measurements data. The retrieve accuracies of LWC and RE by forward modeling are sensitive to the prior values and error thresholds of the droplet spectrum distribution parameters (cloud droplet spectrum N_t , scale parameter R_g and spectral width parameter W_g). Based on the p_2 and p_3 , the retrieved LWC and RE in mixed phase convective and stratus were studied. The LWC and RE appears large difference in convective and stratus clouds by contrast.

S4.3

Aircraft Observations of Liquid and Ice in Midlatitude Mixed-Phase Clouds

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This paper reports airborne measurements of midlatitude altostratus clouds observed over Zhengzhou, Henan Province, China on 3 March 2007. The case demonstrates mixed-phase conditions at altitudes from 3200 to 4600 m (0°C to -7.6°C), with liquid water content ranging from 0.01 to 0.09 g m^{-3} . In the observed mixed-phase cloud, liquid water content exhibited a bimodal distribution, whereas the maximum ice particle concentration was located in the middle part of the cloud. The liquid and ice particle data showed significant horizontal variability on the scale of a few hundred meters. The cloud droplet concentration varied greatly over the horizontal sampling area. There was an inverse relationship between the cloud droplet concentration and ice particle concentration.

A gamma distribution provided the best description of the cloud droplet spectra. The liquid droplet distributions were found to increase in both size and concentration with altitude. It was inferred from the profile of the spectra parameters that the cloud droplet sizes tend to form a quasi-monodisperse distribution. Ice particle spectra in the cloud were fitted well by an exponential distribution. Finally, a remarkable power law relationship was found between the slope (λ) and intercept (N_0) parameters of the exponential size distribution.

Key words: cloud structure, liquid water content, droplet spectra, particle measuring systems

S4.4

Vertical profiles of cloud properties measured with a holographic imager on a cable car

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During winter 2015/2016 two field campaigns are conducted with the HOLOGondel platform (see below) on cable cars in the Alps. During these campaigns vertical profiles of the microphysical properties of clouds are obtained. This unique approach allows to improve the understanding of orographic mixed-phase clouds (MPCs) in complex High Alpine terrain. MPCs consisting of an unstable mixture of supercooled liquid droplets and ice crystals are in general very poorly understood contributing to the fact that clouds still remain the largest uncertainty in climate sensitivity studies.

One field campaign takes place at the Eggishorn (2200m-2850m) in the Swiss Alps at the Aletsch Glacier in the vicinity of the High Altitude Research Station Jungfraujoch and one at the Sonnblick Observatory (1500m-3000 m) in the Austrian Alps. With a traveling velocity of a cable car of about 10 ms⁻¹ the HOLOGondel platform allows to observe vertical profiles with a vertical resolution of up to 2 m once per hour.

The HOLOGondel platform is equipped with different instrumentation and mountable on a cable car. Its main component is the HOLOGraphic Imager for Microscopic Objects (HOLIMO 3G). Every image captures a hologram which includes the single particle information (size, position, shadowgraph) of every particle within the sample volume. From this information, cloud properties like size distribution, concentration and water content are calculated for the liquid and ice phase. The HOLOGondel platform is also equipped with auxiliary instruments to measure the local temperature, the relative humidity, and the three dimensional wind velocity and direction.

S4.5

A detailed examination of the microphysical processes leading to ice production within an orographic wintertime cloud with freezing drizzle

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- 4.
- 6.

Super-cooled clouds that produce freezing drizzle pose a serious threat to aviation due to the potential for severe icing. We examine the details of such a case that was composed of two distinct cloud layers, a lower cloud between -1 and -4 °C and an upper cloud with tops around -12 °C. Both clouds had very low droplet concentrations, well less than 100 cm⁻³, which is quite unusual for clouds over the continental US. The larger scale environment in which these clouds evolved is presented in a companion paper (Tessendorf et al).

Here we focus on measurements provided from in situ probes mounted on an instrumented aircraft. In particular we examine cloud droplet spectra, size distribution and phase of larger hydrometeors, and bulk measures of water content. A profile from the base of the lowest cloud to near the top of the upper cloud indicates that the majority of precipitation mass is liquid, although the relatively rare large ice crystal was detected. Interestingly, as the precipitation falls into the top of the lower cloud, significantly more ice is produced and the precipitation mass becomes more equally split between liquid and ice. We conjecture that the initial production of ice in the upper cloud occurs through primary nucleation, likely near the cloud top. As these very few ice crystals grow through vapor deposition and eventually fall into the lower cloud, they interact with cloud droplets producing more ice through secondary processes (presumably Hallett-Mossop).

S4.6

In-situ airborne observations of small ice in turbulent mixed phase altocumulus clouds.

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4, Altocumulus, Mixed-Phase, Small Ice,

Mixed phase layer clouds such as altocumulus are common in the atmosphere, frequently associated with mid-latitude cyclones. The microphysical processes controlling the phase change from liquid to ice is poorly understood but evidence suggests nucleation via immersion freezing.

Here we present in-situ observations of mixed phase mid-latitude altocumulus clouds made by an instrumented aircraft, the FAAM BAe146. The observation of the first small ice particles in mixed phase clouds is a long standing problem in cloud physics. Simultaneous SID2 observations of both the liquid and ice phase are presented. By using SID2 diameter and asphericity data and with knowledge of the impact of coincidence it is possible to positively identify ice as small as 50 microns in the SID2 data within the liquid / mixed phase region. CDP data are used to confirm these observations. This represents a step forward yet there is still some distance to go to be able to identify the very first ice.

The cloud microphysical observations of liquid and ice are collocated with measurements of the thermodynamic and turbulence structure to build up a picture of the nature of these layer clouds. Turbulence observations are made more complicated in the absence of a fixed surface such as the ocean but we exploit a Butterworth filtering technique and show that it has some utility in characterising the dynamical environment in which cloud glaciations occurs. These in-situ measurements compare well with those obtained by others using ground based remote sensing instrumentation.

S4.7

In situ and radar Doppler spectrum constraints of ice sticking efficiency and ice properties in a mid-latitude squall line

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3, 8, 16, 17

We present work combining multiple sources of observations from the stratiform ice region of a mid-latitude squall line to constrain ice properties and aggregation microphysics. We use in situ 2D probe information on ice shape and particle size distributions, together with narrow-beamwidth US Department of Energy Ka-band profiling radar Doppler spectra and unattenuated NOAA S-band profiling radar reflectivity and mean Doppler velocity. All sources of information are combined with a 1D bin microphysics model in a Bayesian estimation framework, using a Markov Chain Monte Carlo sampler, to retrieve maximum a posteriori estimates of ice sticking efficiency, ice mass- and area-dimensional relationships, and gamma particle size distribution parameters. Robust estimates of uncertainty in these estimated values are provided, and are related to observational uncertainties and physical correlations between the retrieved parameters. Values estimated here for ice sticking efficiency at multiple temperature levels are found to be lower than those used in many parameterization schemes and indicated by recent theoretical and laboratory studies.

S4.8

LIMA: A two-moment microphysical scheme driven by a multimodal population of cloud condensation and ice freezing nuclei

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We present the 2-moment microphysical scheme LIMA (Liquid Ice Multiple Aerosols) which relies on the prognostic evolution of a three-dimensional (3D) aerosol population, and the careful description of the nucleating properties that enable cloud droplets and pristine ice crystals to form. Several modes of Cloud Condensation Nuclei (CCN) and Ice Freezing Nuclei (IFN) are considered individually. Partially soluble IFN are also introduced as "aged" IFN acting first as CCN and then as IFN by immersion nucleation. All the CCN modes are in competition with each other. The IFN are insoluble aerosols dedicated to heterogeneous ice nucleation assuming the singular hypothesis. The scheme includes the freezing of cloud droplets and haze, the Hallett-Mossop ice multiplication process and the collisional ice break-up (provisional). We assume that water vapour is in thermodynamic equilibrium with the cloud droplets but deposition(sublimation) rates are computed explicitly to enable free super(under)saturation over ice. The formation of the raindrop spectra is standard. The large crystals and aggregates category is initiated by the deposition growth of the largest pristine crystals. Aggregation and riming are computed explicitly. Heavily rimed crystals (graupel) can experience a dry or wet growth mode. A separate category of hail particles forming and growing in the wet growth mode exclusively, is considered.

The LIMA scheme is inserted in the cloud-resolving mesoscale model Meso-NH. The flexibility of the scheme is illustrated through idealized experiments : sensitivity of orographic ice clouds to IFN types and concentrations, impacts of pure CCN and IFN polluting plumes on a squall line.

S4.9

Microphysics parameterization of explicit partial melting of snow to study the formation of freezing rain and ice pellets

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1. 17
2. 4

Keywords: microphysics parameterization, partial melting, liquid water fraction, freezing rain, ice pellets

Winter storms associated with the passage of a warm front can lead to favourable vertical temperature structure for the formation of winter precipitation types, such as freezing rain, ice pellets and wet snow. The types of precipitation reaching the surface depend on their degree of melting and freezing as they fall through the atmosphere. The goal of this project is to study the impacts of explicit partial melting of solid precipitation on the microphysical processes leading to the formation of these several winter precipitation types. The approach is to predict the bulk liquid fraction of solid precipitation in the Predicted Particle Properties microphysics scheme. The liquid fraction represents the mass of liquid water included in the distribution of solid precipitation, which is the key variable to differentiate the type of precipitation occurring at temperatures near 0°C. First, the explicit partial melting of solid precipitation will be studied using a one-dimensional cloud model initialized with several idealized vertical profiles of temperature. For example, it will be shown that the new scheme produces, for instance, different phases of precipitation when the surface temperatures are slightly above 0°C. Second, the impact of snow partial melting will be studied by simulating the historical 1998 Ice Storm over eastern North America using a complete atmospheric model. Overall, the prediction of the bulk liquid fraction allows a more accurate winter precipitation types differentiation that will improve freezing precipitation forecasts.

S4.10

Effect of Evaporation on Midlatitude Continental Convective Clouds Experiment (MC3E) Melting Layer Simulations

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Key area numbers: 1, 4, 3

Most melting layer analyses in the literature assume that melting occurs within highly saturated environments where the relative humidity is no less than 90%, and that melting begins as soon as the temperature is 0 °C. Previous modeling studies of melting ice particles in these conditions have assumed that mass loss due to evaporation is negligible. However, not all melting occurs within such highly saturated environments. Snowflakes do fall and melt in subsaturated conditions such as beneath mesoscale convective system (MCS) anvils, below the outflow ice cloud base of MCSs, and in elevated precipitation systems advecting over a dry lower layer (such as the leading edge of warm-frontal precipitation). In such instances, precipitation estimates obtained using remote sensing instrumentation (e.g. ground-based and satellite-based radar) may overestimate the amount of rain reaching the surface from evaporative losses.

This study uses a melting layer model to simulate the processes that melting ice particles undergo, including aggregation and evaporation. Sixteen observed temperature and relative humidity profiles from the Midlatitude Continental Convective Clouds Experiment will be incorporated into the melting layer model to show where significant evaporative mass loss is likely occurring within observed melting layer profiles. Model accuracy will be assessed through comparison with observed microphysical measurements. Study results will help to determine whether evaporative mass loss during melting should be considered for future precipitation retrieval algorithm development and melting layer simulations.

S4.11

Synthesis of observations and models using a new Bayesian framework for microphysical parameterization

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Recent advances in observational capabilities, such as widely available polarimetric radars, allow for unprecedented information on microphysical processes. However, the current state of microphysical parameterization schemes renders problematic the assimilation of observational insights into models because these schemes contain numerous assumptions, ad-hoc parameter choices, and structural uncertainties. We propose a novel bulk microphysical parameterization framework that seeks to address these shortcomings, and that facilitates constraint by observations and robust estimation of microphysical modeling uncertainties using Bayesian techniques. Key features are: 1) smooth, differentiable functional forms for the process rates, 2) complexity that can be added systematically by adding parameters and prognostic variables so that the total number of parameters can be tailored to any set of observational constraints and Bayesian methods, and 3) uncertainty that resides as much as possible in parameters with an explicit physical meaning and interpretation, with minimal structural uncertainty. The approach is to formulate microphysical process rates and moments of the drop size distribution (DSD) using generalized power series with a well-defined but limited set of physical parameters. Unlike most current bulk schemes, no a priori assumptions are made concerning the DSD. Application in a rainshaft model will be described, with constraint provided by simulated and real polarimetric observations within a Bayesian framework using Markov chain Monte Carlo sampling. Initial results show that some parameters appear well-constrained, such as those involving drop breakup, whereas other parameters such as the rain mass-weighted fall speed prefactor show limited constraint from the observations on their probable values.

S4.12

Relationship between atmospheric aerosols, hail and polarimetric radar signatures in a mid-latitude storm

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4, 12,17

A mid-latitude hail storm was simulated using a spectral bin microphysics Hebrew University Cloud Model (HUCM) with a detailed description of time-dependent melting and freezing. Calculation of liquid water mass within precipitating ice particles was implemented to describe wet growth of hail, graupel and freezing drops.

Simulations carried out under different aerosol loadings show that an increase in aerosol loading leads to a decrease in the total mass of hail, but to a substantial increase in the maximum size of hailstones. The physical mechanism of these effects was analyzed. It was shown that the change in aerosol concentration leads to a change in the major mechanisms of hail formation and growth. The main effect of the increase in the aerosol concentration is the increase in the supercooled cloud water content. Accordingly, at high aerosol concentration the hail grows largely by accretion of cloud droplets in the course of recycling in the cloud updraft zone. The main mechanism of hail formation in case of low aerosol concentration is freezing of raindrops.

The relationship between processes leading to hail formation and high differential reflectivity (Zdr) is investigated. It is shown that formation of large hail is accompanied by high Zdr. The height of the Zdr column and the value of Zdr can be used for estimation of hail size. Maritime (or low aerosols situations) are not accompanied either by large hail or high Zdr columns. In the last case large Zdr arise as a result of hail melting below melting level.

S5.1

In-situ Observations of Cirrus Cloud Microphysics during CIRRCREX

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Cirrus clouds remain one of the largest uncertainties in climate models. In order to improve the representation of these clouds in models there is a need for additional detailed measurements of the key microphysical parameters in different meteorological environments. The ongoing Cirrus Coupled Cloud-Radiation Experiment (CIRRCREX) is performing co-ordinated measurements of insitu microphysics and remotely sensed cloud radiative properties of cirrus clouds around the UK. In March 2015, the UK's FAAM BAe146 research aircraft performed sorties out of Prestwick, Scotland, UK. This presentation will focus on two flights that used in situ instrumentation to extensively probe the microphysical structure of two contrasting cirrus clouds. Both were associated with fronts, but one was an actively developing cloud while the other had started to decay during the course of the sampling. The two clouds showed distinct differences in particle number concentration, habit and size, although a number of common features were also observed. Both clouds had small crystals present at all levels in the cloud with the highest concentrations present in the coldest regions (below -40C). They also had a distinct bimodal size distribution in the warmer regions of the clouds, caused by the growth and aggregation of ice crystals initiated high up in the clouds. The concentrations of ice crystals were higher in the actively growing cloud which had the stronger updrafts. The relative contributions of homogenous and heterogeneous freezing will be explored. The implications of these results for the radiative properties of these clouds will be considered.

S5.2

Reconciliation of in-situ observations and large-scale simulations of mid-latitude cirrus clouds

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Cirrus clouds play an important role by influencing the Earth's radiation budget and the global climate (Heintzenberg and Charlson, 2009). The formation and further evolution of cirrus clouds is determined by the interplay of temperature, ice nuclei (IN) properties, relative humidity, cooling rates and ice crystal sedimentation. Thus, for a realistic simulation of cirrus clouds, a Lagrangian approach using meteorological wind fields is the best way to represent complete cirrus systems as e.g. frontal cirrus, three dimensional cloud modeling on a large scale. To this end, we coupled the two momentum microphysical ice model with the 3D Lagrangian model CLaMS.

The new CLaMS-Ice module simulates cirrus formation by including heterogeneous and homogeneous freezing as well as ice crystal sedimentation. The boxmodel is operated along CLaMS trajectories and individually initialized with the ECMWF meteorological fields.

Here, we compare a large mid-latitude dataset of in-situ measured cirrus microphysical properties compiled from several aircraft field campaigns around the globe (Krämer et al., 2016, ICCP) to CLaMS-Ice model simulations in mid-latitudes performed during the ML-Cirrus aircraft campaign in 2014. We investigate the number of ice crystals and the ice water content with respect to temperature in a climatological way and found a good and consistent agreement between measurement and simulations.

As a result from the CLaMS-Ice cirrus simulations, we are able to assign the formation mechanism - either heterogeneous or homogeneous freezing - to specific combinations of temperatures and ice water contents, and found that most of the cirrus clouds (66.6 %) formed solely heterogeneously.

S5.3

Aircraft-based single particle mass spectrometric analysis of cirrus cloud residues

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5

14

single particle mass spectrometry

We have conducted aircraft-based in-situ measurements of cirrus cloud residue composition in March/April 2014 during the ML-CIRRUS mission with 13 measurement flights over Western Europe using the High Altitude and Long Operation research aircraft HALO. The main objective of the mission was the investigation of the formation, properties, and life cycle of natural cirrus clouds and anthropogenic contrail cirrus at mid-latitudes.

By using the Aircraft-based Laser Ablation Aerosol Mass Spectrometer "ALABAMA", connected to a counterflow virtual impactor (HALO-CVI), we analysed the residues of ice crystals between approx. 5 and 50 μm that were sampled by the HALO-CVI when flying in cirrus clouds. After entering the CVI sampling tip the ice is evaporated and the residues were transmitted to the mass spectrometer and to other analysis instruments, e.g. an optical particle counter (OPC). Out of cirrus clouds ambient upper tropospheric and lower stratospheric aerosol particles were sampled through a submicrometer aerosol inlet and analysed by the same instrumentation.

Here we focus on the results from two flights during which natural and anthropogenic cirrus were probed. The results show that the identified particles types found in the residues resemble to a large degree the out-of-cloud aerosol sampled in the same altitude, with particles containing sulfate, organics, and potassium being the most abundant particle types. Only a slight enhancement of "typical" heterogeneous ice nuclei (mineral dust, metals) in the residuals was observed. This finding suggests that homogenous freezing dominated the cirrus cloud formation in these two case studies.

S5.4

Model Application of a new Ice Nucleation Active Surface Site Parameterization for Desert Dust and Soot

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12, 14, 5

Aerosols in the Earth's Atmosphere affect weather and climate and show a broad variety regarding their sources and chemical compositions. Therefore, their contribution to cloud and precipitation formation is still one of the major challenges for improving atmospheric cloud, weather, and climate models. However, a uniform handling of the aerosols' ice nucleation ability and efficiency is not possible and therefore, a variety of parameterization schemes exists. Studies comparing different parameterization for heterogeneous ice nucleation in models show a high variability in the resulting ice water path values and their spatial distribution (e.g. Komurcu et al. (2014)).

A newly developed parameterization framework for heterogeneous ice nucleation of desert dust and soot based on 11 years of AIDA cloud chamber experiments (Ullrich et al. to be submitted) was implemented into the online- coupled model COSMO-ART (Vogel et al. (2009)).

This contribution will show a case study on a synoptically driven cirrus cloud over Texas, U.S. observed within the MACPEX campaign. Within this case study the new parameterization scheme (Ullrich et al. to be submitted) is compared to the standard parameterization scheme of Phillips et al. (2008). Furthermore, the contribution will show the comparison of the model results and airborne measurements. In particular, the contribution of desert dust and soot particles as heterogeneous ice nuclei to the total formed ice particles is compared to ice residual particle measurements (Cziczo et al. (2013)). Additionally, the measured size distributions of aerosol and ice are compared to the modelled size distributions.

S5.5

High Ice Water Content in Cirrus Clouds Linked to Biomass Burning

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High ice water content in cirrus clouds pose a major hazard to aviation due to the possibility of engine rollback and sensor degradation, as has been reported in several studies (Mason et al, 2006; Grzych and Mason, 2010; Mason and Grzych, 2011).

In this study we report on the data recorded by commercial airliners in the context of the IAGOS program (Petzold et al, 2015). In particular, backscatter cloud probes (BCP) were installed in five commercial airliners that flew on a number of routes around the world (Beswick et al, 2014; 2015). Over the period from 2012 to the beginning of 2016, these aircraft encountered high ice crystal concentrations in cirrus more than 1000 times. Elevated concentrations of carbon monoxide were also measured from these same aircraft in the cirrus with high ice water. This suggests that the air in these cirrus originated in regions of biomass burning, where a large number of aerosol particles are also emitted.

We combine back trajectory analysis, satellite measurements and fire emissions data to reinforce the hypothesis that cloud condensation or ice nuclei, produced by biomass burning emissions and transported by deep convection, may be related to the high ice concentrations recorded. Our preliminary results are in agreement with recent observational studies (Prenni et al, 2012; Seifert et al, 2015), which suggest a potential important role as ice nuclei of particles emitted during biomass burning.

S5.6

Aviation effects on already-existing cirrus clouds

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¹*University of Hertfordshire, Hatfield, UK*, ²*University of Leeds, Leeds, UK*, ³*Stockholm University, Stockholm, Sweden*

5. Cirrus clouds

Determining the effects of the formation of contrails within natural cirrus clouds has proven to be challenging. Quantifying any such effects is necessary if we are to properly account for the influence of aviation on climate. Here we quantify the effect of aircraft on the optical thickness of already-existing cirrus clouds by matching actual aircraft flight tracks to satellite lidar measurements. We show that there is a systematic, statistically significant increase in normalized cirrus cloud optical thickness inside mid-latitude flight corridors compared with adjacent areas immediately outside the corridors.

S5.7

The Dependence of Cirrus Cloud Formation Mechanism on Latitude, Season and Surface Type

David Mitchell¹, Anne Garnier², Melody Avery³, Ehsan Erfani¹

¹*Desert Research Institute, Reno, Nevada, USA*, ²*Science Systems and Applications, Inc., Hampton, Virginia, USA*, ³*NASA Langley Research Center, Hampton, Virginia, USA*

5, 1, 12, 13, 14, 16, 6

A new understanding of absorption differences in satellite split-window channels has resulted in a new retrieval method for visible semi-transparent cirrus clouds ($0.3 < OD < 3.0$). Using the Imaging Infrared Radiometer (IIR) and CALIOP lidar aboard CALIPSO, ice particle number concentration N , effective diameter D_e , IWC, IWP and visible optical depth (OD) are retrieved for single-layer cirrus having cloud base temperature $T < 235$ K, and are compared against aircraft observations from the Sparticus campaign in the United States during winter and spring 2010.

On a global scale, these retrievals show a pronounced cirrus seasonal cycle in the Northern Hemisphere over land north of 30°N latitude in terms of both cloud amount and microphysics, with greater cloud cover, higher N and smaller D_e during the winter season, especially over mountainous terrains. We postulate that this is partially due to the seasonal cycle of deep convection that replenishes the supply of ice nuclei (IN) at cirrus levels, with homogeneous ice nucleation prevailing during boreal winter north of 30°N when deep convection is relatively absent and orographic waves are possibly present over land, resulting in lower IN and higher N concentrations. In contrast, in the tropics and over oceans, lower N and higher D_e are observed, and heterogeneous ice nucleation appears to prevail. Over pristine Antarctica, IN concentrations are expected to be minimal, allowing homogeneous freezing to dominate. Accordingly, over Antarctica cirrus clouds exhibit relatively high N and small D_e throughout the year.

S5.8

Vertical Velocity Fluctuations Modulate the Aerosol Indirect Effect on Ice Clouds

Donifan Barahona, Andrea Molod, William Putman, Max Suarez
NASA Goddard Space Flight Center, Greenbelt, MD, USA

5, 12, 14

Aerosol emission and transport to the upper troposphere impact the formation and evolution of ice clouds. The strength of this aerosol indirect effect (AIE) however depends on the ambient temperature, relative humidity, dynamical forcing and the physicochemical properties of the emitted aerosol. The role of dynamical forcing on the AIE has been particularly difficult to assess since the relevant scale for cloud formation is much lower than the typical resolution of global circulation models (GCMs). Here we combine ultrahigh resolution simulations with reanalysis products to constraint the dynamical forcing and the thermodynamic conditions in the NASA Goddard Earth System Model (GEOS-5). GEOS-5 is then used to study the effect of dust and black carbon emissions on the simulated cloud fraction, effective size and water content of ice clouds. It is shown that the susceptibility of cloud properties to aerosol emissions is strongly dependent on the variability in vertical velocity. Dynamical forcing thus acts to modulate the AIE. Our results indicate that dynamic variability is as important as aerosol type in determining AIE. In turn dynamics may partially explain the diversity of results regarding the response of ice clouds to aerosol emissions reported in the literature.

S5.9

The Impact of Surface Kinetic Resistance and Particle Shape on the Competition between Heterogeneous and Homogeneous Freezing in Cirrus.

Jerry Harrington¹, Marcus Hanson¹, Hugh Morrison², Benjamin Sherman⁰

¹*Penn State University, University Park, PA, USA,* ²*National Center for Atmospheric Research, Boulder, CO, USA*

5, 1, 12, 14

The competition between heterogeneous and homogeneous freezing in cirrus depends on the supersaturation, and hence is sensitive to controls on the ice mass growth rate. Homogeneous freezing, for instance, is strongly impacted by the degree to which mass growth is affected by surface kinetic resistance. We will present results showing that the competition between heterogeneous and homogeneous freezing is sensitive to surface kinetic resistance and particle shape. Using a model that predicts particle shape and axis-dependent deposition coefficients indicates that the competition depends on the critical supersaturation, the growth mechanism (layer growth vs. dislocation growth), and the particle shape. When crystals are isometric, larger critical supersaturations lead to weaker growth of heterogeneously nucleated particles and more homogeneously frozen particles. However, non-spherical ice particles produce the opposite effect where larger critical supersaturations along the primary growth axis hinder homogeneous freezing.

S5.10

Cryo-Scanning Electron Microscopy of Captured Cirrus Ice Particles

Nathan Magee, Katie Boaggio, Lucas Bancroft, Manisha Bandamede, Kevin Hurler
The College of New Jersey, Ewing, New Jersey, USA

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16.

We present high-resolution cryo-scanning electron microscopy images and microanalysis of cirrus particles captured by high-altitude balloon. Data are presented from multiple cirrus-penetrating balloon flights conducted from November 2015 through July 2016 across the Eastern USA, and timed to coincide with cloud data gathered by NASA's CloudSat, CALIPSO, and MODIS satellite instruments. Cirrus ice particles are captured and sequestered in a balloon-borne cryo-preservation cell that returns to earth by parachute, is retrieved through GPS-tracking, and is then transported and transferred into the SEM. The transfer process employs a state-of-the-art cryo technology and a novel equilibrium-preserving protocol that ensures crystal surfaces are never exposed to additional sublimation or growth environments between capture and imaging. We employ a Hitachi SU5000 Schottky field emission variable pressure SEM, equipped with Quorum 3010 Cryosystem to acquire outstanding SEM images without the need for sputter-coating of crystal surfaces. The SEM/cryosystem configuration allows imaging and analysis of uncoated ice crystals for multiple hours with no perceptible changes or beam effects to the crystal surfaces. High resolution images (up to ~10 nm resolution at high magnification), 3D measurements of surfaces, and energy-dispersive spectroscopy chemical analyses (EDAX Octane) are presented, revealing complex 3D surfaces in various states of growth and sublimation, including examples of previously unseen particle-scale morphologies and microscale structures. These results offer a glimpse of cirrus ice particles in unprecedented detail, offering new clues to understanding physical cirrus cloud processes and new information to help improve cloud models and satellite cloud-property retrievals.

