Newsletter on Atmospheric Electricity

Vol.29, No. 2, Dec 2018

International Commission on Atmospheric Electricity (IAMAS/IUGG)
AMS Committee on Atmospheric Electricity
AGU Committee on Atmospheric and Space Electricity
European Geoscience Union
Society of Atmospheric Electricity of Japan

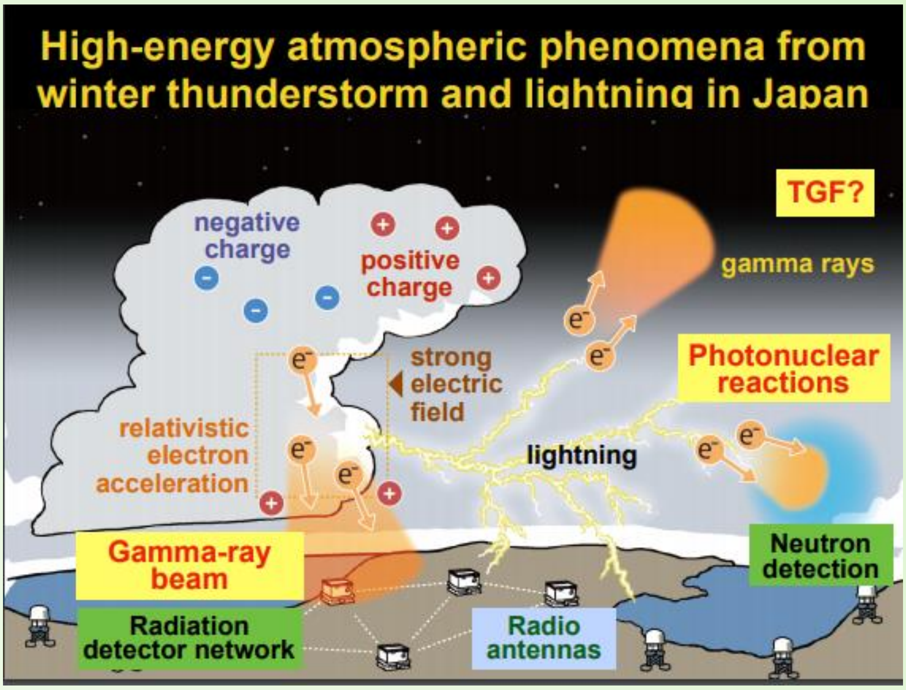


Illustration of high-energy atmospheric phenomena occurring in winter thunderstorms and lighting discharges in the coastal area of Japan Sea. Since 2015, the GROWTH (Gamma-Ray Observation of Winter Thunderclouds) collaboration has been building a new multi-point radiation observation network. The group has already detected photonuclear reactions triggered by a downward terrestrial gamma-ray flash associated a lightning discharge (e.g., Enoto et al. Nature, 2017: https://www.nature.com/articles/nature24630) and gamma-ray glow from winter thunderstorm (e.g., Wada et al. GRL 2018: https://doi.org/10.1029/2018GL077784). This project is aiming to collaborate with measurements of atmospheric electric fields and with radio observations of lightning discharges. (Image copy right) Hayanon's Science Manga Studio and Teruaki Enoto (Kyoto University).

Announcements

Research school of Birkeland Centre for Space Science: Atmospheric Electricity and Hard radiation from Thunderclouds

We are pleased to announce a one-week intensive course at the Research School of Birkeland Centre for Space Science that will take place
At the University of Bergen, Norway: 20-24 May, 2019

Deadline for registration is February 2019

The topic is:
Atmospheric Electricity and Hard radiation from Thunderclouds

lectures on lightning theory and TGF theory will be given by:
Dr. Vernon Cooray
Dr. Joseph Dwyer
other lectures by our group, including some hands-on experiments.

The school is for Master´s and PhD students and early career scientists.
ETCS credits: 10

Full description of the course, curriculum, project description, registration, financial support etc can be found here:
https://birkeland.h.uib.no/atmospheric-electricity-and-hard-radiation-from-thunderclouds/

African Centres for Lightning and Electromagnetics (ACLENet)

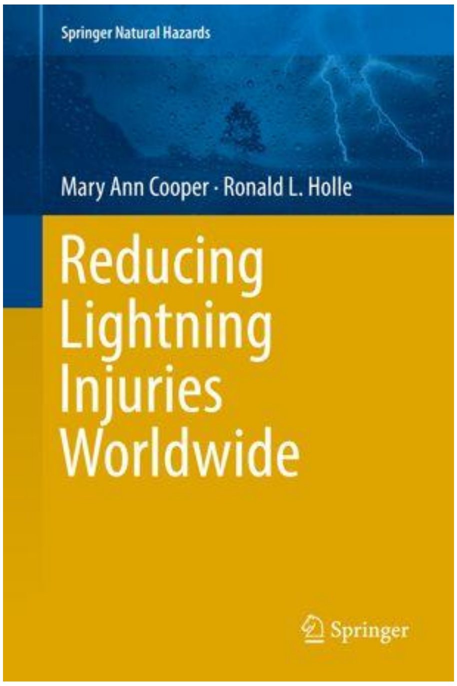
The African Centres for Lightning and Electromagnetics Network (ACLENet, https://ACLENet.org) is pleased to announce that several more schools in Africa have had lightning protection (LP) installed. In addition, the Ugandan Ministry of Education and Sports has consulted ACLENet on LP for the new schools they are building this year with World Bank funding. Recently, ACLENet has received funding to protect another three schools and establish lightning safety education programs across Uganda. Several well-known LP experts have volunteered their expertise in design and are helping ACLENet to decrease the cost of LP by using locally sourced materials instead of expensive imports, and to design templates for typical school buildings that can be used throughout Africa. Additionally, several countries have been approached to be the second ACLE-national centre. ACLE's first national centre, ACLE-Zambia, with assistance from Dr. Chandima Gomes, has been successful in mentoring a new graduate training program in High Voltage Engineering and Electromagnetic Compatibility at the University of Zambia. This program will enable ACLENet to fulfill another of its goals, that of training more lightning experts in Africa. The monthly ACLENet Newsletter with updates on African schools being protected by LP, planned meetings, and a list of casualty reports from Africa can be received by contacting Dr. Mary Ann Cooper at macooper@uic.edu.

2018 Fall ICAE New Book announcement

New Books

Cooper, M.A., and R.L. Holle, 2018: *Reducing lightning injuries worldwide*. Springer Natural Hazards, New York, 233 pp. Print ISBN: 978-3-319-77561-6; Online ISBN: 978-3-319-77563-0

https://link.springer.com/book/10.1007/978-3-319-77563-0



Description

This book is also meant to serve as a resource and sometimes a starting point for students and faculty who may be interested in initiating local studies and projects related to reducing global lightning casualties or in pursuing more in-depth studies, whether an undergraduate project, master's thesis, or doctoral dissertation. It includes overviews of all aspects of lightning from the points of view of medicine, meteorology, safety, and protection, and physics. Each chapter provides an overview of a single topic, and includes research questions and references to provide a beginning reading list, together with sidebars encouraging application to the student's own experience as well as questions that remain to be answered. This book can also serve as a reference for public health officials, geographers, engineers and many other disciplines and individuals interested in lightning. Dr Cooper also notes that she has loaded the entire text to her Research Gate account.

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Research Activity by Institution

Recent Deployments of NASA Marshall Space Flight Center Atmospheric Electricity Instruments

Timothy Lang[1], Rich Blakeslee[1], Steven Rutledge[2], Larry Carey[3], and Eldo Avila[4]
[1]*NASA Marshall Space Flight Center, Huntsville, Alabama, USA*
[2]*Colorado State University, Fort Collins, Colorado, USA*
[3]*University of Alabama in Huntsville, Huntsville, Alabama, USA*
[4]*National University of Cordoba, Cordoba, Argentina*

NASA Marshall Space Flight Center (MSFC) has deployed an electric field meter (EFM) and a Lightning Mapping Array (LMA) to support recent field campaigns. For PISTON (Propagation of Intraseasonal Tropical Oscillations), a ship-based campaign in the Western Pacific Ocean during August-October 2018, NASA MSFC worked in collaboration with Colorado State University (CSU) to deploy an EFM on the *R/V Thomas G Thompson* (Fig. 1a). This instrument was primarily intended to support intercomparisons with the Carnegie curve, as well as to investigate the role of maritime thunderstorms and electrified shower clouds in maintaining the global electric circuit. Polarimetric C-band weather radar observations were collected along with the EFM observations using the new SEA-POL ship radar developed by CSU.

The MSFC LMA is being installed near Cordoba, Argentina (Fig. 1b), in collaboration with University of Alabama in Huntsville (UAH) and the National University of Cordoba (UNC), to support the RELAMPAGO (Remote sensing of Electrification, Lightning, And Mesoscale/microscale

Processes with Adaptive Ground Observations) campaign, as well as to support ground validation of the Geostationary Lightning Mapper (GLM) instrument. RELAMPAGO is aimed at understanding initiation and upscale growth of convection in Argentina, home to some of the most intense thunderstorms on Earth. The 11-station network will operate during approximately November 2018 through April 2019. Similar to PISTON, the electricity observations will be acquired in the context of multiple radar observations.

After all data have been collected and quality controlled, they will be made publicly available on the Internet by NASA MSFC.

(a)  (b) 

Figure 1. (a) Photo of EFM on the *R/V Thomas G Thompson* while in port in Kaohsiung, Taiwan (*credit: Timothy Lang*). (b) Photo of an LMA station installed near Monte Cristo, Argentina (*credit: Matt Wingo*).

