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Optical features of positive cloud-to-ground lightning associated with TLE events and long continuing current from space

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A new era of lightning and thunderstorm observation from space is supporting a wide range of studies, from the electricity of the Earth's atmosphere to climate change analysis, and has given rise to an impressive new generation of space-based instruments to capture imagery of lightning, thunderstorms and related events like Transient Luminous Events - TLEs.
One of these instruments is the Geostationary Lighting Mapper (GLM) aboard the Geostationary Operational Environment Satellite (GOES) 16 and 17, launched in 2016 and 2018 respectively. GLM is the first geostationary and total lightning (intracloud and cloud-to-ground) instrument dedicated to measuring lightning and thunderstorms over the Americas with an accuracy of around 2 ms and spatial resolution of less than 8 km at the nadir position. Together with GLM, the Atmosphere Space Interaction Monitor (ASIM) aboard the International Space Station (ISS) lunched in 2018, is the first high-speed instrument dedicated to observing severe thunderstorms, electricity in the upper atmosphere and its role in the Earth's climate. ASIM is composed of 1) the Modular Multispectral Imaging Array (MMIA) for lightning detection and related events and 2) the Modular X- and Gamma-Ray Sensor (MXGS) which is dedicated to measuring high energy radiation such as X- and Gamma rays throughout the upper atmosphere. Particularly, ASIM-MMIA is composed of three photometers centered at the 377, 180-240 (UV) and 777.4 nm spectral lines with and two one-megapixel cameras centered at 337.0 nm (±5 nm) and 777.4 nm (±3 nm).
This work is first focused on the time accuracy improvement of the ASIM-MMIA using cross-correlations to assess the best time-shifted between both 777 nm photometers of MMIA and GLM. After this correction, an accuracy up to 2 ms is acquired. As a second main goal, we investigated the main features patterns of the three MMIA-ASIM photometers alongside GLM and during positive cloud-to-ground lightning. Preliminary results show that in some cases, after a positive CG is reported, peak emissions in the UV photometer is reported within 10-18 ms, that might be associated with TLEs like sprites. Additionally, long continuing current of positive CGs lightning is analyzed by optical signatures of GLM during some TLE events.

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Successive Observation of Atmospheric Electric Field at Kakioka Geomagnetic Observatory

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The atmospheric electric field (AEF) / potential gradient (PG) measurement, using Kelvin water dropper, has been carried out by the Japan Meteorological Agency (JMA) at Kakioka geomagnetic observatory since 1929. The JMA terminated the AEF measurement the end of February 2021. For the successive observation, therefore, our group installed one field mill with a board range for the AEF intensity developed by Otowa Co. Ltd., sensitive and insensitive field mills developed by Boltek Co. Ltd. and all-sky and cameras at 18 of Feb., 2021. This observation was available on not only traditional fair-weather study but also the study of severe weather accompanying heavy lightning activities. The sampling rates of three field mills are 20 Hz (Otowa) and 10 Hz (Boltek). The time stamp was synchronized by GPS. This paper is a preliminary report of the AEF/PG measurement in the vicinity of the current AEF/PG observation operated by our group. In this study, parallel measurements using JMA's water dropper and our field mills are shown. In addition, the comparison between the fair-weather identified manually by JMA and systematically by our camera images is shown. A future plan for the data distribution is presented.

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Radar Observation of Debris Clouds Making Energetic TGEs with Strong Negative Charge Overhead

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Convective storms with strong electric field on the ground at 3.2 km MSL at Aragats in Armenia have been shown to be accompanied by Thunderstorm Ground Enhancements (TGEs): correlated enhancements of gamma rays and electrons of generally short duration (~5 minutes). The high energy gamma emission supports their origin in a Relativistic Runaway Electron Acceleration (RREA) rather than in emission from radon progeny. Increased use of radar observations of the Aragats storms brings new attention to differences in the vertical development of radar reflectivity that produce TGEs with strong positive and strong negative electric fields. In this study, an unusual category of energetic negative TGE is investigated with S-band radar and surface measurements. Unlike the more common negative TGE cases with strong vertical development in the central dipole region, evidence has also been found for "negative" TGEs beneath deep debris clouds from earlier deep convection, and exhibiting radar reflectivity less than values typical for graupels (>30 dBZ) but still present more uniformly throughout the mixed phase region and more broadly distributed in space. These TGEs also tend to be of longer duration. The radar and electric field observations are compatible with an ice-based precipitation mechanism but the physical process would appear to be different than the traditional graupel/ice crystal collision process of the non-inductive theory. Storms of this kind on May 18 and May 23, 2016, for example, will be studied over their complete lifetimes to shed further light on the mechanisms for their electrification.

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A New Concept of Lightning Hotspot

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Hotspots are commonly known as those areas that significantly receive the most lightning. There are several ways to find these regions. The most common is by the analysis of the flash rate density in the area. The isoceraunic level gives also another description of zones with more lightning.

These places that are frequently lightning stricken could be of interest of activities that are directly affected by lightning like wind energy companies, communication towers or power distribution companies, because they will have to consider this particularity when operating them or taking the lightning protection measures. Also these could be potential places of fire ignition due to lightning, so civil or forest protection should intensify surveillance during storms.

In this work we describe a new concept of lightning hotspot, considering areas where lightning occurrence is recurrent in time with certain periodicity. To validate this new concept, we have made a study of two different regions, one in midlatitudes and one in the tropics using lightning detection data from LINET for a period of 10 years. One of the regions of interest in Europe is Catalonia (North East of Spain) and the one in the tropics is Barrancabermeja (Central North of Colombia).

Partial results show that in Catalonia most of the lightning hotspots are located in elevated towers, wind turbines and top of mountains. In this case, the identified locations are similar to those arising from the classic analysis of the ground flash density. The method produces interesting results in areas with high lightning occurrences. In the selected area, the mere representation of the ground flash density does not always provide evidence of lightning interactions with tall objects or singular orographic effects. When the time periodicity criteria is included tall structures and orographic effects arise.

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Identification of Global Thunderstorm Activity From Schumann Resonance Observations in Mexico

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From observations of the Schumann resonance (SR) station at 19.81 N, 101.69 W, we analyzed and processed the data recorded since the station began operations in 2013 through 2021, and we constructed a time series from the diurnal variations of the amplitude of the first mode of the SR. Here, we present the peaks related to the main three regions of global thunderstorm activity: the Americas, Africa, and the Maritime Continent, as well as the seasonal variations during the time span.

4218

Streamer Propagation in Dry and Humid Air

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A streamer is a filamentary electric discharge that propagates due to a high electric field in a small volume around its tip. This field accelerates electrons up to energies high enough to ionize the air in front. Streamers form complex ramified structures known as streamer coronas. These are precursors of lightning discharges paving the path for the later hot leader phase. They also manifest inside thunderclouds with the emission of blue flashes and Narrow Bipolar Events (NBEs), right above the thunderclouds as the cold phase in the propagation of blue jets and at high altitude as large-scale discharges known as sprites.
In most cases, streamers propagate in highly humid environments. Surprisingly, the study of streamers under saturated and oversaturated air has barely been investigated. The presence of water molecules is known to reduce the conductivity of streamer channels and impede their propagation in the most extreme cases. This conductivity reduction is due to the enhancement of the electron attachment and the inhibition of electron detachment as a consequence of the formation of water clusters around negative ions. In this work, we use a numerical approach to study the effect of water molecules on fundamental properties for the streamer propagation such as the streamer head radius, the peak electric field, and the propagation speed.

4217

LF Receiver Network for Winter Lightning in Hokuriku and Its Recent Observations

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Many incidents caused by thunderstorms in winter on the coast of Sea of Japan, especially damage of power transmission and distribution facilities have been reported. For the countermeasures against lightning strikes, electromagnetic field observation is being conducted with the purpose of monitoring lightning discharges and elucidating their mechanisms. In this study, observation was carried out using the lightning observation equipment with low frequency (LF) band electromagnetic waves. This equipment is the wide area lightning observation networks composed of multiple broadband LF sensors installed on the ground. Each sensor is in 15 sites in Toyama and Ishikawa prefectures, southern Sea of Japan, and applies the time of arrival technique to received electric field waveforms in order to locate lightning channels. The observation range of this equipment is about 300 km, so it is possible to observe the wide range of lightning discharges, and from development of cumulonimbus with lightning to maturity and decline. We succeeded in detailed visualizations lightning channels in three dimension and observations of large lightning discharges on the horizontal scale. This paper focuses the observation results for lightning discharges with very very long horizontal lightning channels in streaky winter clouds around the coast line of Sea of Japan.

4215

High Temporal Resolution Observations of Precipitation Cores With Dual Polarized Phased Array Weather Radar and LF Band Lightning Location System

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The 40 dual polarized weather radars, which consists of a parabolic antenna, have been operating in Japan. The observation network is called ‘the extended radar information network; XRAIN’. The temporal resolution of the XRAIN is more than 5 min for a volume scan. On the other hand, the five X-band phased array weather radars (PAWRs) have also been operating in Japan. The PAWRs give us a high temporal resolution, which is less than 30 sec, and high-density observations for precipitations at high altitude as compared with a weather radar with a parabolic antenna. As a next phased array weather radar development project, a dual polarized phased array weather radar; DP-PAWR, which is also termed as multi-parameter phased array weather radar; MP-PAWR, has been developed in 2018. It can provide dual polarization variables that reveal detailed microphysics of storms. The DP-PAWR simultaneously transmits pulses of horizontal and vertical polarized waves. The center of frequency and observation range are 9.43 GHz and 60 km, respectively. The DP-PAWR provides the dual-polarization radar measurements of precipitation in less than 30 seconds. Additionally, the 114 samples are observed from 0 deg to 90 deg in elevation angles. The spatial resolution for the elevation angles is approximately 0.8 deg. For azimuth angles, the spatial resolution is 1.2 deg.

In 2020, our research group had installed 13 low frequency (LF) bandsensor network to locate lightning discharges in the Kanto area in Japan. The system provides the three-dimensional locations of lightning discharges using the time-of-arrival location technique. The mean distance between stations is approximately 20-30 km. The electric field antenna bandwidth is broad from 51 Hz to 550 kHz. Its signal is sampled at 5 MHz using the universal software radio peripheral; USRP. The recorded waveforms allow detailed analysis of lightning discharge processes such as a preliminary break down, return stroke, and so on. In this paper, we will show the simultaneous observation results of lightning and precipitation observations with 3D Lightning location system and the DP-PAWR, respectively. We focus on the heavy rain case occurred in Tokyo area on August 13, 2020. We found the following by comparing the frequency (or position) of lightning discharges, and the rapid growth and descent of convective core in spatial-temporal distribution. 1) As a result of investigating the relationship between the altitude of initial lightning discharges and that of the radar reflectivity factor, the frequency of lightning was higher in the area of the radar reflectivity factor of 15 dB at the altitude of 18 km, and in the area of the radar reflectivity factor of 35 dB at the altitude of 10 km. These areas at higher and lower altitudes seem to be consistent with the areas of upper positive charge region and the main negative charge region, respectively. 2) The temporal changes of the frequency of lightning occurrence and the

volume of specific differential phase (Kdp) are in good agreement. 3) Kdp volume and lightning discharge increased 20 minutes ahead of ground heavy rainfall.

4213

Optical Emissions During Initiation Process of Negative Stepped Leaders and Positive Cloud to Ground Lightning

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We investigate the initiation of negative stepped leaders and positive cloud to ground lightning by analyzing optical emissions in the 337 nm (blue) and 777.4 nm (red) spectral bands as well as high-speed records. The signals are correlated with satellite-based observations of lightning mainly derived from the Geostationary Lightning Mapper in the GOES 16 (Goodman et al., 2013).

It is known that, blue emissions of lightning are associated with the second positive system of the nitrogen during streamer-leader development of lightning and current pulses, meanwhile red emissions are mainly associated with neutral triplet oxygen emission during hot leader channels (e.g. Bazelyan and Raizer, 1997) and long continues currents as well.

All measurements were carried out in Barrancabermeja, Colombia on October 2021 using two photomultiplier tubes cantered at 777 nm and 337.4 nm with a sample rate of 2.5 MSa/s. Optical emissions data is compared with (Geostationary Lightning Mapper) GLM and VHF lightning mapping systems as Lightning Mapping Array (LMA).