S6.1

Diagnosing the development of a severe thunderstorm in the Amazon Region during the 2014 CHUVA/GO-Amazon 2nd IOP Field Campaign

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Key-Area: 3-Convective Clouds

Although the Amazon region presents continuous lightning activity all year long, severe thunderstorms (high flash rates) are not common and deserve special attention. For example, On September 8th of 2014 a severe thunderstorm, enhanced by the river breeze circulation, crossed the ARM Manacapuru T3 super site during the 2nd IOP of CHUVA and GO-Amazon field campaigns. This thunderstorm lasted less than 2 hours and produced more than 7600 lightning discharges with a maximum lightning rate of 601 flashes per minute (575 IC/min and 78 CG/min) as observed by LINET network. Coincident 3D S-Band weather radar measurements indicate the presence of vertical shear during the maximum(region) lightning activity. Cloud to ground flashes were observed over the convective cores while intra-cloud strokes were aloft of these cores. Based on the inverse problem of Coulomb's law, vertical electrical field (E_z) (network of 6 field mills) and lightning polarity measurements over T3 site indicated the presence of negative charge centers between 0 and -10oC and positive ones around -40oC. A classical End-Of-Storm-Oscillation (EOSO) signature was evident as the thunderstorm crossed the field mill network. Correlating this temporal evolution with the vertical pointing rain radar, we found that initially the rain was carrying positive charges than switching to negative after the maximum lightning activity. Finally to explain micro-physically and dynamically why such thunderstorm became severe, we will retrieve the hydrometeors types from the coincident X-band radar polarimetric measurements and couple with lightning, E_z and S-Band to understand how the electrification process evolve.

S6.2

Current Understanding in Cloud Electrification

James E. Dye

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Cloud electrification was an important topic in early ICCP conferences. But few papers on this topic have been presented in recent years. This contribution discusses recent findings in Cloud Electrification to emphasize the importance of cloud physical processes.

Laboratory findings ~40 years ago showed that large charge is separated when ice crystals collide with simulated graupel in the presence of supercooled water (SLWC). Observational and modeling studies with the lab results now convincingly demonstrate that this non-inductive mechanism is the dominant mechanism of electrification in convection clouds, even though we lack understanding of the physical mechanism of charge separation and the charge sign reversal temperature.

We now know other clouds in which electrification occurs. Recent observations in long-lived anvils and winter storms suggest that electrification can occur in the absence of SLWC. Anvils, winter storms and extensive stratus provide long periods for ice particle interactions. Weak charge separation without SLWC as found in early laboratory studies of colliding ice particles might explain this electrification. Another region in which electrification is known to occur is near 0C in trailing stratiform regions of MCSs, a zone with many complex microphysical processes of melting, shedding, and mixed phase particle interactions. Observations have shown charge layers of both polarities near 0C, thus it seems unlikely that the non-inductive mechanism is responsible for this electrification.

Examples of electrification including microphysical measurements in both of these situations will be presented with the hope of spurring additional joint studies of cloud physics and cloud electrification.

S6.3

Cloud-aerosol-precipitation interactions in cloud electrification over the Amazon

Rachel Albrecht¹, Ramon Braga², Carlos Morales¹, Luiz Machado², Meinrat Andreae³, Daniel Rosenfeld⁴, Hartmut Höller⁵, Manfred Wendisch⁶

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Key areas: 12, 3, 9, 14

Microphysics and thermodynamics of deep convection together determine separation and cloud electrical structure. Cloud thermodynamics and changes in life cycle and cloud particle distribution can potentially induce alterations in the electrification of clouds and lightning activity. Particularly in the Amazon, deforestation deepens planetary boundary layer, increasing cloud base heights, leading to anomalous higher conditionally thermodynamical instability and shallower warm cloud depth. This region also experience periods of biomass burning, ingesting elevated concentrations of cloud nuclei in the atmosphere. Possible pollution effects in cloud electrification are (i) decrease in total charge transferred (and lightning) due to smaller ice particles, and (ii) change in the polarity of charge transferred due to changes in the relative diffusional growth rate of ice particles.

The role, isolated or combined, of all these factors in cloud electrification are yet not understood and mostly unexplored. In this study, aircraft in-situ cloud microphysics, radar and lightning data are combined to identify and quantify the role of thermodynamics and pollution in the Amazon during wet and dry-to-wet seasons. Data used is from GoAmazon and ACRIDICON-CHUVA field experiments. To depict cloud electrification, a total (intracloud and cloud-to-ground) lightning network was installed around Manaus. Lightning data from long range networks are also used. Clouds that developed into thunderstorms show a distinct shift from warm- to mixed-phase dominated microphysics in both seasons, with differences in cloud particle spectra and thermodynamical instability. River breezes also show influence in forcing convection on the east side of Rio Negro.

S6.4

First evaluation of the aerosol – microphysics – electrification coupling in the Meso-NH model : lightning activity within a tropical cyclone of the South-West Indian Ocean

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While tropical cyclone (TC) track forecasts have been improved for the past few decades, TC intensity forecasts, in particular, rapid intensity changes, are still a difficult task. In the last decades, several studies have suggested that lightning activity could be an indicator of TC intensity or track change.

To investigate the relationships between tropical cyclone intensity change and structure, and lightning activity, we are developing a coupling between an aerosol scheme (ORILAM ; Tulet et al., 2005), a 2-moment bulk microphysics scheme (LIMA ; Vié et al., 2015) and an explicit electrification and lightning scheme (CELLS ; Barthe et al., 2012) in the French mesoscale model Meso-NH. The MACC analysis from ECMWF are used to initialize and feed the lateral boundary conditions for the prognostic aerosol fields. A parameterization of the emission of sea salt aerosol is also introduced to produce realistic aerosol concentrations in the context of the South-West Indian Ocean clean maritime environment.

We will present the results of a kilometer-scale simulation of TC Bejisa (2014) that passed close to Réunion Island in the South-West Indian ocean. The simulation will be evaluated through comparisons with satellite (Meteosat, TRMM...), ground-based radars and lightning (WWLLN, TRMM/LIS) data. The lightning activity in the different parts of the system (eyewall, rainbands) will be analyzed along with its intensity and structure. This configuration of the model will also allow us to investigate the sensitivity of lightning activity to aerosols.

S6.5

Evaluation of thunderstorm forecasts using two microphysics schemes

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3. ; 8. ; Lightning; Hail; Graupel; Storms; Modelling; Modeling; Unified Model; CASIM

Thunderstorms produce a variety of hazards, such as lightning, strong gusty winds, hail and turbulence. Accurate forecasts of when and where lightning are likely to occur is important for those working outdoors, as well as the aviation and utilities industries.

However, as the location and timing of thunderstorms has a degree of stochasticity, the exact position of storms within the model and their structure may significantly change as a result of altering the model physics.

In this paper, we examine forecasts of thunderstorm activity based on forecasts produced by the Met Office Unified Model using two different microphysics schemes: the standard Single-Moment Wilson and Ballard scheme, and the new multi-moment Cloud-Aerosol Interacting Microphysics scheme (CASIM). The location and timing of lightning-producing storms will be assessed against observations for storm cases. In addition, the structure of the storms and lightning produced by the different microphysics schemes can be examined, highlighting differences between the microphysics schemes as well as where they show similar results.

S7.1

Airborne Radar and Lidar Observations of Cloud-Environment Interactions, Entrainment, and Drizzle Formation in High CDNC Convective Cloud Complexes

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1,3,16

Observations collected from in situ and remote sensing instruments on the University of Wyoming King Air on July 10, 2013 as part of the CONvective Precipitation Experiment (COPE) are examined in order to investigate not only how growing convective turrets impact the surrounding environment, but also entrainment and drizzle formation. This case has been examined previously in the context of cloud-environment interactions, which due to the presence of fine-scale aerosol layers in the environment the convective turrets are growing into, allows the displacement of the surrounding environment to be visualized. Here, this analysis is extended by examining circulations within the cloud derived from the Wyoming Cloud Radar Doppler velocities. Due to the lack of precipitation – resulting from cloud droplet number concentrations in excess of 1500 cm^{-3} inhibiting drizzle formation despite liquid water contents sometimes in excess of 3 g m^{-3} -- the Doppler velocities are uncontaminated by particle fallspeeds, making this an ideal case for examining circulations within cloud. Finally, while the convective turrets sampled during the first 45 minutes were completely free of precipitation, some precipitation-sized particles were observed and became more common during the final 45 minutes of sampling. This appears to be the result of new turrets growing up through existing convective complexes and entraining the drizzle-embryos formed during the lifecycle of earlier turrets, and is explored using vertical profiles of radar reflectivity as observed by the Wyoming Cloud Radar.

S7.2

High-resolution Simulations of Cumulus Entrainment

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Entrainment, 3. Convective clouds

A long-standing problem in meteorology has been to reproduce how quickly entrainment dilutes a cumulus cloud. Currently, all models fail to model the cloud top ascent rate, the updraft speed, and the distribution of liquid water content in the cloud. It has long been assumed to be a problem of inadequate spatial resolution, where the smallest scales of turbulence must be parameterized and their effects are improperly represented. It could also result from a fundamental problem in our conceptual understanding of cumulus entrainment.

Three-dimensional large-eddy simulations of a single cumulus cloud are used to investigate the change in entrainment as the model resolution is increased. Entrainment is calculated directly at the cloud edge as it develops in time. The simulated cloud tops, updraft speeds, and liquid water content are compared to those in non-precipitating cumuli observed from a single day during the Convective Precipitation Experiment (COPE) over Wales in July 2013. Observations of eddy size at the cloud edge from the Wyoming Cloud Lidar are also compared to those in the simulation as the resolution increases. The results will be used to understand computational issues related to cumulus entrainment, in addition to improving our knowledge of the underlying physics.

S7.3

Entrainment and Dilution Rates of Successive Thermals in a Simulated Cumulus Congestus

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Key numbers: 1, 3. Key words: entrainment

Cumulus clouds are frequently observed as comprising of multiple, successive thermals, but yet our understanding of entrainment and dilution is limited to studies of one thermal of a cloud or bulk properties of a cloud field. In this study, an idealized, simulated cumulus congestus, consisting of three successive thermals, is used to analyze changes in entrainment and dilution as a single cloud evolves. Entrainment and detrainment are calculated directly at the edges of the cores of thermals, over short temporal scales. Strong entrainment rates occur at the rear of the toroidal circulation in each thermal. Fractional entrainment values were consistent with past studies.

The dilution rate of the least diluted parcel within each thermal is also tracked during its ascent. When the thermals climb through pristine environmental air, the dilution rate is greatest, but an order of magnitude less than the entrainment rates. Successive thermals ascending into the remnants of previous thermals are shown to entrain a narrower spectrum of mixtures between cloud core and environmental air, and have a lower probability of entraining environmental air. However, the timing/position between successive thermals also affects their dilution rates. The last thermal climbs into the collapsing remnants of its predecessor, impeding its ascent, and increasing its dilution rate. Thus, successive thermals can either benefit from their predecessors by mitigating the entrainment of environmental air, or be hampered by their collapse, allowing entrainment of negatively buoyant air and negative vertical momentum.

S7.4

Analysis of homogeneous and inhomogeneous mixing in liquid clouds

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1, 2, 3 homogeneous mixing, inhomogeneous mixing, entrainment

Entrainment and mixing continue to be one of the long-standing problems in cloud physics. Over the years, a multiplicity of studies and approaches using analysis of in-situ observations were undertaken to identify whether in-cloud mixing follows homogeneous or inhomogeneous scenario. Until now no consensus about this matter has been reached. Understanding the mixing process is important for its proper description in numerical simulations of clouds in weather predictions and climate models. In this work, relationships between basic microphysical parameters are studied within the framework of homogeneous and extreme inhomogeneous mixing. Analytical expressions and numerical simulations of the relationships between droplet concentration, the extinction coefficient, liquid water content, and mean volume droplet size, formed during homogeneous and inhomogeneous mixing are presented. The numerical simulations of mixing suggest that multiple mixing events break the functional relationships between different moments of droplet size distribution during homogeneous mixing. However, the functional relationships between the moments are preserved during inhomogeneous mixing. The obtained analytical relationships between the moments were used to identify the type of mixing for in-situ observations in liquid clouds. It was shown that for the set of observations investigated here, the interaction between cloudy and entrained environments is dominated by inhomogeneous mixing. Comparisons of different characteristic times of mixing suggest that within the same mixing environment, depending on mixing fraction, some volumes may be dominated by homogeneous mixing whereas others may be dominated by inhomogeneous mixing.

S7.5

Examination of Entrainment-Mixing Mechanisms in Observed and Simulated Cumuli

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Key area numbers: 2, 1, 3.

The entrainment-mixing mechanisms are examined in the cumulus clouds observed during the Routine AAF [Atmospheric Radiation Measurement (ARM) Aerial Facility] Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO) field campaign over the ARM Southern Great Plains (SGP) site near Lamont, Oklahoma, US and simulated with a large eddy simulation (LES) model. The relationships of two quantities (homogeneous mixing degree and transition scale number) commonly used to gauge the mixing mechanisms are analyzed. The results show that the two quantities are positively correlated if the evaporation time or reaction time is used as the microphysical time scale in the calculation of transition scale number; however, the two quantities are not related if the phase relaxation time is used as the microphysical time scale. The LES-simulated cumulus clouds during the RACORO campaign are also examined with the same approach. The two quantities are positively correlated if the evaporation time scale is used, but if the reaction time scale or phase relaxation time scale is used, the correlation between the two quantities is positive when the transition scale number is small, and is negative when the transition scale number is large. The reasons/mechanisms underlying the differences in using different microphysical time scales and discrepancy between observational and LES results will be analyzed and presented.

S7.6

Investigation of DSD variations in a developing monsoon cloud: Analysis from numerical simulation and field observation

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Basic cloud and precipitation physics

DNS, Bi-modal DSD, CAIPEEX

A 3D direct numerical simulation (DNS) of cloud droplet has been carried out to study variation of droplet size distribution (DSD) of monsoon convective clouds during their developmental stage. DNS is performed for Eulerian description of velocity, temperature and vapour fields in combination with Lagrangian ensembles of cloud droplets in a decaying turbulence. Initial conditions are taken from airborne observation during Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX).

Characteristics of mixing process, in particular, inhomogeneous and homogeneous mixing have been studied and microphysical parameters derived are compared with observations. DSDs in cloud edges and cloud core from both simulation and CAIPEEX showed considerable similarities in their microphysical nature and mixing characteristics. Strong dilution at cloud edge is found in comparison to cloud core. Droplet number densities, mean radius and spectral width show considerable variation, however, at cloud core, they remain invariant. This indicates a dominance of inhomogeneous mixing at cloud edges while homogeneous mixing or a combination of homogeneous and inhomogeneous mixing is present at the cloud core. In the turbulent kinetic energy spectrum, a peak appears in the higher wave number after 15 seconds of simulation which is attributed to breaking of eddies at smallest scale.

For high resolution observations, distribution of mean radii matches with that obtained from DNS. Furthermore, at cloud edges, a bimodal DSD is obtained from both DNS and observation. This bimodality is due to partial evaporation of droplets as they are subjected to mixing.

S7.7

Impact of cloud microphysics on the phase composition of a tropical mesoscale convective system

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9, 3, 1

Simulations of tropical convection are evaluated with the focus on the model's ability to simulate the observed high ice water contents associated with the outflow of deep convection, and to investigate the processes that control the phase composition of tropical convective clouds.

It is shown that the growth of ice is less dependent on vertical velocity than is liquid water, with the control on liquid water content being the updraft strength due to stronger updrafts having minimal entrainment. Larger liquid water contents are produced when cloud droplet number concentrations are increased or when including a parameterisation of heterogeneous freezing rain. These changes reduce the efficiency of the warm rain processes generating greater supercooled liquid water contents. The control on ice water content is the ice sizes and available liquid water, with the larger ice particles growing more efficiently via accretion and riming. Limiting or excluding graupel produces larger ice water contents due to greater ice mass contained in slow falling snow particles. This results in longer in-cloud residence times and more efficient removal of liquid water.

It is demonstrated that entrainment in the mixed-phase regions of updrafts is most sensitive to the turbulence formulation. Greater mixing of environmental air into cloudy updrafts produces more detrainment and the generation of a larger stratiform area. In the purely ice region of the updrafts, the entrainment and buoyancy of air parcels is controlled by the ice particle sizes, demonstrating the importance of the microphysical processes on the convective dynamics.

S7.8

The Effects of Entrainment and Mixing on Droplet Size Distributions: Bridging the DNS-LES Gap

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1,2

The fundamental difficulty that large-eddy simulation (LES) faces when attempting to represent the effects of entrainment and mixing on droplet microphysics is representing the subgrid-scale variability of subsaturation and its impact on the droplet size distribution (DSD).

Direct numerical simulation (DNS) resolves the smallest scales of fluid motion, but is restricted to domains of about one meter in extent. This limits the range of Damkohler (Da) numbers (ratio of a flow time scale to a droplet evaporation time scale) to values ~ 1 . The limits, $Da \ll 1$ and $Da \gg 1$, correspond to homogeneous and inhomogeneous mixing, respectively.

The EMPM (Explicit Mixing Parcel Model) predicts the evolving internal variability due to entrainment and finite-rate turbulent mixing using a 1D representation of a parcel. It calculates the growth of thousands of individual cloud droplets based on each droplet's local environment. The 1D formulation allows the model to resolve variability down to the smallest turbulent scales (about 1 mm) in large domains (20 to 200 m), thereby bridging the DNS-LES gap, and allowing large Da to be achieved.

Kumar, Schumacher, and Shaw (2014, 2015) performed several DNSs of the response of a droplet population to entrainment and mixing that are ideally suited for evaluating the EMPM. We compared EMPM results to their DNS results for identical configurations, and obtained excellent agreement for the evolution of the DSDs and the droplet subsaturation PDFs. We will present these results and EMPM results for scenarios that DNS is not presently capable of simulating.

S7.9

Impact of Aerosol Amount on Drop Environments and Mixing Characteristics of Warm Continental Cumulus During GoMACCS

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12.

2.

1.

Aerosol-cloud interactions are a primary topic of study in the cloud physics community, especially how aerosols modify clouds and precipitation processes. Data from the Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS) in Aug-Sept 2006 near Houston, TX and over the Gulf of Mexico are used. Phase Doppler Interferometer (PDI) data, soundings, and meteorological observations for non-precipitating clouds are used to characterize the environments in which cloud droplets are observed as a function of drop diameter and background aerosol concentration. Environmental characteristics include, for example, vertical velocity, humidity, temperature, and observed drop-size distributions. To provide insight into how aerosol amount is related to drop-environments, data are sorted into three aerosol categories, low, medium and high. When combined with aerosol information, a thorough understanding of drop-by-drop environments allows us to investigate entrainment mixing process, precipitation initiation, and precipitation suppression. By focusing on a subset of low aerosol (clean) flights and high aerosol (polluted) flights we are able to characterize the environmental differences between clean and polluted clouds. In general, clean days have broader size distributions and larger drop sizes (Albrecht Effect) than polluted days. We summarize these differences, and test their significance, for a suite of meteorological parameters. We also provide an entrainment mixing analysis to determine differences in entrainment processes (inhomogeneous vs. homogeneous mixing) using a simple mixing and condensation model.

S7.10

Exploring the Interaction Web of Aerosol-Cloud-Precipitation System

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1, 2, 12

It is generally recognized that a cloud is a complex open system with a web of interactions among aerosols, cloud microphysical (e.g., droplet concentration and spectral shape), dynamical (e.g., vertical velocity and entrainment rate), and thermodynamic (e.g., environmental moisture and temperature) properties. However, the relationships among them, underlying mechanisms, and interaction web remains elusive, prohibiting complete understanding of the aerosol-cloud-precipitation system and its adequate representation in climate models. This study aims to improve the situation by examining the relationships between the key quantities/processes and the underlying mechanisms. The interaction web will be explored by applying advanced approaches of data mining and causality analysis to observations and LES simulations from different types of clouds. Idealized models (e.g., parcel model and LES) will also be used to help dissect the underlying mechanisms. The results are expected to shed new light on several cloud-related challenges, including aerosol-cloud interactions, entrainment-mixing processes and their effects on cloud microphysics, and cloud variability at sub-grid scales of climate models.

S7.11

The role of organic compounds in cloud formation: Relative importance of entrainment, co-condensation and particle-phase properties

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Area numbers: 2,12

Keywords: co-condensation, entrainment, microphysics, cloud parcel

Droplet activation of non-volatile CCN is considered to be relatively well understood, however, there are fewer systematic studies on the activation of aerosols containing semi-volatile organic compounds that co-condense alongside water vapour. Although the significance of co-condensation of organic vapours for cloud droplet number concentration predictions has recently been identified, it remains uncertain how this process may interact with atmospheric dynamics. In addition to co-condensation of in-cloud material, additional semi-volatile mass can be entrained from the surrounding environment. Reduced cloud droplet concentrations are expected as the parcel is diluted with clean air; however, additional soluble mass in the particle phase promotes activation.

In this work we study the simultaneous impact of entrainment and co-condensation, the relative importance of these two processes at different atmospheric conditions, their interactions with each other, and the particle-phase chemistry in terms of cloud microphysical properties.

To assess the importance of the entrainment of semi-volatile materials as compared with their co-condensation and chemical properties, a pseudo-adiabatic cloud parcel model with detailed bin microphysics is employed. We have added the co-condensation process to the model such that it is coupled with the parametric entrainment representation. The effects of entrainment and co-condensation are benchmarked independently and simultaneously against a control simulation. Furthermore, we probe the sensitivity of cloud microphysical properties to perturbations in the prevailing meteorology and aerosol physiochemical parameters. Future work will be focused on the evaluation of coupled atmospheric dynamics and gas-particle phase interactions in global climate models.

S7.12

Impacts of entrainment on the microphysical properties of stratocumulus clouds observed during the Marine Stratus/Stratocumulus Experiment (MASE-II)

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2, 12, 1 (Entrainment, adiabaticity, droplet spectra)

Current parameterisations used to estimate the activation of aerosols to form droplets in many global circulation models (GCM's) are usually based upon adiabatic parcel model theory. Diabatic processes, such as entrainment, are not commonly accounted for in the calculation of droplet activation. The current structural uncertainty inherent in droplet activation parameterisations propagates through global estimates of the aerosol indirect effect calculated using a GCM.

Previous attempts to compare diabatic droplet activation parameterisations against observations have focussed on total droplet number concentrations using cloud averaged observations. In reality the influence of entrainment on cloud microphysical properties varies considerable in time and space. This study provides a new approach to organize in-situ aircraft observations into regimes corresponding to self-similar characteristics, in order to facilitate a statistically more robust comparison between observed and simulated droplet spectra using cloud parcel models.

By applying a statistical approach termed clustering, observations with the same droplet spectra are grouped together and can be divided into different regimes. We analyse these to provide information regarding the role of entrainment on the evolution of the droplet spectra. This strategy is applied to observations from the Marine Stratus/Stratocumulus Experiment (MASE-II) undertaken over the eastern Pacific Ocean.

By isolating LWC Adiabatic ratio (ARL) regimes we compare the cloud parcel model to these clusters and show the dependence on entrainment. Inherent structural weaknesses and applicability of current droplet activation parameterisations that have been developed to account for entrainment effects on droplet activation are highlighted.

S7.13

Evaporative Cooling and Entrainment in POST Stratocumulus

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2., 16.

Entrainment literature for stratocumulus (Sc) usually deals with moisture and temperature "jumps" between Sc top and free troposphere (FT). Mixing air related to these two sources can affect evaporative cooling, BR (buoyancy reversal), and MFA (mixing fraction analysis) causing entrainment instability.

This effort investigates evaporative cooling and entrainment by analyzing high-resolution measurements from the POST (Physics of Stratocumulus) aircraft field campaign held off the CA Coast in unbroken Sc. The featured probes are UFT (ultra-fast temperature) probe and PVM (LWC and effective radius).

Observations are presented showing that most of the LWC evaporation occurs just above unbroken cloud in the CTMSL (cloud-top mixing sublayer). This behavior differs little for Sc with and without predicted buoyancy reversal. Depleted LWC in entrainment holes is primarily a result of dilution with air conditioned in CTMSL to a near buoyancy match with cloud top. Cloud top only occasionally approaches close to FT, with the upper part of the inversion layer being cloud free. And reduced LWC in entrainment holes lacks correlation with temperature reduction in the holes.

These observations lead to conclusions that evaporative cooling and BR in the unbroken POST Sc are small, and that radiative cooling dominates entrainment into the unbroken cloud. Evaporation of LWC and sensible heat cool the CTMSL affecting the entrainment rate into the unbroken cloud indirectly. The effect of these findings on "Entrainment Rules" is described.

S7.14

Anisotropic turbulence within a capping inversion: a missing piece in the puzzle of stratocumulus entrainment

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2, 1

We investigate high-resolution airborne data collected in the course of the Physics of Stratocumulus Top (POST) project. Analysis of 8 different cases of marine stratocumulus, based on ~400 aircraft penetrations across the entrainment interfacial layer (EIL) reveals a fine-layered structure of the cloud top and capping inversion. Despite maximum static stability, the inversion and the whole EIL remain turbulent with maximum turbulence intensity just below the cloud top. The thickness of the EIL corresponds to the thickness of the shear layer in the cloud top region, and adapts to the velocity- and buoyancy-jump between the cloud layer and the free troposphere in such a way, that the gradient Richardson Number across the EIL sublayers remains critical. This, in turn, suggests that shear at the cloud top, not radiative cooling or large convective eddies in the boundary layer, is the source of the observed turbulence. Anisotropy of velocity fluctuations in the turbulent inversion and the cloud top mixing sublayer, confirmed by small values of Corrsin and Ozmidov scales (tens of centimeters in the inversion and single meters below), indicates significant effect of static stability and shear. Accompanying LES simulations of stratocumulus topped boundary layer based on data from POST and DYCOMS-II campaigns also indicate importance of anisotropy of turbulent mixing process across the inversion and give insight into TKE budget and transport in the entrainment zone.

S8.1

Microphysical and thermodynamic structure of two nocturnal elevated mesoscale convective systems sampled during the 2015 PECAN project

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8,1

Extensive ground based and airborne observations were collected during the 2015 Plains Elevated Convection at Night (PECAN) field campaign that capture the initiation, maintenance, and structure of nocturnal elevated mesoscale convective systems (MCSs) over the United States Great Plains. The sizes and shapes of cloud hydrometeors were measured with a Precipitation Imaging Probe (PIP) and a Cloud Imaging Probe (CIP) installed on the National Oceanic and Atmospheric Administration (NOAA) P-3 aircraft, whereas the large-scale structure, reflectivity and vertical velocity were measured by the NOAA Tail Doppler Radar (TDR).

Twenty-three spirals conducted on two days are analyzed here to determine variations in the vertical distributions of particle habits, median mass diameters, total particle concentrations, derived total mass contents, and relative humidity. The dataset is unique because different spirals were made in the transition zone behind a developing bow echo in the rear-inflow jet of the MCS, and sampled the development and evolution of the enhanced stratiform rain region. Thus, the vertical profiles were placed in context with respect to their location relative to the leading convective line, transition zone, stratiform region, and rear inflow jet within the MCS and the stage of MCS development using the three-dimensional structure of equivalent radar reflectivity (Z_e) and winds for each MCS derived from pseudo dual-Doppler legs flown parallel to the convective line. Comparison against airborne observations acquired during the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX) are made. Implications for understanding physical processes occurring in the stratiform regions of MCSs are discussed.

S8.2

Investigating the parameterization of graupel density on simulated squall line characteristics

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8, 3

To better simulate storms and precipitation within atmospheric models, accurate representation of physical processes is needed. In the Thompson microphysics parameterization in the Weather Research and Forecasting (WRF) model, graupel and hail are represented by a single hydrometeor category (hereafter, referred to as the graupel category) that only predicts mass mixing ratio and therefore sets particle density to a constant value. This is not realistic given that the densities of graupel and hail are known to vary greatly between and within storms. This study investigates the impacts of how graupel density is parameterized on a simulated squall line.