University of Texas at Dallas

The University of Texas at Dallas (Dr Brian Tinsley) is working with colleagues at the East China Normal University (Dr. Limin Zhou and Dr. Liang Zhang); the University of Chicago (Dr. John Frederick): the Australian Antarctic Division (Dr. Gary Burns) and the Russian Arctic and Antarctic Research Institute (Dr. Alexandr Frank-Kamenetsky) on data analysis and modelling of the effects of global atmospheric electricity on clouds and surface pressure. The variations of the ionosphere-earth current density that passes through clouds is inferred from observations of the surface electric field at Vostok, Antarctica, and correlated with data from the NOAA/NCEP global reanalysis data for pressure, and the upward looking cloud measurements (in the longwave infrared) from the South Pole from NOAA/ESRL data.

Data analysis (Zhou et al. 2018) shows statistically significant responses of surface pressure over two decades to both the atmospheric field from the overhead ionospheric potential changes, associated with the IMF (solar wind) By component, that penetrate to the surface in the polar regions, and to the ionospheric potential changes that are due to day-to-day variability in the distant thunderstorm and electrified cloud generators. Non-electrical causes of the surface pressure response can be ruled out by the correlations of the Arctic pressures with the Antarctic Electric field measurements representing global ionospheric potential changes; also the opposite sign of the IMF By-induced ionospheric potential change in the Antarctic as compared to the Antarctic, that goes with the opposite sign pressure responses at the two locations: also, the sensitivity of pressure to ionospheric potential change is essentially the same for both the external and internal inputs.

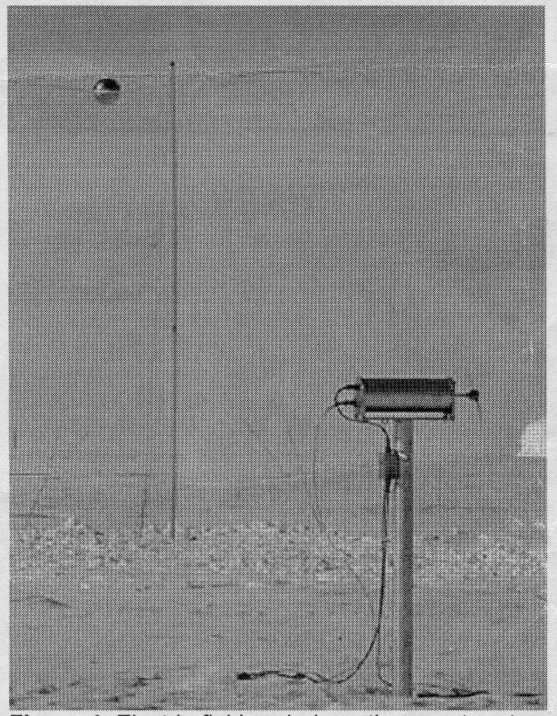

Figure 4. Electric field and air-earth current meters installed at Vostok (Picture taken 4 days before unforseen logistics problem required station closure for Winter, 2003).

The surface pressure responses are considered to be due to changes in cloud cover and cloud opacity, which affects the radiative balance in the atmosphere. The cloud changes are due to a change in cloud microphysics, as the amount of electric charge on droplets and aerosol particles, acting as condensation and ice nuclei, varies with changes in the ionosphere-earth current density. Data analysis (Frederick and Tinsley, 2018) shows that the longwave radiation from clouds above the South Pole is statistically significantly correlated with the Vostok electric field measurements. Frederick (2016, 2017) previously showed similar correlations for Summit, Greenland and the South Pole with external electric inputs for which Ap is a proxy.

The latest paper on modelling the cloud microphysical changes due to the electric charge on droplets and nuclei is by Zhang et al. (2018). The decreases in in-cloud scavenging rates (electro-anti-scavenging) applies to small, sub-micron aerosol particles which predominate in the polar regions. This is due to Coulomb repulsion. The effective increase in the concentration of the nuclei results in more droplets of smaller size, increasing the cloud opacity and its persistence. For larger, micron sized aerosol particles, the models show increases in in-cloud scavenging rates (electro-scavenging) which may be the dominant effect for lower latitudes. This is due to image-charge attraction, and is consistent with observations there.

References:

Frederick, J. E., and B. A. Tinsley, 2018. The response of longwave radiation at the South Pole to electrical and magnetic variations: Links to meteorological parameters and the solar wind. J. Atmos. Solar. Terr. Phys., 179, 214-224. https://doi.org/10.1016/j.jastp.2018.08.003

Zhang, L., B. A. Tinsley, and L. Zhou, 2018. Parameterization of in-cloud aerosol scavenging due to atmospheric ionization: Part 3. Effects of varying droplet radius. J. Geophys. Res. Atmos., 123,10,546-10567. https://doi.org/10.1029/2018JD028840.

Zhou, L., B. A. Tinsley, L. Wang, and G. Burns, 2018. The zonal-mean and regional tropospheric pressure response to changes in ionospheric potential. J. Atmos. Solar. Terr. Phys., 171, 111-118. https://doi.org/10.1016/j.jastp.2017.07.010.

UF Contribution to the November 2018 Issue of the Newsletter on Atmospheric Electricity

Manh D. Tran (advisor V.A. Rakov) defended his Ph.D. dissertation titled "A study of lightning properties using high-speed video and energetic radiation observations synchronized with electric and magnetic field measurements". He is presently with Rhombus Power Inc., Gainesville, Florida.

Adonis Ferreira Raiol Leal (advisors B.R.P. Rocha and V.A. Rakov) defended his Ph.D. dissertation titled "Optimization of Lightning Electromagnetic Field Waveform Detection". He is presently a faculty member at the Federal University of Para, Brazil.

Felipe Lenz Carvalho (advisor M.A. Uman) defended his Ph.D. dissertation titled "Characteristics of triggered lightning radiation sources and sky waves". He is presently with Space Exploration Technologies Corp., Redmond, WA.

F. L. Carvalho, M. A. Uman, D. M. Jordan, R. A. Wilkes, and D. A. Kotovsky authored a paper titled "Triggered Lightning Return Stroke Luminosity up to 1 km in Two Optical Bands". They presented luminosity waveforms measured using two types of avalanche photodiodes (APDs) as a function of time and channel height for 15 triggered-lightning return strokes. Short vertical sections of 20 channel heights ranging from 0 to 1 km were observed by both types of APDs. For APD type I, the return stroke luminosity waveforms decay faster following a single initial peak (IP) than the waveforms recorded by APD type II, which often exhibit a second maximum (SM) following the IP, though the risetimes of the initial luminosity wavefront preceding the IP are similar for both types of APDs. APD type II responds better to longer wavelengths than APD type I, and since the SM occurs about 10 μs after the IP at the

channel-bottom and about 20 μs after the IP at 1-km height, the SM is likely a consequence of spectral lines excited during the cooling of the channel, following the initial high-temperature/pressure stage. The initial optical radiation during the return stroke is likely dominated by ionized atomic species radiated at higher temperatures (NII lines between 450 and 600 nm) better captured by APD type I, while the later optical radiation is likely due to neutral atomic species radiated at lower temperatures (e.g., H-alpha at 656.3 nm, OI at 715.7 nm and 777.4 nm, and the NI at 744.4 nm) better captured by APD type II. The average IP upward speed is 1.3 x 10^8 m/s, while the average SM upward speed is 3.1 x 10^7 m/s. The paper is published in the Journal of Geophysical Research - Atmospheres.

Y. Zhu, V.A. Rakov, M.D. Tran, W. Lyu (Chinese Academy of Meteorological Sciences), and D.D. Micu (University of Cluj-Napoca, Cluj-Napoca, Romania) authored a paper titled “A Modeling Study of Narrow Electric Field Signatures Produced by Lightning Strikes to Tall Towers”. They used the lumped voltage source model proposed by Baba and Rakov (2005b, https://doi.org/10.1029/2004JD005202) for studying the interaction of lightning with tall objects to examine the origin of earlier zero crossings observed in electric field signatures produced by lightning strikes to towers. Different return stroke models of transmission line type were used, and model parameters were varied in wide ranges. Lightning channel was assumed to be straight and vertical. It was found that the observed narrow field signatures cannot be reproduced by traditional models and require a narrower input current waveform or/and its faster decay with height. Contribution to the total electric field peak from a tower whose height exceeds 100 m or so is greater than that from the lightning channel. At distances of 2 to 50 km, the electric field signature due to the tower current was found to be bipolar, while that due to the lightning channel current was unipolar. The narrow bipolar electric field waveforms produced by lightning striking the 257-m tower in Florida were reproduced using two approaches. In the first one, the authors employed as input a typical channel base current waveform and the transmission line with exponential current decay with height model with a very small decay height constant. In the second approach, they used a narrow pulse followed by a steady-level tail as the input current waveform and the transmission line with linear current decay with height model. In both approaches, the computed electric field waveforms matched well the corresponding measured waveforms, at least for the initial half-cycle and opposite polarity overshoot. The paper is published in the Journal of Geophysical Research - Atmospheres.

Israel Atmospheric Electricity Group

Yuval Reuveni (Ariel University), **Yoav Yair** (IDC), **Colin Price** and graduate student **Tamir Tzadok** (Tel Aviv University) continue to conduct continuous gamma-ray measurements (both integrated and discrete energy levels) at the Mt. Hermon geophysical site. We are comparing these gamma ray observations with fair weather atmospheric electricity parameters. In addition, we are developing a miniature gamma-ray spectrometer for future Nano-satellite missions. **Yuval Reuveni** has also started to analyzed ULF measurements along with atmospheric electricity parameters and ionospheric GPS-TEC estimations, conducted during several earthquake evented occurred in 2017, in order to assess the possibility of detecting earthquake precursors.

Postdoc **Roy Yaniv** (Ariel University) is using two stations in Israel to measure the E field (Ez) and the Conduction Current density (Jz) in the atmosphere during times of fair weather and severe weather conditions. Results during fair weather show that the Ez and the Jz changes are subject to daily meteorological variations (e.g sun rise which warms the ground and uplift aerosols, humidity concentrations and wind speed), topographic effect (e.g Austausch phenomena that act as a convergence zone to winds from surrounding areas) and a global effect (e.g thunderstorms activity around the globe).