The observation suggests that initiation of positive cloud to ground lightning has predominant red optical irradiance peaks that could be mainly related with stable leader propagation processes. In the other hand, we have observed in negative cloud to ground lightning, moderate increasing rate peaks in blue optical irradiance that could be associated with streamer development and negative leader stepping.

4210

Study of the Transitory Response of a UAV Equipped With an Active Electrostatic Charge Control System Based on Corona Discharge

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In previous experiments, we controlled the net charge of a UAV aircraft in flight based on charge emission. The charge emission system consists of a thin electrode suspended over the wing of the UAV connected to a high voltage power supply. The power supply's ground connects to the aircraft fuselage, and the voltage is remotely controlled. Corona discharge is generated on the thin electrode, ions produced by the corona discharge that move away from the UAV charge the aircraft in the opposite polarity of the corona. This charging effect happens during an initial transient until the aircraft's potential reaches a saturation level, where all the generated ions are recaptured by the aircraft neutralizing the charging effect or when spurious corona starts on the body. The charging system relies on the aircraft windspeed to more effectively send away ions from the coronating electrode. In the experimental campaigns with UAV, using a power supply, we managed to charge the model aircraft to and relative to the environment (Guerra-Garcia et al. 2020).

This study proposes an experimental setup to analyze the active electrostatic charge control system's transient stage of ion emission with a similar aircraft. In addition to corona currents and aircraft potential measurements, ion counters are installed downwind from the aircraft. Displacement currents and charge collection are measured in a large mesh collector installed downwind of the aircraft airflow. The ion release is quantified and correlated to the net charging dependency to the corona current and windspeed. After studying the limiting factors that saturate the voltage level at which the aircraft can get charged, two methodologies for increasing the saturation charge level are identified: dynamically changing the electrode configuration of the active charge control system and adding lower mobility particles to the airstream. The first method is investigated in this work for its suitability to implement in aircraft.

Charging of the aircraft occurs in a brief period of time (~ 10 seconds) after setting a high voltage level on the electrode between 9kV and 15kV. During that time, ions of the same polarity as the coronating electrode are detected downstream. A stable lecture of 0.15M ions/cm^3 on the ion counter is measured while the charging regime perdures. After the charging period, the aircraft potential saturates at -20kV, and the ion count drops to ambient level. At that stage, increasing the wind speed allows releasing more ions from the electrode, charging the aircraft an additional -3kV. The electrode configuration is changed at that level, moving it away from the wing 1cm to increase the saturation charge level. A new ion release peak is detected downstream, and the aircraft is further charged an additional -5kV.

This electrostatic charge control system based on corona discharge can be used to support electric field measurements and space charge generation from aircraft.

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Regional and Seasonal Variations in Random Forests Model Performance for GLM Flash Type Classification

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Lightning characteristics such as size, duration, and energy vary with region and season. This variation makes it hard to apply a single overarching model for classifying lightning type (cloud-to-ground versus intra-cloud) from flash characteristics observed by the Geostationary Lightning Mapper (GLM). Separate Random Forests (RF) models used for classifying flash type in the GLM data are trained and tested by month across different regions of CONUS known to have differing storm type patterns, using the Earth Networks Total Lightning Network (ENTLN) as the truth dataset. The RF model results vary, with highest skill scores in the Southeast, Great Plains, and the South, and worst performance in the Southwest and West. The spread in RF model performance is even larger seasonally, with the highest skill scores in the Northern Hemisphere winter and lowest in the late summer/early fall. Additionally, a case study from the Propagation, Evolution and Rotation in Linear Storms (PERiLS) field campaign is used to demonstrate how lightning flash characteristics evolve throughout a storm's lifetime, and how these changes might impact RF model performance. This case is from a geographic area in which the RF model performs relatively well, but not the highest expected RF skill seasonally. Overall, we demonstrate differences in lightning type flash characteristics regionally, seasonally, and with storm evolution, which shows the need for consideration of more sophisticated RF models to account for these variations.

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Interpreting New Observations of Initiating Events (IEs), NBEs (CIDs) and Initial Breakdown Pulses (IBPs) Using the KMS Lightning Initiation Mechanism

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Kostinskiy et al. [2020] proposed a mechanism (called the KMS Mechanism hereinafter) to explain lightning initiation including the IE, the Initial E-Change (IEC), and IBPs; the KMS mechanism depends on turbulence, on Extensive Air Showers (EAS), and on relativistic runaway electron avalanches (RREA). In this presentation we show that the KMS Mechanism is supported by our latest observations and calculations.

One important test of the KMS Mechanism concerns groups of NBEs: 2-5 NBEs that occurred within 10 km horizontally and ±660 ms of each other [Bandara et al., 2021]. This study supports the KMS Mechanism for the initiation and development of NBEs, since for each NBE group the number of NBEs, the time period of the group, and the horizontal area of the group were consistent with the expected number of primary cosmic ray particles to provide an EAS.

[Stolzenburg et al., 2021] studied the initial event (IE) of five IC flashes using a high speed camera (6.66 μs frame interval) with high sensitivity in the visible range along with a LF/MF "fast antenna" and a VHF antenna. The observations of only weak visible luminosity coincident with IEs indicate that the IEs did not have a bright, hot, conducting channel, in agreement with the KMS Mechanism in which the IE is a rapid series of positive streamer flashes.

The experimental results [Karunarathne et al., 2020; 2021] concerning the sequences of the initial breakdown pulses in CG and IC lightning flashes were also in good agreement with the KMS Mechanism. The analysis of these data based on the KMS Mechanism [Karunarathne et al., 2021] also made it possible to explain Energetic In-cloud Pulses (EIPs), which are thought to be the radio signals of events producing terrestrial gamma-ray flashes (TGFs) [Lyu et al., 2016].

In all the studies discussed above, the KMS Mechanism was useful for analyzing the experimental data presented, and the experimental and theoretical data did not contradict the KMS Mechanism.

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4201

Influence of Hydrometeors on Relativistic Runaway Electron Avalanches

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The study of the physical phenomenon proposed by Gurevich, the avalanche-like multiplication of fast electrons in matter, which is called runaway breakdown, is of considerable interest for atmospheric physics.
This is commonly used in the analysis of processes in thunderclouds. The study of these phenomena is carried out for homogeneous media. This simplified model does not take into account the presence of many aerosols and hydrometeors in thunderclouds. In this work, models of thunderstorm cells were investigated taking into account hydrometeors. Simulations were carried out in GEANT4 to obtain the dependence of the number of produced electrons, positrons, and gamma-quanta on the mass fraction of ice. The situation with and without the presence of a field was also considered. A difference is noted in the numbers and energies of the particles produced with an increase in the proportion of hydrometeors in the experiment.
This observation makes it possible to correct the theories of TGF formation and the rise length of relativistic runaway avalanches, which will affect the assessment of processes in the physics of thunderclouds.

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Effect of Extremely Low-frequency Magnetic Fields on Light-induced Electric Reactions in Wheat Plants

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All the living organisms of the Earth live and develop in the magnetic field that is not uniform. Oscillations of magnetic field (MF) themselves and in combination with other fluctuating environmental factors (significant changes of illumination, humidity, etc.) can affect the functioning of living organisms. Deciphering the mechanisms determining the biological effects of MF on plants are impeded by a high degree of interaction and mutual effects of physiological processes, as well as by the low level of knowledge about a number of processes that could potentially be sensitive to electromagnetic field. One of such processes is, for example, the generation of electric potential.Electric potential of cell membrane performs a number of essential functions. The most important of them are regulation and energization transmembrane substance transport and informational and signaling function. Change of electric potential of the membrane accompanies and mediates the effects of numerous environmental stimuli, such as fluctuations in illumination, humidity, temperature, etc. Such changes of electric potential are related to alteration of transmembrane ion flow caused by changed activity of ion channels and pumps. Ca^{2+}, H^+, Cl^- and K^+ are considered to be the key ions responsible for progression of electrical reactions. The object of the present study is the effect of extremely low-frequency MF on light-induced electric reaction and mechanisms of such an effect.
The experiments were carried out on 14–16-days-old wheat seedlings (*Triticum aestivum* L.). System for plant treatment by artificial MFs was based on Helmholtz coils. The MF frequency was 14.3 Hz, the magnitude was 9 µT. Changes in the electric membrane potential were recorded in response to the on-off light in the presence and in the absence of MF. The membrane potential was measured in mesophyll cells using microelectrode techniques. Surface potentials were measured by means of a set of Ag^+/AgCl macroelectrodes. The identification of ionic mechanisms was carried out using inhibitory analysis. Dynamics of Ca2+ was registered using Fluo-4 AM fluorescent probe in a fluorescenceimagingsystem. Light-induced electric reaction in wheat leaf comprises depolarization and two waves of hyperpolarization resulting in an increase of the potential to a higher level compared to the dark one. Fluorescent and inhibitory analysis demonstrate a key role of calcium ions and calcium-dependent H^+-ATPase of the plasma membrane in the development of the reaction. Activation of H^+-ATPase by the increased calcium influx is suggested as a mechanism of the influence of magnetic field on light-induced electric reaction.The results of the present work demonstrate the influence of the extremely low-frequency MF on light-induced electric reactions in wheat plants. This effect can be realized through the action of the extremely low-frequency MF on the signaling systems that regulate the intracellular concentration of Ca^{2+} and the activity of H^+-ATPase. In this regard, the revealed effect of the extremely low-frequency MF on electric reactions should be taken into account when analyzing the mechanisms of the impact of MF on plant

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An Updated Balloon-borne Vector Electric Field Meter With Full Inertial Reference Measurement

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The balloon-borne electric field meter has been used for four decades, and has provided the vast majority of in-situ measurements of the vertical profile of the DC electric field in thunderclouds. Based on the design of Winn and Byerly (1975), it has been upgraded several times, most recently in 2003 to enable measurement of the 3D vector electric field. The upgrade added a two-axis horizontal accelerometer and three-axis magnetic field sensor that enabled complete quadrature demodulation of the coupled horizontal and vertical rotating motion of the instrument's spherical sensing electrodes. This paper reports on an updated circuit design and signal processing that utilizes a third accelerometer component to provide a full internal frame measurement. The updated sensor can thereby correct for the final uncertainty in the vector orientation of in prior measurements which includes the penduluming motion of the balloon train. Increased sensitivity (to a few tens of V/m) from an updated ADC and new data transmission accompanying a built-in GPS will also be described. Preliminary flight data will be shown from clear-air and, if available, storm flight

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Identification in Time and Spectral Domain of Reflective Processes Observed During IC Discharges Recorded in 2019 by the Lightning Detection Station in Rzeszow

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This work is aimed at investigating several natural lightning discharges recognised as intra-cloud (IC) strokes which have been detected in a wide frequency range of archived E-field recordings. All such lightning discharge incidents were recorded in a short time interval being only slightly longer than for a typical cloud-to-ground (CG) lightning. The shapes of the E-field of the considered IC events were similar to the so-called compact intra-cloud discharge (CID) events with well pronounced reflections from the ends of the lightning channel. Due to a relatively low level of the used recording frequency bandwidth, being in the ELF range, and in a close distance from the lightning channel, approx. 5 km of horizontal distance, their electrostatic and induction components were also well reproduced. The obtained records of such near occurring CID events can be noted as an unique circumstance, because most of these events presented in the literature are reported and depicted for a very long distance, greater than 100 km, for which only radiated component of lightning electric field is expected. Another characteristic feature of the recorded E-field signatures of closed CID's were a well pronounced multiple reflections after the initial peak of IC impulse. The interval between consecutive reflections suggest that it should be a consequence of natural process involving electrical current flowing inside the lightning channel.

All E-field data used in such post-time analysis were refined from the database of the Lightning Research Station of Rzeszow University of Technology operating in the south-east sub-Carpathian region of Poland. The main parts of its E-field measuring system are: the plate E-field antenna operated in the frequency range from 0.5 Hz up to 3 MHz and the orthogonal magnetic field antenna recorded lightning flash with the similar ELF-MF frequency bandwidth. Both lightning electromagnetic field sensors are supported by the image from the high speed camera dedicated for observation of lightning channel development. All devices are synchronized with UTC time by the GPS receiver with precision better than the applied 25 MS sampling time.