The range of constant graupel density was varied from 200 kg m^{-3} to 800 kg m^{-3} , representing particles more characteristic of soft graupel to those of hard hail, respectively. In addition, tests to investigate the impacts of a diagnostic variable graupel density have been performed. As the density of graupel particles was decreased from being hail-like to graupel-like, the idealized simulation showed a faster squall line with less graupel and more cloud ice. In particular, the lower constant density graupel case had a notable increase in the graupel melting rate, which resulted in more latent cooling and therefore a more intense cold pool and a faster storm propagation speed. This paper will present the results of changing graupel density in these simulations and the implications this may have on improvements that could be made to the graupel parameterization in the Thompson microphysics scheme.

S8.3

Impacts of mesoscale circulation amplification on simulated squall line precipitation biases

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Key area numbers: 8, 3

Cloud-resolving simulations of convective systems often exhibit biases such as overproduction of rimed ice and underproduction of stratiform precipitation. Overly intense updrafts, assumed hydrometeor properties, and parameterized microphysical processes all contribute to these biases. However, in this study, the role of mesoscale circulations in contributing to convective and stratiform precipitation errors are investigated in high-resolution WRF simulations of a large squall line system observed during the 2011 MC3E experiment in Oklahoma. One of these errors is a leading line convective region that is too wide, which is related to a rear inflow jet that is too strong, shears off convective cells, and dominates the low level circulation. Doppler radar observations, on the other hand, show a low level circulation in the convective region that is more controlled by strong convective downdrafts. Mesoscale front to rear flow is also stronger in simulations.

Evolutions of precipitation structure and mesoscale circulations are tracked in time in radar observations and simulations to investigate feedbacks between them. The sensitivity of simulated mesoscale circulations to microphysics representation impacting the latent heating distribution is a primary focus, however model resolution and large-scale environmental representation are also investigated as potential causes for amplification of mesoscale circulations. Preliminary analysis of cloud-resolving simulations of several different tropical mesoscale convective systems shows that amplified mesoscale circulations that promote erroneous squall line formation and/or characteristics may be typical for a range of environmental conditions and convective system morphologies.

S8.4

Impacts of modeling ice particle shape evolution on orographic precipitation and squall-line structure

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1,17,6,8,3,4

Traditional microphysics models categorize ice (e.g. cloud ice, snow, graupel) and therefore must parameterize conversion rates between categories. These conversion rates are unphysical (they cannot be measured) and can lead to biases in models. Also, while categorizing ice accounts for some of the various ice types observed in nature, transitional ice types (e.g. lightly rimed dendrites) are generally ignored. In this study, a bulk adaptive habit (AHAB) microphysics model is used to explore the impacts of allowing ice particle shape, as well as mass, fall speed, maximum dimension, and density to evolve based on process rates and environmental conditions. By predicting ice particle shape evolution, various habits as well as various states of rime, including lightly rimed and densely rimed dendrites, can be modeled without the need for different categories. The impacts of evolving ice particle shape on two WRF simulations are discussed. In a 3-D orographic precipitation case (from IMPROVE-2) the AHAB model produces partially rimed and therefore faster-falling ice on the windward slopes. This leads to less precipitation on the leeward slopes which compares better with observations than traditional models. In a 3-D squall-line case, AHAB leads to improved modeling of squall-line structure compared to traditional models. AHAB produces robust squall line features such as an enhanced stratiform precipitation region and a transition zone between the convective and stratiform regions. This reveals that among other microphysical sensitivities, squall-line simulations may be sensitive to the modeling approach even when significant riming produces ample quasi-spherical graupel.

S8.5

The robustness of cloud model predictions over different aerosol environments.

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12

Cloud physics models provide the means to test our understanding of aerosol-cloud interaction against the real world. When a model is shown to be a reasonably faithful reproduction of real clouds we consider the model to be "validated" and therefore useful for making predictions about how clouds might change in a future climate. The evaluation of such a model is usually performed in terms of variables that describe the cloud state (cloud liquid water content, drop concentrations, cloud top height, for example) and in terms of model responses, such as how these variables respond to changes in aerosols or tropospheric humidity. A cloud physics model can be described as robust if when tuned to agree with observations in a particular environment it can reliably predict cloud properties and responses in other environments.

In this study, we explore the robustness of the cloud physics model MAC3 in the prediction of the precipitation response to aerosol over different aerosol concentration environments. The model is highly complex, with many uncertain processes, and so it is entirely plausible that within these uncertainties there are different model "variants" that lead to different conclusions. We evaluate this by selecting a set of model variants that display a particular precipitation response to aerosols in one aerosol environment, and then using this subset of models to predict the precipitation response in other aerosol environments. We have found that despite essentially tuning the model tightly, the model has little reliability in predicting precipitation responses in different aerosol environments.

S8.6

Rapid Aggregation of Ice Particles explored using multiple-radar Doppler spectra

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5, 1, 16, Aggregation, Radar

Ice particle size distributions, their evolution and ice particle velocity-size relationships can be determined from multi-wavelength Doppler radar data. We use three, co-located, vertically pointing Doppler radars with wavelengths of 3.2mm, 8.6mm and 97.5mm, based at Chilbolton, UK. Because the radar return is a function of ice particle size and radar wavelength, and that different sized particles fall at different speeds, we can use the radar Doppler spectra from each of the radars to both size and quantify ice particles within clouds. High-resolution data from numerous case studies have been analysed to investigate processes such as aggregation and collect statistics on size distributions and velocity-size relationships.

The triple-wavelength Doppler spectra technique is able to provide a wealth of information; this presentation will summarize the Triple-wavelength Doppler spectra technique and the microphysical insights from applying this technique. We will use an example from one case of rapid aggregation of ice particles within cloud, apparently associated with the growth of dendritic crystals, to demonstrate the value of this technique for both understanding microphysical processes and cloud microphysical variability.

S8.7

Increased aerosol concentrations above the PBL impact on MCS stratiform precipitation

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8,12,14,1,4

Mesoscale convective systems (MCSs) are important contributors to regional rainfall as well as producers of severe weather such as flash-flooding. MCS precipitation can be characterized into two regions, convective and stratiform, which differ in dynamical properties, microphysical processes and precipitation rates. Previous numerical simulations of MCSs have found that increases in aerosol concentrations that serve as Cloud Condensation Nuclei (CCN) may impact the amount of precipitation produced by these two regions. Specifically, it can shift the dominant precipitation to be either convective or stratiform, depending on the environmental conditions, primarily available water vapor. This in turn impacts both the precipitation efficiency and the accumulation distribution of MCS precipitation, thereby affecting the likelihood for flash-flooding.

In this study, the sensitivity of precipitation produced by an MCS to increased CCN concentrations were examined by simulating a case study MCS using a cloud resolving mesoscale model, the Regional Atmospheric Modeling System (RAMS). Results from this study indicate that while aerosols had little effect on the total accumulated precipitation, higher CCN concentrations led to an increase in precipitation rates due an increase in convective precipitation and a decrease in stratiform precipitation. Parcel back-trajectory analysis within the stratiform-anvil region indicate that the decrease in stratiform precipitation was attributed to higher aerosol concentrations in both the planetary boundary layer (PBL) as well as the free troposphere due to the role of convective outflow and slantwise mesoscale ascent, respectively. An analysis of aerosol loading within these two air sources will be presented.

S8.8

KiD-A intercomparison: How sensitive are microphysics schemes to the representation of aerosol?

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12, 2, 1, 13

A major uncertainty in numerical weather prediction (NWP) and climate prediction is the response of clouds and precipitation to changes in aerosol concentrations. In order to investigate this uncertainty the Kinematic Driver model with Aerosol (KiD-A) intercomparison was established as part of the Global Atmospheric System Studies (GASS) microphysics project. The overarching aim of KiD-A was to use the Kinematic Driver model (KiD) to compare detailed and bulk microphysics schemes in a dynamically consistent framework, without the complication of dynamic feedbacks and numerical issues, to understand how such schemes simulate aerosol-cloud-precipitation interactions. The main aims are:

1. Undertake the first kinematic intercomparison of detailed microphysics schemes, i.e. size-resolved bin microphysics schemes, superdroplet schemes and 2D aerosol-cloud schemes
2. Examine and compare in-cloud aerosol processing from both detailed microphysics and bulk microphysical representations.

In this presentation we will show details of the KiD-A intercomparison and present results from the second and final round of submissions of 1D and 2D kinematic simulations. We will demonstrate the relative behaviour of current state-of-the art microphysics schemes when considering precipitation from simulations that are initialised with different aerosol concentrations and with and without aerosol processing.

S8.9

Validation of the 2-moment microphysical scheme LIMA based on HyMeX microphysical observations

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12.

Aerosol particles affect the cloud microstructure through their ability to nucleate droplets or ice crystals. They are also involved in complex processes and in many feedbacks impacting both the cloud physics and the cloud dynamics. Thus the LIMA scheme aims at representing at best the diversity of aerosol particles and their different properties regarding the nucleation and cloud system interactions at convective scale.

The 2-moment mixed-phase microphysical scheme LIMA was developed in the MESO-NH (Lafore et al. 1998) non-hydrostatic mesoscale research model. Aerosols are represented by 3D, prognostic number concentrations for as many modes as deemed necessary. CCN activation (Cohard et al. 1998), IFN nucleation (Phillips et al. 2008,2013) and radiative transfer explicitly depend on available aerosols properties and concentrations. This scheme will be introduced in an other presentation.

The HyMeX (Hydrometeorological cycle in Mediterranean Experiment) campaign provides a huge database of ocean-land-atmosphere observations.

Results from simulations run for HyMeX IOP6 and IOP16 cases of heavy precipitation will be shown. The cloud representation with both LIMA and the 1-moment scheme ICE3, is assessed in comparison to HyMeX microphysical observations, including airborne measurements from the Falcon20 (such as RASTA reflectivities and derived microphysical fields) and ground-based polarimetric radars. Aerosols impact both cloud and precipitation. Evidence of the microphysical feedback on cloud dynamics was found, through changes in convection intensity and the formation of a cold pool, which affect both the MCS development and the rainfall intensity and location.

S8.10

Aircraft observations and convection permitting model simulations of cold-air outbreak events

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Cold-air outbreaks occur when polar air masses sweep equatorwards bringing cold air over relatively warm water. This typically leads to large fluxes of heat and moisture from the ocean into the atmosphere and the subsequent formation of low-level mixed-phase stratiform clouds. These can then transition into more open cellular convection downwind. Recent studies show marked deficiencies in the Met Office Unified Models' representation of mixed-phase clouds during these cold-air outbreak events. There are however a distinct lack of in-situ observations available to both evaluate and to provide guidance on how to improve the model.

To address this a series of research flights on the FAAM BAe-146 aircraft to the north of the UK have been undertaken to provide comprehensive measurements of the boundary layer structure, turbulent fluxes and cloud properties in cold-air outbreak scenarios. The cloud microphysical observations show that within the stratiform region the clouds are largely composed of supercooled liquid water drops, but with intermittent pockets of ice embedded in the cloud layer. These ice particles rapidly grow large enough to precipitate below cloud base. Across the transition zone into the more open cellular convection ice concentrations were often found to increase and the precipitating regions became more widespread.

Convection permitting model simulations of these cases highlight that the model struggles to accurately capture the stratiform cloud, with too much ice, a low bias in LWP and often breaking up the cloud layer too early. Modifications to the model microphysics scheme are shown to improve the simulations.

S8.11

Airborne 4-Frequency Radar Measurements of Precipitation and Clouds During IPHEX and RADEX

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Key Areas in priority: 8, 3

NASA GSFC has is flying 3 nadir-looking, X- through W-band, Doppler radars on the high-altitude ER-2 aircraft: the High-altitude Wind and Rain Airborne Profiler (HIWRAP) at Ku and Ka-band [frequencies similar to Global Precipitation Mission (GPM) DPR], the W-band Cloud Radar System (CRS) [frequencies similar to the CloudSat], and the ER-2 X-band Radar (EXRAD). These radars have flown in the Integrated Precipitation and Hydrology Experiment (IPHEX) in the Southeast U.S. during 2014, and in the Radar Definition Experiment (RADEX) off the west coast of Washington State in 2015. IPHEX was sponsored by the Global Precipitation Mission (GPM) and RADEX was sponsored by the NASA Aerosol Cloud Ecosystem (ACE) Decadal Survey study for which a dual-frequency Ka-W-band radar is in planning stages. The ER-2 4-frequencies are used to develop consistent cloud and precipitation retrieval algorithms as well as to expand the dynamic range (i.e., particle size) of the retrievals. There were a total of 15 (12) science flights during IPHEX and RADEX that measured a variety of land-based and oceanic precipitation, convection, and orographic precipitation.

This presentation will provide a history and description of the ER-2 radars and examples of from moderate and deep convection with hail during IPHEX. We will then discuss the general precipitation and updraft properties of the convection from the 4-frequency measurements. Early results from hydrometeor properties retrieved from the observations will then be presented. Finally, we will show preliminary results from orographic rain/snow cases during RADEX.

S8.12

Constraining precipitation susceptibilities of warm, ice- and mixed-phase clouds with microphysical equations

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12 1 4 5 13

The strength of effective anthropogenic climate forcing from aerosol-cloud interactions is related to the susceptibility of precipitation to aerosol effects. Precipitation susceptibility $d \ln(P) / d \ln(N)$ has been proposed as a metric to quantify the effect of aerosol-induced changes in cloud droplet number N on warm precipitation rate P . Based on the microphysical rate equations of the Seifert & Beheng 2-moment bulk microphysics scheme, we estimate susceptibilities of warm, ice- and mixed-phase precipitation and cirrus sedimentation to cloud droplet and ice crystal number. We take into account microphysical adjustments to the initial perturbation in N . For warm rain, we find $d \ln(P) / d \ln(N) < -2 \text{ aut} / (\text{aut} + \text{acc})$, which depends on the rates of autoconversion (aut) and accretion (acc). The precipitation susceptibility of cirrus clouds is given by the exponent of crystal sedimentation velocity and thus around -0.2. For mixed-phase clouds, we identify several microphysical contributions that explain low precipitation susceptibilities: (i) Due to the larger hydrometeor sizes involved, mixed-phase collection processes are less sensitive to changes in hydrometeor size. (ii) Only a subset of precipitation formation processes is sensitive to droplet or crystal number. (iii) Effects on collection processes and diffusional growth compensate. (iv) Adjustments in cloud liquid and ice amount compensate the effect of changes in ice crystal and cloud droplet number. (v) Aerosol-perturbations that simultaneously perturb ice crystal and droplet number have opposing effects.

S8.13

Improving fog diagnosis in the Met Office's operational forecast model

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Met Office, Cardington, UK

7,17

This presentation describes improvements to fog prediction in the Met Office's Unified Model, achieved by redesigning a sub-model that diagnoses visibility from the fields of pressure, temperature, specific humidity and aerosol concentration. This visibility sub-model relies on a Köhler curve to hydrate dry aerosol particles to be in equilibrium with the environmental humidity. If sufficient water is available, the particles activate into water droplets forming fog. The scattering coefficient of the hydrated aerosol is computed employing simple geometric optics.

Analysis shows the hydration scheme is extremely sensitive to the modelled humidity when conditions are on the threshold of fog forming, to the extent that the diagnosed visibility can be an order of magnitude either too low or too high. Noise on the temperature and humidity fields is sufficient to induce this undesirable binary behaviour. The cause of this problem can be traced to the nonlinear hydration scheme using a monodisperse aerosol population. This simplification, although computationally expedient, dictates either all or none of the particles activate into water droplets.

An extension of the hydration scheme exploiting a polydisperse aerosol population improves the resilience of the visibility scheme to noise on the temperature and humidity fields. An aerosol population comprising particles of differing sizes and hygroscopy generates a multitude of hydration products, with intermingled fog droplets and unactivated particles. Incorporating an ensemble of hydrated aerosols requires an attendant upgrade to the scattering treatment, and implementing Mie scattering further improves the diagnosis of visibility across the range from fog to haze.

S8.14

Implementation of a triple-moment modal parameterization for simulating ice crystal growth habit effects on cloud and precipitation during DIAMET

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key area numbers: 1, 4

Ice crystal shape effects on cloud microphysics remain an unresolved issue. This study incorporated a newly developed three-moment modal parameterization with pristine ice crystal shape representation into the WRF model version 3.5.1. This modal scheme allows gradual adaptation of ice crystal habits under varying environmental conditions and thus keeps previous memory of shape. A mid-latitude cold front case on 29 November 2011 during the field campaign of DIAbatic influences on Mesoscale structures in Extra Tropical storms (DIAMET) conducted in the United Kingdom was selected for simulation and compared with aircraft observations. Main features of the narrow rain band and embedded precipitation cells in the cold front were well captured by the model. Also, the vertical profiles of ice crystal properties, including ice particle number concentrations and ice crystal aspect ratios, agreed reasonably with observations especially within the temperature region of secondary ice production. By comparing with simulations that assumed spherical ice particles, the simulation showed that ice crystal shapes have strong influence on these microphysical properties.

S9.1

Understanding Tropical Cloud Feedback from an Analysis of the Circulation and Stability Regimes Simulated from an Upgraded Multiscale Modeling Framework

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9

13

17

S9.2

HAIC/HIWC field project: ice crystal mass-size relationship in high ice water content cloud conditions

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8

Keyword : ice crystals

Two recent HAIC (High Altitude Ice Crystals) / HIWC (High Ice Water Content) field campaigns in Darwin (2014) and Cayenne (2015) provide a unique opportunity to explore the complex relationship between cloud particle mass and size in the ice crystal environments. Numerous mesoscale convective systems (MCSs) were sampled with the French Falcon 20 research aircraft at different temperature levels from -10°C up to 50°C. The aircraft instrumentation included an IKP-2 (isokinetic probe) to get reliable measurements of the total water content (TWC) and the optical array probes 2D-S and PIP recording images of the ice crystals.

The study presented here focuses on ice crystal properties, thereby analyzing in detail the 2D image data from 2D-S and PIP optical array imaging probes to compute number particle size distributions (PSD), parameters α and β of the mass-size relationship $m=\alpha D^\beta$, and median mass diameters (MMD) from mass PSD. Results show that ice crystals properties are quite different in high IWC areas compared to the surrounding cloud regions. Most of the sampled MCS reveal that the higher the measured IWC, the smaller are the corresponding crystal MMD. This effect is overlaid by a temperature trend with colder temperatures leading to smaller MMDs. Finally a parameterization method to retrieve TWC from only the 2D images is presented and tested. The comparison with the observed TWC measurements from IKP-2 shows that this method is able to predict TWC values larger than 0.3 g/m³ with an error close to 20%.

S9.3

On the vertical structure of IWC and 3D wind in deep tropical convection observed during the HIWC-HAIC-experiment at Darwin: a comparison of small scale, bin resolved cloud modeling with airborne cloud radar observations

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From January to March 2014, the HIWC-HAIC experiment took place over Northern Australia. Numerous flights were performed in convective clouds at 10 and 11 km altitudes. The French research aircraft (Falcon 20) was equipped with a 95 GHz Doppler Radar (Rasta) providing profiles of cloud reflectivity and 3D wind components from the surface up to 18 km.

These observations were confronted with model simulations of the bin resolved cloud scale model Descam. The model was run with a resolution of 500 m in the horizontal direction and 200 m in the vertical up to 20 km. Individual cells observed were compared with respect to updraft speed, reflectivity and IWC. Contoured frequency with altitudes diagrams (CFAD) were plotted for each individual flight case, which typically lasted 2 to 3 hours. The same technique was applied for the simulation results. Agreements and discrepancies of this intercomparison will be discussed. A projection of the model results to the regions of strongest convection not accessible to aircraft measurements will also be presented.

S9.4

Ice Particle Initiation and Development in Tropical Convective Clouds around the Cape Verde Archipelago

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3, 4, 12, 14

Airborne measurements of tropical maritime convective clouds around Cape Verde were conducted during summer 2015 as part of the Ice in Clouds Experiment - Dust (or ICE-D). The U.K. BAe-146 large Atmospheric Research Aircraft was equipped with a suite of instruments (including a Two Dimensional Stereo (2D-S) shadow imaging probe, a Cloud Droplet Probe (CDP) and a Passive Cavity Aerosol Spectrometer Probe (PCASP)) to measure cloud microphysical properties and the characteristics of dust particles advected into the region from the African continent. The cloud base temperature of these clouds was significantly higher than 0°C, with the warm rain process playing a significant role in precipitation generation. Many of the clouds also extended above the freezing level and in this paper we focus on the role of aerosol particles including dust as Ice Nucleating Particles (INPs) in the formation of the first ice in these clouds, together with the subsequent explosive glaciation in some of the convective turrets through the production of secondary ice particles. Evidence from the 2DS instrument suggests that a number of secondary ice processes are taking place at slightly supercooled temperatures in these tropical maritime convective clouds including: rime-splintering; fragmentation of large drizzle drops during the freezing process and collision of small columnar ice crystals with supercooled drizzle.

S9.5

Effects of microphysical processes on the aggregation of convective clouds and the evolution to a tropical cyclone

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Cyclone Pam (2015) in the southern Pacific in March 2015 caused severe damages over the islands states. Cyclone Pam, a category-5 storm, was originated from an active convective region in the Madden-Julian oscillation (MJO). In evolving from convective clouds into a tropical cyclone, diabatic heating processes due to cumulus convective clouds play one of the key roles. Thus, this study numerically investigated the effects of microphysical processes on the aggregation of convective clouds and the evolution to Cyclone Pam with the WRF model. The sensitivities to the microphysical schemes, a single-moment scheme (WSM6), and double-moment schemes (the Thompson and the Morrison scheme), were investigated by performing nested regional simulations at 6- and 2-km horizontal resolutions. The numerical simulations successfully reproduced the eastward propagation of the MJO in the outer domain. In the southern part of the convective active region of the MJO, the aggregation of convective clouds in the inner domain was overall simulated in the same way with the three different microphysics schemes. A difference was found in the point that the most sophisticated (M) scheme produced wider-spread areas of convective cells than the other two schemes. This difference plays a relatively minor role in aggregating convective clouds in the initial stage. However, this small difference affects the temporal evolution from the convective aggregation into a tropical storm, which results in slower evolution and a weaker storm in the M scheme. Microphysics processes affects the diabatic heating and therefore the evolution of tropical convection into a tropical cyclone.

S9.6

Observed relationships between cloud vertical structure and convective aggregation over tropical ocean

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9. "Tropical clouds", 15. "Clouds and climate", Other: "CloudSat", "CALIPSO", "convective aggregation"

In the tropics, mean rainfall and convective activity are intrinsically linked. Increases in tropical rainfall can be associated with a shift to more frequent organized convection, consistent with a warming climate. Understanding the mechanism for self-aggregation of convection in the tropics is critical for climate projection. Simulations of idealized radiative-convective equilibrium have been the principal tool to investigate the radiative feedback and net surface fluxes. Here, we present observational evidence to underpin results from these simulations.

Using the Simple Convective Aggregation Index (SCAI) developed in Tobin et al. (2012), we composit five years of CloudSat-CALIPSO cloud profiles on conditions with similar large-scale forcing but different levels of aggregation. For a given average precipitation rate, there is a significant decrease in anvil cloud and increase in clear sky and low cloud as aggregation increases (and SCAI decreases). However, the changes in anvil are proportional to the changes in total cold cloud area, which is positive correlated with SCAI. Interestingly, the increase in clear sky and low-level cloud cover with increasing aggregation occurs in both an absolute sense and as a fraction of [1-CCA]. Overall, the cloud vertical structure depends more on SCAI than on rainfall rate. These results confirm the existence of convective states with the same precipitation rate and similar large-scale forcing but different amounts of environmental moisture, high and low cloud, and clear sky.

Tobin, I., Bony, S. and Roca, R. (2012) J. Climate, 25, 6885-6904.

S9.7

Lagrangian and Eulerian Evolutions of the Tropical Column Humidity-Precipitation Relationship

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[9,8]

The observed and simulated mean relationship between column relative humidity and precipitation intensity in the maritime tropics has received considerable attention for its consistency and useful predictive skill but lacks a cloud process-level explanation. Previously, this relationship and its evolution has only been examined in a horizontally stationary or "Eulerian" sense which fails to capture fully the maturation of precipitating systems as they advect horizontally. Here we move beyond the traditional Eulerian approach to a "Lagrangian" one in which clouds of different types are tracked in time and space. First, tracking codes are developed for temporally finely-spaced cloud resolving model output. The Lagrangian tracker identifies individual clouds in four dimensions from the simulation and records pixel-level environmental characteristics and size information for these clouds. To compare the Eulerian and Lagrangian methods, a direct comparison is made by interpolating both clouds onto a uniform time-grid to form a prototype evolution. It is shown that Eulerian framework underestimates the magnitude and rapidity of the evolution of the precipitation-humidity relationship. Only with a Lagrangian approach are all phases of every storm well captured. This is due to the rapid horizontal translation of the storm centroid during the storm decay phase and wide spatial coverage of potentially terminal shallow convection. Uniquely, the Lagrangian framework suggests that humidity in shallow and stratiform clouds responds to precipitation intensity while the precipitation responds to humidity in deep convection. This allows for attribution of the precipitation-column humidity relationship to specific cloud processes and dynamics.

S9.8

Processes controlling the diurnal cycle of moist convection in the West African Sahel

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8. Mesoscale cloud systems (including severe storms)
9. Tropical clouds
3. Convective clouds (including cloud electrification)

Deep convection and mesoscale convective systems (MCSs) are integral components of the West African Monsoon. The diurnal cycle in rainfall features a minimum around noon and a peak at sunset. It is known that storms tend to initiate in the afternoon and evening and MCSs persist through the night, but mechanisms underlying this diurnal cycle are poorly understood and poorly represented by global models. Observational data, gathered during the AMMA (African Monsoon Multidisciplinary Analysis) campaign, together with Unified Model simulations, are used to study this diurnal cycle. The evening peak in initiations is consistent with daytime heating reducing convective inhibition. The nocturnal monsoon flow, and the embedded low-level jet (LLJ), bring moisture, increasing CAPE above the nocturnal stable layer, which MCSs exploit. Furthermore, the LLJ provides favourable conditions for MCSs by enhancing environmental shear to balance the vorticity of the MCS's cold pools. The nocturnal monsoon flow and the LLJ allow moisture flux convergence (MFC) into storms to increase through the night, generating a secondary rainfall maximum around dawn. After sunrise, boundary-layer (BL) mixing erodes the LLJ, providing less favourable shear and decreasing MFC, and entraining dry air into the BL, decreasing CAPE: all three of these processes combine to provide the rainfall minimum around midday. The results demonstrate the importance of capturing the nocturnal LLJ and its interactions with organised moist convection for modelling Sahelian rainfall and the monsoon.

S9.9

Do deep convective water budgets change in a warmer climate?

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3, 9, 13

Tropical convection is an important driver of the climate system, through production of precipitation, transport of water and heat, and interactions with radiation and large scale circulations. It has been seen that these roles of deep convection may be dependent on sea surface temperature in nonlinear and perhaps unexpected ways. Studies have suggested that with a warmer tropical ocean, convective strength may increase, though the larger scale circulations weaken. From stronger convective storms follows colder cloud tops and more intense precipitation events, though reduced anvil cloud coverage has been seen with warming, suggesting a possible increase in the precipitation efficiency of deep convective clouds. Central to the understanding of these interactions is being able to quantify the fluxes of water both vertically in storm updrafts and horizontally to stratiform anvil clouds and the surrounding environment through detrainment.

We examine changes in convective properties, including transport of water and precipitation production, with increasing sea surface temperature. This is accomplished with a cloud resolving model, using simulations of the tropical atmosphere in a radiative convective equilibrium framework. By examining differences in the characteristics of deep convective clouds with increased sea surface temperature, we can gain understanding to help constrain the role of convection in changing precipitation and circulations in a warming climate.

S9.11

An integrated view of aerosol effects on convection

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12, 3, 13

Atmospheric convection, its representation in climate models and its response to anthropogenic perturbations remains arguably one of the greatest uncertainties in our understanding and prediction of the climate system. In particular, the response of convective clouds to aerosol perturbations remains poorly understood. Current assessments tend to focus on either detailed process studies, the analysis of satellite data or high-resolution cloud modelling with limited synergies between approaches (or in fact communities).