Graduate student **Dekel Shahar** and **Colin Price** (Tel Aviv University) are using the newly installed Earth Networks total lightning network in Israel to study severe weather events, particularly flash floods in Israel. In April 2018 twelve teenagers were killed in a flash flood in the Arava desert. We are studying the correlation and spatial relation between the nature of lightning and the intensive precipitation events that often cause flash-floods.

Graduate student **Judi Lax** and **Colin Price** (Tel Aviv Univeristy) are performing an experimental study of the relationship between atmospheric high relative humidity (RH) and the separation of charge on metal surfaces. This field has been called Hygro-electricity, and is a new idea in renewable energy, based on the humidity of the air and the ions in water molecules. We are investigating the generation of electricity during the interaction between solid surfaces and condensing water droplets. Our preliminary results show that during RH>60%, there is a spontaneous voltage accumulation on a capacitor built from 2 different metals, reaching up to 0.75 Volts, half the voltage of a 1.5V AA battery, and the voltage remains as long as the RH is high.

Graduate student **Gal Elhalel** and **Colin Price** (Tel Aviv University) have completed a study of the impact of the Schumann resonance frequencies on rat heart cells. The results show that the ELF weak fields in the Schumann resonances may protect heart cells under stressful conditions. Gal has completed her PhD thesis, and the results of her thesis have just been accepted for publication in Scientific Reports (Nature).

Graduate student **Maayan Harel** and **Colin Price** (Tel Aviv University) has completed a study looking at trends in African thunderstorms since 1950, showing a large increase in the number and areal coverage of thunderstorms in Africa. The results have been submitted for publication to the Journal of Climate.

Contribution from the Chinese Academy of Meteorological Sciences

The observational experiment by the Chinese Academy of Meteorological Sciences in 2018. We continued to conduct comprehensive observation experiment for lightning research from May 15 to Aug 1 in 2018. Twenty-seven triggered lightning flashes out of 43 rocket launchings were obtained, far more than the average number in the past ten years. We complementally built a new close optical station for the detailed observation of triggered lightning channels. We also developed two-station continuous interferometry in order to study the mechanism of discharges from triggered lightning. The interferometry can get the 3D detailed discharge channel. Ten cases of lightning flashes are obtained. In addition, the thunderstorm electrical activity in Guangdong was observed by the LFEDA (LF electric field detection array) as past years. Most of the strong, close thunderstorm were observed. The observation ability of high building lightning with multi-view and multi-signals strengthened further. We adjusted and optimized the observation scheme, and a new optical observation station and high-resolution image meters of lightning channel were constructed. Up to now, 127 cases of high building lightning flashes have been captured.

Characteristics of electromagnetic signals during the initial stage of negative rocket-triggered lightning. With the measurements in Shandong Triggering Lightning Experiment and Guangdong Comprehensive Observation Experiment on lightning discharge in China, we examined the electromagnetic signals associated with the upward positive leaders during the initial stage of negative triggered lightning. The magnetic field (B field) signals measured at close range (<100 m) for both sites can be divided into two categories (i.e., impulsive and ripple pulses) according to the discernibility of separation between individual pulses. The impulsive pulses are well simulated by using the transmission line model, which suggests that these pulses are generated by leader current pulses propagating downward along the steel wire. Because the length of extended leader channel ahead of the wire is not negligible during the stage of ripple pulses, the waveform of impulsive current pulses is changed after traveling through the high impedance leader channel. Taking the filtered current pulse as the input variable, the waveform of ripple pulse can be simulated properly, which indicates that ripple pulses are caused by the attenuation of impulsive current along prolonging leader channel. In addition, the paper analyzes the fast electric field (E field) changes measured at 60-m range from the launching site during the initial stage by using the transmission line model and shows that the polarity of E field change at a given range is determined by the inception height of upward leader, namely the surface E field change caused by the individual charge transfer of initial upward leader also involves the problem of reverse distance as present for a vertical dipole.

A new method of three-dimensional location for low-frequency electric field detection array. We introduced the empirical mode decomposition algorithm and applied low-frequency filtering and high-frequency noise reduction to the waveform of the electric field changes recorded in 1 ms segments. This algorithm greatly improved the accuracy of the peak time extraction and the number of pulses in the LF/VLF band, which enhanced the accuracy in positioning the pulse of the electric field change. Compared with the previous algorithm, the algorithm can significantly reduce the time error, giving a better positioning result. With a time error estimate of 100 ns and a limit of goodness-of-fit less than 5, the number of pulse locations is increased by nearly seven times. The goodness-of-fit distribution of the pulse location results had a normal distribution and the 95% confidence interval of goodness-of-fit was 0–4; the corresponding positioning space error was <60 m. The continuity of the lightning channel was significantly improved and the development characteristics and fine structure of the lightning channel were clearly distinguished (Figure 1). The LFEDA system gave detailed positioning results for a "bolt from the blue" lightning strike. By comparing the results from the LFEDA with the actual lightning strike point, we objectively demonstrated the positioning performance of the new algorithm. The system gave positioning results for the lightning for all seven return strokes. The maximum horizontal distance between the locating point and the real lightning strike point was 57 m, the minimum horizontal distance between them was 3 m, and the mean distance was 27 m.

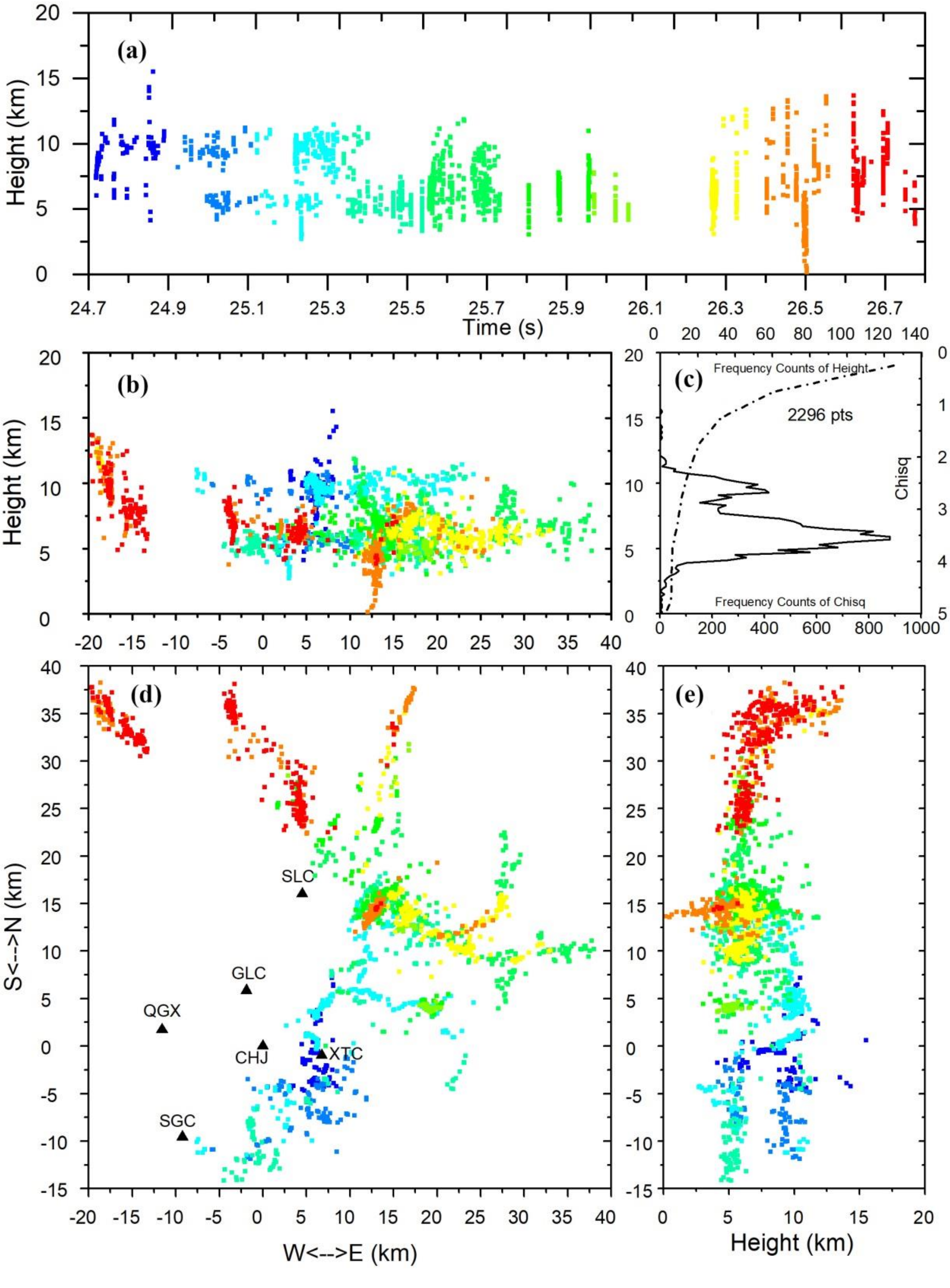

Figure 1. Location results for a flash using the new algorithm. (a) LF/VLF electric field. (b) Height–time plots. (c) North–south vertical projection. (d) Height distribution of a number of radiation events

and frequency counts for X_v^2. (e) Plan view. (f) East–west vertical projection of lightning radiation sources.