The identification of unusual IC events was made by the simplified and fully automated procedure implemented in Matlab. Following initial detection the post-processing analysis included an identification of characteristic features of the IC waveforms made in the time and frequency domain. The special coefficient used in the literature for distinguishing between CID/RS events was determined by the FFT calculations referred to the considered IC signatures. Several peak frequencies, corresponding to the characteristic oscillations noted at the tail of IC stroke stage, were identified by the application of the Power Spectrum Density (PSD) analysis. Finally, a dedicated and much more time efficient detection procedure was developed for purposes of possible implementation in the real-time lightning location systems in future.

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Review of Results of Global Circuit Modelling by the EGATEC Model Compared With Observational Data

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At the beginning of a new project reviving global circuit modelling using the Engineering Global ATmospheric Electric Circuit (EGATEC) we make a review on how the model recreates observed parameters of atmospheric electricity at different places of the globe which are influenced by different solar-terrestrial effects and conditions. We will also briefly present the original model limitations and capabilities, and the current performance. Further we will discuss success and general issues in GEC modelling resulting in discrepancies between model results and observational data. The work is supported by National Science Centre, Poland, grant No 2021/41/B/ST10/04448.

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Simulation of Lightning Using Vertical Wires Deployed by Drones: the Effect of Seawater and Land on the Charging Currents

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Through different remote sensing electromagnetic techniques (*e.g. Turman, 1977; Füllekrug et al., 2002; Light et al., 2003; Said et al., 2013; Rudlosky et al. 2019; Holzworth et al. 2019*) it has been shown the significant asymmetry in the intensity of lightning occurring over land and ocean. Lightning strike over the oceans presents higher intensity in terms of the analyzed radio and optical measurements than lightning strikes over the land. There is no agreement in the reason for this asymmetry which is attributed to thunderstorms, lightning attachment, and conductivity. The last has been the subject of recent works (e.g. *Asfur et al., 2020 and Silverman et al. 2021*).

In this work, we investigate the currents that occur when a ground-isolated vertical long wire is short-circuited to seawater and land. We use a similar technique as the one presented by *Montanyà et al.* (2018) where a multirotor drone is used to deploy and hold a vertical wire above the ground. The wire immersed in the fair-weather atmospheric potential is polarized and acquires a potential similar to the lightning concept introduced by *Kasemir* (1960). The potential of the wire is measured indirectly employing a field mill in a sphere-semi sphere gap (e.g. *Holzworth et al. 1981, Montanyà et al.*, 2018) where the wire is connected to the upper isolated sphere whereas the lower semi-sphere is grounded. This arrangement allows to eventually short-circuit the upper isolated sphere at the lower end of the wire to ground (or sea) and measure the current during the charging process of the wire. One of the advantages of this method is that the water or soil is not part of a return path of a power supply or impulse generator system.

We deployed 100 m of wire. The measured potentials of the isolated wire corresponded to the expected potentials (5 kV) due to the polarization under fair-weather electric fields. The results show that the charging process when the wire was short-circuited to seawater (at 14 ºC) involved peak currents of more than an order of magnitude higher than for the cases when the wire was short-circuited to an agricultural loamy ground. The currents measured on the sea cases were at the order of 40 A whereas the cases on the loamy ground were below 1 A. Contrary, the measured peak currents were very similar between the cases short-circuiting to sea and the seashore. In all the cases, the currents present damped oscillating signals with rise-times of few nanoseconds. In the case of sea, lower frequency current harmonics (1/100) were observed.

The method described reproduce some of the main features of the lightning model introduced by *Kasemir* (1960). The influence of the medium (seawater or loamy soil) on the peak currents and energy for the same potential of the wire (channel) is in the line that the asymmetry on the lightning intensity might be due to the higher conductivity of ocean that land. In future work we will investigate the influence of the conductivity of the wire.

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Acoustical Characterization of Lightning Flash: Three-dimensional Distribution of Thunder Radiation

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From September 13th to October 12th 2018, the EXAEDRE field campaign took place in Corsica, dedicated to the characterization of thunderstorm clouds and electrical activity. Among a wide range of observation instruments, an array of 4 microphones, arranged on a 30-m wide triangle located near the island eastern coast, recorded with a sampling frequency of 250 Hz the acoustical signal, or thunder, associated to lightning flashes. The search for coherent signals between the four sensors within prescribed frequency bands allows to determine the thunder apparent velocity and azimuth (PMCC algorithm [1]). Knowing the flash emission time provided by Meteorage, the French Lightning Location System, as well as the local speed of sound, it is possible to reconstruct in three dimensions the various positions of coherent sound sources within a single lightning flash. Co-localization of acoustic sources with in-cloud detections provided by the Lightning Mapping Array SAETTA located in Corsica, and with ground impacts provided by Meteorage, shows the efficiency and the precision of the method. This one was already used successfully in a previous field campaign (HyMeX-SOP1) in Cévennes in 2012 [2,3,4]. The detection algorithm PMCC also provides the various RMS pressure levels of each detection. Assuming each sound point source radiates a spherical wave, the different propagation distances between the sources and the recording array can be compensated, so that the thunder source powers can also be localized within the flash with their absolute levels. Atmospheric absorption is taken into account using measured humidity. The spatial energy characterization method has been validated on EXAEDRE using 8 isolated sensors in a 10km range, whose envelopes are compared with theoretical envelopes obtained from the propagation of each reconstructed sound source. It allows us to employ this method on the previously published SOP1 data for comparison. For EXAEDRE, two storms have been studied, one with a low electrical activity on October 2nd mainly over the Mediterranean Sea, and one with an intense activity on 17th September mainly overland. The total source sound power of the flashes could be calculated, and it turns out to be extremely variable, extending over at least 4 orders of magnitude. Strong positive Cloud to Ground flash events seems easier to find in SOP1 than in EXAEDRE. In both campaigns, very heterogeneous situations are frequently observed, with most of the power located in only one portion of the return stroke. In general, but there are exceptions, the return stroke is more energetic than the intracloud part. A few homogeneous cases are observed, especially in SOP1. [The authors acknowledge the EXAEDRE program, led by E. Defer, for supplying the data. Present results have been obtained within the frame of the LETMA Contractual Research Laboratory between CEA, CNRS, Ecole Centrale Lyon, C-Innov, and Sorbonne Université.]

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On Applicability of Measurement Results of High-energy Radiation From Long Spark Discharge to Natural Lightning Discharge

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One of the open questions in the description of lightning physics is the origin of the X-ray radiation recorded during lightning discharges. The conditions of the laboratory experiment provide researchers with more opportunities regarding the conditions for studying natural lightning, since the cameras and detectors can be guaranteed to be located near the discharge, and the parameters of the discharge itself are also amenable to control. This circumstance makes the laboratory experiment on the detection of energetic photons created by the the long spark useful both from the point of view of the development of the theory of discharge in general, and for the study of natural lightning in particular.

However, in [Ostgard et al, 2015], which considers the effect of electrons accelerated in a discharge on the results of experiments with sparks on the order of a meter, it is concluded that a significant part of the recorded events are associated not with X-ray radiation, but with the effect of accelerated electrons on scintillators. This is a fundamental difference from the situation with X-rays recorded in experiments with lightning (much greater distances from the source). It seems to us, and the calculation in GEANT4 confirms this that the effect of fast electrons must be taken into account for relatively short (about 1 m) discharges, when the sensors are located at a short distance from the discharge or on its axis.

Experimental studies of a long spark discharge carried out in the fall of 2020 on the GIN-6MV device in Istra demonstrated the absence of significant values of X-ray radiation at the leader stage of the spark discharge. Simultaneous photography of discharges with high temporal resolution demonstrated the presence of a wide streamer zone, which is not typical for lightning discharges. These facts cast doubt on the reality of the X-ray recordings from a spark discharge, since the scintillators used for registration are also sensitive to energetic electrons, the presence of which in large quantities during a spark discharge between metal electrodes is shown experimentally and corresponds to the results of numerical simulation using the program GEANT.

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Lightning Polarity Asymmetry

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The polarity asymmetry in lightning macroscopic behavior is well established for both cloud-to-ground and intracloud flashes. Negative polarity discharges to the ground most often consist of a series of strikes passing through one channel, while positive flashes, as a rule, are limited to one stroke; negative and positive leaders of lightning discharges have significant morphological differences; the growth of positive leaders is accompanied by the development of negative recoil leaders, and positive recoil leaders have never been observed (or do not exist). At present a consistent description of the mechanisms of macro-scale manifestations of the lightning discharge asymmetry causes considerable difficulties. We use the hierarchical Horton -- Strahler scheme to estimate the lightning discharge structural asymmetry and postulate that displacement of the bi-directional leader reversal point (zero charge level of the lightning channel corona sheath) from the place of initiation towards the positive leader development is a fundamental manifestation of the lightning polarity asymmetry [1]. This approach not only has the potential to relate the reversal point displacement rate with the difference in peripheral currents, but also helps uncover the mechanism that provide both the competitive suppression of the positive leader side branches and the negative leader renewal. Our results further indicate that the reversal point displacement determines the lightning principal direction of propagation.

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Identifying Global and Local Effects in Fair-weather Electric Field Variations in Urban and Rural Areas

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One of the most interesting indicators of the global electric circuit generated by activity of a global ensemble of electrified clouds is diurnal variation of ionospheric potential. Direct measurements of ionospheric potential are difficult, so we are forced to use ground-based measurements of electric field and assume that under fair-weather conditions this field is linearly related to ionospheric potential.

For our studies, we proposed new criteria for fair-weather conditions formalizing the studies of long-term electric field series. The criteria are formulated using simple phenomenological considerations and are based solely on the electric field values: constraints on the minimum, maximum and the peak-to-peak amplitude relative to the diurnal mean are introduced.

There are many electric field measurement cites around the world, with significant diversity in their geographical and physical conditions of observation. Nowadays the differences between electric field variations in urban and rural areas is of considerable interest. It is often assumed that the main difference can be attributed to different concentration of aerosols in the atmosphere.

We investigated the diurnal variations of the fair-weather electric field in urban conditions and separate it into a global component, provided by variations in ionospheric potential, and a local component, provided by variations in conductivity in urban conditions. In particular, we compared urban conductivity variation with urban diurnal cycles such as week commuting cycles.

We studied several long-term series of electric field measured under different conditions. We used our own electric field measurements in Nizhny Novgorod region, Russia and several series of GLOCAEM observations as data sources. We detected the emergence of additional maxima of daily field variation in urban conditions. We demonstrated that additional maxima changing the structure of the variation, complicate the interpretation of measurement results, but at the same time make it possible to make diagnose of local environment.

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Patterns Related to the Madden–Julian Oscillation in the Global Electric Circuit Variation

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The Madden–Julian Oscillation (MJO) is the most dominant component of the climate variability in tropics on the timescale of tens of days. Occurring irregularly, the MJO consists of large-scale coupled structures in atmospheric circulation and deep convection which propagate eastwards affecting all longitudes. Here we investigate the effect of the MJO on the direct current global electric circuit (GEC), using both numerical simulations and the results of electric field measurements.

The ionospheric potential (IP), being the sum of contributions from electrified clouds all over the globe, is arguably the most fundamental characteristic of the GEC intensity. We have reproduced the atmospheric dynamics for 1980–2020 with the help of the Weather Research and Forecasting model and meteorological reanalysis data. Based on the results of such modelling, we have simulated 41 years of the GEC variation by parameterising contributions to the IP in terms of precipitation and convection. Besides, we have analysed the results of potential gradient (PG) measurements at the Earth's surface at the Russian Vostok station in Antarctica during 2006–2020. Collected in a clean location at the altitude of 3488 m above sea level, these values make up a unique long-term data set describing the GEC variation.
To characterise the MJO, we have employed the widely used Real-time Multivariate MJO index (RMM). Being based on a pair of empirical orthogonal functions (EOFs) of the combined data on near-equatorial zonal winds and outgoing long-wave radiation, the RMM has two components, RMM1 and RMM2. Depending on the values of RMM1 and RMM2, eight phases of the MJO are distinguished, each of which is associated with some region of enhanced convective activity.