In this work we aim to deliver an integrated view of aerosol effects on deep convection maximising synergy between process studies, satellite data and cloud resolving modelling to constrain aerosol-convection interactions in a global climate model. We conduct detailed case studies for Congo Basin and the Amazon using high resolution WRF simulations and will confront them with observational constraints from i) polar orbiting satellites, such as pdfs of cloud top heights from CALIOP and CloudSat, ii) time-resolved SEVIRI data from a geostationary satellite to provide new insights into the morphology and diurnal cycle of convection and iii) remote sensing and in-situ observations for the GOAMAZON campaign. We use automated tracking of individual convective cells in SEVIRI data to investigate the convective lifecycle and complementary co-located data from MODIS to provide context about the aerosol conditions.

This synthesized view of aerosol-convection interactions is employed to evaluate and constrain aerosol effects on convection in the global aerosol climate model ECHAM-HAM extended by the convective cloud field model (CCFM), an aerosol aware spectral cumulus parameterisation with explicit cloud microphysics.

S9.12

Quantifying aerosol effects on deep convection throughout the cloud lifecycle in high-resolution simulations over the Amazon and Congo basin

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12, 3, 1

Aerosols, acting as cloud condensation nuclei (CCN, IN), affect deep convection through influencing cloud and precipitation microphysics over a wide range of spatiotemporal scales. Recent theoretical and modelling studies have indicated that aerosol-induced precipitation suppression in the warm phase may invigorate deep convection. However, observational evidence has yet to confirm this hypothesis outside of factors such as synoptic covariability, retrieval errors and sampling artefacts, all of which may dominate the observed relationship between satellite-retrieved aerosol and cloud properties.

In this study, we perform high-resolution convection-permitting simulations using the WRF model. We use spectral bin microphysics with a prescribed initial CCN profile (Khain et al., 2011, Iguchi et al., 2012). In the default setup, CCN activation is described using Koehler theory, but aerosol-cloud feedbacks such as wet scavenging remain unaccounted for. We couple the WRF spectral bin microphysics to a simple CCN recycling scheme, giving a more sophisticated representation of aerosol-cloud interactions without the expense of full coupled chemistry.

We use this setup to perform high-resolution simulations in two regions of intense convective activity and significant biomass burning aerosol emissions: the Amazon and the Congo basin. Through detailed analysis of microphysical process rates, we investigate the effect of aerosol perturbations on cloud and precipitation morphology throughout the cloud lifecycle. In the Amazon region we evaluate the model against observations from the GOAMAZON campaign. We also provide the first comments on the convective response to aerosol in the Congo basin, a region with few in-situ observations.

S9.13

Biomass Burning Aerosol Detection in Near Real-Time: An algorithm to aid mission planning in the field

Michael Diamond, Rob Wood
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12/13/16/17

The interactions between clouds and aerosols remain the largest source of uncertainty in quantifying the anthropogenic influence on Earth's climate system. In particular, absorbing aerosols (AA) — black and brown carbon — present the challenge of disentangling direct, indirect, and semi-direct effects of varying magnitudes and directions. Recognising the importance of understanding how AA species and their interactions with clouds affect climate, a number of new campaigns will study the effects of AA due to biomass burning in western and south-western Africa, including: Nasa's ORACLES (ObseRvations of Aerosols and CLOUDs and their intERactionS) from 2016-2018, the U.S. Department of Energy's LASIC (Layered Atlantic Smoke Interactions with Clouds) deployment in 2016-2017, and the Facility for Airborne Atmospheric Measurements's CLARIFY (CLOUDs and Aerosol Radiative Impacts and Forcing) in 2016.

We develop an algorithm that uses MODIS Near Real-Time (NRT) data to compute a proxy for biomass burning aerosol above clouds. Whereas clean clouds should reflect red and blue light in similar proportions, the addition of aerosols above clouds should increase the amount of red light scattered relative to blue light. By removing the unpolluted signal, the residual red:blue colour ratio can be used to identify high aerosol loading over a region within 3-4 hours of the passage of the Terra and Aqua satellites. The efficacy of our product is tested using CloudSat/CALIPSO data in a number of biomass burning regions and with observations from the CSET (Cloud Systems Evolution in the Trades) campaign recently completed in the southeast Pacific Ocean.

S9.14

Microphysical Properties of TTL Cirrus

Sarah Woods¹, Paul Lawson¹, Eric Jensen², Paul Bui², Troy Thornberry³, Andrew Rollins³
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5.

Pervasive cirrus clouds in the Tropical Tropopause Layer (TTL) play an important role in determining the composition of stratospheric air through dehydration of tropospheric air entering the stratosphere. This dehydration affects Earth's energy budget and climate, yet little is known regarding the microphysical processes that govern TTL cirrus. Over 30 hours of TTL cirrus were sampled with the NASA Global Hawk UAS in the western Pacific in 2014 during the Airborne Tropical Tropopause Experiment (ATTREX). In situ measurements made by a Fast Cloud Droplet Probe (FCDP) and Hawkeye onboard the aircraft provide particle concentrations and sizing between 1 and 1280 μm as well as high resolution cloud particle images for habit identification. We present the variability in ice concentrations, size distributions and habit as functions of temperature, supersaturation with respect to ice, and time since convective influence. Supporting measurements of water vapor from the NOAA instrument and pressure and temperature from MMS are used to derive estimates of supersaturation with respect to ice, which demonstrates good correlation with cloud particle observations. Observed ice particles were predominantly spheroidal in shape, with the percentage of spheroids increasing with decreasing temperature. In comparison to the large population of spheroids, the faceted habits (columns, plates, rosettes, and budding rosettes) were found in generally low percentages, and also show correlation with temperature. The trend showing higher percentages of faceted crystals at warmer temperatures may be due to diffusional growth as particles descend through cloud, and/or the more rapid diffusional growth rate at warmer temperatures.

S9.15

Characterization of ice particles in TTL cirrus using 2D light scattering

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9, 5, 13, 16, tropical tropopause

The UK CAST campaign, linked to NASA ATTREX, was focused on in situ observations of the Tropical Tropopause Layer (TTL). A new version of the Small Ice Detector probe called AIITS was developed for CAST at University of Hertfordshire and flown on the NASA Global Hawk high-altitude aircraft. AIITS provided unique data on TTL ice, for the first time showing fine detail of particle geometry. During a flight over eastern Pacific on 5th March 2015 cirrus layers adjacent to the TTL, formed away from deep convection, were sampled at temperatures between 190 and 205K. Data from AIITS indicates that a significant proportion of the ice particles were rounded, with small levels of irregularity. Surprisingly, the rounded particles were present at all saturation ratios, up to nearly the homogeneous nucleation level. These results substantially refine previous observations, based on lower resolution imaging techniques, and typically indicating a mix of faceted and "quasi-spheroidal" particles. However, the latter have until now been presumed to be irregular, by similarity to higher latitude and/or lower altitude ice. The importance of these findings lies in the impact on the scattering properties of TTL cirrus, as represented in climate and weather models, but also in remote sensing retrieval algorithms. Most notably, the presence of rounded ice may shift radiative forcing towards positive values, as such particles tend to have higher asymmetry parameters than "irregular" particles of similar size.

S9.16

Bimodality and variability of particle size distributions in high Ice Water Content regions and their relation to cloud and meteorological conditions

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During Phase I of the High Altitude Ice Crystals / High Ice Water Content (HAIC/HIWC) project conducted out of Darwin, Australia (January - March 2014) a 2-D Stereo (2DS) probe, Precipitation Imaging Probe (PIP) and Isokinetic Evaporator Probe (IKP2) were installed on the French Falcon 20. From these data composite particle size distributions (PSDs) using a combination of the 2DS and PIP data have been derived for each 5 seconds of time. Using an automated technique to identify multiple modes in PSDs and an Incomplete Gamma Fit (IGF) technique, fits to gamma distributions have been performed to derive the intercept (N_0), slope (l) and shape parameters (m) of each mode.

This presentation summarizes how the PSD fit parameters measured in conditions with Ice Water Contents (IWCs) greater than 1.5 g m^{-3} vary with cloud and environmental parameters. Principal findings are: 1) larger m and N_0 are found when flying into high IWC regions while l tends to remain unchanged; 2) instances of both positive and negative correlations between IWC and median mass diameter (MMD) in high IWC regions were found, with cases of positive correlations usually associated with larger m and smaller N_0 ; and 3) bimodal distributions were more frequently found in positive correlation cases. It is also shown that the positive correlation cases are more likely to be associated with longer-aged clouds, but there are exceptions, showing other factors affect the occurrence of frequent small particles in high IWC regions. Implications for modeling of high IWC events are discussed.

S10.1

Airborne observations of Antarctic clouds during the 2015 MAC field campaign

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4, 10, 14

Antarctic clouds are vital to climate predictions at the high southern latitudes. They play a key role in the mass balance of the Antarctic ice sheet and impact lower latitudes by affecting the North-South temperature gradient through their radiative effect. Despite this clouds in Antarctica remain some of the least well studied of any region around the globe.

As part of the Microphysics of Antarctic Clouds (MAC) field campaign, detailed airborne in situ measurements of cloud and aerosol properties were made over the Weddell Sea and Antarctic coastal continent. Twenty-four flights were performed during November and December 2015 using British Antarctic Survey's Twin Otter research aircraft from the Halley station.

This paper will present the first results from this campaign and discuss the cloud properties and processes important in this region. The clouds were often found to be dominated by supercooled liquid water droplets with varying but generally much smaller numbers of ice particles. The observed clouds will be investigated in terms of their phase, air mass history and local aerosol properties (including sources of CCN and IN). The suitability of different primary ice parameterisations to these clouds and the possible presence of secondary ice processes will be examined. Finally, these measurements will be contrasted with similar ones made in Arctic regions as part of the ACCACIA campaign.

S10.2

In-situ observations of "warm ice" over the Southern Ocean

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10 and 4

The prevalence of supercooled liquid water (SLW) as recorded by various satellite observations has been found to be a remarkable feature over the remote Southern Ocean (SO). The underrepresentation of SLW in climate models is hypothesized to be a major contributor to the large simulated radiative bias in this region (Bodas-Salcedo et al. 2016).

An effort has been made to better understand the thermodynamics and microphysical properties of clouds over this measurement-sparse area. In-situ observations were undertaken with a lightly instrumented Hydro Tasmania aircraft under a variety of synoptic conditions off the coast of Tasmania, Australia.

Here, we detail a wintertime research flight during which shallow (~2500m) convective clouds were observed within in a post-frontal environment. The cloud-top temperature was ~ -6° C. The thermodynamics phase of these clouds varied from primarily glaciated to mixed phase to SLW. Ice particles with relatively high concentration were observed at relatively warm temperatures (~-5°C) within and below cloud. The formation of "warm ice" is exceptional given the pristine environment where ice nuclei are considered to be lacking.

The synoptic condition of this case was rather common with a relatively strong southwesterly winds (15-20 m/s) observed at sampling levels. Analyses of back trajectories indicate no obvious history of continental influence on aerosol transport, suggesting a potential oceanic source of ice nuclei. In-situ measurements are combined with the coincident A-Train satellite observations and numerical modeling to further examine the cloud properties, which help understand the formation of warm ice over the SO.

S10.3

In-situ observations of the effect of precipitation on wintertime low-altitude clouds over the Southern Ocean

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10, 2, 17

Cloud microphysical properties such as droplets number concentration (N_d) and effective radius (r_{eff}) are necessary to define both the short-wave scattering and the precipitation of these clouds. Previous research (e.g. Gultepe and Isaac 2004; Wood 2012) have noted the inherent relationship between precipitation and these cloud properties; in general precipitating clouds are characterized by a larger r_{eff} and smaller N_d .

An understanding of this relationship is critical over the Southern Ocean, a region dominated by high fractional cloud cover (~87%) with frequent precipitation/drizzle. This region is further defined by the frequent occurrence of supercooled liquid water, and a persistent bias in the simulated shortwave radiation budget.

Employing the lightly instrumented Hydro Tasmania cloud seeding aircraft, 20 flights taken over the course of three winters (2013-2015) have been analysed to examine the sensitivity of cloud microphysical properties to the presence of precipitation. Observations were made under a variety of synoptic conditions to extend those made during the Southern Ocean Cloud Experiments (SOCEX I & II; 1993, 1995). Two of these flights recorded relatively high N_d , as recently reported in Chubb et al. (2016).

These in-situ observations are employed to evaluate Moderate Resolution Imager Spectroradiometer (MODIS) satellite products, where available. A few flights were made directly under A-train overpasses to examine the retrievals of these properties from a set of radar-lidar products.

S10.4

What is the role of sea surface temperature in modulating cloud and precipitation properties over the Southern Ocean?

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10, 4, 13

Large solar radiation biases over the Southern Ocean (SO) have been a long-standing problem in climate models and reanalysis products. Recent research highlights the underrepresentation of supercooled liquid water (SLW) in contributing to the simulated solar radiative bias over this region. Built on previous work, this study uses 4-year collocated A-Train satellite observations to further investigate cloud and precipitation characteristics in relation to the underlying SO.

Results show that liquid-phase cloud properties exhibit a strong correlation with the sea surface temperature (SST). In summer, ubiquitous SLW is observed over SSTs < 4°C. Cloud-top temperature (CTT) and effective radius of liquid-phase clouds generally decrease towards colder SSTs, whereas the opposite trend is shown for cloud optical thickness and liquid water path. Geographical sector differences are also noticed. In addition, two distinct liquid-phase cloud types are discovered as a function of SST: over the warm water (SSTs > ~7°C) cloud droplet size appears to increase with decreasing CTT, while over colder SSTs the opposite trend is observed. The unique cold water cloud type is virtually absent over the Northern Hemisphere storm-track regions, where the SSTs are generally warmer than 7°C. This contrast underpins the need to further explore the cold SST SO (and associated aerosol and boundary layer characteristics) to better understand the outstanding model biases.

Our study also suggests that precipitation remains poorly observed over the SO with the current generation of spaceborne sensors. Large uncertainties are associated with the ubiquitous boundary layer clouds within the lowest kilometer.

S10.5

A newly identified sea salt aerosol source over sea ice - modeling vs observation

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key area 14 and 10

Blowing snow over sea ice, through a subsequent sublimation process of salt-containing blown snow particles, has been hypothesized as a significant sea salt aerosol (SSA) source in high latitudes. This mechanism has been strongly supported by a winter cruise in the Weddell Sea (during June-August 2013). The newly collected data, including both physical and chemical components, provide a unique way to test and validate the parameterisation used for describing the SSA production from blowing snow events. With updates to some key parameters such as snow salinity in a global Chemistry-transport model pTOMCAT, simulated SSA concentrations can be well compared with measured SSA data. In this presentation, I will report modeled SSA number density against collected data on board of Polarstern ship during the Weddell Sea cruise, as well as modeled SSA massive concentrations against those measured at both coastal sites such as Alert in the North and Dumont d'Urville (DDU) in the South and central Antarctic sites such as Concordia and Kohnen stations. Model experiments indicated that open ocean-sourced SSA could not explain the observed winter SSA peaks seen in most polar sites, while with sea ice-sourced SSA in the model, the winter peaks can be well improved indicating the importance of sea ice-sourced SSA as a significant contributor to the salts (Na^+ , Cl^-) recorded in the ice core. This newly identified sea salt source on sea ice could potentially act as a large source of ice nuclei and cloud condensation nuclei in high latitudes.

S10.6

Satellite Insights into the Influence of Mixed-Phase Clouds on the Arctic Climate

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4, 13

Observations from active sensors aboard polar orbiting satellites have yielded valuable new insights into the character and impacts of clouds and precipitation in polar regions. Prior to these observations, evidence of the importance of super-cooled liquid containing clouds in the Arctic climate was limited to ground-based observations on local scales. Recent analyses of CloudSat and CALIPSO datasets have confirmed the importance of these clouds in modulating surface properties across the entire Arctic. This presentation will summarize recent efforts to quantify the radiative impacts of Arctic clouds and probe the elusive relationships between the presence of super-cooled liquid water, falling snow, and surface energy and mass balance poleward of 60°N. It is found that emission from super-cooled liquid accounts for up to half of the enhanced downwelling longwave radiation from cloud cover over snow and ice covered surfaces. Current climate models appear to significantly under-estimate the frequency of occurrence of super-cooled liquid in the Arctic and, therefore, likely under-estimate enhanced surface warming owing to enhanced cloud emission. Simultaneous observations of falling snow from CloudSat further suggest that climate models over-estimate snowfall frequency and accumulation across the Arctic hinting that model cloud biases may be partially linked to the overly efficient removal of liquid water by falling snow.

S10.7

Characterization of Arctic mixed phase clouds at regional and small scales

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¹*LaMP, Université Blaise Pascal, Clermont-Ferrand, France*, ²*LATMOS, Université Versailles-St Quentin, Guyancourt, France*

4,16,13

Previous observations suggest that Mixed Phase Clouds (MPC) occur frequently in the Arctic and often persist for many days due to a combination of local processes (microphysical and radiative for instance) and larger scale meteorological conditions. These low-level liquid containing clouds exert a large influence on the surface radiative fluxes and feedbacks on Arctic climate. However, understanding the spatial phase distribution within MPC remains a challenge.

In this study, the MPC macrophysical and microphysical properties are investigated at a regional scale using CloudSat and CALIPSO observations (2007-2010) and at smaller scale with airborne in situ measurements performed in the Svalbard region.

Results show that MPCs have a mean frequency of occurrence ranging from 30% (end of winter) to 55% (in autumn) in the Arctic. In the Svalbard region, the frequencies of occurrence are significantly higher with values ranging from 45% to 60%. MPCs are especially located at low altitudes, below 3000m, where their occurrence reaches 90%, particularly in winter, spring and autumn. Moreover, results highlight that MPCs are statistically more frequent over open sea than sea ice or land. These observations also allow us to assess how already performed small scale airborne measurements are representative of the variety of clouds encountered in the Arctic. In situ measurements (44 vertical profiles obtained during ASTAR, POLARCAT, SORPIC) are statistically analyzed to derive representative profiles of MPC microphysical and optical properties (optical depth, liquid/water fraction, ice crystals habit). These analyses should contribute to a better understanding of processes occurring in arctic MPC.

S10.8

Aircraft observations of arctic stratus clouds and clouds in arctic air outbreaks over the sea

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4,1 Arctic clouds, mixed phase clouds

The microphysics and dynamics of arctic layer cloud is central to understanding the radiation balance in that region. Further the evolution of these clouds as they pass over a warmer ocean is important to weather forecasting in middle latitudes.

To address this a series of flights on the FAAM BAe-146 research aircraft were performed during the winter season to the north of the UK and over the arctic ice as part of the ACCACIA and PIKNMIX campaigns making detailed measurements of the boundary layer structure, and cloud properties. The cloud microphysical observations show that over the arctic ice the clouds are dominated by super cooled water droplets and a few ice particles. Primary nucleation of ice leads to a few ice particles forming which grow and precipitate but generally they have little impact on the water budget of the cloud. The evidence suggests that dust particles are the likely source of the Ice Nucleating Particles. As air moves over the ocean the main effect is that the clouds become deeper with higher liquid water contents and initially similar ice crystal concentrations. This leads to the generation of super cooled drizzle by collision coalescence. These particles freeze leading to the initiation of secondary ice processes. These processes are explored as is their role along with drizzle and entrainment in determining the water budget and evolution of the cloud

S10.9

Large eddy simulations using immersion-freezing ice nucleation in coupled sub-Arctic mixed-phase clouds

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4

Models on various scales are notoriously poor at reproducing the persistent, mixed-phase stratocumulus (MPS) clouds commonly observed in the Arctic. As the ice phase is critical to precipitation formation, the treatment of its origin and development is critical to understanding these clouds. The ubiquity of MPS with cloud top temperatures between -25°C and -10°C may suggest the inefficiency of deposition ice nucleation in this regime, whilst inferring the importance of liquid-based nucleation modes, such as immersion-freezing. More generally, this suggests that ice nucleation parameterisations used in mid-latitude clouds may not always be applicable to the Arctic.

This study utilises the Large Eddy Model (LEM) - a cloud-resolving model from the UK Met Office - to replicate observations from the European sub-Arctic in order to establish a realistic treatment of cloud ice formation in this region. Cloud microphysical data from the Aerosol Cloud Coupling and Climate Interactions in the Arctic (ACCACIA) campaign are used for comparison with the model. Conducted in 2013, detailed airborne measurements of cloud structure over sea-ice, marginal ice and ocean were collected. Simulations employing different primary ice nucleation modes were performed to investigate which yields the best comparison to the cloud observations, taking account of the microphysical processes in the cloud. Significantly, the ability of the model to achieve this was strongly dependent on the presence of liquid-water within the cloud and whether the modelled cloud was coupled to or decoupled from a surface heat source.

S10.10

Arctic Aerosol-Cloud Interactions during ASCOS

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Key areas: 4, 12

Future decreases in Arctic sea ice are expected to increase fluxes of aerosol and precursor gases from the open ocean surface within the Arctic. The resulting increase in cloud condensation nuclei (CCN) concentrations would be expected to result in increased cloud albedo (Struthers et al, 2011), leading to potentially large changes in radiative forcings.

However, Browse et al. (2014) have shown that these increases in condensable material could also result in the growth of existing particles to sizes where they are more efficiently removed by wet deposition in drizzling stratocumulus clouds, ultimately decreasing CCN concentrations in the high Arctic. Their study was limited in that it did not simulate alterations of dynamics or cloud properties due to either changes in heat and moisture fluxes following sea-ice loss or changing aerosol concentrations.

Taken together, these results show that significant uncertainties remain in trying to quantify aerosol-cloud processes in the Arctic system. The current representation of these processes in global climate models is most likely insufficient to realistically simulate long-term changes.

Using the Met Office Unified Model (UM) including Cloud AeroSol Interactions Microphysics (CASIM), we perform a case study of summertime high Arctic (>80N) clouds in order to better understand the processes currently governing Arctic clouds, and how they may change in the future. We compare our results with observations obtained during the 2008 ASCOS campaign.

Browse, J., et al., Atmos. Chem. Phys., 14(14), 7543-7557, doi:10.5194/acp-14-7543-2014, 2014.

Struthers, H., et al., Atmos. Chem. Phys., 11(7), 3459-3477, doi:10.5194/acp-11-3459-2011, 2011.

S10.11

Investigations of adaptive habit ice microphysics using polarimetric radar techniques

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4,1,16,17

The prediction of ice particle properties has become a prominent focus in microphysical parameterizations. The adaptive habit model (AHM, Harrington et al. 2013) is a three-moment scheme that predicts and evolves ice particle shape/habit during vapor diffusional growth in a physically consistent manner and is an improvement upon previous methods that assume particles as spheres or assign a mass-size relationship. Appropriately evolving particle shape impacts predictions of mass, size, fall velocity, and subsequently affects liquid and ice water paths as well as other microphysical and precipitation processes. The full extent to which ice particle habit affects a myriad of processes is underway, and preliminary investigations reveal promising results.

An advantage to predicting ice particle shape (and density) is the ability to reproduce dual-polarization radar variables that depend on these properties. The forward operator of Ryzhkov et al. (2011) is applied to the AHM microphysical output from WRF to create simulated fields of the polarimetric radar variables. These variables are then cross-referenced with AHM microphysics (mass, shape, density, and others) to investigate and ascertain polarimetric signatures and microphysically dissect simulated cases. Initial results indicate the ability of the AHM to produce informative radar variables of an Arctic stratocumulus in WRF-LES and may prove useful in comparisons to radar observations (Sulia and Kumjian, to be submitted to MWR) through simulations of an upslope snow event within Advanced Research WRF.

S11.1

Secondary Ice Multiplication – current state of the science and recommendations for the future

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Increasingly complex cloud microphysical representations are being used in Numerical Weather Prediction and climate models to provide more realistic simulations of clouds. This drive towards greater complexity is motivated by the recognition of the importance of microphysical processes as models use increasingly higher resolutions, and the need to address fundamental questions such as assessing the impact of aerosol and cloud interactions.

One important challenge for the successful implementation of cloud microphysics is the prediction of ice crystal concentrations. While the understanding and quantification of primary ice nucleation has experienced a renaissance in recent years, the secondary production of ice is a process that has received relatively little attention but is potentially more important for controlling the ice concentrations found in some types of clouds. Consequently, the results from the initial ground breaking work done in the 1970s are still found in present day cloud models.

In November 2015 an international workshop was held to discuss the current state of the science and look forward to what should be done in the future to better understand and constrain secondary ice production processes. Questions asked included: How prevalent is secondary ice production in the atmosphere? What is the dominant mechanism in the atmosphere? Is the mechanism related to any of the processes identified in the laboratory?

Examples and recommendations for in-situ observations, remote sensing, laboratory investigations and modelling approaches will be presented.

S11.2

Production of secondary ice particles and splintering of freezing droplets as a potential mechanism of ice multiplication

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1, 9, 14

The mystery of rapid glaciation of tropical cumulus clouds has been a subject of extensive research for decades. Possible mechanisms responsible for the rapid freezing have been suggested but the direct quantification of their efficiency has been lacking. The production of secondary particles by freezing drizzle droplets has been suggested as one of the possible mechanisms. In the past years, we have studied the freezing of 100 μm size water drops suspended in the electrodynamic balance with high speed video microscopy. We have been able to identify the temperature range and other conditions beneficial for droplets splintering and production of secondary ice fragments due to the expulsion of gas bubbles. Recently, we have extended our study to larger droplets (around 300 μm in diameter), that allowed us to get a better insight into the mechanisms driving the fragmentation. In this contribution, we discuss in detail the microphysics of droplet freezing, starting with the propagation of ice through the freezing droplet, building of ice shell around it and eventual rise of the pressure leading to the ice shell deformation or to splintering and expulsion of ice fragments. Finally, the atmospheric implication of the observed phenomena will be discussed.

S11.3

Sticking Efficiencies and Multiplication by Fragmentation in Ice-Ice Collisions

Vaughan Phillips

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Key area numbers:

4.

1.

3.

Abstract:

There are two aspects of the phenomenon of ice-ice collisions that are especially uncertain and influential. First, there is the probability of two colliding particles sticking together, given that they have collided. Second, there is the problem of fragmentation in re-bouncing collisions involving snow crystals, graupel or hail.

In the presentation, the full physics of both aspects is formulated in terms of energy. Parameters of the theory are determined by off-line simulation of published results from past laboratory and field observations spanning several decades. Moreover, results are shown about the influence from mechanical breakup from simulations with an aerosol-cloud model that has emulated bin microphysics, detailed ice morphology and a semi-prognostic aerosol component. The aerosol-cloud model represents all the known and empirically quantified mechanisms of initiation of ice in terms of the aerosol conditions of chemistry, size and loading. Mechanical breakup is predicted to boost average number concentrations of ice, in deep convective clouds with a high cold base near 0 degC over the US High Plains, by up to two orders of magnitude, when copious graupel and hail are present.

Both processes in ice-ice collisions combine to influence the formation of ice precipitation and electrification processes, since charge is separated in rebounding ice-ice collisions. The new schemes presented should improve the ability to forecast snow.

S11.4

Observed and simulated cloud-top phase changes

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4, 3, 14

The transition from liquid water to ice in the atmosphere can occur either via homogeneous freezing at temperatures of approximately -37°C , or with the help of an aerosol particle or an ice crystal as ice nucleating particle. Once the first crystals have formed, they can grow on the expense of evaporating droplets and/or induce ice multiplication processes, both leading rapidly to a full glaciation of the cloud. In-situ data show that the phase transition typically occurs around -15°C , but these observations are based on a very limited dataset and mostly refer to stratiform clouds with moderate liquid water contents. In recent years, advanced retrieval schemes for the liquid and ice occurrence at cloud top have been developed for passive satellite sensors on polar orbiting satellites, offering global coverage at high spatial resolution. Here, we use the Pathfinder Atmospheres Extended (PATMOS-x) AVHRR Climate Data Set to study the frequency of occurrence of liquid and ice as a function of cloud top temperature and region. The phase transition temperature and altitude (the cloud glaciation point) is inferred by a robust estimation technique. We find a substantial latitudinal variation of the mean glaciation temperatures, with the lowest glaciation temperatures in the Tropics where deep convection dominates. Furthermore, we use a cloud resolving model to address the question how the cloud top glaciation temperature relates to the value of the same variable in-cloud, and show the role of updraft velocity and secondary ice processes in a deep convective cloud.