Characteristics and discharge processes of M events with large current in triggered lightning. Observations have been obtained of M events during triggered lightning flashes with a broadband very high frequency interferometer and measurements of electric field changes, channel-base current, and high-speed video. The current characteristics of 239 M events in 18 triggered lightning flashes are analyzed, and the discharge processes leading to large M currents are investigated. Sixty-eight of the M events (28%) had peak currents exceeding 1 kA. The geometric average values of peak current, duration, 10–90% rise time, half peak width, charge transfer, interval from return stroke to M and background current are 2.358 kA, 0.627 ms,0.078 ms, 0.165 ms, 0.417 C, 2.172 ms, and 579 A, respectively. Compared to other M events, the M events with large peak current occurred closer in time to the preceding return stroke, and their corresponding current changes were more rapid. Three cases associated with the initiation processes of M events reveal that some large M events were initiated by fast positive streamers propagating away at a velocity of about 10^7 m/s followed by a possible recoil event (Figure 1), or by a dart leader while the channel of continuing current generated by previous leader still existed. It is found that a fast current pulse with 10–90% rise time of less than 300 μs is a necessary, but not sufficient, condition for the occurrence of large M events. The fast current pulse often corresponded to a low/close junction site.

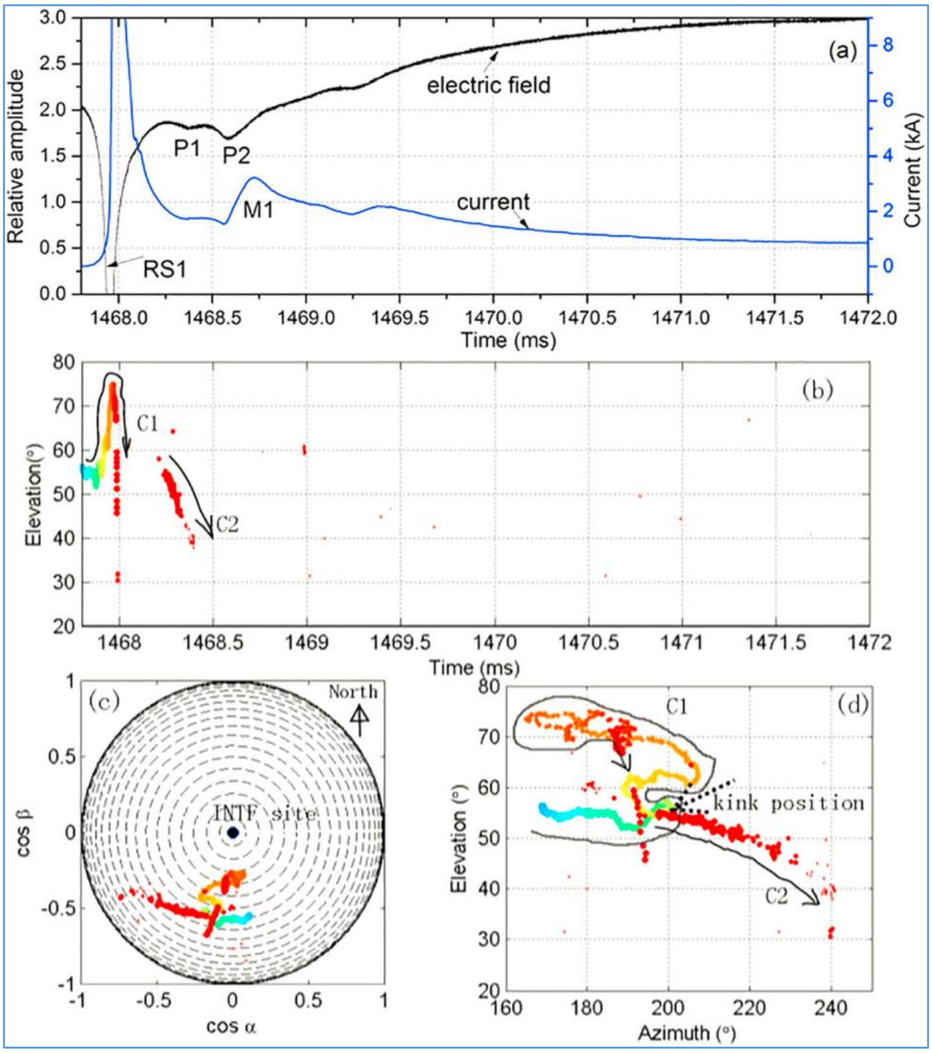

Figure 1. Radiation sources distribution, channel-base current, and the corresponding electric field of M1: (a) waveforms of electric field and channel-base current versus time, P1: the first electric field pulse, P2: the second electric field pulse, M1: M component 1; (b) elevation of radiation sources versus time; (c) hemispherical projection of radiation sources; (d) elevation of radiation sources versus azimuth. Colors of the radiation sources from blue to red correspond to increasing time in (b)–(d). C1 indicates the leader path, C2 indicates the forward propagation of M1. RS = return stroke.

Three-dimensional optical observations of an upward lightning triggered by positive cloud-to-

ground lightning. Based on dual-station optical records, electric field and radar data, a detailed analysis of an instance of upward lightning initiated from Canton Tower, in the city of Guangzhou, Guangdong Province, China, was presented. The upward lightning was triggered by a positive cloud-to-ground (PCG) flash nearby. The upward lightning channel and part of the horizontal PCG lightning channel obtained by dual-station optical systems were reconstructed in three dimensions, providing us with spatial channel information on how the PCG lightning process triggered the upward lightning from Canton Tower. Figure 1 presents the three-dimensional image of the upward lightning channel and the projection of the upward lightning and PCG flash channel in the horizontal plane. The length of the three-dimensional reconstructed part of the PCG lightning channel was about 3660 m. Its height increased from 3410 m to 4170 m along the development direction, with an average height of 3640 m. The upward lightning occurred in the trailing stratiform cloud area behind a squall line system. The radar echo intensity in this area was relatively weak (30–40 dBZ), and the height of the strongest radar echo center was about 4 km. Based on the above result, as well as previous studies on the charge structure of the stratiform region, we infer that the height of the positive charge layer was roughly consistent with the height of the strongest echo center.

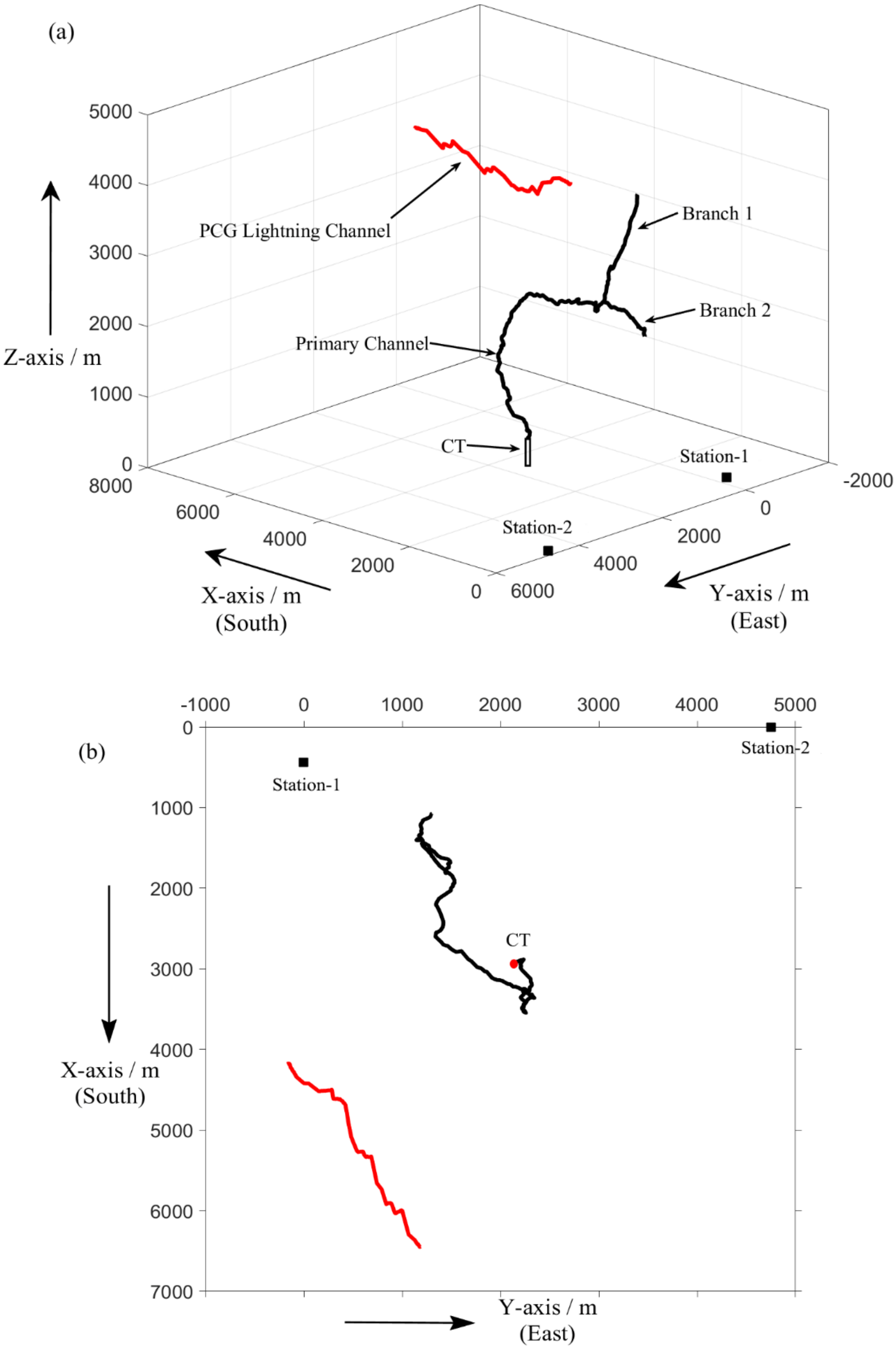

Figure 1. (a) Three-dimensional image of the upward lightning channel and (b) the projection of the upward lightning and PCG flash channel in the horizontal plane. The black line represents the upward lightning channel and the red line the 3D reconstructed portion of the PCG flash RS channel. The

position of two observational stations are shown in the figure. The coordinate system is consistent with the coordinate system in Gao et al. (2014): the origin of the coordinates is the intersection of the longitude of the Station-1 and the latitude of the Station-2; the z-axis is 0 at sea level; the x-axis is positive in the south; and the y-axis is positive in the east.