To identify patterns related to the MJO in the GEC variation, we have averaged the simulated IP and the fair-weather PG measured at Vostok over each phase of the MJO. Thereby we have established that the variation of the GEC intensity with the MJO phase (when averaged over many MJO cycles) has a universal characteristic shape. Both the simulated IP and the PG at Vostok show a clear periodic variation with the MJO phase, reaching a maximum in the second or third phase (there is a small phase shift between the IP and the PG, probably owing to the shortcomings of the parameterisation of the GEC sources and the uncertainties related to measurements).

In order to explain the observed effect, we performed a more detailed analysis. Computing the EOFs for contributions to the IP from thunderstorms at different longitudes and looking at the principal components (coefficients of these EOFs in the decomposition of variation), we have found that nearly all of the IP variation on the MJO scale corresponds to a superposition of two major oscillations of the deep convection intensity over the Maritime Continent and over the Indian Ocean (these oscillations can also be naturally associated with RMM1 and RMM2 respectively). Putting the two basic oscillations together explains the observed variation of the GEC with the MJO phase.

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Forecasting Thunderstorm Over Bulgaria Using Machine Learning Techniques

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The accurate forecast of thunderstorm is one of the main challenges for the numerical weather prediction (NWP) models. Despite the last years development of numerical modeling and transition to cloud resolving models used for numerical forecast, thunderstorm prediction remains a topic to be improved. Machine Learning techniques can help to accurately predict lightning activity based on a set of input features, which can include the previous values of detected lightning, measured temperature, relative humidity, rain and wind speed measurements, among others, as well some forecasted by the NWP model parameters, as graupel and cloud water mixing ratios. For the study lightning data from ATDnet over Bulgaria will be used. Measured meteorological data will be taken from the synoptic stations in Bulgaria, while forecasted data – from the operational NWP model AROME.

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Effect of Extremely Low-frequency Magnetic Fields on Biophysical and Biochemical Processes in Pea and Wheat Plants

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The influence of extremely low-frequency electromagnetic fields with frequencies close to geomagnetic field variations on living objects is a debatable topic in modern biology. The presented article presents the results of a study of the susceptibility of photosynthesis and redox metabolism processes of wheat and pea plants to the effects of ELF EMF at frequencies of 7.8 Hz, 14.3 Hz, 20.8 Hz and intensity 18 µT. The EMF expositions were 30 minutes or 18 days ("short-time" and "long-time", respectively). Variables of the magnetic field were created using coaxially located Helmholtz coils, the area of uniform magnetic field with a diameter of 20 cm was located in the center between the coils. Plants of the control group were outside the influence of the magnetic field in the same room and under the same illumination as the experimental plants.

The studies were carried out on wheat (*Triticum aestivum* L.) and pea (*Pisum sativum* L.) plants. After the ELF exposure ended the main parameters of light reactions of photosynthesis were recorded by PAM-fluorimetry (maximum quantum yield of photosystem II, effective quantum yield of photosystem II, non-photochemical quenching NPQ, photochemical quenching PQ), lipid composition of membranes, MDA content, activity of antioxidant enzymes superoxide dismutase (SOD) and catalase, isozyme composition of SOD.

It was found that the amplitude of changes in biophysical and biochemical parameters was greatest in wheat plants. Thus, wheat plants were more susceptible to the effects of the studied ELF EMF than pea plants. «Short-time» exposure to ELF EMF causes the most pronounced response in wheat plants compared to «long-time» exposure. Pea plants only responded to «long-time» exposure to ELF EMF.The greatest response of biophysical and biochemical parameters of plants was found after exposure to ELF EMF with frequencies of 14.3 Hz and 20.8 Hz, both with «short-time» and «long-time» treatment with ELF EMF.

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Variations of Electric Field Potential Gradient During the Passage of the Mesoscale Convective Complexes on Western Siberia

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It is widely known that the presence of low clouds leads to the reduction in absolute value of potential gradient and to the change of sign of potential gradient relative to fair weather conditions. The most significant distortions of the electric field are observed during the passage of cumulonimbus clouds (Cbs). Mesoscale convective systems, and especially their subtype termed “mesoscale convective complexes” (MCCs) are a largest and longest clusters of Cbs. The MCCs in a general sense are a jumbo complexes of Cbs united by a quasi-oval common top (anvil). Additional conditions are usually imposed on the size of the anvil and the duration of the existence of the complex. MCCs significantly change the environment in which they develop including a strong disturbance of the electrical state of the atmospheric surface layer. MCCs are registered in different regions of world, including in Western Siberia. However, in temperate latitudes, their sizes may be significantly smaller than those for tropical regions.
The study aims to assess the slow variations parameters of atmospheric electric field caused by passing of the MCCs in Western Siberia.
Data from the monitoring of atmospheric-electric quantities collected at the geophysical observatory of the IMCES SB RAS (Russia, Tomsk) during the warm half-year (April–September) from 2009 to 2020 were used to evaluate the variability of slow variations during the MCCs passage.
Potential gradient (PG) of surface electric field was measured with electric field mills Pole-2 (2009–2017) and CS110 (2017–2020). MCCs passage was determined by data of Aqua, Terra and Suomi NPP polar orbiting satellites and Himawari-8 geostationary satellite.
The cases were selected in the first stage when the variability of PG values surpassed 1 kV/m and the duration of these variations lasted an hour or longer. At the same time, satellite data was integrated to identify the MCCs presence and its passage over or near the PG measuring point. Throughout the study period, 31 cases of MCC passing over Tomsk were identified based on satellite images and PG data.
It was noted that the electric field in the surface layer of the atmosphere is strongly disturbed during the passage of MCCs. In most cases, the one prolonged negative disturbance of electric field (duration more than 30 minutes) was marked, followed by one or several short-lived positive perturbations alternating with negative ones.
The total duration (Dv) and the range (Av) of PG slow variations for each case determined. Values of Dv during the passage of MCCs are from 1 to 6 hours, having an average duration of about 2 hours. The average value of Av is 12.5 kV/m.
When comparing these results to those earlier obtained for isolated intra-mass Cbs, it was found that the Dv and Av of MCCs aremorethantwotimesand five greater respectively than these of isolated intra-mass Cbs.

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Microphysical Properties of TGE-producing Clouds Inferred From Satellite Data

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Electrified clouds can generate energetic radiation – fluxes of electrons and gamma-rays. Thunderstorm ground enhancement (TGE) is energetic radiation of a cloud observed on the ground and accompanied by a variation of the electric field. A great set of measurement data on TGE is obtained on the Aragats Research Station (Armenia, 40.47N, 44.18E, 3200 m above sea level), providing statistics of TGE and meteorological conditions of its occurrence. The analysis of the energetic radiation of clouds is of interest from a fundamental point of view as considering the processes of interaction of energetic particles and is also closely related to the problems of numerical modeling of convective phenomena, including clouds which produce the potentially dangerous enhancement of the flux of energetic particles.
Analyzed data on electric field and count rate measured in Aragats characterizing TGE events and data of satellite EUMETSAT – 8 show correlations which provide information on TGE-producing clouds and can be useful for recognition of convective patterns associated with TGE.
The source of the analyzed satellite data is SEVIRI (Spinning Enhanced Visible Infra-Red Imager) - an optical scanner operating in 12 spectral channels. The SEVIRI radiometer, installed on MSG satellites, has 12 channels that provide images of the Earth's surface every 15 minutes. The high-resolution channel in the visible range has a resolution of 1 km (for low latitudes), the other channels - 3 km. The frequency of updating satellite data is 15 minutes, which makes it possible to characterize in detail the dynamics of the development of convective phenomena.
Based on the detected correlation between satellite data and data on particle fluxes for TGE events, an index based on a linear combination of measuring channels is proposed. The index is useful for the automatic determination of TGE, which may simplify obtaining data on the phenomenon and conditions of its occurence, and can further be helpful for TGE forecast.

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High-speed Camera Observations of Intracloud Flashes in Brazil

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Intracloud lightning is the most frequent type of flash but it is also the most difficult to be observed. Although they do not present risks to living beings or cause damage to structures, they affect the atmospheric chemistry and the global electric circuit. Moreover, the study of their behavior and development can contribute to the understanding of physics and events common to other types of lightning.
The present study characterizes intracloud (IC) lightning flashes that occurred in Brazil from 2003 to 2018, through high-speed camera videos and data from a flat plate electric field antenna. We selected 113 IC lightning that had visible leaders in the videos.
From the analysis of these videos, it was possible to classify these IC flashes as normal, when the development of the negative leader is toward the charge center at the top of the cloud; and inverted, when the development of the negative leader is toward the charge's center at the cloud base. This classification was realized by observing the characteristics of leader propagation near the cloud base and the presence of recoil leaders in the channel. Out of 113 flashes, 89 were classified as normal IC and 20 as inverted IC. The other 4 were flashes that had already started when the video recording beguns. In these cases, it was not possible to see the initial leader propagation that defines the classification of the IC flash.
The average duration of all IC flashes is 515 ms, with a maximum observed value of 1504 ms and a minimum value of 28 ms. Normal IC has average duration of 561 ms and inverted IC has 359 ms. The geometric mean duration of normal IC (496ms) is twice the duration of inverted IC (263ms). We also found that, on average, videos lost about 30% of the IC duration given by electric field measurements (comparing 32 complete videos with complete electric field data).
Within this sample, there were 47 IC that lasted longer than 515 ms, and of these 96% are of the normal type. Recoil leaders are a common feature among these long durations IC, showing that in addition to promoting processes such as M-Components, subsequent return strokes and attempt leaders in cloud-to-ground flashes, they maintain the IC channel active.

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The Dependence of Lightning Generated Underwater Acoustic Noise on Lightning Intensity

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In 1984, Arnold recorded and reported for the first time the acoustic signature of a lightning strike at the sea surface in the Gulf of Mexico, approximately 50 km away from the receiving hydrophone. Following that report, Hill estimated in 1985 that approximately 1% of the energy of the lightning strike at the sea surface had been converted to acoustic energy. Since then, to the best of our knowledge, there have been no studies considering the effect of lightning strikes at the sea surface on submarine acoustic noise. Nonetheless, previous studies and reports have suggested that the acoustic noise generated by lightning is equivalent to that produced by air-guns, which are used regularly in seismic surveys of the sea bottom for mineral, gas and oil prospecting.In the current study we are revisiting this issue, by employing lightning strike location and intensity measurements from existing networks (e.g. WWLLN, ENTLN) and Boltek antennas located along the Israeli Mediterranean shoreline together with hydrophone measurements deployed in the shallow coastal waters of the Eastern Mediterranean Sea. The measurements from the different location networks and antennas will be combined to locate the lightning with a high degree of accuracy. The time stamp of the distinct acoustic signature of lightning strikes recorded by the hydrophones will be used to determine the lightning strike location and intensity. Considering that the Eastern Mediterranean is a hotspot for superbolt activity, we hope to record their acoustic signature as well. Together with the acoustic intensity of the events, we will develop a model to predict the acoustic signature of lightning strikes as a function of its intensity, polarity, speed of sound in water (salinity and temperature) and distance from the strike. This model can be used to produce maps of lightning generated noise during storms in the ocean, which can also be used to determine the effect of this noise source on the behavior of marine biota, such as sea turtles and cetaceans

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Analysis of the Atmospheric Electrical Activity Over Wind Farm in Argentina, in a Context of Climate Change

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The density of discharges and thunderstorm days (TD) are very important measures for studying atmospheric electrical activity. In 2005, with the installation of the World-Wide Lightning Location Network (WWLLN) in Argentina, Nicora et al. 2014 made the first isoceraunic maps (equal number of TD) They used data from the National Meteorological Service and WWLLN, for the period 2005-2011. In addition to this work, Bertone 2020 elaborated isoceraunic maps, where they defined a TD as that day in which the WWLLN network detected at least one event in a given area (observation radius of approximately 20 km). In this last work, they noted an increase in the number of TDs in the country. Having data on thunderstorm days and discharge density over such a long period of time may provide us with evidence of changes in electrical activity in a context of climate change. (Bertone 2020)

In December 2015, the Paris Agreement was signed, which seeks to limit the global temperature increase to 2ºC or less by the year 2100 (4). One of its objectives is to reduce greenhouse gas emissions, which come mainly from non-renewable energy generation. (5). Because of this, Argentina passed laws to promote the participation of renewable energies in the national matrix. (5). The installation of these wind farms has two key aspects with respect to climate change. On the one hand, they reduce CO2 emissions "with an installed capacity of more than 800 GW worldwide, they help to avoid more than 1.1 billion tons of CO2 emissions per year, which is equivalent to the annual carbon emissions of all of Latin America" (6). But, on the other side, as wind turbines are tall structures in low areas, wind turbines are not only exposed to the point charge effect, where the charge tends to accumulate at the tips of tall towers, but also to the effect generated by the movement of their blades. The rapid movement of turbine blades plays a key role in the initiation of unloading (Montanyà et al 2014).