S11.5

Dual-polarization weather radar observations of secondary ice production regions

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1, 16, 4

Secondary ice particles are produced from preexisting ice. The processes that lead to secondary ice production, while generally known, are not always well represented models. It is not clear whether and how secondary ice affects precipitation. Dual-polarization radar observations are well suited for detection of regions of ice clouds or precipitation where new ice is formed. These regions manifest themselves as areas of increased values of dual-polarization radar variables, such as differential reflectivity and specific differential phase (K_{dp}). Typically, the main discriminating factor between primary and secondary ice particles is the number concentration. The number concentrations of secondary ice could exceed the concentrations of primary ice particles by several orders of magnitude. K_{dp} values are proportional to number concentrations of hydrometeors, which make it an attractive tool for detection of secondary ice production regions and for documenting their occurrence. Data from one year of dual-polarization weather radar observations in Finland is used to assess the occurrence of K_{dp} bands at altitudes with temperatures ranging between -3 and -8 °C. This temperature regime was selected to focus on Hallett-Mossop process of ice multiplication. It is found that the K_{dp} bands are not uncommon. Surface precipitation observations coinciding with K_{dp} bands occurring at altitudes close to the surface, confirm presence of secondary ice. Furthermore, a large number of needle aggregates are observed below the bands and these are associated with increased surface precipitation. At the conference well-documented case studies and one year statistics of the events will be presented.

S11.6

Microphysical analysis of a warm front using radar and in-situ data

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University of Manchester, Manchester, UK

4, 16

The northward movement of the Azores anticyclone over the ENE coast of Canada on 20th January 2009 caused the formation of a well-organized low pressure system in North Atlantic Ocean. That system was followed by a trough which approached the UK from the WNW on 21st January 2009. The corresponding warm front affected the UK with multiple rainbands. We present an analysis of the microphysical properties of the afore-mentioned situation using radar and in-situ data. The ground-based radar is located in Chilbolton (South England) and operates at 3 GHz frequency. Its high resolution (0.4 Km in vertical and 0.3 Km in horizontal dimension) and dual-polarization technology offers a view of the different features of the hydrometeors over large scales. The in-situ measurements have been taken during a flight over the SW England in the framework of the APPRAISE Clouds project, funded by the Natural Environment Research Council (NERC). The data from microphysical probes (CDP, 2D-S, CIP15, CIP100) provide a complete picture of hydrometeor properties (cloud droplets, ice particles and snow) are used for the microphysical analysis of this well-defined warm front. Using these datasets, features like embedded convection within mixed-phase clouds (where the Hallett-Mossop and Bergeron-Findeisen processes occur) and the warm conveyor belt of the front are identified. The main goals of this work are: a. the identification and interpretation of areas with specific ice crystal habits by comparing radar and in-situ observations and b. the determination of the polarimetric and microphysical characteristics of a warm front.

S11.7

On the importance of updraft speed and dwell time on the production of secondary ice based in convective clouds in southwest England

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Summertime convective storms were the focus of the Convective Precipitation Experiment (COPE), conducted over the southwestern peninsula of the UK during July and August of 2013. As part of the overarching objective of improving quantitative precipitation forecasts, a primary aim of COPE was to document the microphysical evolution of convective storms and determine the relative importance of the various microphysical pathways that can lead to heavy convective rainfall.

Here we investigate the details of the microphysical and dynamical evolution of clouds on four days using in situ observations from an instrumented aircraft and an airborne cloud radar. In some cases, we observe a rapid transition from cloud liquid to ice with a correspondingly high concentration of ice particles (up to 250 L^{-1}), presumably amplified through secondary ice production. In others, we find very little production of ice at similar temperature levels and ice concentration of only a few per liter. In our analysis, we consider factors such as droplet concentration and size, availability of liquid precipitation, updraft speed, effects of shear, and location of the observations in relation to the overall cloud structure. In general, we conclude that cases with high ice concentrations occur in clouds with weaker updrafts, suggesting that the dwell time within the Hallett-Mossop zone (-3 to $-8 \text{ }^\circ\text{C}$) plays an important role in the production of ice in these clouds.

S11.8

The Origin of Ice at a High-Alpine Site

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4,6,14,12,1

A new mechanism of secondary ice particle production in clouds from snow covered surfaces has been identified. Measurements of cloud properties were conducted as part of the Ice Nucleation Process Investigation and Quantification (INUPIAQ) project together with the Cloud Aerosol Characterisation Experiments (CLACE) the winter season of 2013 and 2014 at Jungfraujoch, Switzerland. A suite of instruments including a Cloud Droplet Probe (CDP) and a 3-View Cloud Particle Imager (3V-CPI) were used, with several hundred cloud events detected during the campaigns, where rapid transitions between liquid, mixed phase and glaciated cloud states were frequently observed. Concentrations of ice particles during some cloud events were in excess of 1000 L⁻¹ and we are unable to explain these using existing primary ice nucleation parameterizations. Secondary ice production through rime-splintering was also ruled out. We conclude that the snow covered surfaces close to the measurements site were the source of the observed concentrations of ice crystals. We considered several mechanisms including: blowing snow; contamination of clouds with pre-activated aerosol; surface based rime splintering and fracture of fragile vapour grown ice deposits on the surface that may explain our observations. We find that blowing snow contributed in a limited number of cloud events and that another secondary ice production mechanism originating from the surface is the likely cause of such high concentrations of ice. The evidence supports fragile vapour grown frost on the surface as the most likely source of the ice particles.

S11.9

Observation of orographic clouds at the high alpine site Jungfraujoch, Switzerland.

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6,4

During the past winter seasons, the microphysical properties of orographic clouds at the high alpine site Jungfraujoch (JFJ), Switzerland, were observed. Phase resolved measurements of the size distributions, the concentrations, and cloud water contents were obtained by the holographic imager HOLIMO.

Mixed-phase clouds (MPCs), consisting of a mixture of supercooled liquid droplets and ice crystals, were observed at a high frequency at the mountain-top station JFJ. Although MPCs are thermodynamically unstable, they were observed over long periods. This can be explained by orographic lifting. Updraft velocity high enough to exceed saturation with respect to liquid water cause the simultaneous growth of water droplets and ice crystals.

The finding that the two main wind directions at the JFJ leads to distinctly different cloud properties supports the explanation of stabilization of the mixed-phase cloud due to orographic lifting. A larger frequency of mixed-phase clouds is observed during north-westerly wind cases which are associated with a steeper accent than south-easterly wind cases. The higher updraft speeds during mixed-phase cloud cases are confirmed by simulations with the regional climate model COSMO.

In addition, high ice crystal concentration up to 1 cm^{-3} were observed. As the measured ice-nucleating particle concentrations were at least two order of magnitude lower, these high ice crystal concentrations cannot be explained by primary ice nucleation, but indicates that a ice multiplication process is active.

S12.1

On impacts of solar-absorbing aerosol on the transition of stratocumulus to trade cumulus clouds

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12, 2

The effects of a layer of solar-absorbing aerosol initially overlying the planetary boundary layer on the transition of stratocumulus to trade cumulus clouds are examined using large-eddy simulations. In contrast to the recent study of Yamaguchi et al. (2015), we find the cloud transition to be hastened, resulting mainly from an increase of cloud droplet number concentration induced by the entrained aerosol. The increased numbers reduce the sedimentation rate of cloud droplets and their relaxation time for diffusional growth, both of which accelerate entrainment of overlying air and thereby the breakup of the stratocumulus clouds. The competing effects of soot heating in the free troposphere and in the planetary boundary layer serve to increase cloud water at night while reducing it during daytime, enhancing its diurnal cycle. The decrease of albedo from soot heating is more than offset by redistributing cloud water over a greater number of droplets, such that the diurnal average shortwave aerosol forcing at the top of atmosphere is moderately negative on the third day. This negative radiative forcing is more than doubled by changes in longwave fluxes, which result from greater cloud breakup as well as reduced boundary layer depth attributable to soot heating in the free troposphere and planetary boundary layer. It is recommended that such sizable longwave forcings not be ignored when considering semi-direct aerosol forcings in the context of stratocumulus breakup. Sensitivity of aerosol radiative forcings to the single scattering albedo of the absorbing aerosol is found to be quite modest.

S12.2

Understanding aerosol-cloud interactions in Arctic mixed-phase clouds

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Key areas: 12, 4, 16, 13, 14

Of the uncertainties surrounding our understanding of global climate, one of the largest involves the effects of aerosol particles on cloud radiative transfer and precipitation intensity. Due to limited profiling of aerosol properties, traditionally aerosol-cloud interactions are statistically evaluated using surface aerosol measurements as a proxy for aerosol at cloud height. At low- and mid-latitudes, clouds often form atop a well-mixed atmospheric boundary layer, meaning that the use of surface-based aerosol measurements may not be unreasonable. At high latitudes, however, the atmosphere is often very stable. This stability limits vertical mixing of aerosols, meaning aerosol properties (e.g. number, hygroscopicity, scattering, size) observed at the Earth's surface may be very different from those at cloud height. This limitation makes it challenging to interpret previous efforts to understand the impacts of aerosols on liquid-containing Arctic clouds (e.g. Lubin and Vogelmann, 2006; Garrett and Zhao, 2006).

In this presentation, I will present recent and ongoing efforts to better understand relationships between aerosol particles and clouds. This will include evaluation of in-situ and ground-based remote sensing datasets to evaluate the impact of different atmospheric stability regimes on the vertical distribution of aerosol. Finally, I will provide updated estimates of the influence of aerosol particles on longwave broadband emissivity in thin, liquid-containing Arctic clouds, taking into account the possible disconnect between surface-based aerosol and those at cloud height.

S12.3

Cloud processing effects on CCN and cloud microphysics

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12

Bimodal spectra observed by DRI CCN spectrometers in two campaigns with different cloud types showed opposite relationships with droplet concentrations (N_c). Clouds associated with bimodal CCN had higher N_c than clouds associated with monomodal CCN in MASE stratus clouds whereas clouds associated with bimodal CCN in ICE-T cumuli had lower N_c than clouds associated with monomodal CCN. There are commensurate contrasts of droplet mean diameter and spectral width. Drizzle relationships with CCN modality are correspondingly opposite: order of magnitude fewer drizzle drops and lower drizzle liquid water content in clouds closest to bimodal CCN than clouds closest to monomodal CCN in stratus, but in cumuli order of magnitude more drizzle in clouds closest to bimodal CCN compared to clouds closest to monomodal CCN. Moreover, when observed spectral modalities from extreme bimodal to extreme monomodal are sorted on an eightfold scale, drizzle amounts in clouds closest to CCN of each modality group follow in the same order; i.e., mean drizzle amounts for each modality group are in the same bimodality order for all eight groups in both projects. Thus, the main cause of bimodal CCN in stratus clouds, chemical transformations of trace gases dissolved within droplets, produce an additional indirect aerosol effect (IAE) on these most climatically important clouds; higher N_c and precipitation suppression. Anthropogenic contributions to sulfur dioxide, ozone, hydrogen peroxide and nitrogen oxides that generate chemical cloud processing are yet another IAE. For cumuli where coalescence processing dominates, opposite cloud processing effects ensue, lower N_c and precipitation enhancement.

S12.4

The impact of aerosol particles on cloud formation and precipitation: a numerical study based on the HyMeX IOP7a case

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6 HYMEXcampaign

Within the framework of the HyMeX program dedicated to the hydrological cycle and related processes in the Mediterranean, a major field campaign (Special Observation Period 1) studied heavy precipitation and flash-floods in 2012. For the project MUSIC (MULTIscale process Studies of Intense Convective precipitation events in Mediterranean), the extreme precipitation event IOP7a (26th September 2012) of SOP1 in the Cévennes-Vivarais region in the South of France was selected to assess in particular the role of aerosol particles on precipitation development and quantity. A synergy of aircraft and ground based observations during the IOP7a (the 95 GHz cloud radar RASTA and two X-Band fast scanning weather radars respectively, as well as aerosol particle measurements by SMPS and GRIMM on-board the ATR-42 research aircraft) are used and confronted with the results of the 3-D mesoscale model DESCAM using bin resolved microphysics and multiple staggered grids. Particular emphasis is put on the impact of different aerosol particle scenarios.

S12.5

A Path to Constraining the Aerosol-Cloud Radiative Effect

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13, 2, 12

Aerosol perturbations change the microphysical structure of clouds, which in turn results in dynamical responses (adjustments) often in the form of changes in cloud water L and cloud fraction f_c . Because L and f_c exert a strong control on the radiative properties of clouds, the aerosol-cloud radiative effect has proven very difficult to quantify. Attempts to parse the problem out into a series of partial derivatives that chain together to give the overall effect have proven woefully inadequate for a variety of reasons, including measurement uncertainties and an inability to quantify causal relationships in a tightly coupled, adjusting system. An alternative approach adopted here is to consider the adjusting system in terms of the properties that most strongly drive radiation (L , f_c , and albedo A). Relationships amongst these parameters are particularly robust, amenable to analysis by both models and remote sensing, and represent a well-constrained framework for relating cloud microphysical processes to radiative effects. In this presentation we will use results from 14 years of ground-based observations and large volumes of cloud resolving model output ($\Delta x = 200$ m) to demonstrate the utility of the A - f_c framework for constraining the cloud radiative effect. Using model output and theoretical analyses we will explain why different cloud regimes line up surprisingly tightly along a trace in the A - f_c phase space and how meteorological and/or aerosol perturbations affect the system in ways that retain the shape of this trace through cloud system adjustments.

S12.6

Microphysical and Dynamical Factors Controlling the Precipitation Efficiency Response to Changes in Aerosol Loading

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1,12 - Precipitation efficiency

Recent modeling efforts have suggested that the precipitation efficiency (PE) response to changes in aerosol loading is likely a function of cloud type, in which PE in convective (stratiform) clouds is less (more) susceptible to changes in aerosol loading. Thus, the two primary goals are (1) to understand why stratiform clouds are more susceptible to changes in aerosol loading in the context of PE and (2) to determine to what extent dynamical feedbacks play a role in determining the sign of the PE response. Regarding the latter objective, it is clear that PE should decrease due to microphysical effects alone via suppressed collision-coalescence (at least in the context of warm clouds); however, the effects of dynamical feedbacks on PE are uncertain. Does PE increase due to microphysical-dynamical interactions? Or, is the dynamical feedback positive, enhancing the decrease in PE? These questions will be addressed by a detailed model analysis using piggybacking simulations for a variety of cloud types, spanning from tropical convective clouds to continental convective clouds and marine boundary layer clouds, using high-resolution Weather Research and Forecasting (WRF) simulations with a two-moment bulk microphysics scheme. Microphysical piggybacking is shown to provide a useful tool for separating microphysical and dynamical effects on changes in PE. The results demonstrate that in certain cloud types, dynamical feedbacks play a critical role in regulating the overall PE response to changes in aerosol loading.

S12.7

3D numerical simulation of orographic cloud seeding using a bin microphysics scheme

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17, 6, 1

A bin microphysical scheme was implemented into WRF to study the effect of seeding on the precipitation formation in orographic clouds. The previous version of the bin scheme was developed to simulate the collection of AgI particles by different scavenging mechanisms. The new scheme allows tracking of AgI particles inside of the water drops for proper simulation of immersion nucleation. The ice formation by deposition, condensational-freezing and contact nucleation of AgI particles was also added in the new scheme. A study using 2D flow past an idealized barrier has shown that the efficiency of seeding is significantly impacted by the efficiency of natural precipitation formation and the type of the cloud. In some cases the seeding was shown to be counterproductive. For instance, the amount of the surface precipitation was reduced due to the seeding in the case of the convective clouds. However, due to the under-resolved turbulence and mixing within the 2D framework, the dispersion of the AgI particles was unrepresentative. Therefore this current study expands the results to consider more realistic three dimensional flows to examine the impact of AgI seeding on a variety of cloud types. In particular, we will examine the impact of seeding on stable layer orographic clouds and embedded convective orographic clouds, one of the most commonly observed cloud types seeded in many parts of the world.

Key words: weather modification, orographic clouds, mixed phase

S12.8

Do soil dust particles from semi-arid areas enhance the influence of dust on clouds?

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12; 14; 13

Mineral dust particles are known to be the most important ice nuclei (IN) in Earth's atmosphere and therefore have a large influence on cloud properties. Soil dust, emitted from semi-arid croplands by wind erosion or tillage, might have similar or better properties regarding ice nucleation than many mineral dust types. In a changing climate, their influence on clouds might even be larger due to land use changes.

We analyze the influence of soil dust on clouds with the Norwegian Earth System Model (NorESM; Bentsen et al., 2013). The parameterization of immersion freezing on soil dust is based on findings from the AIDA cloud chamber (Steinke et al., in prep.). Contact angle and activation energy for soil dust are estimated in order to be used in the dust immersion freezing scheme of the model, which is based on classical nucleation theory.

Our first results highlight the importance of soil dust for ice nucleation on a global scale. Its influence is expected to be highest on the northern hemisphere. The immersion freezing rates from soil dust can on average increase by a factor of 1.5 compared to a mineral dust-only simulation. This can result in changes e.g. in the ice water path and cloud radiative properties.

Bentsen, M., I. Bethke, et al. (2013): The Norwegian Earth System Model, NorESM1-M - Part 1: Description and basic evaluation of the physical climate, *Geosci. Model Dev.* 6(3): 687-720.

S12.9

Influence of ice nuclei on precipitation in deep convective clouds

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12, 3, 14

Aerosol particles affect cloud microphysical properties by forming cloud droplets and ice crystals. However, the influences are uncertain for precipitation, which is the final outcome in a chain of many microphysical processes. This model study is driven by the question how liquid and ice precipitation of deep convective clouds is modulated by ice nuclei (IN) such as mineral dust particles.

We highlight the high sensitivities to the freezing of rain drops. A common assumption in aerosol-dependent freezing parameterizations is that each ice nucleating particle corresponds to exactly one cloud droplet, while freezing rain is independent of specific aerosol types and concentrations. To make rain immersion freezing sensitive to aerosols, we extended the two-moment microphysics to explicitly account for particle accumulation in rain drops by tracking the rates of drop-drop-collisions.

In our cloud-resolving simulations of idealized deep convective clouds, we find that the direct influence of IN on precipitating liquid and ice particles yields large differences in the simulated sensitivities. At altitudes relevant for freezing, most of the potential IN have been converted from cloud droplets into rain drops. With a less efficient freezing, higher rain water contents in the convective core yield enhanced surface precipitation of both rain and hail because of enhanced growth of hail stones by riming.

S12.10

Inclusion of forest fire smoke in WRF-CHEM simulations and its impact on deep convective clouds: A DC3 case study

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12, 3

deep convective clouds, forest fire smoke

Abstract:

Forest fires emit vast amounts of aerosols into the atmosphere, though these fire-related bursts in aerosol emission are episodic and heavily dependent on the location, season, and interannual variability. Once large amounts of small particles are emitted, however, some of those aerosols may have the potential to serve as cloud condensation nuclei or ice nuclei and modify cloud properties. Among many types of clouds that can be affected by such massive aerosol injections, this study specifically focuses on deep convective clouds (DCCs) that are commonly observed in the tropics and over summertime mid-latitude continents. Given the heavy rainfall often produced by DCCs and the spatial coverage of anvil clouds on their tops, smoke-induced changes in any DCC properties may significantly impact both local weather and global climate. This study uses the Weather Research and Forecasting model coupled with Chemistry (WRF-CHEM) to investigate how the inclusion of high-resolution fire data changes the simulated properties of DCCs observed over the continental U.S. during summer 2012. The properties of these DCCs were well observed both *in situ* by aircrafts and remotely by ground-based instruments during the Deep Convective Clouds and Chemistry (DC3) field campaign. Combination of these observational datasets with both short- and long-term cloud-resolving simulations suggests that the DCC properties were altered in the presence of smoke aerosols. We found that not only the number of aerosols, but also their compositions are important in determining the response of DCCs to forest fire smoke.

S12.11

Separating dynamical and microphysical impacts of aerosols on deep convection applying piggybacking methodology

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Traditional methodology to investigate the impact of cloud microphysics on the cloud dynamics is to use parallel simulations with different microphysical schemes or with different scheme parameters. Such methodology is not reliable because of the natural variability of a cloud field that is affected by the feedback between cloud microphysics and cloud dynamics. In a nutshell, changing the cloud microphysics leads to a different realization of the cloud-scale flow, and separating dynamical and microphysical impacts is difficult. A novel modeling methodology, the microphysical piggybacking, was recently developed to separate purely microphysical effects from the impact on the dynamics. The idea is to use two sets of thermodynamic variables driven by two microphysical schemes or by the same scheme with different scheme parameters. One set is coupled to the dynamics and drives the simulation, and the second set piggybacks the simulated flow (it responds to the simulated flow but does not affect it). By switching the sets (i.e., the set driving the simulation becomes the piggybacking one, and vice versa), the impact on the cloud dynamics can be isolated from purely microphysical effects. Application of this methodology to the daytime deep convection development over land will be discussed applying single-moment and double-moment bulk microphysics schemes. The new methodology documents a small indirect aerosol impact on convective dynamics, and a strong microphysical effect. These results question the postulated strong dynamical invigoration of deep convection in polluted environments, at least for the case of scattered unorganized deep convection considered in this study.

S13.1

On the Representation of Cloud Phase in Global Climate Models, and its Importance for Simulations of Climate Forcings and Feedbacks

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Key areas: 4, 13, 14

Despite the growing effort in improving the cloud microphysical schemes in global climate models (GCMs), most of this effort has not focused on improving the ability of GCMs to accurately simulate phase partitioning in mixed-phase clouds. Getting the relative proportion of liquid droplets and ice crystals in clouds right in GCMs is critical for the representation of cloud radiative forcings and cloud-climate feedbacks. Here, we first present satellite observations of cloud phase obtained by NASA's CALIOP instrument, and report on robust statistical relationships between cloud phase and several aerosols species that have been demonstrated to act as ice nuclei (IN) in laboratory studies. We then report on results from model intercomparison projects that reveal that GCMs generally underestimate the amount of supercooled liquid in clouds. For a selected GCM (NCAR 's CAM5), we thereafter show that the underestimate can be attributed to two main factors: i) the presence of IN in the mixed-phase temperature range, and ii) the Wegener-Bergeron-Findeisen process, which converts liquid to ice once ice crystals have formed. Finally, we show that adjusting these two processes such that the GCM's cloud phase is in agreement with the observed has a substantial impact on the simulated radiative forcing due to IN perturbations, as well as on the cloud-climate feedbacks and ultimately climate sensitivity simulated by the GCM.

S13.2

The dehydration-Greenhouse Feedback

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13, 5, 12

The dehydration-Greenhouse Feedback

Eric Girard, Jean-Pierre Blanchet, Setigui Keita, Ludovick Pelletier and Ana Cirisan

Ice clouds play an important role in the Arctic weather and climate system. Consequently, it is essential to understand their properties and especially their formation process. Remote sensing observations over the Arctic have revealed the existence of two types of ice clouds (TIC). The first type, TIC-1, is characterized by a high concentration of small ice crystals and is typically observed in non-polluted areas. On the other hand, TIC-2 is characterized by a low concentration of larger precipitating ice crystals. In this study, it is hypothesised that TIC-2 are linked to highly acidic aerosols. Past field experiments have shown that most aerosols in the accumulation mode are coated by sulphuric acid in polluted episodes in the Arctic during winter. Recent laboratory experiments have shown that sulphuric acid coating can alter the efficiency of ice nuclei (IN) to nucleate ice crystals. In this study, we hypothesize that the resulting lower IN concentration found in polluted air masses leads to the decrease of the ice crystal concentration. Since there is in less competition for the available moisture, ice crystals reach precipitating sizes leading to the formation of TIC-2. This research aims to better understand the formation process of these two types of TIC through observations of TICs during field campaigns and modeling. Modeling of these TICs will be presented and their impacts on the radiative budget and the large scale atmospheric circulation will be discussed.

S13.3

Regime dependence of precipitating cloud impact parameters

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13

Precipitating cloud systems, from shallow to deep convection, are influenced by the environment, but also feedback on their environment through both surface and atmospheric radiative effects and latent heat (LH) release. Here we explore a set of cloud impact parameters that characterize the degree to which a precipitating cloud cools the surface or heats the atmosphere, respectively. The surface radiative cooling efficiency, r_c , represents the ratio of the shortwave cloud radiative effect at the surface to LH release from precipitation. The atmospheric heating efficiency, r_h , describes the cloud's ability to heat the atmosphere per unit LH. Estimates of precipitation and radiative fluxes from CloudSat/CALIPSO observations are used to examine the regime dependence of r_c and r_h . Results will be sorted by cloud type according to cloud vertical structure and precipitation characteristics to examine the cloud regime dependence. Precipitating cloud impact parameters will also be conditionally-sampled by environmental dynamic and thermodynamic properties including sea surface temperature, column-integrated water vapor, lower tropospheric stability, and vertical motion. This analysis will help further our understanding of the links between cloud radiative and latent heating and will provide insights into the factors that control the impact of different cloud and precipitation regimes on atmospheric and surface energy budgets.

S13.4

How well do GCMs simulate transitions between closed and open marine stratocumulus clouds?

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12, 13, 2

Marine stratocumulus clouds occur in two main cloud regimes of open and close cells that differ significantly by their cloud cover. Closed cells gradually get cleansed of high CCN concentrations in a process that involves initiation of drizzle, and undergo transition from closed to open cells, together with a significant reduction of the cloud cover.

Detailed analysis of satellite observations collocated with chemical transport model showed that continents can act as huge aerosol sources and form "continental tracks", similar to ship tracks, but at a much larger scale. The high aerosol concentration in the continentally polluted air mass in which the closed cells form is assumed to delay the initiation of drizzle and thus to keep the clouds in the closed cells regime for longer time and larger distance away from land. Such fully cloudy areas potentially constitute a substantial radiative forcing that is currently not accounted for by climate models.

Here we present a study investigating how well GCMs are able to capture this large scale effect of anthropogenic aerosols on the lifetime and cloud cover of closed cell stratocumulus. We used the aerosol-climate model ECHAM6-HAM2 to simulate an observed case of a "continental track". Analysis of the simulations examines the ability of the model to mimic the closed to open cells transition in terms of cloud life time effect.

S13.5

Exploring the representation of humidity variability by an assumed probability density function scheme

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2

Clouds cover a large area of the earth surface and are essential for several processes, but they are also one of the main contributors to the uncertainties in today's climate change simulations. Due to the coarse resolution of global climate models the variability in humidity and temperature at scales responsible for the development and evolution of clouds is still unresolved. One way to represent this variability is to assume probability density functions (PDFs) for one or more quantities. Here, a single PDF scheme modeling the subgrid-scale variability of total water is implemented into the ICON model. The PDF is described by its higher moments - here variance and skewness - which are included by additional prognostic equations. This study is focusing on the representation of the parameterized source and sink terms or more general on the coupling and interaction of the PDF scheme to other processes, especially for warm boundary-layer clouds.

Large-Eddy Simulations (LES) are used to evaluate the evolution of the moments and the contribution by connected processes. One example are the microphysical processes, where accretion can be estimated as a sink term for the variance of total water.

While the first aim of assumed PDF schemes is to diagnose a cloud fraction in coarser models, the provided subgrid-scale variability can also be used in other ways - e.g. as a heterogeneity of clouds. In this presentation first results of the implementation of the PDF scheme as well as further ideas to use the parameterized variability will be discussed.