Characteristics of lightning flashes associated with the charge layer near the 0°C isotherm in the stratiform region of mesoscale convective systems. Data from an S-band Doppler radar and a three-dimensional VHF radiation source location system in Chongqing, southwest China, was used to investigate the characteristics of stratiform lightning flashes associated with the charge layer near the 0 °C isotherm (SL0 events). During the summers of 2014 and 2015, 10 of 55 thunderstorms were observed to generate SL0 events. A total of 88 SL0s were classified and more than 97% occurred during the dissipating stage of the thunderstorms. The mean reflectivity at the first detected radiation source (FirstS) of the SL0- events was less than that of the SL0+ events. The reflectivity at the FirstS of the SL0- events of the grouped thunderstorms (thunderstorms with infrequent SL0 activity) and storm 6 (a thunderstorm with frequent SL0 events) were 16 ± 6.1 and 21 ± 5.7 dBZ, respectively. For the SL0+ events, the reflectivity at FirstS in the grouped thunderstorms and storm 6 were 19 ± 2.4 and 23 ± 4.6 dBZ, respectively. These values, together with our further analysis, also indicated that the SL0 events in the thunderstorms with infrequent SL0 activity tended to be initiated from those locations with weaker reflectivity than those in the thunderstorms with frequent SL0 activity. About 90% of the SL0 events showed a bright band near their FirstS. For the rest of the SL0 events, a clear bright band was identified within the lightning area, although the bright band was not clearly observed near their FirstS. The SL0 events in the thunderstorms with infrequent SL0 activity were more likely to start from locations with a clear bright band. This suggests that the charges in the bright band area played an important role in the initiation of SL0 events. Although the initiation of the SL0 events had a close relationship with the bright band, they were not initiated from the reflectivity core within the lightning area. The difference between the maximum reflectivity within the lightning area (MaxR) and the reflectivity at the FirstS of the SL0 events was about 16 dBZ on average. More than 86% of these differences were between 5 and 30 dBZ, with more than 52% from 10 to 20 dBZ. These differences showed a linear increase with increases in MaxR, suggesting that SL0 events tend to occur at a greater distance (where that distance is measured using the reflectivity (dBz) rather than the real spatial distance) from the reflectivity core of the bright band when this core becomes stronger. Although SL0 events that were associated with thunderstorms showing infrequent SL0 activity tended to be initiated from locations with relatively weak reflectivity, the MaxR in their lightning area was larger than that of the thunderstorms that showed frequent SL0 activity. If we assumed that (1) the reflectivity cores corresponded to the charge centers and (2) the charge density of stratiform clouds with infrequent SL0 activity was weaker than that of stratiform clouds with frequent SL0 activity, these phenomenon could be explained logically. In the stratiform region of a thunderstorm showing infrequent SL0 activity, the relatively weak charge density made both a stronger reflectivity core (corresponding to the charge center) and a longer growth path necessary for the electric field to reach the breakdown threshold. The height of the FirstS in stratiform lightning flashes, including normal stratiform lightning flashes and SL0 events, shows two typical structures: (1) the height of the FirstS of stratiform lightning flashes decreases gradually with time and SL0 events are active when the FirstS height of most of the stratiform lightning flashes decreases to lower levels and (2) the SL0 events occur frequently accompanied by the frequent normal stratiform lightning flashes initiated at higher levels. In this situation, the height of the FirstS of the normal stratiform lightning flashes remains at a high level, and the frequent SL0 events break out at a low level after the normal stratiform lightning flashes have been active for some time.

A performance evaluation of the World Wide Lightning Location Network (WWLLN) over the Tibetan Plateau. Three years (2013–15) of data from the WWLLN and the Cloud-to-Ground Lightning Location System (CGLLS), and two years (2013–14) of data from the WWLLN and TRMM LIS were compared over the Tibetan Plateau and surrounding area. For the first time, the performance of the WWLLN in the Tibetan Plateau area is analyzed. In the mid-southern Tibetan Plateau (MSTP) region, the WWLLN observed 9.97% of the CGLLS flashes, and the average spatial location separation magnitude compared with the CGLLS was 9.97 km. Over the Tibetan Plateau, the WWLLN detected 2.62% of the LIS flashes, and its average spatial location separation magnitude was 10.93 km. The detection efficiency (DE) of WWLLN decreases with the direction from the east to the west over the plateau, which is consistent with the spatial change of the average flash radiance. The DE of the WWLLN increases with increasing return stroke peak current. According to the results of the CGLLS, in the MSTP region the average peak current of the WWLLN strokes is 62.43 kA for positive strokes, and –56.74 kA for negative strokes, and the corresponding peak distribution intervals are 40 to 50 kA and –30 to –20 kA. The WWLLN detects only 0.80% of CGLLS return strokes when the peak current is less than 20 kA, but it detects 53.8%, 68.0%, and 71.1% for peak current greater than 50 kA, 75 kA, and 100 kA, respectively. LIS flashes also detected by the WWLLN have significantly greater scale and stronger optical radiation energy, and their duration, area, and radiance are respectively 1.27, 2.65, and 4.38 times greater than those not detected by the WWLLN. Considering the estimates of CGLLS and LIS DE in previous studies, and combining the matching ratio of the WWLLN and the CGLLS or the LIS, we estimate a WWLLN DE of 9.37% for CG lightning and 2.58% for total lightning in the MSTP region. In the selected region of the Tibetan Plateau, WWLLN DE for total lightning is 2.03%. The low DE of WWLLN may be partly attributed to the weaker lightning discharge intensity over the plateau relative to other places. The CG flashes account for 71.98% of all WWLLN flash data in the MSTP region. Combined with the DE estimates, it is estimated that the ratio of IC flashes to CG flashes is about 4.05 in the MSTP region.

Lightning climatology over the northwest Pacific region: An 11-year study using data from the World Wide Lightning Location Network. Lightning data from the World Wide Lightning Location Network for the period 2005–2015 were used to investigate climatic characteristics of lightning activity over the northwest Pacific region (0°–55°N, 100°–180°E). The highest lightning densities (LDs) were observed over the coastal areas of Southeast Asia and the tropical islands, which differs significantly from the distribution of the highest precipitation rates. The LD in the South China Sea (SCS) was much higher than that over the deep ocean and showed a peak that was 3 h ahead of that seen in the open sea. A sharp increase in LD on the Indo-China Peninsula and in the SCS was observed during the pre-monsoon season. The monthly variations show that the highest lightning activity occurred during July, August, and September, which is consistent with the variations in the monthly precipitation rate. The contribution of tropical cyclones (TCs) and the impact of El Nino and La Nina events on lightning climatology over the northwest Pacific region were also examined. Two areas of maximum TC lightning were observed to the east of the Philippines and south of China, indicating that frequent lightning is produced when TCs are approaching landfall. The average LD during El Nino events increases by 10.3%, whereas during La Nina events it decreases by 4.8%. A northward shift in the positive lightning anomaly was observed in the SCS, from the southern SCS during the El Nino to the central and northern SCS during the La Nina periods.

Atmospheric Electricity at Bristol University

Aerospace Engineering, Dr Karen Aplin

Dr Aplin has recently moved to Bristol from Oxford and is now building up a new research group in atmospheric and planetary electricity based in the Aerospace Engineering Department. Her team are currently working on novel technologies for ionisation measurement including a small scintillator-based detector, which is being prototyped on balloon flights and is also available commercially.

Standalone commercial ionisation detector

School of Biological Sciences, Prof Daniel Robert

The group of Professor Daniel Robert is currently investigating the electric interactions between insects and plants, and between spiders and other arthropods and their environment in general. They are particularly interested in the role played by atmospheric electricity in the acquisition of charge by honeybees and bumblebees. This research in so-called electric ecology contributes to our further understanding of the how and why of the sense of electroreception in air by insects, spiders and such small and electrically charged animals.

Modelling of the electric fields as a bee approaches a petunia.

Chemistry, Dr James Matthews

Members of the Atmospheric Chemistry Research Group have been making measurements of atmospheric potential gradient alongside aerosol number concentration and weather conditions in cities including Bristol, Manchester and Bangkok to explore the relationship between the two and explore whether atmospheric potential gradient can be a useful measurement to aid understanding of aerosol dynamics and local meteorology within cities.

CTR Wilson Meeting on Atmospheric Electricity in Bath

The largest ever CTR Wilson Meeting on Atmospheric Electricity took place in the Department for Electronic and Electrical Engineering in the second week of November, 2018. More than ~100 scientists from around the world, including the United States, various European countries, South Africa and China gathered at the University of Bath to discuss their latest research on lightning discharges and discharge processes above thunderclouds. The meeting consisted of three parts. In the first three days, the newly emerging field of lightning interferometry with VHF and LF radio waves was discussed. Spectacular movies of the spatio-temporal development of lightning discharges inside thunderclouds were reconstructed from the radio waves and novel physical processes of the streamer to leader transition were discussed. On Thursday, movies and photos from the most amazing lightning discharges above thunderclouds were on display. The principal investigator of the ASIM payload on the International Space Station showed the first videos recorded on board the spacecraft during the commissioning phase. In the afternoon, the use of electric fields by bees to navigate to rewarding flowers and their biological sensing technology was demonstrated. The last day was reserved to honor the life time achievements of Prof. Michael Rycroft who worked on atmospheric electricity and space science and was a visiting Professor in the Department. Many former PhD students and colleagues enjoyed the meeting. The attendants included the former UK ambassador to the United Nations, the former science director of the European Space Agency and the vice-president of the International Union of Radio Science. The organizer of the meeting, Dr. Martin Fullekrug was very happy with the large international attendance. 'It was a great meeting, informative, and a most sociable occasion', he said.