For this reason, the aim of this work is to study the changes that could be generated or may occur in the atmospheric electrical activity in Argentina, due to the installation of wind farms. In the center of the country, 11 strokes/km2/year were observed, while in the south 3 to 6 strokes /km2/year were observed. Regarding the peak current of Cloud to Ground (CG) discharges, peak currents of 200 kA or more associated mainly with positive CG discharges (+CG) have been observed. In contrast to these, negative CG discharges (-CG) had higher multiplicities (greater than 5 on average), which is in agreement with the work of Zhu,Y et al 2021. Finally, significant increases of 2.3 TD/decade were observed between 1970 and 2018 (Bertone 2020). Therefore, the results show current values within the limits of the IEC 61400-24 (2019) standard, which demonstrates the importance of knowing the meteorological systems in Argentina to be able to perform protection systems in wind turbines according to local characteristics

4114

Long-range Lightning Interferometry Using Complex Coherency

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The ability of long-range lightning location networks to geolocate lightning can be limited by the interference of ground waves and sky waves at long propagation distances. This interference arises because the ground wave amplitudes decay faster with distance than the sky wave amplitudes as a result of the ground conductivity and the effects of the Earth's curvature (e.g., Cooray, 2009; Hou et al., 2018).

The coherency is a quantity that is based on the phase of an analytic, or complex, signal. This coherency exhibits less attenuation effects for ground and sky waves when compared to the amplitudes which are normally used for long range lightning interferometry (Zhu et al., 2021). For example, an initial study of amplitude and coherency waveform banks of electromagnetic waves has shown that the coherency is able to exhibit as many characteristics of lightning as the amplitude and it is therefore interesting to investigate using the coherency for long range lighting interferometry.

The coherency waveform bank was calculated based on a large quantity of data, such that more in-depth analysis of coherency with less lightning data is needed. This work quantitatively analyzes the mean and maximum coherency from -1 ms to +5 ms of N lighting events. It is found that the maximum coherency occurs during the peak of lighting waveform around 0 ms, while the coherency before and after the lightning drops with $1/\sqrt{N}$ as expected by theory.

Subsequently, interferometric lightning geolocation is simulated by using the coherency at the peak electric field of lightning discharges. This method effectively maps the lightning location into an area rather than a single location. In this map, each pixel corresponds to a lightning location with different coherency and time of arrival difference. These time of arrival differences are simulated by shifting the lightning waveforms. As time progresses, the coherency map changes and shows the arrival of the ground wave and sky waves.
Finally, simulations with different numbers of receivers at varying locations loosely related to lightning detection network receiver locations are used. This study offers insights of how to decide on the number and locations of radio receivers to achieve a reasonable detection rate and location accuracy. A comparison of the dynamic coherency map with the amplitude map shows that the coherency is a promising parameter to preserve the ground wave component which can potentially help to distinguish the ground wave from sky waves at long propagation distances.

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4112

Predicting the Occurrence of Extreme El Nino Events Based on Schumann Resonance Measurements?

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Multi-station observations of Schumann resonance (SR) intensity document common behavior in the evolution of continental-scale lightning activity in two super El Niño events, occurring in 1997/98 and 2015/16. The vertical electric field component of SR at Nagycenk, Hungary and the two horizontal magnetic field components in Rhode Island, USA in 1997, and in 2014-2015, the two horizontal magnetic field components at Hornsund, Svalbard and Eskdalemuir, United Kingdom as well as in Boulder Creek, California and Alberta, Canada exhibit considerable increases in SR intensity from some tens of percent up to a few hundred percent in the transition months preceding the two super El Niño events. The UT time distribution of anomalies in SR intensity indicates that in 1997 the lightning activity increased mainly in Southeast Asia, the Maritime Continent and India, i.e. the Asian chimney region. On the other hand, a global response in lightning is indicated by the anomalies in SR intensity in 2014 and 2015. SR-based results are strengthened by comparison with independent lightning observations from the Optical Transient Detector and the World Wide Lightning Location Network, which also exhibit increased lightning activity in the transition months. The increased lightning is attributable to increased instability due to thermodynamic disequilibrium between the surface and the mid-troposphere during the transition. Our main conclusion is that variations in SR intensity may act as a precursor for the occurrence and magnitude of these extreme climate events, and in keeping with earlier findings, as a precursor to maxima in global surface air temperature. As a continuation of our research we plan to set up a webpage dedicated to monitoring global lightning activity based on SR measurements which may contribute to the early identification of increased instability preceding the next super El Niño event.

4111

Towards Machine Learning-based Classification of ELF-transients

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Lightning acts as a natural electromagnetic (EM) antenna radiating electromagnetic waves in a wide frequency range. In the extremely low frequency (ELF) band (3 Hz - 3 kHz), lightning-induced EM waves have a very weak attenuation while they propagate in the waveguide formed by the Earth’s surface and the lowest part of the ionosphere. These EM waves can travel a number of times around the globe before losing most of their energy and in case of the most powerful lightning discharges the round-the-world signal is clearly identifiable in the ELF recordings. These signatures are called Q-bursts. On the other hand, Q-bursts are not the only transient signals in ELF recordings as nearby lightning as well as local noises are able to produce strong transient signals as well. Although it is possible to distinguish these different events manually, it is highly time consuming. To process a large amount of data, which would contribute to a better understanding of their source and propagation, an automated algorithm is needed. Our group proposes a machine learning-based approach to solve this classification problem. In this work, we show examples of ELF-transients detected in the broadband ELF measurements at Hylaty, Poland including certain cases which are difficult to categorize. We also provide some initial results of our machine learning-based classification approach.

4107

On the Features of Corona Discharges From Grounded Rods

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Under thunderstorm conditions, charged particles present in storm clouds cause the background electric field to increase at ground level. At the ends of grounded structures, the enhancement of the local electric field from tips and sharp structures can, in turn, lead to the onset of corona/point discharges.
In the literature, the manifestation of such discharges has been known for a long time. However, there is a lack of experimental data available for measurements performed in nature under real thunderstorms since very few authors have published data with the pulsating regime of the discharges. In this work, we investigate in three different sites the features of these discharges under high background electric fields and when lightning strikes are registered in a few kilometers range.
We used a low current sensor optimized for measuring low-level currents through the grounded rod. It consists of a current transformer, able to measure high-frequency current pulses. We corroborate in the laboratory the behavior of corona discharges when the rod was subject to a high electric field in a plate-to-point setup.
Corona current pulses have fast rise time (tens of nanoseconds) and slow decay (hundreds of nanoseconds). For the initial stage of the discharges, above a certain threshold, the frequency of pulses increases with the voltage applied. In the field, similar pulses were detected using the sensor. The observation of pulses is not related to only nearby lightning activity, but also to the enhancement of the background electric field.
For one installation, the frequency of pulses is correlated with the ambient electric field and wind speed measured 250 meters away. Pulses of positive corona were no longer observed when the electric field magnitude was lower than 1.8 kV/m, whereas pulses of negative corona were more atypical and presented a higher threshold, of about 3.8 kV/m. The increase in wind speed significantly increased the pulse frequency for the same electric field level.
Complementary, the same sensor was installed in two other sites: a rooftop and a flat-ground installation. The recordings show that the pulses can occur for several seconds after or before lightning strikes in the vicinity. When lightning activity is far from the structure; but the electric field remains high, pulses are still detected.This study is relevant for understanding the production of corona and space charges in high structures, such as wind turbine blades, towers, and buildings in general.

4106

Atmospheric Electric Field During the Solar Eclipse on 14 December 2020

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In the atmosphere there is a vertical electric field also known as potential gradient (PG). This variable measured at ground level is affected either by global storms as well as by the influence of local meteorological factors. Within the latter group it is important to remark the condition of the atmospheric boundary layer. In turbulent conditions a greater mixing is promoted, a greater thickness of the layer, a greater density of aerosols reducing the conductivity of the air and thus increasing the PG.The change in radiation due to an eclipse may be able to alter the boundary layer behavior.

In this study the response of atmospheric electrical and meteorological variables at three different sites of Argentina are studied during the total solar eclipse of December 14, 2020: Valcheta (100% darkening), Buenos Aires (73%) and El Leoncito (71%). The reduction in solar irradiance caused by the solar eclipse was expected to directly affect the near-surface electric field, known as the potential gradient (PG), through a reduction in turbulence and an increase in air conductivity. From the analysis of the observed meteorological parameters (temperature, relative humidity, and wind), no effects on the PG were observed that can be unequivocally attributed to this event solely on boundary layer dynamics. The prevailing synoptic situation altered the response that the boundary layer could have given to a clear drop in radiation, particularly at Valcheta which was very close to a frontal zone, and had occasional cloud coverage and reports of atmospheric suspended dust. PG measurements at Valcheta during the eclipse showed PG values several orders of magnitude higher and of opposite sign to the global daily mean fair weather (FW) PG curve and the local FW-PG curves calculated at CITEDEF (940 km away) and CASLEO (1200 km away). The PG values at Valcheta were shown to be more closely related to disturbed weather conditions than FW. On the contrary, at the other two locations studied, CITEDEF and CASLEO, further north away from the frontal zone, the observed PG values on the day of the eclipse showed a higher consistency with the local daily mean FW-PG curves. A comparison between the FW-PG local curves at these two sites and the evolution of PG during the day of the eclipse, however, reveals a drop in PG values during the eclipse.

It is important to note that in Valcheta and CITEDEF, after the moment of maximum occultation, although the wind intensity at both sites was of the order of 10 ms-1, it is observed that the PG measurements were very different. This could be related to differences in the patterns of suspended atmospheric dust at both stations.

4101

Type "V" Recoil Leaders Observed in Upward and Intracloud Lightning

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The aim of this work is to explain a common pattern of propagation trend of recoil leaders at bifurcations of upward and intracloud lightning. This pattern occurs when a recoil leader encounters a bifurcation and instead of continuing to propagate through the main channel, it proceeds through another of this bifurcation (a phenomenon known as type “V” recoil leader). According to Warner et al. (2011), a possible explanation for these events would be that the bifurcations would be more conductive than the main channel. Considering this characteristic, the current research developed a hypothesis, showing that previous recoil leaders would reionize the ramifications before the observed pattern occurs, leaving the branches of the bifurcations more conductive.
Using a high-speed camera (Phantom v711) with a minimum acquisition rate of 10,000 fps, six negative upward lightning (#UP 67, 68, 76, 154, 166 and 167) and two intra-cloud lightning (#R 82 and 85) were filmed at a tower located at the peak of Jaraguá (Brazil). To prove the hypothesis, 150 type “V” recoil leaders were analyzed. With the results obtained, it was shown that the hypothesis created based on the ideas of Warner et al. (2011) was wrong, it was noticed some inconsistencies that invalidated it. From the luminosity profile of some cases of type “V” recoil leaders it was noticed that less intense (less luminous) recoil leaders tend to propagate towards the bifurcation. This occurs, because, the cross-sectional area of the channels of the positive leader at the bifurcations are smaller than in the main channel. In addition, when they decay, the remnants of the decayed channel tend to get closer together, making the electric potential difference necessary for the recoil leader to reionize the path to be smaller at the bifurcation, explaining the observed pattern. This research is of great relevance, as it contributes to the understanding of the propagation mechanisms of recoil leaders through decayed channels of positive leaders.

