Lightning Activity Over Tropical Water Bodies

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Recent observations placed the world's lightning hotspot at Lake Maracaibo, a tropical lake in Venezuela with nighttime thunderstorms. Several other tropical water bodies also exhibit deep nocturnal convection with enhanced lightning activity, such as the world's largest tropical lake, Lake Victoria, in Africa, and the Amazon river and their tributaries. This study investigates the precipitation structure and the diurnal cycle of thunderstorms over the major tropical water bodies, as well as further physical (size, shape, local topography and water temperature) and regional-environmental (meso and large-scale circulations) characteristics of these lakes and their relationship to the nocturnal thunderstorms. We use data from the Integrated Surface Database (ISD) and ERA5 reanalysis to assess the local boundary layer conditions and windflow, and the Tropical Rainfall Measuring Mission (TRMM) satellite to examine the Radar Precipitation Features (RPFs) profiles, the Microwave Imager (TMI) and lightning observations to infer the precipitation structure of water bodies storms.
The Amazon river and its tributaries show clear suppressed convection over the rivers and enhanced lightning activity along the east side of the rivers from noon to 15 local solar time (LST), persisting towards the end of daylight. Storm and lightning occurrences increase over the rivers during the evening from midnight to early morning. The east side of the rivers with NW-SE orientation (perpendicular to the average northeasterly wind across the Amazon Basin), show increased PF occurrences than the rivers that have SW-NE orientation or E-W orientation.

Comparing Lakes Maracaibo and Victoria, the first presents higher flash rates, with greater percentage of convective area and deeper convection, while the second lake, being the largest, allows the development of more extensive storms and with more volumetric rain. Lake Victoria has a higher frequency of storms and 10.2% of them have lightning activity, while Lake Maracaibo shows 7.7% of the storms with lightning associated. At the largest lakes, it is clear that thunderstorms initiate at a preferred portion of lakeshore during the afternoon (12-19 LST), move towards the adjacent lakewaters in the early night hours (20-23 LST), then occupy the entire lake during the rest of the night (00-07 LST), dissipating in the early morning (08-11 LST). The consensus explanation for nocturnal thunderstorm dominance over these lakes are based on the thermal contrast between the lakewaters and the surrounding land. The nearby elevated topography, size and shape of the lake are important to invigorate the local driven circulations responsible for the development of deep convection and increased lightning activity. A nearly linear relationship between the lake area and lightning activity exists over tropical lakes that are not subjected to large-scale subsidence. We also investigate the thermal hypothesis using simple kinematics relations between the area and the anomalous nocturnal boundary layer of the lakes with distinguished warm waters.
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A New Model for Proton Transfer During Ice Particle Collisions: Application to Thunderstorms

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Field observations and laboratory experiments strongly support the idea that the development of electric fields in a thundercloud is caused by rebounding collisions between graupel and ice crystals. and their gravitational separation.Various processes (for example, the Workman-Reynolds effect [1948],the thermoelectric effect [Latham and Mason, 1961], the induction theory [Müller-Hillebrand, 1954], and the transfer of surface liquid films [Dash, Mason, and Wettlaufer, 2001] have all been proposed as plausible microphysical mechanisms of charge separation between colliding ice particles. However, these various mechanisms have been found to be inconsistent with the experimental evidence, and a new approach to understanding the charging mechanism is necessary.

In the past several decades, significant progress has been made in understanding the mechanism of electrical charge conduction in ice, which involves the motion of ionic and orientational defects in the ice lattice [Petrenko and Whitworth, Physics of Ice; Oxford University Press: Oxford; New York, 1999; Uritski, Presiado, and Huppert, J. Phys. Chem. A, 113, 959-974, 2009] as well as the structural, dynamical, and electrical properties of ice surface [Lee and Kang, J. Phys. Chem. B, 125, 8270-8281, 2021]. A knowledge of these basic properties of ice is crucial for understanding the microphysical charging mechanism of ice particles. In this presentation, we introduce a new mechanism for charge separation between colliding ice surfaces based on these basic properties of ice. The role of H+ ions (excess protons) in ice for charge separation is emphasized, which enables efficient charge transport between interacting ice surfaces due to the uniquely high proton diffusivity in ice. The ice-ice collision leads to the formation of a transient crystalline ice bridge at the contact point, which is spontaneously driven by the tendency for ice sintering, and rapid interparticle H+ diffusion occurs through this ice bridge. Charge separation is achieved by the asymmetry in the trapping efficiency of H+ ions in *L*-orientational defects in the two colliding ice particles. The proposed H+ transport mechanism at a molecular scale is in keeping with the macroscopic empirical rule that the faster-growing ice surface by vapor deposition is positively charged at the expense of negative charging of the slower-growing ice surface during collisions. [Baker, Baker, Jayaratne, Latham and Saunders,1987], with the understanding that negative growth is sublimation. The tripole structure of thunderstorms can be accounted for on this basis.