Links:

Meeting programme: https://www.ctrwiae.org/assemblies.

Thursday community meeting overview: https://twitter.com/i/moments/1063842687126769664
Michael Rycroft meeting overview: https://twitter.com/i/moments/1063836432337436672

This lightning flash in Blackpool, UK won the best weather photographer of the year, awarded by the

Royal Meteorological Society (https://www.bbc.co.uk/news/uk-england-46223996).

Contribution from Max Marchand (CIRA/CSU), Steven Rutledge, Jeffrey Pierce, and Brody Fuchs (CSU)

The spatial distribution of annual intra-cloud polarity (Fig. 1) from Earth Networks Total Lightning Network (ENTLN) correlates with ammonia concentrations (Fig. 2; from Kharol et al. [2018]) and emissions across the contiguous United States. In particular, greater occurrence of negative polarity intra-cloud (-IC) flashes corresponds to greater ammonia concentration, both of which have small year-to-year variation. -IC flashes are typically low altitude and associated with IC dominant storms that may also produce a greater number of positive polarity cloud-to-ground (+CG) flashes than -CG. These are the anomalous polarity storms in contrast to normal polarity storms mostly composed of +IC and -CG. Greater ammonia concentrations are typically in agricultural areas due to animal waste and fertilizer application to cropland. Although the Tennessee River Valley in northern Alabama and Shenandoah Valley in Virginia are not readily apparent as locations of greater ammonia concentrations in Fig. 2, they too are locations of high ammonia emissions (see U.S. National Emissions Inventory for county-level emissions data). Consequently, these locations are minima in the +IC percent (Fig. 1). The strength of this relationship and the producing-mechanism is being further explored, including through use of weekly station data from the National Atmospheric Deposition Program. Examination of NLDN (National Lightning Detection Network) CG data over the previous two decades also indicate an increase in +CG occurrence as a percent of all CG flashes across the contiguous United States (not shown) coinciding with a nationwide decrease in sulfur dioxide emissions, which form sulfate aerosols. Although the NLDN trends may be due to changes in the network, the increase in +CG and reduction in sulfates would support the charging mechanism proposed by Jungwirth et al. [2005]. Additionally, this may suggest an association between rain/hydrometer acidity and flash polarity since ammonia is associated with basic solutions and sulfate with acidic solutions. We are also working to explore possible couplings between ammonia emissions and the established role of CAPE and warm cloud depth in contributing to high IC/+CG storms.

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Jungwirth, P., D. Rosenfeld, and V. Buch (2005). A possible new molecular mechanism of thundercloud electrification. Atmos. Res., 76, 190-205. https://doi.org/10.1016/j.atmosres.2004.11.016

Kharol, S. K., et al. (2018). Dry deposition of reactive nitrogen from satellite observations of ammonia and nitrogen dioxide over North America. Geophys. Res. Lett., 45, 1157–1166. https://doi.org/10.1002/2017GL075832

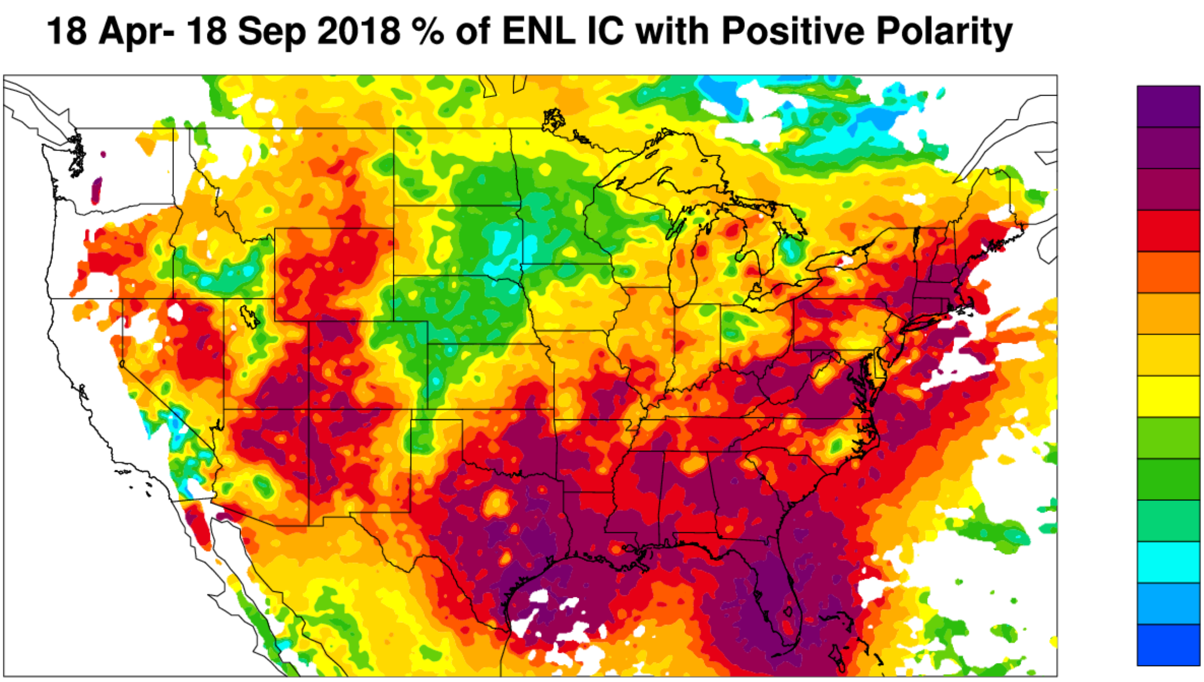

Figure 1. Percent of ENTLN intra-cloud flashes with positive polarity from 18 April to 18 September 2018 using a 15-km Gaussian spatial filter. Areas with IC flash densities less than 0.5 fl km^{-2} are masked out in white. Note that ENTLN DE is less over the ocean, Mexico, and Canada and, consequently, IC polarity and flash type is less likely to be accurately estimated there.

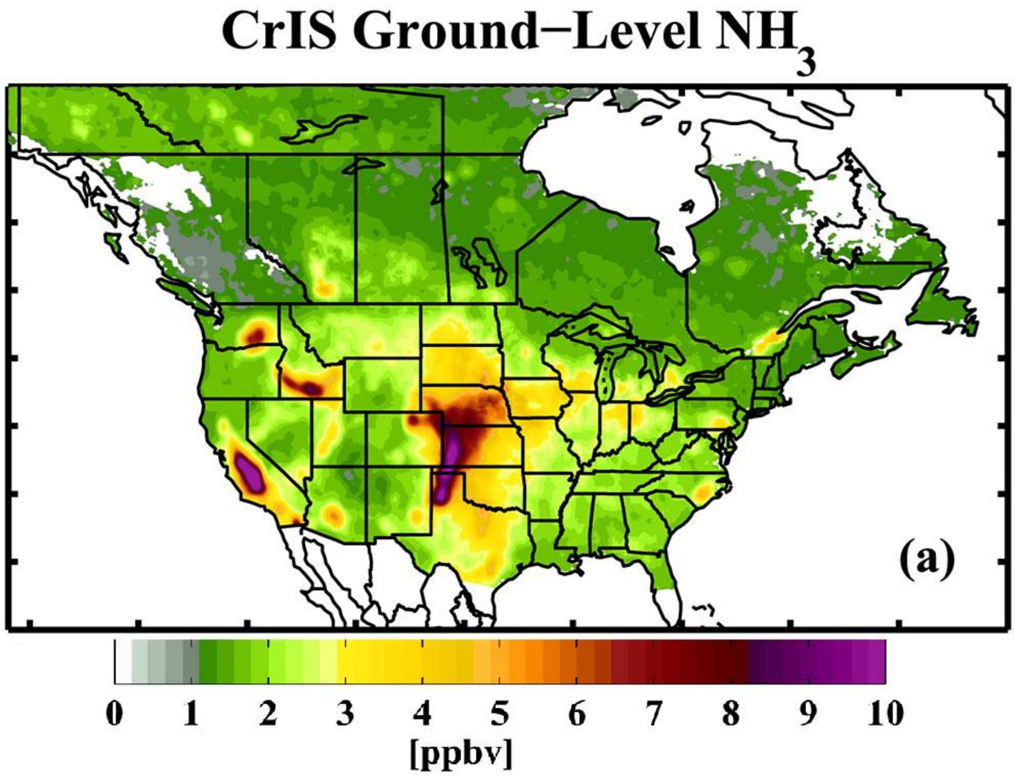

Figure 2. From Kharol et al. [2018] (their Fig. 1a), mean ground-level concentration of ammonia during April-September 2013 derived from Cross-track Infrared Sounder (CrIS).

Lightning Research Group of Gifu University (Gifu, Japan)

Observations with the Fast Antenna Lightning Mapping Array (FALMA)

We have developed a lightning mapping system called Fast Antenna Lightning Mapping Array (FALMA). As the name suggests, FALMA is a system consisting of multiple fast antennas. First observation was made during the summer of 2017 in Gifu, Japan. Detailed description of the system and 3-D location results of three interesting flashes can be found in the paper *Lightning Mapping With an Array of Fast Antennas* published in GRL.