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4100

First Positive Subsequent Return Stroke Records Observed in Negative Upward Lightning

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Positive cloud-to-ground lightning are rare, accounting for 10% of all discharges that touch the ground(RAKOV; UMAN, 2003). These lightning produce long continuing currentand in some cases have high current peak, causing complications for the affected structures. The present work aims to show the first records of positive leaders remaking decayed channels of negative upward lightning, generating positive subsequent return stroke on the same tower that initiated the upward positive leader. This type of discharge increases the complications generated in the affected structures, by the combination of the initial continuous current (ICC) of the upward lightning with the long continuous current produced by the positive subsequent return stroke.
Using two high-speed cameras (Phantom v310 and v711) configured with acquisition rates of 10,000 and 20,000 fps, we recorded two negative upward lightning (#UP 44 and #UP 76) initiated in a telecommunication tower at the peak of Jaraguá (Brazil). In the videos, simultaneous intracloud lightning activity was observed during the development of negative upward lightning. In the two events after the upward lightning channel decays, a recoil leader appears that propagates towards and connects to the positive leader in the cloud (intracloud lightning). Subsequently, the positive leader in the cloud retraces the path taken by the recoil leader and reionizes the entire decayed channel of the negative upward lightning, generating a positive subsequent return stroke. There are no records of these connections and positive subsequent return stroke in negative upward lightning in the literature, making this study of great relevance.

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Secondary Recoil Leader Connections with Precedent Recoil Leader Observed in Negative Upward Lightning

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Wu et al. (2019) analyzed a negative upward lightning filmed at the tower in Canton, China. An unprecedented feature was shown in this work: the presence of a floating channel originated in front of the positive end of a recoil leader. This floating channel developed and connected to the recoil leader.

The current research investigates the origin of floating channels and shows the impact caused by these connections in the development of some physical processes observed in negative upward lightning. With the aid of two high-speed cameras (Phantom v310 and v711) configured with acquisition rates of 10,000 and 37,819 fps, respectively, two negative upward lightning were recorded (#UP 44 and #UP 154) from a telecommunication tower on top of the Jaraguá peak, in Brazil. In these events, some floating channels were seen connecting to recoil leaders. All floating channels had the same characteristics.

From lightning #UP 44, it was shown that floating channels originate in decayed branches of positive leaders, and can be classified also as recoil leaders (MAZUR et al., 2013). They were termed here secondary recoil leaders due to the fact that they appear near the positive end of a preceding recoil leader and connects to it. In the analysis of upward lightning #UP 154, the influence of secondary recoil leaders on previous recoil leaders was determined. It was observed that the secondary recoil leaders give energy so that the preceding recoil leader continues to propagate through the decayed channel of the positive leader. Thus, they seem to be essential for the development of some physical processes in the upward lightning such as: dart leader; initial continuous current pulses; and M components.

Many recoil leaders decay before reaching the ground, as they do not have enough energy to reionize the lightning channel, generating an attempt leader. This work shows that propagation of recoil leaders to the initiation point of the upward lightning depends on the channel conductivity of the decayed channel and on the intensity of the recoil leader that will travel through it. In order to a less intense recoil leader, traveling through poorly conductive channels, reach the initiation point of the upward lightning; it is necessary that they be re-energized by secondary recoil leaders.

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Electrical Activity of Explosive Volcanic Eruptions at Low Latitudes

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We live in a dynamic planet and as such, there are natural phenomena that manifest this dynamism. A clear example that occurs frequently is volcanic eruptions. The impact that volcanic eruptions have on society is important both in the long and short term, causing damage to society and may even produce meteorological changes at local or regional scales in the case of very intense eruptions.
Explosive volcanic eruptions are frequently accompanied by different electrical activity. The electrical discharges generated in the volcanic plume during the eruption evolve with the eruption, having different characteristics over time. According to Thomas (2010), three types of electrical discharges can be distinguished, starting with the *vent discharges* generated at the beginning of the eruption and of short length and energy; then, *near-vent lightning* are generated at low altitude once the eruptive column develops and do not exceed tens of meters; and finally, the *plume lightning* are generated in the convective zone once the volcanic plume has developed and these are usually most energetic, reaching important lengths.
These*plume lightning* are very similar to those associated with meteorological thunderstorms and for this reason it is possible to register them remotely using existing meteorological lightning location systems.
Currently, in addition to the ground-based lightning location networks such as WWLLN (World Wide Lightning Location Network) and ENTLN (Earth Networks Total Lightning Network), which have been used for some time now, there are also meteorological satellites that remotely monitor different regions of the world, especially geostationary satellites, with varied sensors continuously scanning wide regions, provide an invaluable source of atmospheric information. These tools, together or individually, have proven to be useful in detecting an explosive eruption and the presence of volcanic ash in the atmosphere by remote sensing. A number of related papers have demonstrated the connection between changes in the dynamics of the eruption and the generation of electrical discharges. But they have also shown the difficulty of distinguishing whether the nature of the detected electrical discharge is volcanic (due to the generation of a volcanic plume) or meteorological (due to a thunderstorm at the site). This implies a problem for remote monitoring of eruptions using lightning location systems, mainly in tropical regions where thunderstorm days can reach 100 thunderstorm days per year.
In our work, we use the plume lightning detected by terrestrial and satellite lightning location systems, during volcanic eruptions occurred from 2018 onwards in a set of volcanoes located in the tropical zone, together with satellite images and bulletins and reports that inform the evolution for each eruption. With this information, we characterize the electrical activity in each eruption, its temporal evolution and the relationship between electrical activity and other parameters of the volcanic eruption, in order to obtain similarities and differences in the

analyzed cases and to be able to improve the future use of discharge location systems for monitoring volcanic eruptions and the presence of volcanic ash in the atmosphere.

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Thunderstorm Days Over Argentina in Climate Change Context

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Argentina is located in the south of South America, being one of the 200 countries in the world with one of the largest territorial extension, so it exhibits different topographic and climatic characteristics, which makes it unique. The Andes Mountains, the natural boundary between Argentina and Chile, is one of the natural conditions that influence the climate in the country.
In the present work, the spatial distribution and historical evolution of the stormy day in Argentina was studied. Discrete surface synoptic observations (SYNOP messages) such as those reported in different conventional weather stations of the National Meteorological Service (SMN) and continuous information observed by the WWLLN detection network were used, understanding as a Thunderstorm day (Td)that day when an observer hears thunder at the weather station in the first case or when the World Wide Lightning Location Network (wwlln.net) detects at least one electrical discharge during the day in a certain area centered on the station, in the second case. Thus, one of the main challenges was to achieve a good integration of these two sources of information.
The first objective before achieving this integration was the preparation of a robust database from the application of a quality control methodology to the observations of the conventional weather stations of the SMN (SYNOP messages).
With an improved database of storm days, the second proposed objective was to establish a "human observations of thunder" by comparing the days with storms reported by observers from SYNOP reports at conventional weather stations belonging to the SMN with data from the WWLLN network for the same period. This radius was found to be on average 21 km for the whole territory.
The next objective was the elaboration of climatological maps of storm days taking into account the previous radius, and using the data provided by the WWLLN detection network. The annual isokeraunic map presented in this work shows an absolute maximum located in the Northwest region with values higher than 100 Td/year followed by relative maxima in the Northeast (80 Td/year) and the Central hills (50 Td/year).
In this sense, the fourth objective of this work focused on investigating the Td time series using the historical information available in digital format from different SMN meteorological stations. The results showed that, out of a total of 36 weather stations analyzed, 23 of them presented significant increases in Td/decade while no station presented significant decreases. The analysis of the regional Td series for a 50-year period (1968-2017) showed significant increases in the annual series in the Northeast (4.5 Td/decade), Central region (2.3 Td/decade), and Patagonia (0.3 Td/decade) regions, while the Northwest region (0.4 Td/decade) showed positive trends, but not statistically significant.

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Ion Environment Effects on Point Discharge Measurements

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Point discharge measurements have a long history in terrestrial atmospheric electrical measurements, but were also used on 1980s planetary exploration missions of the Venera probes to Venus. As part of re-evaluating the Venera measurements, the behaviour of point discharge measurements in a range of environmental conditions have been investigated using modern instrumentation.

Point discharge (also referred to as corona discharge) occurs when an electric field becomes strong enough to ionise the atmosphere around a conductor, causing a “discharge current” to flow from the conductor to the environment. This phenomenon can occur from objects such as the branches of trees during times when the atmospheric electric field is particularly strong [1,2]. It is believed that point discharge is an important process in bringing charge to the surface of the Earth as part of the global electric circuit [1,3]. Point discharge sensors have been used to study the electrical environment for many years, however, with more data, the relation between electric field and measured discharge current can be improved [1].
In 1936 Whipple and Scrase [2] investigated the discharge current from an electrode during times of high atmospheric electric field. An empirical relation of $I = A(E^2 - M^2)$ was found, where I, E were the discharge current and electric field respectively, and A, M were constants. This relation was later derived theoretically by Chalmers in 1952 [3]. It is known that the removal of ions from the vicinity of an electrode strongly affects the magnitude of discharge current that is possible. In Chalmers’ theoretical derivation, it was assumed that all ions would be removed from the electrode by the electric field alone. This assumption is not valid in all circumstances, such as for falling probes in Earth’s or other atmospheres, and later investigations have found that the wind speed can be more important in removing ions.
On this note, in 1957 Kirkman and Chalmers [4] recorded the discharge current from a point discharge electrode, along with the electric field and wind speed of the electrode’s environment. From this investigation, an alternate empirical relation was found: $I = K(W + c)(E - M)$, where W was the wind speed, and K, c, M were constants.
To study the wind speed effect further, for the planetary application in particular, a point discharge system has been deployed at the Reading University Atmospheric Observatory. This implementation features a logarithmic amplifier, allowing it to have a sizable operational range. The discharge current data recorded by this electrode will be compared with atmospheric electric field and wind speed measurements taken simultaneously by other sensors at the atmospheric observatory. The aim of this work is to strengthen understanding of the point discharge measurements made in the falling probe situation, ultimately for the Venera application.

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On the Strength of Atmospheric Electric Field During Thunderstorm Ground Enhancements (TGEs)

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Recently we estimate the overall maximum voltage on mountains Aragats and Lomnicky Stit to be 500 and 300 MV. However, it is very important to get insight into the profile of the electric field in the atmosphere during thunderstorms. Till now balloon soundings provide the only available data to sample the depth of a storm. Based on balloon measurements overall understanding was reached in previous years that a strong electric field started on heights above 1-2 km from the earth's surface. Large electric fields were measured well above 2 km over the ground.
In the presented report we demonstrate that at Aragats, a strong accelerating electric field can be continued almost to the earth's surface. We present 10 TGE events observed in 2018-2021 allowing recovering electron energy spectra and estimating the heights of the termination of the strong electric field above the ground. The estimates vary from 10 to 150 m above ground, thus the electric field can reach ≈ 2.0 kV/cm at altitudes 3200 – 3350 m.

4077

Microscintillator Ionisation Detector Performance Aboard A North Atlantic Voyage

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Within atmospheric electricity the Carnegie set the precedent for maritime research vessels, providing vital understanding into the global atmospheric electrical circuit and leaving an impressive legacy in the Carnegie curve. The NRP Sagres ventures out in the wake of the Carnegie carrying a host of meteorological instrumentation on its recent SAIL missions. The scientific potential from SAIL is vast, and this research aims to investigate precipitation induced changes in background radiation over the ocean using a novel ionisation detector, as well as comparing the detector to an established gamma ray counter.

The increase of background radiation during rain and snow is a well-established phenomenon deriving from the aggregation of atmospheric radon progeny within water droplets. The effect provides a noticeable change to ground level gamma activity, and by investigating abundances of radon progeny, in the context of precipitation events, understanding can be gained into cloud formation and other atmospheric processes. The ionisation detector was brought aboard the NRP Sagres from 22-30th July 2021 and operated during periods of increased precipitation and decreased visibility.