Exploring the Microphysical Controls on Scattering of Lightning Emission Using Monte Carlo Methods

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Optical emission observed from lightning is the result of in-cloud scattering, lightning channel geometry, and optical energy of the source discharge. To better understand how scattering affects cloud-top optical emission for satellite lightning missions, a Monte Carlo scattering model is used to simulated optical emission at 337nm and 777.4nm.

Within the Monte Carlo model lightning discharges are simulated as point and line sources. These idealized simulations are replicated at each wavelength of interest for one homogeneous, and two inhomogeneous scattering environments. The two inhomogeneous scattering environments are from a simulated storm using two-moment bulk microphysics in the Weather Research and Forecasting model, including the concentration and size distribution of cloud droplets and ice particles.

The importance of the 777.4nm wavelength is well established in the lightning community, while lightning emission at 337nm has shown potential as a complementary measurement due to recent results from two instruments on the International Space Station (ISS): the Modular Multispectral Imaging Array (MMIA) which is part of the Atmosphere-Space Interactions Monitor (ASIM), and the Global Lightning and Sprite Measurements on JEM-EF (JEM-GLIMS). Understanding in-cloud scattering within these narrow bands will advance our understanding of lightning emission measurements as a function of in-cloud microphysics.

Scattering at 337 differs from that at 777.4nm wavelength due to differences in the ice and liquid water optical constants (where these two optical constants are virtually equal at 777.4nm).The simulations in this study reveal how differences in optical constants impact cloud-top optical emission. By extension, the vertical distribution of liquid and ice scatterers is discussed, as this highly impacts emission reaching cloud-top. This study focuses on characterizing emission reaching cloud boundaries, and the gradient of the microphysical profile, which is shown to modulate optical emission at cloud-top, specifically at 777.4nm.

Preliminary Mobile Lightning Mapping Array Observations During the PERiLS Field Campaign

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The NOAA / OAR National Severe Storms Laboratory will deploy eight Lightning Mapping Array (LMA) sensors in targeted deployments coordinated with the Propagation, Evolution and Rotation in Linear Storms (PERiLS) meteorological field campaign during March-April 2022 in the southeast United States. This will be the first formal excursion of these sensors as a full mobile network supplementing the data collected by a semi-nomadic meteorological field campaign. For each Intensive Observing Period (IOP), the sensors will be deployed in one of eleven target regions in coordination with other meteorological observation platforms including radar, surface observations, profilers and others. Prior to the field campaign itself, the expected LMA performance was characterized and each sensor's deployment site was optimized to provide an estimated flash detection efficiency of >90% over a 100 km radius with minimal errors in each target region. Our scientific objectives include determining if total lightning data could serve as a useful precursor to storm evolution through mixed phase updraft and microphysical variability, and the consequential cold pool evolution, all of which indirectly couples to forecasts of tornado risk. All collected LMA data will be made openly available. We will present preliminary results from these mobile LMA deployments and lessons learned for acquiring research-quality lightning data with nomadic field campaigns going forward. We welcome discussions of future collaborations, strategies and potential uses for targeted LMA observation sets.

Land–ocean Contrast in the Direct Current Global Electric Circuit

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For many years it had been widely thought that electric fields and currents comprising the global electric circuit (GEC) are maintained primarily by thunderstorms and electrified shower clouds (ESCs) over land areas. First attempts to interpret the observed diurnal variation of the fair-weather electric field back in the 1930s were based on combining the data on global thunderstorm activity over different continents. More recent aircraft and satellite measurements have shown that oceans also contribute substantially to the GEC, providing nearly the same portion of the total current and ionospheric potential as land areas. In this connection it is important to distinguish the direct current GEC from thunderstorms and ESCs, of which the latter have no lightning, as well as to compare the ionospheric potential (IP) and lightning flash rate (LFR) parameterisations.

Here we present an analysis of land and oceanic contributions to the direct current GEC on the basis of simulations using the Weather Research and Forecasting model (WRF) and meteorological reanalysis data. These simulations allowed us to reproduce the atmospheric dynamics for 1980–2020 and obtain the variation of the GEC by parameterising regional contributions to the ionospheric potential in terms of geographical distributions of convective available potential energy (CAPE) and precipitation. Note that over the last few years a similar parameterisation based on CAPE and precipitation has been suggested for LFR; we believe that these quantities are more representative of contributions to the GEC and characterise LFR only indirectly.