- 3-D location results of preliminary breakdown in positive CG lightning

With the data obtained in the summer of 2017, several studies have been carried out. One study is about the preliminary breakdown of positive CG lightning. We analyzed 3-D location results of PB pulses in 46 +CG flashes. The majority (40) of the +CG flashes started with positive PB pulses

(+PBPs), the same polarity as the positive return stroke. Only 6 +CG flashes started with -PBPs. According to the location results, we found that +PBPs were produced by leaders propagating upward and -PBPs were produced by leaders propagating downward, indicating that PB pulses of both polarities in +CG flashes were produced by negative leaders. Possible charge structures responsible for different types of PB pulses in +CG flashes were also analyzed. These results can be found in the paper *Locating Preliminary Breakdown Pulses in Positive Cloud-to-Ground Lightning* published in JGR.

- IC flashes initiated at high altitudes and dominated by downward positive leaders

IC lightning flashes are normally initiated below 10 km and start with upward negative leaders. With the observation of FALMA, a new type of IC flash called "downward +IC flash" is identified. Downward +IC flash is initiated at high altitudes (mainly above 12 km) and does not contain initial upward negative leaders. Instead, downward +IC flash is dominated by downward positive leaders with speeds on the order of 10^4 m/s. Figure 1 shows a typical example of a downward +IC flash. We further demonstrated that downward +IC flashes are produced in thunderstorms with deep convective updrafts (radar echoes of cloud tops typically higher than 14 km). The charge structure responsible for downward +IC flashes is inferred to be a positive dipole including a negative charge region at a normal altitude (near the -10°C isotherm) and an upper positive charge region at a relatively high altitude (usually above the -50°C isotherm), with downward +IC flashes likely initiated from the upper positive charge region.

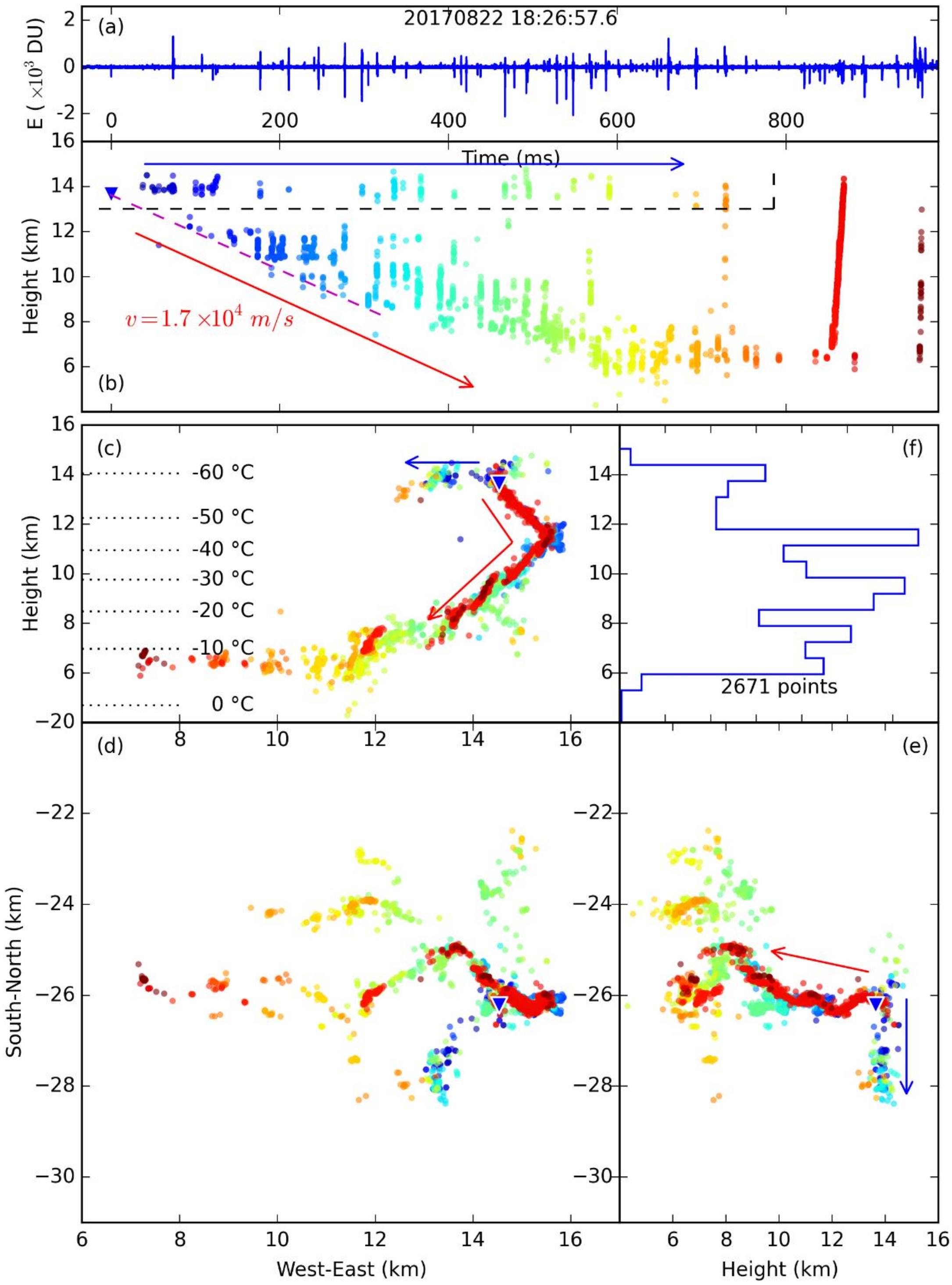

Figure 1. 3-D location results of a downward +IC flash.

LMA observation of three upward bipolar lightning flashes in winter thunderstorms

In the Japanese winter season of 2014, we have observed the leader progression of three upward bipolar lightning flashes (UBLFs) using the lightning mapping array (LMA). We found that leader polarity-reversal processes in three flashes share the same features.

(1) Initial sources of the polarity-reversal leader are characterized by relatively strong VHF power (average value in lightning A, B and C: 24 dBW, 18 dBW and 14 dBW) and obvious upward progression.

(2) During the several tens of milliseconds (lightning A: 56 ms; lightning B: 21 ms; lightning C: 67 ms) before the initiation of the polarity-reversal leader, one branch of the preceding leader in bipolar flashes was nearly decayed while other branches of the preceding leader were still in propagation. Then the polarity-reversal leader will be initiated at the end of the decayed branch of the preceding leader.

(3) Two of the three upward lightning (lightning A and B) occurred at a normal dipolar charge structure, while the remaining one (lightning C) occurred at an inverted dipolar charge structure.

Based on the common features of the polarity-reversal leader and charge structure, we have proposed a scenario to interpret the formation process of UBLFs, as shown in Figure 3. These results can be found in the paper *Leader Polarity-Reversal Feature and Charge Structure of Three Upward Bipolar Lightning Flashes* published in JGR.

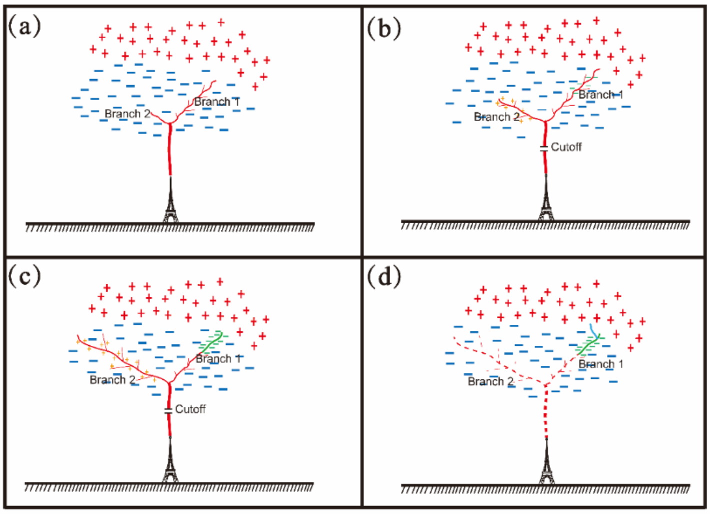

Figure 3. Process of leader polarity reversal in UBLFs. Red and green lines indicate the upward positive and negative leaders, respectively.

High-speed video observation of step and branch formation features in an upward negative

leader

We have analyzed the high-speed video of an upward negative leader that exhibited multiple branches. From the video, which was recorded at a frame rate of 300 kilo-frames per second (3.3 μs per frame), we have identified 75 leader steps, 21 being from the leader main channel and 54 from 4 branches of the leader. By numbering the light intensity of each pixel in all frames, we have been able to distinguish even slight luminosity changes between frames. Taking this advantage, we have made the most detailed analysis of the development process of a stepped leader. We have also presented the most series of frames to reveal the connection among different steps for the first time. Through analyzing each individual leader step and branch in detail, we found a similar formation pattern for both the leader step and the branch as illustrated in Figure 3. This pattern can be described in the following sequence: (1) the streamer area forms ahead of the leader tip, (2) the streamer area and the backward leader channel increase in luminosity, (3) the streamer area and the leader channel decrease in luminosity, (4) the streamer area reilluminates ahead of the leader tip, and (5) the reilluminated streamer area develops to a new leader tip and a new streamer area is emitted forward ahead of the new leader tip. These results can be found in the paper *Formation Features of Steps and Branches of an Upward Negative Leader* published in JGR.