The ionisation detector uses a 1x1x0.8 cm^3 CsI(Tl) microscintillator coupled to a PiN photodiode and is capable of spectroscopic energy discrimination and count rate data collection. The small form factor and low-power detector has been calibrated using laboratory gamma sources up to 1.3 MeV and gamma peaks from terrestrial radiation up to 2.6 MeV, and is additionally sensitive to gamma rays up to 17 MeV. During the voyage from Terceira Island to Lisbon, the detector was able to identify gamma peaks from Bi-214 and K-40, as well as cosmic ray muons.

From this voyage, we will show the performance of the ionisation detector and behaviour of discrete gamma energies during periods of interest to assess how well the novel detector can characterise precipitation induced gamma increases. Additionally, we will show a comparison of the ionisation detector and the onboard gamma ray counter composed of a larger NaI(Tl) scintillator. This research is both a test of a novel ionisation detector and an investigation into atmospheric electrical processes, echoing that of the Carnegie over a century later.

4073

Comparison of Different Atmospheric Electric Fair-weather Criteria Based on Potential Gradient Data

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The atmospheric electric potential gradient (PG) is the reverse of the vertical atmospheric electric field measured usually near the ground most often at 1–3 m heights in Vm-1 units. The PG is a fundamental parameter of the DC part of the Global Electric Circuit (GEC) which is a framework of electric currents connecting the Earth's surface and the lower ionosphere. By analyzing PG data, important information can be obtained about various environmental processes such as long-term changes in the GEC, air pollution, radioactive contamination, changes in the regional climate, etc. One huge difficulty in interpreting PG data is, however, that data recorded in fair weather conditions must be selected in order to exclude the impact of the local foul weather so that the records better represent the state and changes in the GEC on large spatial scales. As there are several different fair-weather data selection methods and criteria this can prove to be a challenging task.

PG measurements at the Széchenyi István Geophysical Observatory at Nagycenk, Hungary (NCK, 47.632°N, 16.718°E) started in 1961 and digitized PG data are available from 1962 in an hourly temporal resolution. Basic meteorological measurements such as total precipitation, temperature, surface wind speed and direction, relative humidity, surface solar radiation, etc. are available only from 2000. In this study fair-weather PG data selected by different fair-weather criteria supplemented by the measured meteorological data at NCK and by meteorological data from the ERA5 reanalysis are compared. The difference between the various fair-weather data selection methods is studied and interpreted. We show how the application of different fair-weather data criteria affect long-term trends and the distribution of fair-weather PG data and how these differences should be taken into account when interpreting PG data.

4068

Global Distribution of Vertical Charge Moment Change of Intense Lightning Strokes as Inferred From Q-bursts Recorded at Nagycenk, Hungary

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The vertical charge moment change (vCMC), i.e., the amount of transferred electrical charge multiplied by the altitude range of the transfer, is a property of lightning discharges that can be used to quantitatively characterize these events using the remotely detected extremely low frequency (ELF, 3 Hz - 3 kHz) electromagnetic (EM) radiation produced in the process. ELF-band sferics can be detected anywhere on the globe as they suffer relatively small attenuation while they propagate in the Earth-ionosphere waveguide (EIWG). EM waves from lightning strokes with an above-average vCMC may travel multiple times around the Earth so that their passages over a recording station are detected as a series of transient signals. In these EM wave packets called Q-bursts, components at the lowest eigenfrequencies of the closed EIWG (i.e., Schumann resonances) dominate. EM properties of the source lightning stroke, including the vCMC, can be obtained from the records of the corresponding Q-burst. These events represent the high energy tail of the distribution of lightning vCMC. Although only a few Q-burst occur in a minute, their contribution to the total vCMC of the global lightning activity can be significant.

On the road towards quantifying the contribution of Q-burst-producing lightning strokes to the cumulated vCMC of the global lightning activity, a procedure has been developed and automated for recognizing and processing Q-bursts in the atmospheric EM field and to find the vCMC of their sources. Source lightning strokes of some of the Q-bursts could be identified in the lightning database of the World Wide Lightning Location Network (WWLLN). Our method was tested on ELF data from Nagycenk, Hungary (47.632°N, 16.718°E) where time series of both the vertical electric and horizontal magnetic components of the atmospheric EM field are recorded. Data recorded in November, 2014 has been processed. The number of Q-bursts, the geographical distribution of the identified sources and the obtained vCMC values are presented along with their variation within the test period.

4064

Long Term Measurements of the Global Atmospheric Electric Circuit

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The diurnal variation in the Potential Gradient (PG), as established over the oceans by the *Carnegie* survey vessel in its cruises between 1909 and 1929, is a fundamental characteristic of the global atmospheric electric circuit. It brings together the regular solar heating of the different continents from Earth’s rotation. Changes which may have occurred in the global circuit due to climate change are, however relatively unexplored, in part because of the absence of comparable data. Some oceanic air atmospheric electricity measurements have been made since those of the *Carnegie,* notably those of the *Oceanographer* and the *Meteor* in the 1960s, which have allowed some long-term trends to be investigated. A further set of measurements is now available, as the Portuguese naval vessel *Sagres* has been equipped with atmospheric electricity instrumentation, and cruises have been undertaken in the Atlantic during the 2020 SAIL (Space-Atmosphere-ocean Interactions in the marine boundary Layer) campaign. The absolute values of PG depend on the confidence with which the measurements, both old and new, are calibrated, which influences how reliably any changes can be found. However, the shape of the Carnegie curve, and its phasing, is in principle more robust to the precise circumstances of the measurements. Through using the original technique of the Carnegie Institution’s scientists – harmonic analysis – to evaluate this, the different datasets are compared, a century after the *Carnegie*’s measurements.

4063

Lightning Monitoring as a Tool to Improve Flash-floods Warnings: Event of Nahal Tzafit, Israel, as a Case Study

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Abstract

At the end of April 2018, a severe thunderstorm struck Israel, claiming the lives of ten students in a flash flood in Nahal Tzafit on April 26 and three other people in nearby floods. This despite the general floods warnings.
The atmospheric instability indices supported the development of a significant storm, while the synoptic background was exceptional for the season with an upper-level cut-off low as an active Red Sea trough entered from west.
In this study we investigate the ability of improving early warnings of severe rainfall, by analyzing lightning data obtained from Earth Networks' ENTLN lightning detection system.A comparative study was done between lightning flashes together with rain gauges of the Israel Meteorological Service (IMS), both for total rainfall and rainfall peaks, and we also compared the lightning data with the rain radar of IMS for selected regions. The lightning data was collected in few different spatial and temporal resolutions.
For the entire synoptic system and the total area studied, a correlation of 48% (R2=0.48) were obtained between lightning amount and rainfall measured by rain gauges, and up to 56% when compared with rainfall from radar. When analyzing 222 independent rain events, a correlation of 80% was found for a time window of 30min (Lag=0) between the lightning data and the radar data, while 63% was obtained for lightning data that precedes the radar by only 10 minutes. Additionally, in the lightning spatial maps and animations for the event itself, a significant increase in the amount of lightning was detected before the flash flood, similar to "Lightning Jump" observations from heavy rain events in other parts of the world.
In conclusion, for this specific synoptic system, the storm intensity and certain synoptic indices (e.g. CAPE with BRN) appear to affect the strength of the lightning-to-rainfall relation. The high correlations obtained during the storm's peak supports further research to show the potential for lightning data to be used as an additional warning parameter for flash floods in our region.
instability, larger 0–6 km AGL wind shear.

4042

Transport of Water Vapor from Tropical Cyclones to the Upper Troposphere

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This paper looks at the influence of tropical cyclones on water vapor concentrations in the upper atmosphere above these storms.We use independent data sets of tropical storm intensity, water vapor and lightning activity to investigate this relationship.Water vapor in the upper troposphere is a key greenhouse gas, with direct impacts on surface temperatures. Both the amount of water vapor and the altitude of water vapor impact the radiative balance and the greenhouse effect of the atmosphere.The water vapor enters the upper troposphere through deep convective storms, often associated with lightning activity.The intensity of the lightning activity represents the intensity of the convection in these storms, and hence the amount of water vapor transported aloft.In this paper we investigate the role of tropical cyclones on the contribution of water vapor to the upper atmosphere moistening.Tropical cyclones are the largest most intense storms on Earth and can last for up to two weeks at a time.There is also evidence that the intensity of tropical cyclones is increasing, and will continue to increase, due to global warming.In this study we find that the maximum moistening of the upper atmosphere occurs at the 200 hPa level (~12km altitude), with a lag of 1-2 days after the maximum sustained winds in the tropical cyclone.While the water vapor peaks after the maximum of the storm intensity, the lightning activity peaks before the maximum intensity of the storms, as shown previously [1].We show here that the absolute amount of water vapor in the upper troposphere above tropical storms increases linearly with the intensity of the storms.For every 10 hPa decrease in minimum pressure of tropical storms, the specific humidity increases around 0.2 g/kg at the 200 hPa level.

4038

Various Transient Luminous Events Observed From the Summit of Mt. Fuji in Japan

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Transient luminous event (TLEs) in summers has been observed from the summit of Mt. Fuji which is the isolated highest mountain in the central Japan. Various TLEs, such as sprites, gigantic jets and elves, have been succeeded in the detection from there since 2013. Three dimensional structures of parent thunderstorm above the sprite-producing cloud-to-ground discharges in addition some gigantic jet-producing thunderstorm were analyzed. We will present TLEs observed from Mt. Fuji, and their parent thunderstorm structures in detail.

4035

Rupture of Pollen Particles During Thunderstorms Due to Atmospheric Electric Fields

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During the mature stage of thunderstorm evolution, cold outflows may develop below the cloud-base because of evaporation and precipitation of particles. These strong down-drafts reach the ground and can eject large concentration of pollen and dust particles into the air. Based on the results of a recent laboratory study, it was suggested that pollen rupture and release sub-pollen particles (SPPs, r<2.5 µm) following their exposure to the humid conditions occurring during a thunderstorm (Stone et al., 2021). SPPs can be inhaled into the respiratory system, where they often cause an acute allergic response. During the flowering season of certain plants, which are known for their allergenic potential, this process may result in Thunderstorm Asthma epidemics (D'Amato *et al*., 2016; 2017; Yair *et al.*, 2019), which are expressed as severe respiratory problems, especially in sensitive populations (infants, senior citizens).
However, previous studies did not account for the role of the sustained exposure of pollen to strong electric fields occurring inside and below the thunderclouds. We report, for the first time, on the results of laboratory experiments conducted with *Ambrosia Spp.* (ragweed) pollen exposed to electric fields with strengths of up to 30 kV/m. The experiments were conducted with and without water (moistening), under various exposure times to the electric field. Microscopic analysis by optical and SEM clearly shows the rupture of pollen particles due to the action of the electric fields, confirming the hypothesis of SPP production and the release of allergens into the air. Repeated experiments with other plant species native to Israel will be discussed, as well as the complex synergistic interplay between humidity, electric field strength and the exposure duration of pollen to these conditions.

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4034

A Newly-designed Observation and Analysis of Atmospheric Electric Field for a Global Electric Circuit Study at the Polar Region

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During blizzards/snowstorms in the polar regions, an intense positive atmospheric electric field (AEF) in the order of 1 kV/m of the same polarity in fair weather was observed using an electric field mill at 1.4 m in height. According to various studies on blowing/drifting snow dynamics and electricity in laboratory experiments and field observations, snow particles colliding with the snow surface are charged, and the charge of suspended and saltating particles during the snowstorm is negative on average. To verify the AEF observed during and after the blizzards, we numerically estimated the electric field surrounding the conductive sensor unit of the electric field mill using a three-dimensional Poisson equation. Under blizzard conditions, the polarity of the estimated AEF was the opposite of that of the observed AEF. From the noise study of the field mill, we deduced that the positive AEF variations were caused by the collision of negatively charged snow particles with the electric probe on the sensor unit [Minamoto et al., *Atmos. Res*., 2021].