S13.6

Cloud Retrievals for Climate and Weather Using Combinations of Geostationary and Polar-Orbiting Satellite Imager Data

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13, 17, 16

Clouds play a critical role in the radiation and hydrological budget over all regions of the globe. A climate-grade cloud property dataset has been developed using MODIS and NPP-VIIRS data for the Clouds and Earth's Radiant Energy System (CERES) to help interpret the CERES radiation measurements and to gain understanding of the relationships between clouds and the radiation budget. These measurements are crucial for characterizing changes in climate. The Satellite Cloud and Radiative Property retrieval System (SatCORPS) was first developed for application to the imagers used for CERES. To extend the 15+ year CERES record back in time, the CERES cloud retrieval methodology has been adapted to analyze the 35+ year AVHRR record. Additionally, the SatCORPS has been adapted to analyze all satellite imager data having a 3.8- μm channel and thus has been applied to GOES, Meteosat, MTSAT, Himawari-8, and INSAT-3D imager data to cover the entire diurnal globally. The data are analyzed for historical periods to develop climate records and in near real time to provide nowcast products and cloud properties. The near-real-time products are used for numerical weather model assimilation and for field programs to aid mission guidance and match with aircraft and surface measurements to improve our understanding of meso- and large scale cloud processes and effects of aerosols on clouds. This paper summarizes these cloud products, their availability, their uncertainties, and their use for weather, climate, and air safety applications.

S13.7

A Multi-Instrument Satellite View of the Global Three-Dimensional Distribution of Cloud Liquid Water

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16,13,2

Given the well-known inaccuracies of clouds and precipitation in climate and numerical weather prediction models, reliable global reference measurements are needed in order to evaluate these models and the effect of potential improvements. Satellites provide global observations, but their indirect measurements require interpretation. A single measurement can often not fully constrain the desired variables.

In order to reduce the uncertainties of cloud liquid water climatologies, we have developed a Bayesian multi-instrument cloud liquid water retrieval algorithm using data from the CloudSat radar, the MODIS optical spectrometer on the Aqua satellite, and the CALIPSO lidar. The radar reflectivity is particularly sensitive to the cloud droplet size, while MODIS produces a robust estimate of the cloud optical depth. An algorithm using both of these data can effectively constrain the cloud microphysical parameters. The combined CloudSat-CALIPSO cloud phase product allows us to distinguish between cloud liquid water and ice, and thus to restrict our analysis to liquid clouds.

The algorithm produces results that are consistent with the CloudSat-measured microwave path integrated attenuation, indicating that the retrieved cloud water path is nearly unbiased. We examine the distribution of cloud liquid water given by the algorithm and demonstrate that the new algorithm is an improvement over both the current CloudSat products as well as the MODIS-only cloud liquid water. We also discuss the usability of the new cloud liquid water product as a reference for evaluating climate models. In the future, the algorithm will be used as part of a combined ice-liquid water retrieval.

S13.8

The missed marine warm clouds by the Cloud Profiling Radar and its impact on the accuracy of cloud microphysical property statistics

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Although the Cloud Profiling Radar (CPR) has unique advantage in global cloud measurements, it usually fails to detect some specific clouds, which is examined in this study by using collocated measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) and Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP), with focus on the single-layered marine warm clouds. It was found that over global oceans, marine warm clouds with lower cloud water path (CWP) are more likely to be missed by CPR, which indicates CWP as a feasible indicator for CPR missed detections. For the four major types of marine warm clouds, Cu, Sc, St, and Ac, the extent of missed detection is largely different, which is revealed to be relevant with their macrophysical and microphysical properties. Results show the overall miss rate of CPR for all the types is about 0.39 over global oceans, while St and Cu exhibit the maximum and minimum miss rate at 0.61 and 0.23, respectively. Besides, the statistical biases of cloud microphysical properties induced by missed detection of CPR show a consistent overestimation for all types, such as cloud droplet radius (CDR) by 9.8~25.0% and cloud optical depth (COD) by 23.6~49.5%. Given the lower CWP of St and Ac, their relative biases reach up to 56.3% and 59.8%, respectively. It is found that the overestimation on cloud microphysical properties is more severe to those warm clouds below 1.5 km and mitigates with increasing cloud top height, which is closely related to the height dependence of miss rate.

16,17,1

S13.9

Cloud-aerosol interactions and precipitation scavenging in the Accelerated Climate Model for Energy (ACME)

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Key Aera Numbers: 12., 13.

Aerosols as short-lived climate forcers have large spatial and temporal variability. Having accurate three-dimensional distributions of aerosols in climate models is critical for assessing their radiative and microphysical impacts. Many current global aerosol-climate models have large biases in their predicted aerosol distributions. Several new treatments of the representations of clouds, aerosols, and cloud-aerosol interactions have been implemented in a new-generation climate model, the US Department of Energy ACME model (version 1), which has recently evolved from the NCAR Community Earth System Model (CESM1.3). The ACME improvements include new treatments for aerosol particle formation, explicit aging of carbonaceous aerosol species, wet scavenging processes (i.e., aerosol activation, cloud processing, and wet removal), ice nucleation, ice crystal to snow conversion, and deposition of light-absorbing particles to snowpack and sea ice. Preliminary results show that aerosol residence times and spatial distributions, impacts on clouds and precipitation, and aerosol deposition onto snow and ice surfaces have changed significantly due to some of the individual new treatments, compared to the original model (CESM1.3). The revised treatment to precipitation scavenging alone leads to a 25% reduction in global mean cloud droplet number concentration and a 10% reduction in liquid water path. A full evaluation of high-resolution simulations using these new treatments along with recent advances in other components of the ACME model is underway. In this presentation, we will discuss these new features and their impact on cloud-aerosol interactions and aerosol radiative forcing in the climate system.

S13.10

Online comparison between droplet activation parameterisations and an embedded cloud parcel model in the GCM ECHAM-HAM

Daniel Partridge

Stockholm University, Stockholm, Sweden

13, 2, 12: (GCM, embedded, cloud parcel model, parameterisation)

Current parameterisations used to estimate the activation of aerosols to form cloud droplets in many global circulation models (GCM's) are based upon some form of adiabatic parcel model theory. These parameterisations determine the number of activated droplets from the maximum supersaturation (S_{max}). Determination of the S_{max} attained in an air parcel is the greatest source of uncertainty in droplet nucleation. This uncertainty propagates through to GCM estimates of the aerosol indirect effect.

Many offline evaluations have been performed between droplet activation parameterisations and adiabatic cloud parcel models; however, these only explore a portion of the full multi-dimensional input parameter space explored by a general circulation model (GCM).

In this work, we embed an adiabatic parcel model into the GCM ECHAM6.1-HAM2.2, and for the first time quantify the discrepancy to droplet activation parameterisations online. A further advantage of this new framework is that for the first time we provide global maps of the variation of droplet spectral shape at cloud base to facilitate more rigorous comparisons of GCMs with in-situ observations.

We show that state-of-the-art droplet activation parameterisations result in an overestimation of global average droplet concentrations at cloud base by ~8%, with largest discrepancies found over the southern ocean. Spatial variations in simulated droplet size distributions are discussed, particularly in relation to current parameterisations of the aerosol dispersion effect, and subsequent estimates of the aerosol indirect effect by GCMs.

S13.11

Optimal Estimation retrieval of cloud droplet number concentration for synergistic ground-based observations

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13, 17, 3

The cloud droplet number concentration (CDNC) is an important diagnostic for the investigation of aerosol-cloud interactions. It is however a challenging quantity to retrieve from ground-based remote sensing instruments. Given the cloud radar and microwave radiometer observations available from the Cloudnet and ACTRIS network of observational sites, various cloud properties can be retrieved. The retrieval of the CDNC (zeroth moment) from the third and sixth moment of the droplet size distribution (DSD) is however very sensitive to the required assumption about the width of the DSD. Adding observational constraints to such a retrieval is highly desirable, e.g. using cloud optical depth (proportional to the second moment of the DSD) observations from a multi-filter rotating shadowband radiometer. We introduce an optimal estimation method for the retrieval of CDNC, which allows to easily add new observations only requiring a forward operator from the state to the observation vector. Its results are compared to the simpler radar-radiometer approach used in previous studies. Synthetic cloud profiles (vertically homogeneous, adiabatically stratified, homogeneously and inhomogeneously mixed) are used for the comparison, where all microphysical quantities are constrained by the given DSD. Observations are simulated by adding instrument-specific noise. Given these well-known reference cloud profiles, we investigate the sensitivity regarding the assumptions about the DSD in the retrievals, and the influence of instrument uncertainties. It is found that the Optimal Estimation retrieval provides a more robust estimate of the CDNC, especially regarding the width of the DSD in the retrieval.

S13.12

Sub-millimetres, a new wavelength region for retrievals of cloud ice properties

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16, 13

To open up the sub-millimetre region for cloud measurements is particularly important for ice water path satellite retrievals. This will increase the sensitivity of microwave retrievals with at least two orders of magnitude and a very competitive accuracy is expected. To improve the performance of passive observations is important to e.g. complement the narrow horizontal coverage of active instruments.

Existing operational microwave sensors operate at wavelengths longer than 1.5 mm and atmospheric observations at sub-millimetre wavelengths are yet restricted to aircraft flights and limb sounding missions, but the situation is about to change. Most importantly, it is now decided that the second generation of Metop satellites will include the Ice Cloud Imager (ICI) sensor, that will cover wavelengths down to 0.45 mm. As preparation for the ICI mission, the ISMAR aircraft demonstrator has been developed and it has now performed its first scientific flights. In about one year, the NASA IceCube nano-satellite will explore a band around 0.34 mm, during a shorter mission.

Accordingly, this is a very active period regarding sub-millimetre cloud ice measurements, and the potential and status of this observation technique will here be summarised. Results from the first ISMAR campaigns and the experience gathered from cloud retrievals based on satellite limb sounding sub-millimetre data will be outlined. Already these initial retrievals give a practical demonstration of important aspects of this measurement approach.

S13.13

On the Influence of air mass history on aerosol-cloud interactions in the South-East Atlantic

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Ruhr-Universität Bochum, Bochum, North-Rhine Westphalia, Germany

12

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This study qualitatively investigates the influence of air mass histories and aerosols on cloud optical properties in a regional analysis of geostationary satellite and reanalysis data for the South-East Atlantic.

Aerosol-cloud interactions (aci) are highly variable on diurnal and local scales depending on the meteorological regime. Accordingly, the understanding of aci at the process level is an important aspect of climate system research and estimates of the Earth's radiation budget.

In order to clarify to what extent cloud properties are dominated by aerosol species and meteorological conditions, case studies during the biomass burning season in the South-East Atlantic are analyzed using SEVIRI (Spinning Enhanced Visible and InfraRed Imager) satellite, MACC (Monitoring Atmospheric Composition and Climate) and ERA-Interim reanalysis products.

During one month of satellite observations, it is frequently observed that the influence of advected air masses on cloud properties might be stronger than the local diurnal cycle of the otherwise persistent cloud cover. Advected air masses often feature very different meteorology and composition of aerosol species, leading to rapid changes in cloud properties. The study suggests relevant determinants of cloud optical properties and aci in the South-East Atlantic.

S13.14

MARINE CLOUD BRIGHTENING [MCB] – REGIONAL APPLICATIONS

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The idea behind the marine cloud-brightening (MCB) geoengineering technique – formulated by Latham (1990) and substantially refined and extended in about 30 other papers - is that seeding marine stratocumulus clouds with copious quantities of roughly mono-disperse sub-micrometre sea-water particles might significantly enhance the cloud droplet number concentration, and thereby the cloud albedo and possibly longevity. This would produce a cooling, which general circulation model (GCM) computations suggest could - subject to satisfactory resolution of technical issues - maintain the Earth's average surface temperature at roughly current values, at least up to the carbon dioxide-doubling point.

Although our primary goal re MCB concerns the planet as a whole this paper is mainly concerned with sub-global, regional effects of MCB in (1) reducing or eliminating ice-loss, (2) preserving or restoring coral reefs. (3) reducing the wind-speeds and thus damage associated with typhoons; (4) possible reduction of methane release .. such limited-area applications of MCB will be significantly less worrying to the general public and therefore might ease minds worried about MCB and also, possibly other cooling techniques. This presentation will present results from recent publications, demonstrating the regional scale effects of a change in marine stratocumulus cloud droplet number concentrations.

Latham, J., 1990: Control of global warming? Nature 347. 339-340

S13.15

How well can we represent the subgrid distribution of convective clouds in a climate model?

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3. Convective clouds

12. Aerosol-cloud-precipitation-interactions and processing

13. Clouds and climate

Representing the subgrid-scale distribution of convective clouds within one gridbox is very challenging, but crucial for an accurate estimation of climate effects of convection and for aerosol-convection interaction. We use the Convective Cloud Field Model (CCFM) in the aerosol-climate model ECHAM-HAM to simulate a spectrum of convective clouds of different sizes. The cloud types compete with each other for the available large-scale generated CAPE and, assuming quasi-equilibrium, the cloud spectrum is obtained by solving Lotka-Volterra type equations. An entraining plume model, with higher adaptive vertical resolution and embedded microphysics is used to model each cloud type.

We analyse the impact of different environmental factors on the modelled spectrum of convective clouds, using the standard bulk 1-moment CCFM microphysics and two newly implemented versions (an improved version of the standard scheme and a new state-of-the-art 2-moment scheme adapted for CCFM). The cloud spectrum properties (sub-grid scale distribution of convective cloud top height and radii, vertical velocities / mass flux) and the total cloud fraction are compared with satellite retrievals and ground based radar products, in order to better understand the impact of the convective microphysics and to assess the model performance in different regions (mid-latitude, tropical warm pool, Amazon) and under various meteorological conditions and aerosol loadings.

S13.16

Mechanisms of convective cloud response to aerosol in a global model with a cloud field parameterisation

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Keywords:12,3,13

Many potential mechanisms have been proposed for aerosol effects on convective clouds, from the classic albedo and lifetime effects to semi-direct effects and invigoration/suppression by modulating latent heat release. While such effects may be reproducible in an idealised context using large eddy simulations, these are typically unable to capture larger-scale dynamical processes which may act as feedbacks to enhance or dampen the aerosol effects.

The Convective Cloud Field Model (CCFM) is one of the few convective parameterisations able to include aerosol effects using a microphysical approach accounting for the sub-grid-scale heterogeneity of convective cloud. CCFM dynamically determines the spectrum of cloud types within each column, based on competition for resolved-scale CAPE. Each cloud type is represented by its own one-dimensional entraining plume model with embedded aerosol activation and cloud microphysics.

Using CCFM within the global aerosol-climate model ECHAM-HAM, we have extended its representation of aerosol-cloud-precipitation interactions to include convective cloud, giving enhanced effective radiative forcing (ERF_{aci}) and regionally-varying responses of cloud-field morphology to aerosol. Using this model set-up, we decompose these responses to understand the relative contribution of each mechanism to the overall climate impact of aerosol. In particular, by combining in-cloud latent heating profiles with larger-scale cloud-field properties, radiative fluxes and precipitation statistics, we assess the extent to which invigoration (increased latent heating due to reduced warm rain) and suppression (where the updraught has insufficient energy to reach the colder freezing level for smaller droplets) have an impact when feedbacks at cloud-field, regional and global scales are included.

S13.17

Predator - Prey: a viable concept for the parameterisation of convection?

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3, 8

The Convective Cloud Field Model (CCFM) is a multi-plume convection scheme. Using an entraining parcel model the scheme calculates possible clouds of different initial radii for a given environment and large scale forcing. The distinctive feature of CCFM is the cloud spectrum calculation which determines the actual number of possible clouds. The spectrum calculation is described by a multivariate Lotka-Volterra system in which clouds (predators) compete for CAPE (convective available potential energy, prey) through their cloud work function. From the individual clouds and their number, mass fluxes and thus convective heating and moistening can be derived. CCFM has been successfully coupled to the ECHAM climate model. Despite this success, so far the calculated cloud spectra and their underlying assumptions have not been tested against observations or LES simulations. Since observations are limited we have analysed the cloud spectra as simulated by the UCLA-LES model. The two cases analysed are a precipitating shallow cumulus case based on RICO and an idealised case of deep convection typically occurring during summertime over midlatitude continental areas. LES simulated cloud spectra and their properties will be discussed and compared to the CCFM predicted cloud spectra.

S13.18

Evidence for Convective Invigoration from A-Train Observations

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12

The 'convective invigoration' hypothesis posits that aerosol affects precipitating clouds by delaying the onset of precipitation until the cloud has grown above the freezing level, making more efficient ice-phase precipitation processes available and leading to more intense precipitation than would have been produced by the same cloud in a less polluted atmosphere. In the IPCC AR5, evidence for a systematic aerosol effect on precipitation intensity is described as 'limited and ambiguous'.

We use a combined dataset of spaceborne radar (CloudSat) and lidar (CALIPSO) retrievals of precipitation and cloud thermodynamic phase to derive a climatology of rain occurrence from liquid-phase cloud ('warm rain') and ice-phase cloud ('cold rain'). The cloud-top phase of precipitating cloud serves as a proxy for rain intensity, with warm clouds preferentially producing drizzle and cold clouds preferentially producing more intense rain. In conjunction with aerosol data, the cloud-top phase can be used to test convective invigoration; according to the hypothesis, increasing aerosols should lead to an increase in the cold-rain fraction.

We find that warm rain is extremely rare over the extratropical continents (1.5% of rain occurrences). Warm rain is rarer in the most polluted tercile of observations (measured by reanalysis dry AOD) over wide areas of land and ocean outside the tropics, consistent with expectations under the convective invigoration hypothesis. Extrapolating the observed relationship between warm-rain fraction and AOD to preindustrial conditions shows a large anthropogenic aerosol influence on precipitation over the extratropical continents. We propose this as evidence supporting the convective invigoration hypothesis.

S13.19

Space-borne observations of the most extreme storms on Earth: a new perspective from the NASA-JAXA GPM mission

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8,3,13, multiple scattering, extreme storms, hail

The Global Precipitation Measuring (GPM) mission core satellite, with its first ever dual frequency (Ku-Ka) precipitation radar in space and a radiometer system operating at 13 different channels ranging from 10 to 188 GHz, offers unprecedented opportunities to improve our knowledge about the distribution and intensity of precipitation globally. Monitoring the change in intensity and in the regional and seasonal distribution of extreme weather events is critical for understanding the impact of climate change on humankind.

By exploiting an abundant number of extreme weather events observed simultaneously by the GPM suit of sensors and the NEXRAD ground-based S-band radars over continental US we developed proxies based on GPM observables for the identification of high density ice (hail/graupel) layers. When adopting the hydrometeor classification based on polarimetric measurements as truth the algorithm performs well with Probability of Detection exceeding 70% and Critical Success Index of 39%. Global maps of hail occurrences, based on the first two years of GPM data, will be presented.

Current GPM retrieval products are not reliable for such systems because of ubiquitous multiple scattering effects, which tend to strongly bias precipitation estimates. A new optimal-estimation algorithm capable of accounting for multiple scattering and of the a-priori knowledge gained from the NEXRAD dataset will be discussed.

S13.20

Impact of the collection efficiencies in ice phase processes on clouds and climate

Ulrike Lohmann, David Neubauer
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1,13,12

Clouds are important in the climate system because of their large influence on the radiation budget. They scatter solar radiation and with that cool the climate. On the other hand, they absorb and re-emit terrestrial radiation, which causes a warming. Clouds are also an integral part in the hydrological cycle. In mid-latitudes most of the precipitation originates via the ice phase and melts on the way to the surface. However, the ice phase in clouds is much less understood than the warm phase and the simulated ice water content from different models varies greatly.

One uncertainty is the collection efficiency for the different processes, aggregation of ice crystals to form snowflakes and accretion of snowflakes with ice crystals and cloud droplets. In this talk, we will show sensitivity studies with the global climate model ECHAM6-HAM in which we used different collection efficiencies from the literature for these processes. We will analyze the impact of different collection efficiencies in ice phase processes on clouds in the present-day climate and compare it with different observations. We will also estimate its impact on the radiative forcing due to aerosol-cloud interactions.

S13.21

Satellite observations of cloud glaciation processes

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12, 4, 5

Significant progress has been made in recent years towards constraining the radiative forcing from aerosol cloud interactions, especially from liquid clouds, although the interaction of aerosols with mixed phase and ice clouds remains highly uncertain. By acting as ice nucleating particles (INP) aerosols can nucleate ice crystals heterogeneously, glaciating supercooled clouds. An increase in the number of INP may increase the ice crystal number concentration (ICNC) in glaciated clouds. However, the competition between homogeneous (with no requirement for an INP) and heterogeneous nucleation means that it is possible for an increase in the number of INP to cause a decrease in the ICNC under certain situations. Meteorological factors also play a strong role in determining the ICNC, making the influence of aerosols on the ICNC difficult to determine in observational studies.

In this work, we present results gained using combined satellite lidar and radar retrievals of ice cloud properties and the ICNC, which are combined with satellite retrieved and reanalysis aerosol and meteorological parameters to investigate glaciation processes in mixed phase and ice clouds. Similar to previous studies, we find a strong link between the satellite retrieved cloud phase and the aerosol environment. The results also demonstrate the important role that meteorological factors play in determining the ICNC in glaciated clouds and the role that aerosols play as INP.

S13.22

Climatology and long-term changes in cloud cover over the ocean by using frequency distribution

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13

We analyze cloud cover characteristics over the Ocean for the last several decades. Characteristics of cloud cover were derived from the Voluntary Observing Ship (VOS) reports available from the ICOADS (International Comprehensive Ocean-Atmosphere Data Set). Frequency distribution of fractional cloud cover was approximated by 3-parameter PDF, accurately capturing most of variants of cloud cover probability density distribution. First, we analyzed climatology parameters of PDF. Also we compared day and night observation. Interannual to decadal changes in characteristics of cloud cover (linear trends and shorter term variations) are analyzed in terms of the distribution parameters. Next, the changes in the cloud cover characteristics over the world ocean were associated with variability of short-wave radiation fluxes derived from VOS reports for the last 6 decades using a new parameterization, which accounts not only for the cloud amount but also for the cloud types. The latter is critically important for the conditions close to overcast and may strongly affect short-wave radiation fluxes. Computations demonstrate generally slightly decreasing over the last decades shortwave radiation flux in mid latitudes and also an evident interdecadal variability in the tropics. These changes are discussed in the context of variability of cloud cover characteristics and in conjunction with changes in turbulent heat fluxes.

S13.23

Measuring ice clouds at millimeter/submillimeter wavelength – how much information can we gain?

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16, ((4))

Reliable global measurements of ice clouds are challenging. Yet ice clouds are amongst the major uncertainties for climate models and data for their evaluation is needed. Existing passive space-based measurements in the visible and infrared provide information about the radiation of clouds, yet the link to the bulk mass of ice is difficult. Passive millimeter/submillimeter sensors such as ICI (Ice Cloud Imager), however, could provide information about ice mass and particle size globally and continuously.

We explore potential and challenges of a spaceborne sounding instrument working in the frequency range from 89GHz up to 325GHz. We employ a high-resolution model simulation with detailed two-moment microphysics and use the radiative transfer simulator ARTS to calculate virtual satellite measurements from that simulation. In order to investigate the information content gained from the measurement, we also calculate the corresponding cloudy Jacobians with ARTS.

Naturally, the Jacobians turned out to be highly variable as the clouds themselves, and they much depend on the atmospheric composition. Even their sign can change, depending on the presence of other hydrometeor types. In general, with the chosen set of frequencies, much information about cloud ice and snow profiles can be gained. For rain and cloud water, the information more depends on the presence of other hydrometeors and the surface properties. A comparison with a neural network retrieval shows that, even though the information content for a single hydrometeor type might be high, the correlations in the training dataset may hinder an independent retrieval of different types.

S13.24

Dependence of the Ice Water Content and Snowfall Rate on Temperature, Globally: Comparison of In-Situ Observations, Satellite Active Remote Sensing Retrievals and Global Climate Model Simulations

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Cloud ice microphysical properties from in-situ aircraft observations are compared to satellite active remote sensor retrievals and global climate models. The intention of this study is to identify strengths and weaknesses of the various methods used to derive ice microphysical properties.

Specific variables compared are the temperature (T) dependence of the ice water content and snowfall rates. The in-situ data are measured with total water hygrometers, condensed water probes, and particle spectrometers. Data from polar, midlatitude and tropical locations are included. The satellite data are retrieved from CloudSat/CALIPSO (2C-ICE, 2C-SNOW-PROFILE), and GPM (Level2A). Although the 2C-ICE retrieval is for ice water content, we developed a method to simulate the IWC to get snowfall rates. The GPM retrievals are for snowfall rate only. Model results are derived using the Community Atmosphere Model (CAM5) and the UK Met Office Unified Model.

The retrievals and model results are matched to in-situ observations using temperature, partitioned by location, then evaluated. Some anomalous behavior is noted. Both the 2C-SNOW_PROFILE and GPM retrievals show unrealistic snowfall rates that increase when the temperature decreases below about -25C. For a given temperature, the retrieved snowfall rates are about an order of magnitude higher for GPM than 2C-SNOW-PROFILE, presumably because CloudSat has a lower reflectivity detection threshold than GPM. The Unified model exhibits IWCs and snowfall rates that are about a factor of 3 below those of CAM5, whereas, for tropical regions, the snowfall rate for CAM5 increasingly decreases as temperature increases above -25C).

S13.25

Report from the International Cloud Modeling Workshop: Exeter, UK, July 18-22, 2016

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1

The International Cloud Modeling Workshop, which is commonly held the week preceding the ICCP meeting, provides a unique opportunity for cloud physicists to convene and discuss critical issues related to cloud microphysical modeling. Moreover, participants are encouraged to participate in cases that focus on advancing our understanding of cloud and precipitation physics from a modeling perspective. For the 9th edition of this meeting, to be held in Exeter on July 18-22, 2016, these cases include organized mid-latitude continental deep convection and aerosol impacts (led by Jiwen Fan, Hugh Morrison, and Adam Varble); convection over SW England observed during COPE (led by Phil Rosenberg, Annette Miltenberger, and Adrian Hill); orographic clouds and the effects of silver iodide seeding (led by Lulin Xue and Istvan Geresdi); and aerosol-cloud-precipitation interactions during VOCALS (led by Adrian Hill and Zach Lebo). In this talk, we will (1) summarize the key findings of these model intercomparisons, (2) describe the current state-of-the-art cloud microphysical modeling techniques, and (3) review future directions for the cloud physics community.

S14.1

Intercomparison of ice nucleation measurement methods during the Fifth International Ice Nucleation Workshop and during ambient aerosol sampling

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14, 12

Various measurement methods for ice nucleating particles (INPs) have been introduced in recent years. It is important to understand how these methods compare. Most such comparisons have been performed for specific laboratory aerosol systems. We present intercomparisons of online and offline INP measurement methods for dust particles generated for the non-formal component of the Fifth International Ice Nucleation Workshop activity 2 (FIN-02), held at the KIT AIDA facility in March 2015. Broad correspondence in measuring INP number concentrations was seen amongst online and offline immersion freezing methods separately, but systematic discrepancies sometimes exist between these two basic methods.

We compared three immersion freezing measurement methods and an online method (continuous flow diffusion chamber [CFDC], operated in excess of water saturation) for a variety of ambient aerosol scenarios. We found that sampling particles into liquid versus onto a filter before immersion into liquid yields comparable results regarding INP number concentrations via immersion-freezing. A modest temperature-dependent bias exists in comparison to the CFDC for two standard immersion freezing methods, but does not exist for a method that condenses water onto particles prior to cooling and freezing. Uncertainty in measuring INP number concentrations via all methods is typically within a factor of three-fold. Thus, there is presently no indication that the immersion freezing methods fail to effectively capture INPs that activate as single particles (i.e., in the online measurement) in the investigated atmospheric scenarios.