To study the land–ocean contrast in the GEC, we have divided the Earth's surface so as to single out contributions from specific continents and oceans. Apart from the well-known fact that contributions from all land regions to the GEC have pronounced maxima at about 14:00–18:00 local time, our simulations have also shown that contributions of all oceans have maxima at about 2:00–6:00 local time; it is interesting that contributions of oceanic regions with many islands (the Maritime Continent, Middle America) have maxima at both 14:00–18:00 local time and 2:00–6:00 local time.

The land–ocean contrast is also observed in the effect of the El Niño—Southern Oscillation (ENSO) on regional contributions to the GEC. Our simulations have shown that the oceanic contribution is positively correlated with the ENSO cycle (i.e., the sea surface temperature in the Niño 3.4 region), largely owing to increases in convection over the Pacific Ocean. In contrast to the oceans, the land contribution shows a negative correlation with the ENSO due to decreases in convection over the Maritime Continent and South America (here we count oceanic regions with many large islands as land). The observed correlations are statistically significant and are clearly seen on the decadal timescale.

When summing the contributions of land and ocean, two strong effects of opposite signs nearly counterbalance each other and we obtain a much less pronounced effect of the ENSO on the total ionospheric potential.

Influence of the El Niño—Southern Oscillation on the Global Electric Circuit

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The El Niño—Southern Oscillation (ENSO) is one of the most remarkable modes of climate variability on Earth. Being made up of irregularly alternating warm (El Niño) and cold (La Niña) phases, the ENSO affects atmospheric circulation, global temperature and rainfall patterns, agriculture and economic output. While links between the ENSO and lightning have been investigated before, it appears that there have been only few studies addressing the influence of the ENSO on the direct current global electric circuit (GEC). Here we further address this question using both numerical simulations and the results of electric field measurements to reveal new links between the ENSO and the GEC.

It is known that the GEC intensity can be characterised by a single global index, namely the ionospheric potential, made up of contributions from electrified clouds all over the globe. Using the Weather Research and Forecasting model (WRF) and meteorological reanalysis data, we have reproduced the atmospheric dynamics for 1980–2020 and simulated the variation of the GEC by parameterising regional contributions to the ionospheric potential in terms of convection and precipitation. Apart from that, we have analysed fair-weather electric field measurements at the Earth's surface performed during 2006–2016 at the Russian Vostok station in Antarctica. Such clean locations on the high Antarctic plateau offer an exceptional opportunity to monitor the variation of the GEC.

Both ionospheric potential simulations and fair-weather electric field measurements indicate that the shape of the diurnal variation of the GEC is significantly different for El Niño and La Niña years. During strong El Niños the GEC intensity relative to the diurnal mean is generally higher than usual around 8:00–14:00 UTC and lower than usual around 16:00–0:00 UTC; La Niñas are characterised by the opposite behaviour. Further analysis shows that anomalies in the Niño 3.4 sea surface temperature, which characterise the ENSO phase, and anomalies in the relative ionospheric potential at certain hours of the day are tightly correlated.

Thus we have identified clear and statistically significant patterns related to ENSO in the variation of the simulated ionospheric potential and measured surface electric field. It is noteworthy that super El Niño events are accompanied by especially pronounced deviations of the diurnal variation curve from the long-term average.

Simulations with the WRF also allowed us to identify the mechanism behind the observed effect of the ENSO on the GEC. Simulations clearly demonstrate how changes in global convection patterns due to ENSO over the Pacific Ocean, Maritime Continent and South America lead to changes in the global distribution of electrified clouds (which maintain the electric fields and currents in the entire GEC) and how this eventually results in the patterns observed in the simulated ionospheric potential and in the electric field measured in Antarctica.

The results of our study provide further evidence of the influence of climate fluctuations on the Earth's global electromagnetic environment. We have shown that atmospheric electricity measurements at a single location can give us significant information about the global climate variability.