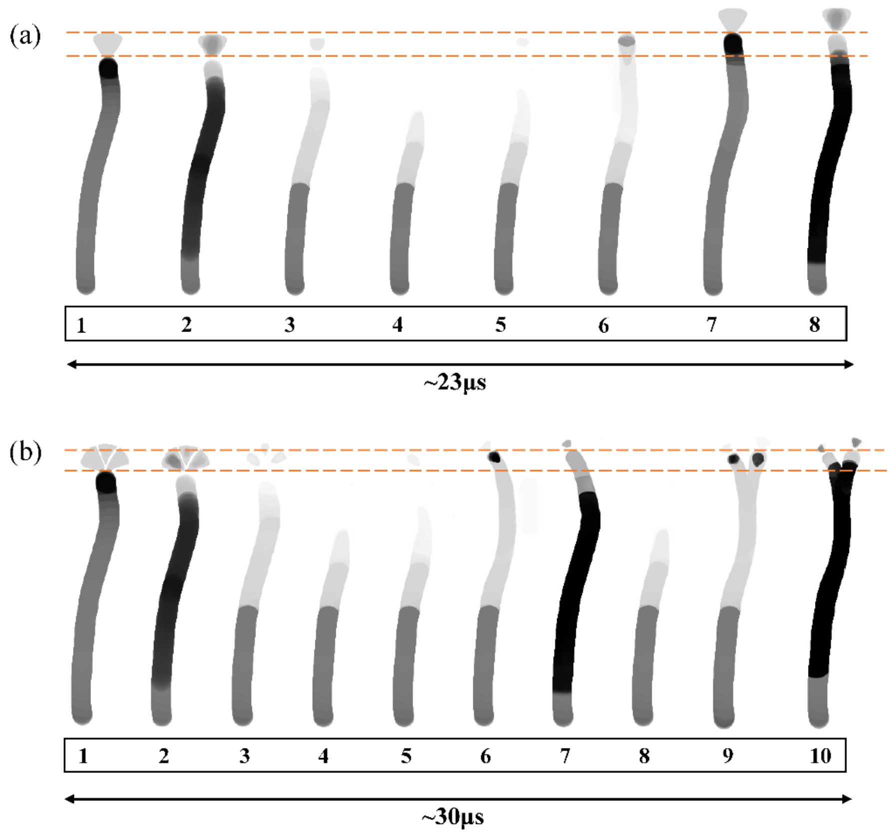

Figure 4. Illustration of the formation process for (a) leader step and (b) leader branch. The dashed lines are used as the reference to illustrate the development around leader top. The time interval between adjacent channel images is 3.3 μs.

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In the end of April, Veronika Barta spent a week at the Frederick University (Nicosia, Cyprus) in the framework of a Short-term scientific missions (STSM) of the ESF COST Action CA15211 (ELECTRONET, https://www.atmospheric-electricity- net.eu). The main objective of the STSM was to investigate possible ionospheric anomalies prior to large European earthquakes using a multi-technique approach, by applying both statistical and spectral analysis on TEC data obtained from the GNSS global network and on atmospheric electric potential gradient (PG) measured at Nagycenk Geophysical Observatory, Hungary or at other European atmospheric electricity measuring stations which were situated within the preparation area of the selected earthquakes. The preliminary results show a bay-like or multiple bay-like reductions of the PG a couple of hours to 1,5 days prior to four large European earthquakes among the 7 selected events.

Attila Buzás undertook another STSM mission in the framework of the COST ELECTRONET Action during the summer of 2018 to contribute to the movement for the intercomparison and standardisation of PG measurements at different measuring sites in Europe. He visited the atmospheric electricity measurement site of Reading University (UK) and conducted PG measurements there with a portable reference field mill parallelly to the permanently installed local PG sensor. The survey confirmed that various sensors, accessories, buildings, and objects don’t affect the electric field measurements in Reading University Atmospheric Observatory.

Extremely low frequency (ELF) records from Nagycenk Observatory, Hungary were used to characterize red sprites, which were observed for the first time from the ground in South Africa, by the charge moment change (CMC) of their parent lightning strokes. The obtained CMC estimates were in good agreement with the known threshold for mesospheric dielectric breakdown. A linear relationship was found between the brightness of the sprite and the CMC of its parent lightning stroke (Nnadih et al., 2018).

Analysis of dancing red sprites recorded simultaneously at two European observation sites led to an interpretation of the appearance of these dynamic sequences of discharges in the mesosphere. Location of the appearing sprite elements were triangulated and compared to the timing, location, and current moment variation of their parent lightning strokes. The results suggests that dancing sprites often correspond to contiguous lightning flashes of extreme duration and length in which several sprite-producing +CG lightning strokes occur (Bór et al., 2018).

An automatic procedure was implemented and tested to identify Q-bursts in the ELF time series measured in the Széchenyi István Geophysical Observatory, Hungary. The method is based on the analysis of the Poynting vector which is calculated from the locally measured components of the atmospheric electromagnetic field. The results were presented on the EGU 2018 general Assembly in Vienna (EGU2018-7992). This method will be used to study the dynamic properties of the Earth-ionosphere waveguide by analyzing the properties of the detected Q-bursts statistically.

Professor Earle Williams from MIT visited our research team in GGI, Sopron in November 14-21. Current stages of ongoing collaborative scientific projects were looked through in the frame of the workshop (Figure 1). The main focus was on two approaches to the problem of multi-station Schumann resonance (SR) inversion which aims at reconstructing the global lightning activity in absolute units ($Coul^2$ km^2/sec). One of the solutions known as “FULLGEAR” method was developed by Vadim Mushtak and the MIT team and the other one, based on the PhD thesis of P. H. Nelson (1967), was further developed by Ernő Prácser and the GGI team. Recently, our model has been tested thoroughly via synthetic data. SR inversion based on real SR measurements for selected days had been processed with both models and the results were compared. The discrepancy found between the two inversion results was partly resolved. Remaining tasks (e.g., handling of the issue of non-uniqueness, day-night asymmetry, etc.) were also discussed.

SR measurements indicate that sometimes “non-lightning” sources of magnetospheric origin can also contribute to the measured SR intensities. These events are studied by Tamás Bozóki and Gabriella Sátori in order to determine their exact origin.

Figure 1. Participants of the workshop in GGI on 19. Nov. 2018.

Contribution to the Newletter on Atmospheric Electricity: Massachusetts Institute of Technology, Cambridge MA, USA

Following up on the recent initiative by the World Meteorological Organization (WMO) to make lightning a climate variable (Aich et al., EOS, 2018), the assistance of a number of fellow atmospheric electricians has been solicited at the recent ICAE in Nara, Japan to explore the archive on thunder days for their respective countries. Gabriela Nicora (Argentina), Farhad Rachidi and Marcos Rubinstein (Switzerland), Jozsef Bor (Hungary), Ute Ebert (Netherlands), Colin Price (Israel), Marni Pazos and David Adams (Mexico), Samia Faiz Gurmani (Pakistan) and Antii Mäkelä (Finland) have all been particularly proactive in this exploration in their respective countries. The overall goal here is to augment the NOAA GSOD global dataset on thunder days. The thunder day portion of this dataset been reorganized by Anirban Guha (Tripura University in India) to simplify the augmentation which is most needed in years prior to 1973 when the GSOD dataset was initiated. The working concept here is that the thunder day observation can represent the behavior of global lightning over the many decades prior to its quantification by modern lightning networks. The involvement of the WMO in this augmentation effort is most appropriate given their key role in assembling the excellent global climatology on thunder days (WMO, 1953).

Earle Williams received a kind invitation to participate in the 100th Birthday celebration for long-standing investigator of atmospheric electricity Stanislaw Michnowski at the Institute of Geophysics, Polish Academy of Sciences. This birthday coincided with the 100th anniversary of the end of World War I, and the beginning of Polish independence. The hosts for this event were Stanislaw's collaborators and students Marek Kubicki, Anna Odzimek and Ptor Baranski.

This visit to Poland provided an opportunity for a following week-long visit to Schumann resonance collaborators (Erno Pracser, Tamas Bozoki and Gabriella Satori) in Sopron, Hungary. The comparison of the behavior of two inversion approaches for common sets of multi-station Schumann resonance observations on individual days was well suited to exposing the virtues and shortcomings of each method. One notable advantage of the Nelson method for inversion is the allowance for a larger number of regional lightning sources, often well-positioned on the basis of VLF network observations, and with limits set by the eigenvalue distribution in the inversion. Preliminary findings also suggest that the ranking of the three major chimneys is more reliable with this method.

Yakun Liu will return to MIT later this fall as a post-doc study for two years on the Schumann resonance inversion work. He worked earlier as part of his PhD work on the instability of 1-ampere DC arcs in air.

As part of the collaborative work in Hungary, Gabriella Satori and Earle Williams have examined the response of Schumann resonances (with station observations in Hungary and in Rhode Island) to the two super-El Nino events in 1997 and 2015. (These events bound the recent hiatus in global warming from 1998 to 2013.) Rough doublings of lightning activity in the Maritime Continent are observed in time frames of several weeks in both events (during April of 1997 and during June of 2015), coincident with the months of maximum sea surface temperature in this chimney. These lightning episodes precede the maxima in surface air temperature that is likely the result of the subsequent heat transfer from the ocean.

Menghui Wang and Earle Williams are working closely with Danny Rosenfeld on the comparative analysis of cloud condensation nuclei (CCN) at cloud base height (following the satellite method of Rosenfeld et al., 2016) in the three chimney regions of the global electrical circuit. A motivating question is what role CCN may have in explaining why Africa often predominates in lightning activity and the AC global circuit, but is secondary to America in the DC global circuit. A presentation on this work is scheduled for the upcoming AGU meeting in Washington, D.C.

ICAE 2018 Newsletter-Input from Vaisala

A 64-page educational booklet about lightning has been prepared in a horizontal format. It has questions, true/false entries, fast facts, photos, and references for many of the most commonly-asked questions about lightning. It is appropriate for schools and the general public. The English version is at https://www.vaisala.com/en/lp/so-you-think-you-know-lightning. The Chinese version is at http://cn.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/%E7%BB%B4%E8%90%A8%E6%8B%89%E9%97%AA%E7%94%B5%E7%9F%A5%E8%AF%86%E5%B0%8F%E6%B1%87%E7%BC%96.pdf. The authors are Ron Holle, consultant to Vaisala in Tucson, Arizona, and Daile Zhang, Ph.D. candidate at the University of Arizona in Tucson and a Vaisala Giant Leap intern in 2015.

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