Acknowledgments: The FIN-02 Workshop science team and FIN-02 referees are gratefully acknowledged for their valuable contributions.

S14.2

Suppression of the feldspar ice nucleation activity by thin coating layers of secondary organics and sulphuric acid

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14, 5, 4, Fifth International Ice Nucleation Workshop (FIN)

Primary ice formation in tropospheric clouds has important impacts on the climate system and the hydrological cycle, but its model formulation still suffers from an incomplete knowledge of ice nucleation processes and the nature of ice nucleating particles (INPs). During recent years, Feldspar was identified as a remarkably ice-active mineral and was suggested to significantly contribute to the atmospheric INP concentration. However, many atmospheric mineral particles carry variable but small amounts of organic and inorganic material. Such coatings have been shown to reduce the ice-nucleation activity of various aerosol particle types.

During the Fifth International Ice Nucleation Workshop FIN-1 hosted at the KIT AIDA facility we took advantage of the presence of several single particle mass spectrometers to generate and measure atmospherically relevant coatings of secondary organics and sulphuric acid to feldspar aerosol particles, and investigated the ice nucleation efficiency of the uncoated and coated aerosol in AIDA cloud expansion experiments, both for immersion freezing and deposition ice nucleation.

The aerosol coating was induced by chemical reactions inside the AIDA chamber and monitored by online measurements with the single particle mass spectrometers. Suppression of ice nucleation by both coating types was well pronounced in the deposition nucleation mode, but less significant in the immersion freezing mode. Mass spectrometric and ice nucleation results will be reviewed and discussed in this contribution.

Acknowledgements: The valuable contributions of the FIN organizers, their institutions, and the FIN-1 Workshop science team are gratefully acknowledged.

S14.3

Comparing ice nucleation measurements from a suite of instrumentation: LINC, the Leipzig Ice Nucleation counter Comparison campaign

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14, 12

We present an overview and main outcomes of the LINC campaign, during which ice nucleation measurements made by the following instruments were compared to each other:

- LACIS (Leipzig Aerosol Cloud Interaction Simulator, Wex et al., 2014)
- PIMCA-PINC (Portable Immersion Mode Cooling Chamber + PINC)
- PINC (Portable Ice Nucleation Chamber, Chou et al., 2011)
- SPIN (Spectrometer for Ice Nuclei, DMT)

While LACIS and PIMCA-PINC measured immersion freezing, PINC and SPIN varied the supersaturation from well below to above 100% RH_w. Size selected particles from a suite of different samples were examined: K-feldspar (pure and treated with sulfuric or nitric acid), Fluka-kaolinite and two different types of birch pollen.

Immersion freezing measurements performed in LACIS and PIMCA-PINC agreed excellently. PINC and SPIN generally compared well. Deviations that occurred in some cases will be discussed. At the highest RH_w (prior to droplet breakthrough), frozen fractions detected by PINC and SPIN were below those detected by LACIS and PIMCA-PINC. Particle losses in the instrument might contribute to the observed discrepancies.

When considering particle losses, measurements below water vapor saturation generally were reproduced based on immersion freezing parameterizations from LACIS and PIMCA-PINC, together with a freezing point depression, similar to what was suggested for coated kaolinite particles in Wex et al. (2014). The respective process can be considered to be immersion freezing in concentrated solutions, hence deposition ice nucleation was not observed.

Literature

Chou et al. (2011), ACP, 11, doi:10.5194/acp-11-4725-2011.

Wex et al. (2014), ACP, 14, doi:10.5194/acp-14-5529-2014.

S14.4

Ice nucleation on size-selected aerosol using PINC and SPIN in sub- and super-saturated conditions with respect to water during LINC

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14.&IN measurement techniques

Aerosol particles, which initiate the freezing process in the atmosphere at $T > -38^{\circ}\text{C}$, are called ice nucleating particles (INPs) and are not completely understood. In recent years, the number of ice nucleation devices for ambient measurements has increased, making inter-comparisons important in order to standardize measurement and data analysis approaches.

During the Leipzig Ice Nucleation chamber Comparison (LINC), four on-line ice nucleation instruments were compared by measuring size-resolved aerosol particles. These instruments are the Portable Ice Nucleation Chamber (PINC, Chou et al., 2011) and the Spectrometer for Ice Nuclei (SPIN), which is the commercially available version of PINC, investigating deposition nucleation/condensation freezing. The Leipzig Aerosol Cloud Interaction Simulator (LACIS, Hartmann et al., 2011) and the Portable Immersion Mode Cooling chamber (PIMCA) measure in the immersion freezing mode. One of the goals during LINC was to compare PINC and SPIN using size-segregated aerosol particles under controlled laboratory conditions.

Here, we present the measurements performed with PINC and SPIN on size-selected mineral dusts and birch pollen washing water. The comparisons showed in general good agreement. However, differences were found for ice nucleation onset RH in the sub-saturated regime and maximal activated fraction (AF) obtained above water saturation. Possible reasons for the discrepancies, as selected ice size-threshold, scanning rates or ice nucleation time are discussed.

Acknowledgements

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References

Chou et al. (2011), *Atmos. Chem. Phys.*, 11, 4725-4738.
Hartmann et al. (2011), *Atmos. Chem. Phys.*, 11, 1753-1767.

S14.5

The adsorption of fungal ice-nucleating proteins on mineral dusts: a terrestrial reservoir of atmospheric ice-nucleating particles

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Key area numbers: 14.

The occurrence of ice-nucleating particles (INPs) in our atmosphere has a profound impact on the properties and lifetime of supercooled clouds. However, the identities, sources and abundances of airborne particles capable of efficiently nucleating ice at relatively low supercoolings ($T > -15$ °C) remain enigmatic. Recently, several studies have suggested that unidentified biogenic residues in soil dusts are likely to be an important source of these efficient atmospheric INPs. Here we show that proteins from a common soil fungus (*Fusarium avenaceum*) do preferentially bind to and impart their ice-nucleating properties to the common clay mineral kaolinite. The ice-nucleating activity of the proteinaceous INPs is found to be unaffected by adsorption to the clay, and once bound the proteins do not readily desorb, retaining much of their activity even after multiple washings with pure water. The atmospheric implications of the finding that nanoscale fungal INPs can effectively determine the nucleating abilities of lofted soil dusts are discussed.

S14.6

Heterogeneous ice nucleation ability of fresh and cloud-processed α -pinene SOA particles

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14

Measurements of the heterogeneous ice nucleation ability of secondary organic aerosol (SOA) particles are still scarce and show contradictory results, e.g. regarding the activity in the deposition nucleation mode. The frequently discussed phase transition of the SOA particles into a highly-viscous or glassy state at low RH and/or temperature could affect their ice nucleation ability. It is also argued that processing of the SOA particles, e.g. by pre-cooling or by atmospheric freeze-drying in ice clouds, could be a controlling factor for their efficiency to act as ice nucleating particles (INPs). Ice-cloud processing could provoke the formation of highly porous SOA particles with an enhanced ice nucleation efficiency compared to unprocessed particles with a compact, near-spherical shape.

About a decade ago, we have performed first experiments on the heterogeneous ice nucleation ability of SOA particles from the ozonolysis of α -pinene at our laboratory, the large cloud simulation chamber AIDA (Aerosol Interaction and Dynamics in the Atmosphere) at the Karlsruhe Institute of Technology. The experiments were performed at a temperature of 210 K, where the SOA particles proved to be very inefficient INPs. In view of the resurged interest in ice cloud formation by secondary organic matter, we have recently extended these measurements to a much broader temperature range (210 - 243 K) and have specifically explored the processing of the α -pinene SOA particles in subsequent cloud formation cycles. In this contribution, we summarise our new findings and compare them to recent measurements in the CLOUD chamber at CERN.

S14.7

Moving contact lines due to electrowetting enhance ice nucleation rates

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14

Laboratory measurements of heterogeneous ice nucleation in liquid water drops resting on a substrate show strongly enhanced freezing rates under transient electrowetting conditions. The electrowetting geometry consists of a 20 microliter pure water droplet resting on a thin, nonconducting substrate, with a metal electrode immersed within the droplet and a grounded planar electrode beneath the substrate. When a high electric voltage of up to 2000 V is applied to the electrode, droplets are observed to wet the substrate more efficiently, known as electrowetting. The freezing temperature without the electric field is -24.7 ± 0.7 °C with a 2 °C/min cooling rate, and there is no significant difference if we apply up to 1000 V on the electrode while above 0 °C and decrease the temperature with the same cooling rate. However, the freezing temperature is observed to increase to above -10 °C if we first cool down the temperature then turn on the field (i.e., during transient electrowetting). The initial freezing location always occurs at the air-water-substrate contact line. In order to find the possible nucleation mechanism, a range of substrates, such as glass, silanized glass, mica sheet, polymer film and graphene covered glass, have been tested. The experiments indicate that electric field alone (smaller than 10 V/ μm) has small effect on ice nucleation, but the moving boundary of the droplet on the substrate due to electrowetting leads to large increases in nucleation rate. We speculate that this moving boundary effect is related to the phenomenon of contact nucleation.

S14.8

Observations of Ice Nucleating Particles during the ICE-D Campaign.

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14. Ice nuclei and cloud condensation nuclei

12. Aerosol-cloud-precipitation-interactions and processing

Abstract

The recent ICE-D (Ice in Clouds Experiment - Dust) took place during August 2015. It was designed to study aerosol-cloud interactions and in particular the impact of mineral dust on the cloud microphysics and its role as ice nucleating particles (INP). Utilising both ground based and aircraft observations, ICE-D was based in Cape Verde off the coast of Senegal, west Africa giving it access to freshly advected mineral dust from the African continent as well as air masses that had undergone some degree of atmospheric processing.

Filter samples were collected on-board the UK BAe146 research aircraft over a range of atmospheric conditions. Using a microdrop assay technique, we have determined the concentration and efficiency of ice nucleating particles present in the samples. The technique produces INP concentration over a range of temperatures, during ICE-D we observed INP as warm as -7°C. Measured INP concentrations ranged from 20-200 m⁻³ at -10oC and 103 -105 m⁻³ at -20oC with a detection limit determined to be around 20 INP m⁻³.

Parallel filters were collected to allow compositional analysis to be performed. A number of different atmospheric tracers will be used to further differentiate the air masses encountered during the sample collection. In addition the INP concentrations will be compared to predictions as generated by various parameterisations from the literature.

S14.9

Layered structure of dust and their origins in the Cape Verde region during the ICE-D campaign

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14

ICE-D (Ice in Clouds Experiment - Dust) aims to study the impact of mineral dust on cloud microphysics. The field campaign took place in August 2015. Various instruments on board the UK BAe 146 research aircraft were used to measure aerosol properties, cloud microphysics, and meteorological variables in the Cape Verde region. Analysis will be presented of the aerosol data and the satellite images to identify the vertical structure of aerosols and the possible origins of dust particles. We found the common presence of the layered structures except in a few cases that were under direct influence of easterly wave troughs. We performed back trajectory analyses and found that there were two origins of dust aerosol. The dust particles in the upper layer were transported with the easterly winds in the Sahel region, while in the lower layer at about 850 hPa dust particles were from the Mauritania and West Sahara region. The images from CALIPSO indicate the dust particles were externally mixed with smoke in some cases. Results will be shown of the impact on convective clouds of the different aerosol size distribution, chemical composition and mixing state using numerical models.

S14.10

Observation of Ice Nucleating Particles and Cloud Microphysics with Active Remote Sensing

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4, 12, 14

Mixed-phase clouds play an important role in current weather and climate research. The complex interaction between aerosols, clouds and dynamics taking place within these clouds is still not understood. The unknown impact of ice nucleating particles (INP) on cloud lifetime and precipitation evolution introduces large uncertainties into weather prediction and future climate projections. At the same time balance equations between INP and ice crystals are beginning to play a role in numeric modeling. Recently, DeMott (2010) and Niemand (2010) provided parameterizations for the efficiency of available INP at a certain temperature. These techniques opened, for the first time, the possibility to derive INP number concentration with Raman lidar instruments from ground as shown by Ansmann and Mamouri (2015). This is a giant step for INP research, because now INP can be researched in the atmospheric column on a continuous basis.

The INP retrieval method of Ansmann and Mamouri (2015) has been validated with ground based in-situ measurements in a measurement campaign on Cyprus in 2015. In this work, we present, for the first time, a closure between INP number concentration at cloud height and the simultaneously measured properties of ice crystals falling from a cloud. The INP number concentration is retrieved with the above mentioned method via Raman lidar. Simultaneously, we use combined lidar/radar instrumentation together with the Cloudnet algorithms to measure the microphysical properties of the liquid and the ice particles within the mixed-phase cloud layer.

S14.11

Conditions Influencing Transport of Fluorescent Biological Aerosol Particles in the Atmosphere and Implications for Ice Nucleation

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14 12 4

Primary biological particles are known to nucleate ice at relatively warm temperatures, with the potential to influence cloud microphysical and radiative properties. However, available information is dominated by laboratory and ground-based measurements, with little known about the abundance of these particle types above the atmospheric boundary layer and in clouds. This work will present aircraft measurements of fluorescent biological aerosol particles (FBAP) in the free troposphere over the United States and investigate the conditions that influence their number concentration.

A Wideband Integrated Bioaerosol Sensor (WIBS-4A) was used to measure fluorescent biological particles in the atmosphere at temperatures between 280K to 220K. The number concentrations of these particle types at mixed-phase cloud temperatures varied widely from day to day. Conditions responsible for these variations will be presented, including evaluation of sources (origin and anthropogenic influence), atmospheric stability and humidity, and potential sinks such as cloud processes, advection and sedimentation. Implications for ice formation in mixed-phase clouds will be discussed via correlation to ice nucleating particle (INP) measurements and comparison to a parameterization relating FBAP and INP number concentrations.

S14.12

Sea spray aerosols influence atmospheric ice nucleating particle populations

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14, marine aerosols

The abundance of ice nucleating particles (INPs) is spatially variable throughout the atmosphere due to the complex distribution of aerosol types (e.g. mineral dust, smoke, etc.). Sea spray aerosol (SSA) is considered a unique source of INPs; for a given aerosol number and surface area, lower numbers of INPs are detected in SSA compared to known continental sources. SSA INPs are also known to show complex relations to ocean biological activity. New measurements are needed to comprehensively elucidate the variability and influences of INPs in SSA

We investigated number concentrations of INPs in three regions with the CSU continuous flow diffusion chamber (*in-situ*) and CSU ice spectrometer (offline). Analyses of collected INPs and measurements of single-particle chemistry, aerosol size distributions and meteorology are used to describe INP compositions and air mass types. Measurements at the Bodega Marine Laboratory (California) and the Mace Head Observatory (MHO, Ireland) represented two contrasting remote coastal sites. Dynamic variations in INP number and composition occurred at these sites, with strong variations related to clean marine versus continental influences. The impact of organic-rich plumes originating from biologically active ocean regions on marine INPs at MHO will also be presented. Finally, observations during the March–April 2016 CAPRICORN cruise from Tasmania to 57°S will be reported; this pristine ocean is perhaps the region most sensitive to variations in INP populations. These data are applicable to modeling studies to determine the importance of marine INPs in cloud ice formation in these regions under a changing climate.

S14.13

Global synthesis of long-term cloud condensation nuclei observations

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Ice nuclei and cloud condensation nuclei

long-term global observations

aerosol chemical and microphysical properties

Numerous intensive field campaigns have explored detailed characteristics of CCN in many locations around the world. However, these short-term observations can generally not address seasonal or inter-annual variations and a comparison between sites can be difficult. Here, we present results of long-term CCN and aerosol number concentrations as well as size distribution and chemical composition data covering at least one full year between 2006 and 2014. The 12 locations include stations in Europe, North America, Brazil and Korea.

The sites are located in different environments allowing for temporal and spatial characterization of CCN variability in different atmospheric regimes. Those include marine, remote-continental, boreal forest, rain forest, Arctic and monsoon-influenced environments, as well as boundary layer and free tropospheric conditions.

The aerosol populations and their activation behavior show significant differences across the stations. We explore the influence of seasons, environmental factors such as rainy seasons, e.g., in the Amazon or Korea, and also the impact of anthropogenic pollution episodes, e.g., during the Arctic Haze period. Persistence of CCN concentrations varies strongly as well. At some sites similar concentrations persist over more than one week, while at others concentrations change rapidly within few days.

We show results in terms of CCN concentrations, activation ratios, geometric mean and critical diameters as well as submicron particle chemical composition. We also discuss uncertainties associated with monitoring type data and implications for model-measurement comparison studies.

S14.14

Physical, chemical and hygroscopic properties of urban aerosols in Seoul measured during the KORUS-AQ pre-campaign

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14, 12, 13

Despite the importance of atmospheric aerosols as the crucial factor for air quality and climate change, our understanding of physical, chemical and hygroscopic properties of atmospheric aerosols are still very limited. The KORUS-AQ Campaign, jointly organized by National Institute of Environmental Research (NIER) of Korea and National Aeronautics and Space Administration (NASA), aims at understanding various aspects of air quality problem in East Asia and will be held in spring, 2016. In preparation for this campaign, pre-campaign was held in spring, 2015, in Seoul where local anthropogenic sources and influence of Chinese continental outflow are intermingled.

Here we present some of the important results from the pre-campaign. Aerosol number concentration, size distribution, chemical composition, hygroscopic growth factor, and cloud condensation nuclei (CCN) number concentration were measured at Korea Institute of Science and Technology (KIST) in Seoul. Aerosol number concentration varied diurnally due to traffic and new particle formation. Organic aerosol comprised a major fraction of the non-refractory submicron aerosols. The hygroscopicity parameter (κ) estimated from H-TDMA measured hygroscopic growth factor ranged 0.17-0.27 but the κ values estimated with aerosol chemical composition information were larger especially when volume fraction of ammonium nitrate was relatively high. The predicted CCN number concentration based on the measured aerosol size distribution and hygroscopicity parameter agreed well with the measured CCN number concentration. During new particle formation events, high organic fraction tended to reduce aerosol hygroscopicity. Details will be discussed at the conference. Preliminary results from the KORUS-AQ Campaign may also be presented.

S14.15

IMPORTANCE OF CHEMICAL COMPOSITION OF ICE NUCLEI ON THE FORMATION OF ARCTIC ICE CLOUDS

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Extensive measurements from ground-based sites and satellite remote sensing reveal the existence of two Types of Ice Clouds (TICs) in the Arctic during the polar night and early spring. TIC-1 are composed by non-precipitating very small (radar-unseen) ice crystals whereas TIC-2 are detected by both sensors and are characterized by a low concentration of large precipitating ice crystals. It is hypothesized that TIC-2 formation is linked to the acidification of aerosols, which inhibit the ice nucleating properties of ice nuclei (IN). As a result, the IN concentration is reduced in these regions, resulting to a smaller concentration of larger ice crystals. Over the past 10 years, several parameterizations of homogeneous and heterogeneous ice nucleation have been developed to reflect the various physical and chemical properties of aerosols. These parameterizations are developed according to two main approaches: stochastic (that nucleation is a probabilistic process, which is time dependent) and singular (that nucleation occurs at fixed conditions of temperature and humidity and time-independent). This research aims to better understand the formation process of TICs using a newly-developed ice nucleation parameterizations. For this purpose, we implement some parameterizations (2 approaches) into the Limited Area version of the Global Multiscale Environmental Model (GEM-LAM) and use them to simulate ice clouds observed during the Indirect and Semi-Direct Arctic Cloud (ISDAC) in Alaska. Simulation results of the TICs-2 observed on April 15th and 25th (acidic cases) and TICs-1 observed on April 5th (non-acidic cases) are presented.

S14.16

Combining Theoretical and Laboratory Studies to Parameterise Contact Nucleation by Mineral Dust

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Key Area: 14

Preferred: Oral presentation

A parameterisation for contact nucleation is presented, which combines theoretical expressions for determining the collision efficiency, with experimentally determined surface area normalised freezing efficiency results. The parameterisation has dependencies on aerosol and cloud droplet physical properties, including electric charges, as well as ambient temperature and humidity. The parameterisation predicts the highest concentrations of ice nucleating particles (INPs) at large aerosol and large cloud droplet sizes, and at cold temperatures and low relative humidities. The number concentration of INPs produced in the contact mode are generally lower than those in the immersion or deposition mode, however under certain conditions contact INP concentrations can exceed those of the other modes. Along with descriptions for immersion and deposition nucleation, the new parameterisation is used in a high resolution, semi-idealised simulation of a deep convective cloud, and a number of sensitivity studies are performed. At a temperature of around 260 K, both contact and immersion freezing contribute equally. But overall, immersion freezing is the dominant INP production mechanism, followed by contact nucleation, with deposition nucleation contribution very little to total INP number concentrations. Results indicate the greatest sensitivity is to the best fit function to laboratory data. Large changes in the soluble fraction of dust aerosols result in less than a factor of 3 change in contact INP concentrations, and electrically charged droplets and aerosol particles only marginally enhance contact INP production.

S14.17

The competition for water vapour between INP and CCN results in a suppression of ice

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There is strong evidence that a dominant pathway for heterogeneous ice nucleation in the atmosphere, at temperatures above around -35°C , requires the formation of liquid particles as the first step. This means that INPs are in direct competition with other particles within the same cloud, specifically CCN for water vapour. CCN are generally more hydrophilic and better able to compete for water vapour than, INPs which are typically insoluble. Therefore water is more likely to condense onto a CCN than an INP. This may leave INPs without enough condensed water to be able to freeze. This suppression effect was predicted by a detailed microphysical model. However results from cloud chamber experiments involving external mixtures of aerosol particles did not show the effect. In order to reproduce chamber results with the model, it is necessary to define a threshold mass of condensed water required for immersion or condensation freezing. This is a currently unconstrained quantity. The magnitude of the suppression effect shows significant sensitivity to this value of the threshold mass of water. Other significant sensitivities of the suppression effect are the diameter of the INPs and cooling rate within the cloud.

In this presentation, situations where the suppression of ice formation by the presence of CCN is likely to be most significant will be discussed. Attention will also be given to possible ways to constrain the threshold mass of condensed water required for freezing in the immersion or condensation mode.

S14.18

A Modelling Study of the Impact of Ice Nucleation by Different Aerosol Types on the Development of a Convective Cloud.

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1. 3. 4. 12. 14.

The 1.5D bin-resolved microphysics model DESCAM (Flossmann et al., 1985) was used to assess the role of different aerosol particles and their nucleation modus in the ice initiation of the CCOPE cloud (Dye et al., 1986). In this study, six aerosol distributions are used: four different types of mineral particles (Feldspar, Kaolinite, Illite and Quartz) as well as aerosols of biological origin, considered as ice active, and a background aerosol distribution. Each ice active aerosol type was used in the immersion freezing, contact freezing and deposition freezing mode, with explicit parameterizations when available. The new aerosol distributions are initialized to have a standard case comparable to our previous study (Hiron and Flossmann, 2015).

In sensitivity studies, the different aerosol types and nucleation modes were treated separately and in competition to assess their relative importances. The first results indicate an increase of the ice formation in comparison to our previous results, where we used non-specific ice nucleation parameterizations.

S14.19

Marine organic aerosols and k-feldspar as ice nucleating particles in the atmosphere.

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14 4 5 13 12 10

Ice nucleating particles (INP) are known to affect the amount of ice in mixed-phase clouds, changing many of their properties. However, the importance of different aerosol species towards ice nucleation in different contexts is not well understood. Here, I will show the simulated distributions of k-feldspar (the ice-active component of desert dust), and marine organic aerosols (from sea spray), and relate them to an INP distribution in different contexts. We do this by using a global aerosol model (GLOMAP-mode) and relate the concentration of these aerosols to an INP concentration by using laboratory derive parameterizations of their ice nucleating ability. We found that k-feldspar dominates the INP distribution in most of the contexts, however, marine organic aerosols can be important in regions such as the southern ocean. Then we compare our predictive ability of INP with a dataset of INP observations. We also test other INP parameterisations against the field observations. This study advances our understanding of which aerosol species have to be included in order to adequately describe the global and regional distribution of INPs in models and guides us where to focus future experimental work.

S15.1

The retention of organics during riming: wind tunnel and model results

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15,4

In mixed phase clouds ice hydrometeors grow primarily by riming, i.e. by accretion of supercooled droplets. Water-soluble trace substances present in the supercooled droplets might be released to the gas phase during freezing, so that the concentration in the rimed ice could be lower than its initial value in the aqueous phase. Retention determines the amount of the trace substance which is trapped in the ice phase and, thus, it affects the vertical redistribution in the troposphere. Organic species such as formic, acetic, oxalic, and malonic acids as well as formaldehyde were investigated in the Mainz vertical wind tunnel. A cloud of supercooled droplets containing a single component of these substances was produced upstream of the rime collector. The rime collectors were captively-floated ice particles with diameters of 8 mm and quasi-floated snowflakes with diameters between 8 and 12 mm. The conditions during the experiments corresponded to those where riming is most effective in mixed phase clouds; temperatures between -16 and -7°C, liquid water contents between 0.5 and 1.5 g/m³, and wind tunnel air speeds between 2 and 3 m/s depending on the rime collector type. Measured values of the retention coefficients were between 0.5 (acetic acid) and 1 (e.g., oxalic acid), depending on the effective Henry's law constant. For validation the experimental data are compared to results from model simulations with a one-dimensional retention model.

S15.2

Tracking the footprint of collisions and aqueous-phase chemical reactions on aerosol size distribution using a lagrangian cloud-microphysics scheme

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12, 15

Clouds can alter the size distribution and chemical properties of aerosols that serve as a cloud condensation nuclei (CCN). This can happen due to collisional growth of cloud droplets or irreversible aqueous phase chemical reactions (e.g. SO₂ oxidation) occurring within cloud droplets. The altered CCN can be removed from the atmosphere by wet deposition, or in cases with no precipitation, can be recycled back to the environment through the evaporation of cloud droplets changing the ambient conditions for the next generation of clouds.

To study the footprint of clouds on aerosol size distribution we have developed a particle-based cloud-microphysics and aqueous-phase chemistry scheme that allows to track aerosol properties within the clouds. The developed scheme covers: (i) particle-level formulation of condensational growth (including CCN activation and evaporation), (ii) collisional growth of cloud droplets (using Monte-Carlo approach of Shima et al 2009), (iii) and newly implemented particle-level representation of aqueous phase SO₂ oxidation by H₂O₂ and O₃.

In this work the particle-based scheme will be used in a 2D framework mimicking a vertical slice through a stratocumulus topped boundary layer. The simulation scenarios will cover high and low initial aerosol concentrations. The presentation will evaluate the impact of both collisions between cloud droplets and aqueous-phase chemical reactions on a size distribution of aerosol particles.

S15.3

A new method for estimating aerosol mass flux in the urban surface layer by LAS

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Atmospheric aerosol has a great influence on human health and the natural environment as well as the weather and climate system. Therefore, atmospheric aerosol has attracted significant attention from the society as a whole. Despite consistent research efforts, there are still uncertainties in our understanding of its effects due to poor knowledge of aerosol vertical transport caused by our limited measurement capability of aerosol mass vertical transport flux. In this paper, a new method for measuring atmospheric aerosol vertical transport flux is developed based on the similarity theory of surface layer. The theoretical results show that aerosol mass flux can be linked to the real and imaginary parts of the atmospheric equivalent refractive index structure parameter (AERISP), and the ratio of aerosol mass concentration to the imaginary part of the atmospheric equivalent refractive index (AERI). The real and imaginary parts of AERISP can be measured based on the light propagation theory. The ratio of aerosol mass concentration to the imaginary part of AERI can be measured based on the measurements of aerosol mass concentration and visibility. The observational results show that aerosol vertical transport flux varies diurnally and is related to the aerosol spatial distribution. The maximum aerosol flux during the experimental period in Hefei City was $0.017 \text{ mgm}^{-2}\text{s}^{-1}$, and the mean value was $0.004 \text{ mgm}^{-2}\text{s}^{-1}$. The new method offers an effective way to study aerosol vertical transport over complex environments.