19 Days of Global Lightning Activity as Inferred From Schumann Resonance Observations and Seen by Ground-based Global Lightning Detection Networks

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The importance of lightning has long been recognized from the point of view of studying climate-related phenomena. The fact that the World Meteorological Organization (WMO) has accepted lightning as an essential climate variable has significantly raised the scientific interest in atmospheric electricity in general. However, detailed investigation of lightning climatology on global scales is currently hindered by the incomplete and spatially uneven detection efficiency of ground-based global networks and by the restricted spatio-temporal coverage of satellite observations. This available technology prevents the detailed quantitative comparison of lightning activity on continental scales on time scales ranging from the diurnal to the interannual. Our group is developing different methods for investigating global lightning activity based on Schumann resonance (SR) observations. Due to the extremely weak attenuation of lightning-radiated electromagnetic (EM) waves in the SR-band (~3-50 Hz) all lightning strokes with vertical extent contribute to the measured EM field which makes SR measurements very much suitable for climate-related investigations. Since the ice-based process of charge separation in thunderstorms is gravity-driven, charge is basically separated vertically in the thundercloud so every lightning flash in the atmosphere (intracloud and cloud-to-ground alike) is expected to contribute to the SR intensity.

We processed SR data from 13 to 31 January 2019 measured at about 20 different SR stations around the globe to obtain a detailed picture about the evolution of global lightning activity during this 19-day-long period. We compare the obtained results with independent ground-based global lightning detection as provided by the WWLLN, GLD360 and ENTLN networks and with independent satellite-based lightning detection provided by the GLM instrument. Our results confirm that SR observations are adequate to infer large-scale changes in lightning activity. We demonstrate that SR intensities obtained from records at distant stations exhibit extremely high similarity day-to-day. We also reveal that a low frequency variation is present in the global lightning activity over the 19 consecutive days which may be a footprint of planetary waves. The inferred intensity of the global lightning activity changes by a factor of 2-3 on this time scale.

Global Climatologies of Lightning, Earth Ionosphere Cavity Resonances and Surface Temperatures

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The World Meteorological Organization (WMO) recently declared lightning to be an essential climate variable. Lightning flashes cause a globally resonant electromagnetic wave field known as Earth ionosphere cavity resonances which are designated as an emerging essential climate variable by the WMO. Earth ionosphere cavity resonances are simulated here with a stochastic model based on lightning flashes reported by the OTD/LIS space missions [1, 2, 3]. The incoherent superposition of earth ionosphere cavity resonances at each location results in simulated time series, spectra and radiant energy distributions. These simulations of earth ionosphere cavity resonances agree very well with measurements of magnetic fields with a radiometer at Arrival Heights in the Antarctic as part of the Stanford ELF/VLF Radio Noise Survey. Subsequently, the simulations are extended to the diurnal and annual time scales which define a climatology of earth ionosphere cavity resonances around the globe that can be used as a reference for various scientific studies. Here we compare the global climatologies of lightning, earth ionosphere cavity resonances and surface temperatures reported by the latest climate re-anlaysis of the European Centre for Medium Range Weather Forecast (ERA5). It is found that the diurnal variation of continental lightning in the tropical belt around the globe exhibits a significant degree of similarity with the surface temperature as both follow the longitudinal migration of the solar irradiance, whereas the diurnal variation of earth ionosphere cavity resonances reflects a globally integrated measurement based on the spatial teleconnection of thunderstorm areas attributed the global electromagnetic wave propagation. The results can be used to develop novel strategies to relate lightning, earth ionosphere cavity resonances and surface temperatures to global climate change.

Simulation of the Seasonal Variation of the Ionospheric Potential for 1980–2020

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The seasonal variation of the main parameters of the global electric circuit is still a debatable issue. In this paper we have reproduced the atmospheric dynamics for 1980–2020 and simulated the variation of the GEC using the Weather Research and Forecasting model (WRF) and meteorological reanalysis data, by parameterising regional contributions to the ionospheric potential in terms of convection and precipitation.
Ionospheric potential simulations on the basis of real meteorological data show that there exists a stable trend in the seasonal variation of the global electric circuit. The separation of ionospheric potential variation into individual contributions of the Northern and Southern hemispheres reveals much more stable and conspicuous trends in their annual variation. The Southern hemisphere has a maximum contribution around February and March and a minimum contribution in August, while the contribution of the Northern hemisphere has a minimum in February and a maximum around July–September. It is not surprising that the contributions of the two hemispheres to the global electric circuit change in antiphase with respect to each other. It should not also be surprising that the variation of their sum is much less pronounced (being the sum of two strong effects with opposite signs) and hence rather difficult to determine.
Detailed maps showing the geographical distribution of contributions to the ionospheric potential and the evolution of this distribution throughout the year indicate that the seasonal variation of contributions to the global circuit may be influenced by shifts in deep equatorial convection (mostly over the oceans). The seasonal dynamics of contributions of large regions shows that the resulting seasonal variation of the entire global electric circuit is to a large extent determined by the total contribution of oceans (while the total contribution of land does not vary so much). However, a more detailed analysis is needed to fully understand revealed patterns and temporal trends.
Comparison and discussion with the some experimental data of ground electric field measurements will be also presented.