In accordance with the above findings, we present a novel method to discriminate AEF variations originating from the global electric circuit and local meteorological-induced AEF variations; this is performed by comparing the AEF values measured at two heights at Syowa Station, Antarctica, which provides the identification of the fair-weather period. In general, the volume density of the blowing snow particles rapidly decreases with increasing height. Therefore, the measured AEF values at the two heights were different. The difference between the AEF values measured at the wo heights increased at a wind speed of 6 m/s or more. Meanwhile, the statistical analysis showed that the AEF with and without clouds was less than approximately 1 V/m at Syowa Station, which is negligible. In addition, this case study at Syowa Station found no relationship between cloud extension/dissipation and AEF. Accordingly, we propose a practical method to identify the fair-weather conditions by the AEF values at two heights and wind speed observed in the polar region, such as at Syowa Station [Minamoto et al., submitted to *J. Geophs. Res. Atmos*, 2021].

For the application of this methodology, we show the aurora-substorm-generated atmospheric electric field variations, which would contribute to further investigation on the relationship between the global electric circuit and the ionosphere.

4032

Effects of Short-term Solar Disturbances on the Potential Gradient Measurements Recorded in Two Different Stations

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The effects of solar phenomena, such as solar proton events, Forbush decreases and geomagnetic storms affect the Global Electrical Circuit (GEC) at high latitudes. Additionally, several studies reported a solar influence on the GEC parameters (e.g., potential gradient, air-Earth density current) recorded at the ground at mid and low-latitude. However, these studies were performed for isolated cases. In this paper, we performed a statistical analysis of the effects of solar proton events (with >100MeV), Forbush decreases and geomagnetic storms on the potential gradient recorded at two different stations (Argentina, CASLEO: 31.78°S, 2550 m a.s.l., and Poland, SWIDER: 52.12°N, 100 m a.s.l.). We applied the superposed epoch analysis to the potential gradient (PG) deviations to enhance possible weak effects. Preliminary results for CASLEO shows not significant effects on the PG during geomagnetic storms. However, for high energetic solar proton events and intense Forbush decrease we found an increase of the PG. Possible mechanisms will be discussed. For SWIDER, our results showed not significant effect during solar proton events and Forbush decreases. The work is supported by Polish National Agency for Academic Exchange through Ulam Programme scholarship, agreement no PPN/ULM/2019/1/00328/U/00001.

4029

The Possible Role of Electric Fields Strengths Below Relativistic Runaway Electron Avalanche Threshold in Gamma-ray Glow Emissions

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Gamma-rays related to thunderclouds are detected in ground-based, airborne, and space observations. These High Energy Atmospheric Phenomena (HEAP) cover a wide range both in time and energy, from Terrestrial Gamma-ray Flashes (TGFs) in a scale of micro to milliseconds up to gamma-ray glows (also known as Terrestrial Gamma-ray Enhancements, TGEs) lasting for minutes; both reaching tens of MeV. Thunderstorms create, at the troposphere, electric fields that accelerate charged particles inducing these phenomena by bremsstrahlung emission.
The electric field strength of 0.216 MV/m is the so-called minimum ionization threshold as it equilibrates the local air friction minimum for the MeV electron energy range while 0.284 MV/m is the Relativistic Runaway Electron Avalanche (RREA) threshold above which the electrons can multiply their population within a high-energy range with a theorized average of, approximately, 7 MeV. Below 0.284 MV/m, the thundercloud electric field accelerates the electrons sustaining their energy for longing distances which enables a larger bremsstrahlung emission than the natural background by Modification Of Spectra (MOS). Both, RREA and MOS, are possible mechanisms for gamma-ray glows but their long duration and electric field requirements are still open research topics.
The Gamma-Ray Observation of Winter Thunderclouds (GROWTH) collaboration is dedicated since 2006 to measuring and analyzing radiation from lightning and thunderstorms. It has a catalog of gamma-ray glow measurements to serve as a comparison basis for the development of further theoretical framework. This work focuses on the electric field strengths below 0.284 MV/m, as they are easier levels to achieve in nature, and their effects upon atmospheric electron acceleration and the further gamma-ray emission. Electric fields below the RREA threshold can extend electron spatial range by a factor between 2 and 10, the gamma-ray yield enhancement associated with this extension may be significant to gamma-ray glow measurements within the context of winter thunderclouds in Japan which are known for their low altitude levels.
Monte Carlo simulations, together with analytical calculations, provide electron and gamma-ray spectra data for comparison with the GROWTH catalog to evaluate the role of the MOS mechanism in the gamma-ray glow generation. The simulations use GEometry ANd Tracking 4 (GEANT4) kit to evaluate a primary electron beam and detect its electron and gamma-ray spectra footprint at multiple distances starting in a finite electric field region within homogenous air. In principle, the photons are not affected by the electric field presence, but the gamma-ray spectra show the modifications throughout distance as their sources, the electrons, serve as energy storage that keeps feeding the gamma emissions as their primary energy is sustained by the electric field.

4027

Overview of Studies with a Bulk Lightning Model Coupled With an Atmospheric Model, SCALE

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A bulk lightning model (Sato el al. 2019) coupled with a meteorological model, Scalable Computing for Advanced Library and Environment (SCALE) was developed for simulating the lightning events and aiming the lightning prediction by the numerical simulation in future. The bulk lightning model includes the non-inductive charge separation mechanism based on Takahashi (1978), the Poisson solver based on the biconjugate gradient stabilized method (Bi-CGSTAB: van der Vorst 1992), and the lightning discharge based on MacGorman et al. (2001) and Fierro et al. (2013).
Using the bulk lightning model, we have investigated the effects of the aerosol upon the vertical structure of the charge density in an idealized hurricane-like vortex (Sato et al. 2019) and the relationship between the lightning frequency and the lifecycle of an idealized hurricane-like vortex (Sato et al. 2021a). The bulk lighting model was also applied for real-case simulation (i.e., downscaling simulation). In addition, the symmetric Gauss-Seidel preprocessing was applied for the Poisson solver to accelerate the computational speed of the bulk lightning model, and the preprocessing reduced the elapsed time of the lightning model to 15 % of that without preprocessing.
We evaluated the model's performance through the comparison between the lightning frequency simulated by the downscale simulations and the ground-based observations operated by Japan Meteorological Agency (lightning detection network system (LIDEN), Ishii et al. 2014).
Our analyses indicated that the lightning models successfully simulated the lightning frequency of the lightning events in both summer and winter over Japan except for the winter lightning in the Hokuriku area. Our analyses also showed that the explicit simulation of the lightning using the bulk lightning model has advantages for reducing the overestimation of the lightning frequency compared to the implicit methods that diagnoses the lightning frequency based on the simulated mass of solid hydrometeors (e.g., McCaul et al. 2009, Hayashi et al. 2020).
We also conducted detail analyses for the results of the two heavy rain events in summer. Heavy rainfall occurred in both events over Japan, but the lightning frequency of the two events largely differed. Our analyses elucidated that the difference of the lightning frequency in the two events was originated from the difference in the height where the graupel mainly distributed (Sato et al. 2021b).
In addition, the lightning model have also been applied for an observing system simulation experiment (OSSE) to explored the potential use of the lightning observations by the geostationary lightning mapper (GLM) (Honda et al. 2021).

4021

An Experimental Study of the Breakthrough-phase and Return-stroke Processes in Long Sparks

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The dynamics of the brightness of a long-spark channel during the breakthrough and the return-stroke phases of discharge development were experimentally studied using streak-camera images synchronized with current recordings at the high-voltage electrode. The velocities of primary positive leader developing from the high-voltage electrode and connecting negative leader extending from the grounded electrode during the breakthrough phase were measured as a function of the discharge current and the distance between leader tips. The velocities of the return-stroke waves propagating upward and downward along the positive and negative leader channels, respectively, were also measured. The connection region exhibited channel splitting and reduced brightness relative to the channels above and below it.

4020

Capabilities of Earthquake Forecast Based on Negative Anomalies of Atmospheric Electric Field

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Negative anomalies of electric field potential gradient (PG) were observed before earthquakes in the near-ground air during fair weather conditions in different regions of the world. The most likely mechanism for such anomalies to occur is air ionization by radon. PG measurements much depend on weather conditions. The PG value during rain, snow, fog, strong wind, and overcast clouds is many times higher than the PG value from earthquake precursors. The paper estimates the capabilities of earthquake forecast based on negative anomalies of atmospheric electric field in fair weather conditions. The precursor was calculated from the continuous observations of electric field in Kamchatka over the period 1997-2002. It turned out that the efficiency of this forecast method under any weather conditions is not more than 10% [1].

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4019

Relation of Winter Thunderstorms in Kamchatka With Seismic and Solar Events

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Kamchatka is the region with very low thunderstorm activity, and winter thunderstorms are a very extraordinary phenomenon. According to Paratunka observatory (53^0 N), thunderstorms in winter may occur in the result of tropical cyclone passage over the North-Eastern part of the Pacific Ocean. Tropical cyclones are a powerful source of hot and humid air. However, in general case, that is insufficient for the development of thunderstorm processes in Kamchatka. For winter thunderstorms to occur in the region, additional factors of heat inflow should be involved. Thunderstorm processes in Kamchatka were investigated for the period 2004-2018. In a number of cases, solar flares, accompanied by radiation intensification in visible and infrared spectra, were the additional source of heat. In other cases, the Earth infrared radiation, penetrating into the atmosphere from closely located earthquake epicenters, were the additional source of heat [1,2,3].

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Planning a LMA-based Field Campaign in Africa in Support of MTG-LI Validation

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In support of Meteosat Third Generation (MTG) Lightning Imager (LI) cal/val activities, a preparatory study has been conducted to deliver several scenarios of Lightning Mapping Array (LMA)-based campaigns in Africa. A multiple-source storm climatology has been built based on 10-year EUMETSAT Spinning Enhanced Visible and InfraRed Imager (SEVIRI), 16-year NASA Tropical Rainfall Measuring Mission (TRMM) Lightning Imaging Sensor (LIS) and 6-month Vaisala Global Lightning Dataset 360 (GLD360) records. The climatology has been analyzed in terms of location and severity over the whole African continent through seasonal and diurnal cycles of the convection. Three regions, i.e. Kenya/Uganda/Lake Victoria, Ivory Coast and South Africa, have then been studied in more details in terms of geographical distributions of the lightning activity and deep convection at different (decade, yearly, seasonal, monthly, diurnaReRegional and Seasonal Variations in Random Forests Model Performancel) temporal resolution. Properties of the lightning activity like flash rate and flash density have also been quantified. For each of the three regions of interest, between three and four scenarios of LMA campaign have been proposed, each scenario corresponding to a specific regional coverage at a specific period of the year. Interactions with Kenya, Ivory Coast and South Africa National Weather Services (NWSs) help consolidate and rank these scenarios according to their feasibility, their scientific relevance and their benefits relative to MTG-LI validation.

The methodologies, the different scenarios and the main outcomes of the study will be first presented. The objectives, requirements and milestones of the LMA-based field campaign will then be described. A preliminary risk analysis in order to propose mitigation plans due to uncertainties (extreme weather events, sanitary conditions, national and international issues) will also be discussed.

It has to be emphasised that the present study only provides an outline and estimated costs of an LMA campaign in Africa while the next steps are subject to EUMETSAT decision and funding. If the campaign will be run then it should be opened to the scientific community for additional contribution on self-funding and bigger scientific returns.
equatorial stratospheric Semi-Annual Oscillation.

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Charge Distribution in the Thundercloud, Electron Acceleration, and Lightning Initiation

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The comparative analysis of three thunderstorms on Aragats in May 2021 demonstrates that relativistic runaway electron avalanches (RREAs) are developing in large areas of the thunderous atmosphere. In the active storm zone, RREAs last tens of seconds to a few minutes, until lightning flashes terminate electron acceleration. Thus, RREAs development is paired with lightning activity, creating huge electron fluxes preceding the development of lightning leaders. If the lightning activity is far from the detector site, measured particle fluxes (thunderstorm ground enhancements - TGEs) are smoothly enhanced and decayed when the atmospheric conditions cannot anymore sustain the electron runaway process. In this case, the TGE has a more or less symmetrical shape and can last up to 10 minutes and more. Thus, the total surface area exposed to ionizing radiation can reach 100 km2 and a total number of gamma rays directed to the earth's surface – 2*1018. The differential energy spectra of electrons and gamma rays recovered by particle spectrometers are used to estimate the heigh of a strong accelerating electric field region, which can extend down to tens meters above the earth's surface.