Key words: aerosol mass upward flux, urban surface layer, Large Aperture Scintillometer(LAS)

S15.4

Cloud residual particle composition measurements in convective clouds over the Amazon during ACRIDICON-CHUVA

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9, 3, cloud residual particles, mass spectrometry, aircraft-based measurements

ACRIDICON-CHUVA was a measurement campaign to investigate the interaction of aerosols, clouds and radiation in tropical convective clouds, conducted over the Amazon in September 2014. The platform of this aircraft-based campaign was the High Altitude and Long range aircraft HALO. We operated a Compact Time-of-Flight Aerosol Mass Spectrometer (C-ToF-AMS) to investigate the chemical composition of submicron aerosol and cloud residual particles. The instrument was connected alternating to two different inlets: The HALO Aerosol Submicrometer Inlet (HASI) that samples aerosol particles, and to the HALO Counterflow Virtual Impactor (HALO-CVI) that samples cloud droplets and ice particles during in-cloud measurements, such that cloud residual particles can be analyzed.

Clean as well as polluted convective clouds were sampled at different altitudes to investigate possible influences of anthropogenic aerosol on clouds. Here we want to focus on the chemical composition of cloud residual particles.

In general the non-refractory mass of cloud residuals is dominated by organic material and, to a lesser extent, sulfate and nitrate. A comparison of the cloud residual composition at different altitudes shows an enrichment of organic material at higher altitudes (9-12 km).

Cloud residual particles sampled in polluted convective clouds contain besides organic material also sulfate and nitrate. The mass spectra of these organics show indications for particles from combustion processes, especially at high altitudes (10-13 km), probably resulting from transport from cloud base to cloud top. At low altitudes the organic mass spectra show indications for hydrocarbon like organic aerosol.

S15.5

Examination Of The Potential Impacts Of Dust and Pollution Aerosol Acting As Cloud Nucleating Aerosol On Water Resources In The Colorado River Basin

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Mixed phase clouds; Orographic clouds

The main objective of this research is to quantify the impacts of dust and pollution aerosols on wintertime precipitation in the Colorado Mountains. The combined effects of dust serving as ice nuclei, cloud condensation nuclei (CCN) and giant (GCCN) on precipitation in combination with anthropogenic pollution aerosol acting as CCN and on water resources in the CRB has been examined for the winter of 2005. We hypothesized that dust will enhance precipitation, while aerosol pollution will reduce water resources in the CRB via the "spill-over" effect. Since dust is more episodic and aerosol pollution is more pervasive throughout the winter season, we anticipate that the combined response to dust and aerosol pollution is a net reduction of water resources in the CRB. The Colorado State University Regional Atmospheric Modeling System (RAMS) version 6.0 is used for this study. RAMS was modified to ingest GEOS-CHEM output data and periodically update aerosol fields. GEOS-CHEM is a chemical transport model which uses meteorological data from the NASA GEOS. The aerosol data comprise of a sum of hydrophobic and hydrophilic black carbon and organic aerosol, hydrophilic SOAs, hydrocarbon oxidation and inorganic aerosols (nitrate, sulfate and ammonium). A RAMS-based dust source and transport model is also used for prediction of regional dust sources. It was found that the combined effects of dust and aerosol pollution lead to a 1.9 % loss of precipitation in CRB or 4,020,000 acre-feet loss compared to a run with no anthropogenic sources and no dust.

S15.6

Multiphase production of oxalates on the global scale

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15. Cloud and precipitation chemistry

Oxalates and the corresponding oxalic acid represent one important class of low molecular weight organic molecules (dicarboxylic acids) which are found in many aerosol particles. A major production pathway of oxalates is found to be the cloud phase, but also aerosol chemistry in deliquesced aerosol particles contributes to the global oxalate budget and therefore to the secondary organic aerosol. Due to its strong acidity oxalates are unlikely to recombine and hence the oxalates remain in the particulate phase, representing a relatively stable form of SOA.

This modelling study presents an algorithm for aqueous phase oxalate production from glyoxal, methylglyoxal and glycolaldehyde, which is applied in a global chemistry climate model, using an explicit interactive cloud chemistry scheme together with a comprehensive set of gas phase reactions forming the above mentioned precursors from e.g. isoprene oxidation.

Both the global distributions as well as an analysis of production pathways is going to be presented.

S15.7

Modelling cloud chemistry at the puy de Dôme station

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15, 12

Clouds favor chemical reactions that would not occur in gas phase or with a rate much slower than in aqueous phase. Reactivity in clouds is favored by photochemical processes highly enhanced in cloud droplets and is boosted by some reactions implying ions that do not take place in gas phase. In-cloud chemistry also relies on the possible interactions between aqueous and particulate phases.

A new cloud chemistry model has been developed based on CLEPS (Cloud Explicit Physicochemical Scheme), an explicit aqueous phase oxidation mechanism including oxidation pathways for organics up to C4. Structure-Activity Relationships (SARs) based upon experimental data are used to derive reaction rates or equilibrium constants in case of species that are not well documented in the literature. SARs are also used to determine the branching ratios and further select the major oxidation pathways to be included in the mechanism. CLEPS is integrated in a box model based on DSMACC and using the Kinetic PreProcessor (KPP) modified to consider an aqueous phase.

This model has recently been coupled with a warm microphysical scheme module that predicts the number concentration of cloud droplets and raindrops resulting from the activation of a given aerosol particle spectrum and taking into account the subsequent processes that affect the droplets distributions. To evaluate the accuracy of this new modelling tool, simulation of several real and contrasted cloud events (various seasons, air-mass origins) observed at the puy de Dôme station have been performed and modelled concentrations in cloud water are compared to experimental values.

S15.9

Combining cloud physics instruments with geochemical analysis of rain and cloud samples - a tool for better understanding aerosol-cloud interactions.

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15

12

14

Better aerosol-cloud interactions understanding is needed in order to improve climate predictions. We present a simple method to study these interactions by combining geochemical analysis of rain and cloud samples with satellite images and ice nuclei (IN) concentrations provided by IN counters. Geochemical analysis provides a reliable tool for determining the aerosol type in a given rain sample, while satellite images provide a convenient tool for estimating a variety of variables of clouds. By combining these two tools, important insights are obtained.

Since 2008, rain has been collected in northern Israel and its chemical composition was determined. The chemical composition was used to identify the aerosols in the air mass and their sources. By combining the chemical data with satellite retrieved cloud properties, we were able to link the aerosols' types, sources, and concentrations with the cloud's glaciation temperature (T_g). We found that Saharan dust glaciates clouds from -12°C. This T_g is already achieved under low dust concentrations. In addition, we found that marine air mass also encourages ice initiation but in this case, freezing is enhanced by low aerosol concentrations, resulting in large droplets. Anthropogenic aerosols suppress ice initiation in clouds.

Use of geochemical data from cloud samples was also made at the High Altitude Research Station Jungfraujoch. During winter 2014 and 2015 cloud samples were collected in parallel to IN measurements. By combining the geochemical data with IN concentrations, we were able to relate IN activity to the aerosol's type and identify its source.

S15.10

Chemical and microbial content of clouds collected at the Reunion island in the Indian Ocean

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15. Cloud and precipitation chemistry, **oral**

keywords: Cloud chemistry, microbiology, tropical cloud

Abstract:

Microphysical, chemical and microbial description was performed on cloud waters sampled in april 2014 and 2015 at the Reunion Island. The cloudy air-mass crossing this island located in the Indian Ocean is mainly under marine influence. This study is the first one combining biological and chemical analysis on tropical clouds.

The 11 samples were collected with a single stage cloud collector under sterile conditions. The size distribution of the cloud-droplet and the liquid water content were determined for each collected cloud events with a CDP probe. For the chemical analysis, we have quantified the main inorganic ions, the major carboxylic acids, the formaldehyde and the hydrogen peroxide concentration. The concentration of formaldehyde, H₂O₂, carboxylic compounds (acetic, formic, succinic and oxalic acid) and inorganic ions are coherent with the marine influence on the chemical cloud composition over this tropical island.

For the microbial analysis, we have measured the total microbial cells count, the energetic state (ATP concentration), and isolate cultivable microbial strains. More than 90 bacterial strains were isolated and identified by 16s or 26s rRNA gene sequencing. Most frequent genera included *Sphingomonas*, *Bacillus* and *Arthrobacter*. They presented high similarities with those originating from vegetation, soil and aquatic environments.

The chemical and microbial composition of these tropical clouds will be discussed and compared to those measured in tempered cloud events collected at the puy de Dôme station (1465 m.a.s.l.).

S15.11

Aerosol wet deposition at Appalachian Mountains site in the United States

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12, 15, 17

The wet removal of airborne particulates is a significant component of atmospheric deposition in the Eastern United States. This study analyzed the daily wet deposition of major ions at the Canaan Valley site in Appalachian Mountains in Eastern US, for the time interval 2000-2014. The site is part of the Atmospheric Integrated Research Monitoring Network (AIRMoN), and is significantly impacted by acid precipitation, caused largely by anthropogenic sources of SO₂ and NO_x. Results show that the precipitation rate, R , varies mainly in the interval [0.01-100] mm/day, and the daily wet deposition flux, F , varies about two orders of magnitude for most ions. The largest daily wet depositions are for SO₄ and NO₃ with extreme values over 30 mg/m²/day. In the case of NH₄, the largest daily wet depositions are over 10 mg/m²/day. Seasonal variations are illustrated by contrasting the winter and summer. In general, there are much larger daily wet deposition fluxes in summer than in winter. For SO₄ there is more conversion of SO₂ to SO₄ in the gas phase and in cloud droplets during summer. Similarly, NH₄ has a distinct seasonal variation with a maximum in summer, consistent with larger sources of NH₃ during the growth season. Analysis shows that precipitation events are more frequent and more intense in summer than in winter. For the Canaan Valley, the summer precipitation events are effective in wet removal of aerosols providing episodes with some of the highest rates of acid deposition.

S16.1

Development of Stochastic Parameterizations of Cloud Microphysics for Models and Retrievals: Use of Uncertainty in In-Situ Observations

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16, 1, 17

Characterization of ice microphysical properties, such as number distribution functions ($N(D)$), aspect ratios, extinctions, number concentrations and ice mass contents from aircraft in-situ probes is needed for developing model and remote sensing parameterizations. Although prior studies have computed such quantities for many meteorological settings, there is no comprehensive study that quantifies their dependence on environmental conditions taking into account parameter uncertainties.

Here, measurement errors, statistical uncertainties due to particle sampling, and parameter variability as a function of spatiotemporal scale are considered when developing representations for microphysical properties as functions of environmental conditions using data collected during the High Ice Water Content project, Small Particles in Cirrus Experiment, Plains Elevated Convection at Night Experiment, Profiling of Winter Storms Project and Mid-Latitude Continental Convective Clouds Experiment. Rather than representing derived parameters by single values, surfaces or volumes of equally realizable solutions for measurements in similar environmental conditions are determined in the phase space of those parameters based on measurement or sampling uncertainty and inherent parameter variability.

Specific applications of this technique to represent mass (m)-dimension (D) relationships as surfaces in (a, b) parameter space (where $m = aD^b$), projected area (A)-dimension relationships as surfaces in (c, d) parameter space (where $A = cD^d$) and $N(D)$ as gamma functions in (N_0, λ, μ) space (where $N(D) = N_0 D^{\mu} e^{-\lambda D}$) as functions of environmental conditions are presented. It is shown that previous parameterizations do not adequately characterize measurement uncertainty, inherent parameter variability, or variation on spatiotemporal scales. Implications for the implementation of this approach in Monte Carlo stochastic parameterization schemes are discussed.

S16.2

Toward the future of cloud particle characterization with large sample volume ensemble particle probes

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Typical cloud probes operate by recording the characteristics of one particle at a time and assimilating the observation into a histogram. In order to ensure that only one particle is in the sample volume during a measurement, cloud probes such as the FSSP and CDP have very small sample volumes. They also implement rejection criteria, where samples are ignored if the occurrence of a coincident particle is likely. As a result, relatively long flight paths are required to build up statistically meaningful histograms particularly in low density clouds.

We present here an algorithm that enables a fundamental shift in particle probe operation by allowing particle distribution retrievals through ensemble observations and therefore the use of large sample volumes. This creates the opportunity to capture particle distributions on smaller spatial scales and in low concentration clouds. The approach is founded on the discovery of a mathematically explicit relationship between cloud particle ensemble statistics and their individual particle statistics. This allows a high speed inversion process because the relationship and its derivatives have analytical definitions. In contrast to high performance holographic imagers, the technique has relatively low processing time (less than one second on a standard PC) and low data system storage and bandwidth requirements. Furthermore, the analysis is not limited to single parameter retrievals. It can accommodate correlated multi-parameter statistics such as particle scattering cross section, polarization and extinction cross section.

S16.3

How biased is the sampling of clouds by aircraft?

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Only aircraft are currently able to provide high-frequency, high-accuracy in situ measurements of clouds. However, operational constraints and the large costs involved mean that a sampling strategy is usually adopted when deciding which clouds to sample during a sortie. The role of human decision-making raises the possibility that systematic biases may be introduced. We present an analysis of a simplified model of aircraft cloud-sampling, where a strategy based on choosing the largest cloud is always employed. In this model, the resulting biases in cloud properties can be understood exactly using order statistics. For example, for gamma-distributed properties, a bias of a factor of 1.5 can result.

S16.4

Quantification of Mixed Phase Cloud Properties with Single Particle Light Scattering Polarimetry

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16, 4

Single particle light scattering polarimetry

Abstract

Mixed phase clouds represent probably the most frequent type of clouds that contain ice with respect to the range of altitudes and temperature over which they are encountered. They present potential hazards to safe aircraft operations while at the same time being the most producers of precipitation. Imaging probes such as the 2D-C, CIP and 2D-S are able to distinguish liquid water from ice once the size of these particles exceed approximately 5-10 times the minimum resolution of these instruments; however, this leaves a critical gap in the size range from approximately 5-50 μm . This size range is critical for processes like ice multiplication, riming and graupel and hail formation. The Cloud Aerosol Spectrometer with Polarization Detection (CAS-POL), Cloud Particle Spectrometer with Polarization Detection (CPSPD) and Backscatter Cloudprobe with Polarization Detection (BCPD) measure the S and P components of polarized scattered light from single particles from which droplet and ice crystals can be distinguished. The basic theory and examples from laboratory evaluations and three field campaigns will be presented that demonstrate how ice fraction, riming potential and glaciation rates can be evaluated.

S16.5

A Submicron Cloud Particle Imager (CPI) for Small UAV and Manned Aircraft

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16, 17, 1, 4, 5, 13 A cloud particle imager (CPI) with 0.7 micron pixel resolution has been fabricated and tested in the laboratory. The submicron CPI can be flown on small UAV and piloted research aircraft. A custom, high-resolution microscope objective with a 20-mm working distance is key to providing the high-definition imagery. The 1951 USAF test pattern conforms to the MIL-STD-150A standard, which is widely accepted as the gold standard. Laboratory tests with 1951 USAF show that the submicron CPI can resolve line pairs that are 0.7 microns in width using red laser light. Even better resolution is obtained with blue laser light. A prototype instrument was fabricated and evaluated by comparing the imagery of tiny particles (salt crystals, dust, small water droplets, etc), with side-by-side comparison of the same particles imaged with an Olympus model CX41 laboratory microscope. The submicron CPI will provide high-resolution images of ice crystals in cirrus that will resolve the shape of particles as small as a few microns. The high-resolution imagery will also provide improved discrimination between small water droplets and first ice in wave clouds and convective clouds. The shapes of some large aerosol particles will also be identifiable. The submicron CPI imagery will greatly improve the retrievals of radiative transfer products in cirrus and mixed-phase clouds. A prototype version of the submicron CPI that weighs 3 Kg was fabricated and is applicable for installation on small UAV's. A larger version with a robust housing will be designed for application on jet aircraft.

S16.6

Measurements of mixed-phase and ice cloud microphysical properties with spectrum-resolved water Raman lidar and their use in evaluating cloud radar/lidar retrieval methods

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16, 5, 4

A novel lidar technique is presented that allows for direct measurements of mixed-phase and ice cloud properties such as liquid water content, ice water content (IWC), and effective particle size (EPS). Experimentally, the method is based on a spectrometer that has been added to the receiver of the German Weather Service's RAMSES lidar to measure the Raman spectrum of water. The lidar measurements are used to assess the accuracy of standard cloud retrieval products obtained from combined ground-based radar and lidar observations.

Current advanced cloud retrieval methods employ profiles of radar reflectivity factor (Z), temperature (T) and, if available, lidar extinction to derive water content and EPS under assumptions about the particle size distribution, the ice crystal habit and density. Differences in these assumptions and in the correlations underlying such methods give rise to large differences among the retrieval results. Hence, evaluation of their accuracy is important. The new lidar technique is well suited for this task because, in contrast, it does not depend on any critical input parameters.

First comparisons of mixed-phase and cirrus IWC profiles obtained at the Lindenberg Meteorological Observatory, Germany, are presented. It is demonstrated that the IWC retrievals provided by CLOUDNET (IWC-Z-T approach) are systematically smaller than the IWC profiles measured with RAMSES but compare well in terms of vertical distributions and temperature dependence. Analyses of other retrieval schemes and products are in progress. Results are expected to improve current cloud property retrieval methods and the accuracy of the retrieved microphysical properties.

S16.7

Improved synergy retrievals of precipitation rates and ice cloud properties using cloud radar with Doppler capability

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¹*University of Reading, Reading, UK*, ²*ECMWF, Reading, UK*

16. Measurement techniques (of cloud and precipitation properties) and uncertainties

The accurate representation of clouds and precipitation in climate models is crucial to predicting the global hydrological cycle and energy budget. However, it remains difficult using current remote sensing techniques to simultaneously measure cloud properties and precipitation rates, especially of drizzle and snowfall, where there is insufficient information to distinguish various hydrometeor species. While radars with Doppler capability have long provided such information from ground-based observations by exploiting the dependency of hydrometeor fall speeds on their composition and microphysical properties, Doppler radars have been underused from air- and space-borne platforms for cloud and precipitation observations.

In this talk we demonstrate how Doppler velocity observations help constrain retrievals of precipitation rates and resolve vertical motion within convective clouds, using measurements from two Doppler radars aboard a high-altitude aircraft during the Tropical Composition, Cloud and Climate Coupling (TC4) campaign. We also show how Doppler velocities can reveal riming processes, using ground-based radar observations of ice clouds with independent in-situ measurements for evaluation. This work is part of the development and evaluation of an official retrieval algorithm for the upcoming EarthCARE satellite mission, which will include the first Doppler cloud radar in space and promise better global synergetic retrievals for clouds and precipitation.

S16.8

Diagnosing Raindrop Breakup and Coalescence from Vertically Pointing Radar Observations

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This study bridges the research areas of Precipitation Remote Sensing and Precipitation Modeling. Thus, this study consists of two parts. The first part describes the way in which vertical air motions and raindrop size distributions (DSDs) were retrieved from 449-MHz and 2.835-GHz (UHF and S-band) vertically pointing radars (VPRs) deployed side-by-side during the Midlatitude Continental Convective Clouds Experiment (MC3E) held in Northern Oklahoma. The differences in VPR sensitivities of these two radars facilitates the identification and estimation of vertical air motion and DSD parameters from near the surface to just below the melting layer.

The second part of this study used the retrieved DSD parameters to decompose reflectivity and liquid water content (LWC) into two terms, one representing number concentration and the other representing DSD shape. Reflectivity and LWC Vertical Decomposition Diagrams (Z-VDDs and LWC-VDDs) are introduced to highlight interactions between raindrop number and DSD shape in the vertical column. Analysis of Z-VDDs provides indirect measure of microphysical processes through radar reflectivity. Analysis of LWC-VDDs provides direct investigation of microphysical processes in the vertical column including net raindrop evaporation or accretion and net raindrop breakup or coalescence. During a stratiform rain event (20-May-2011), LWC-VDDs exhibited signatures of net evaporation and net raindrop coalescence as the raindrops fell a distance of 2 km under a well-defined radar brightband. The LWC-VDD is a tool to characterize rain microphysics with quantities related to number-controlled and size-controlled processes.

S16.9

Using a Ground Based Integrated Sensor System to Remotely Detect Supercooled Cloud Layers in Cold Climates

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16.4. In-flight aircraft icing (IFAI) is a major weather hazard to aviation. It occurs when an aircraft passes through a cloud layer containing supercooled liquid drops (SLD). Prediction of IFAI requires accurate predictions of SLD sizes, liquid water content (LWC), and temperature (T). The current weather predicting models are not capable of making accurate predictions of these parameters. Icing environments are normally studied using research aircraft, which is quite expensive. Thus developing a ground-based system for remote detection of supercooled liquid clouds and characterization of their impact on IFAI is one of the important tasks for improving and testing NWP models. In order to contribute to this effort, Environment and Climate Change Canada in cooperation with the Department of National Defense installed a number of specialized ground based vertical profiling instruments and present weather sensors at Cold Lake (CL), Alberta including a multi-channel microwave radiometer (MWR), a K-band Micro Rain radar (MRR), a Ceilometer, a Vaisala PWD22 sensor. In this paper, 9 pilot icing reports and a freezing precipitation case that occurred at CL during the 2014-2015 winter period will be examined using the observation and the Canadian Regional Deterministic Prediction System model data. Results indicated that most of the icing events occurred during descent or climb, the maximum LWC from MWR ranged 0.04-0.14 gm⁻³ and T ranged 0 - (-23) °C. The model predicted vertical motion ranged from 0.01-0.075 ms⁻¹. The MRR was unable to detect the icing events, but able to detect the melting layer during freezing precipitation.

S16.10

Statistical Assessment of Rainfall Properties Over Varying Scales

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16, 17

When discussing rainfall, it is often assumed that rain properties remain consistent over small temporal and spatial scales. With a very dense network of rain measurement equipment, a novel data set was used to investigate rainfall variability over scales of just 1-100 meters. Using temporally precise instrumentation, the temporal variability was explored on a range of timescales from seconds to days. These investigations utilized the drop diameters and arrival times to determine variability and how it affects derived quantities such as rain rate. Statistical methods were used to determine the effects of sampling in measuring these quantities, and what sampling is sufficient to reflect the “true” behavior of rainfall. The data and their derived quantities were examined to determine behavior below scales typically observed in, for example, RADAR and tipping bucket rain gauge studies. These investigations have shown how rain may fluctuate more than previously expected, and how assumptions about rainfall distributions in space in time may be more complex than previously treated.

S16.11

Examination of the catch efficiency of precipitation gauges based on the type of snow

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16.

Systematic errors in snowfall measurements are often observed due to wind speed. It is well documented that the catch efficiency of typical gauge-shield configurations decreases with increasing wind speed, with a lot of scatter for a given wind speed. The cause of the scatter is currently thought to arise from the variability in the turbulence and the type of snow as well as other unknown factors. This study will examine the variability of snow characteristics at the Marshall Field site near Boulder, Colorado during the SPICE WMO solid precipitation experiment using a variety of instruments including a Thies optical particle probe and weighing snow gauges for the period 2013-2015. A detailed analysis of the characteristics of solid precipitation such as their terminal velocity and sizes will be diagnosed and investigated. These will be related to the collection efficiency of single Alter shielded and unshielded snow gauges. The measured snowflake characteristics will be compared to the theoretical collection produced with computational fluid dynamics and a Lagrangian model. Overall, this study contributes to improve our understanding of the relationship between the type of snow and the automatic measurement of solid precipitation.

S16.12

Development of a New Theoretical Framework for the Analysis of Disdrometer Data

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16, 17

Rain disdrometers are instruments that record the arrival time and drop properties of individual hydrometeors; data from these instruments have been used widely throughout the hydrological sciences to understand spatial and temporal variability of rainfall. Some disdrometers have temporal resolution with enough granularity that the investigator has the freedom to choose time-bins of arbitrary duration. Most studies nevertheless resort to temporal binning that matches some historical standard (e.g. 5 minute binning to match radar data, or hourly/daily binning for climatological studies).

In this study, we use data from a Joanneum 2-Dimensional Video Disdrometer (with temporal resolution finer than 1 ms) to investigate a new way to identify natural integration time-scales for disdrometer data. Results using this new binning technique are compared to standard 1-minute, 5-minute, 15-minute, and hourly binning to demonstrate the relative merits and shortcomings of this new approach. Additional discussion of the implications of these results for hydrological measurement will be presented.

S16.13

Exploring the Microphysical Properties of Exoplanet Clouds (or Bringing Exoplanet Clouds Down to Earth)

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17, 16, 13

By observing the planets and moons in our solar system it is clear that clouds are not a unique Terrestrial phenomena. However, from Jupiter's raging red spot to Venus' persistent sulfuric acid clouds, Terrestrial based microphysical knowledge has helped expand our understanding of these extreme and exotic atmospheres, and vice versa. We take this theme a step further, leveraging lab-based terrestrial cloud particle instrumentation and knowledge to better understand the microphysical properties of clouds in the atmospheres of planets orbiting other stars, also known as exoplanets.

The work presented here focuses on the scattering phase functions of single particles, believed representative of the condensates in exoplanet atmospheres, levitated in an electrodynamic balance. Once levitated, these particles are illuminated with a red (660 nm), green (532 nm), or violet (405 nm) laser and the scattered light is collected at prescribed angles from incident while chamber conditions are precisely controlled. I will discuss specifics of the cloud chamber used in this work, how we leverage terrestrial based cloud knowledge, our initial investigation of the light scattering properties of ammonium nitrate (NH_4NO_3) across temperature dependent crystalline phase changes, and results with exoplanet atmospheric condensates under various atmospheric compositions, pressures, and temperatures.

S16.14

Quantitative evaluation of seven optical sensors for cloud microphysical measurements at the Puy-de-Dôme Observatory, France

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This work presents results from a cloud instrumentation intercomparison campaign, performed at the Puy de Dôme in May 2013. During this campaign, a unique set of cloud instruments was operating simultaneously in ambient air conditions and in a wind tunnel. A Particle Volume Monitor (PVM-100), a Forward Scattering Spectrometer Probe (FSSP), a Fog Monitor (FM-100), and a PresentWeather Detector (PWD) were sampling on the roof of the station. Within a wind tunnel located underneath the roof, two Cloud Droplet Probes (CDPs) and a modified FSSP (SPP-100) were operating. The main objectives of this paper are (1) to study the effects of wind direction and speed on ground-based cloud observations, (2) to quantify the cloud parameters discrepancies observed by the different instruments, and (3) to develop methods to improve the quantification of the measurements.

The results revealed that all instruments showed a good agreement in their sizing abilities, but most of them displayed large discrepancies in their capability to assess the magnitude of the total number concentration of the cloud droplets. This intercomparison study highlights the necessity to have an instrument which provides a bulk measurement of cloud microphysical or optical properties to standardize the measurements. Moreover, the effect of a change in the orientation of the FM and FSSP was investigated in terms of particle sampling losses and assessment of the effective diameter.

S18.4

Development of a Cloud Physics Family Tree

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Driven by the efforts of the hurricane and tropical meteorology community within the American Meteorological Society, an academic lineage ("family tree") was developed to document the history of contributors to the tropical meteorological community (<http://moe.met.fsu.edu/familytree/>). In honor of the Sir John Mason symposium at the 17th International Conference on Clouds and Precipitation (ICCP-2016), the same software, methodology and viewers are being used to further populate the meteorological family tree, emphasizing the specialty of cloud physics. In order to populate the family tree with those in the cloud physics discipline, an email was sent to all those who submitted an abstract for the conference, asking them to identify name, mentor(s), year of degree, institution of degree, meteorological discipline (i.e., cloud physics), and contact email for both themselves and all students they had advised. They were also encouraged to forward the email to other cloud physicists who were not attending the meeting.

Based on the replies received to this email, a cloud physics lineage has been constructed and will be presented at the conference. The approach to generating the family tree is very dynamic, so that further contributions are allowed and will be implemented in future versions of the lineage.