Combining Electrical and Optical Measurements to Analyze Fog

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It is well known that local weather conditions can disturb fair-weather atmospheric electricity measurements. In particular, fog can cause the potential gradient to rise significantly and to exhibit increased variability. Since fog can cause major disruptions to transportation, there is particular interest in the possibility of using this effect to better forecast fog by taking measurements of electrical conditions before or during its onset.

While in general, fog causes the potential gradient to rise, some instances of fog do not show this affect clearly, and a connection within one fog event between the visibility (the defined indicator of fog) and potential gradient can be difficult to see. Since both electrical properties and visibility are affected by droplets in the air, we explore an unusual combination of measurements of optical and electrical quantities to improve understanding of fog in the real world.

In this study, we combine measurements of the potential gradient and visibility during fog events and analyze them. Theory predicts a relationship between the potential gradient and visibility which changes depending on size and concentration of droplets. Previously, this could only be roughly compared with physical data, since visibility measurements were infrequent and taken manually. However, in recent years, the development and implementation of new instrumentation has enabled more accurate automatic measurements to be made, sampled on rapid timescales. Here, we compare the predictions from theory with high temporal resolution visibility and atmospheric electrical measurements over multiple fog events.

E-field Variations Caused by Low, Mid- and High Altitude Clouds Over Israel

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The atmospheric electric field (Ez; sometimes referred to as the Potential Gradient, or PG) is one of several observable parameters that are used for studying the global electrical circuit (GEC). With measurements going back more than a hundred years, the PG has been shown to be affected by anthropogenic and natural processes, among them are clouds [Harrison 2006, Aplin 2012, Rycroft et al 2012].
Harrison (2011) found that PG values during overcast conditions are slightly reduced compared to fair weather clean conditions. The reason is an increase in the columnar resistance by the clouds layer compared with that of clear air; They found that the relative contribution will vary with the depth and height of the cloud layer. Harrison and Nicoll (2018) further reported that during overcast conditions, when the cloud base is above 1 km there is little associated variability in the PG data but when the cloud base is well below 1 km, the PG variability is substantial.
Ground measurements of the electric field from a station located in the arid Negev region of southern Israel have been conducted continuously since 2013 (Yaniv et al 2016, Yaniv et al 2017). We present preliminary results of 14 days showing the vertical electric field (Ez) variability during times of cloudy days compared with fair-weather mean values. The results show an increase of PG (~+10 to +70 V m-1) from mean fair weather values during times of low altitude clouds. During times of mid altitude (alto) clouds or during a superposition of low and high clouds there is no or little difference in PG (~0 to -30 V m-1) values compared with the mean fair weather PG values. During times of high-altitude cirrus clouds there is a decrease of the PG (~-40 to -90 V m-1). The data was compared with the Israeli meteorological service cloud data and MODIS cloud top height maps.

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Atmospheric Electric Field Anomaly Observed Immediately Before and After Earthquakes

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One of the earthquake-related electromagnetic phenomena is the anomaly of the atmospheric electric field. The atmospheric electric field is an electrostatic field generated in the atmosphere because the potential of the ionosphere is maintained at a high potential of about 300 kV relative to the earth's surface due to the electric charge carried to the sky by global thunderstorm activity. In normal conditions, the atmospheric electric field is about 100 V/m vertically downward near the earth's surface around the world, but it is easily affected by various local external factors other than global thunderstorm activity, especially meteorological disturbances in the atmosphere near the observation point. This field can easily change by several kV/m by local thunderstorm activity. Previous studies have reported that the atmospheric electric field has been disturbed during the period from about 10 days to several days before earthquakes. However, since the time window for identifying these anomalies is wide and the date of anomaly occurrence varies from earthquake to earthquake, therefore it is generally difficult to clearly show the causal relationship between these anomalies and earthquakes. In this study, we report on the anomalies of the atmospheric electric field in Japan, focusing on the period immediately before and after an earthquake (several hours). Using atmospheric electric field data from three spatially separated stations in Japan (Iwaki, Kakioka, and Memanbetsu), we demonstrate for the first time the results ofcases study for several earthquakes (magnitude 4 or greater) that occurred close to the observation points (within 100-200 km of the epicenter) under relatively fair local weather conditions. We found the common features for different earthquakes at different field sites such as 20~60 min period of clear anomalous signatures in wavelet spectrograms within few hours from main shock. We propose the physical mechanism of the observed electric field anomalies considering AGW originated from epicentric region propagating above the field site and disturb the local atmospheric electric field.