be presented. This discharge originated at a distance of more than 50 km from DFW airport, traveled a total path of approximately 150 km, and initiated four isolated cloud-to-ground discharges one of which resulted in a safety-related incident at DFW airport.

AE21A-08 1105h

Comparison of New Mexico Tech VHF Interferometer and Arecibo radar data of lightning

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The New Mexico Tech InterferometerSferic (NMT INTF) system records both broadband electric field data and narrowband VHF phase and amplitude information at 274 MHz. Previous studies have shown that the NMT INTF system can identify and map most forms of slow and fast negative breakdown processes, but generally has difficulty detecting slow positive breakdown processes.

The Arecibo Observatory UHF radar (430 MHz) was used between August 25 and September 10, 2001, to detect the backscatter from lightning leaders. When lightning was over or near the observatory, the radar was operated in a special "leader mode" with an interpulse period (IPP) of 1 ms and a pulse width of 2 μs. The radar beam had a width of about 300 m and could detect a conducting object with a cross section of as little as 10−10 m−2 at a distance of 100 km. The NMT INTF system was situated about 8 km north of Arecibo Observatory, an ideal location for mapping lightning both in the main beam of the radar as well as (more typically) in the sidelobes. Data obtained by the interferometer will be compared with that of the radar and some preliminary results of this comparison will be presented.

AE21A-09 1120h

Combined Lightning Observations Using the TRMM and FORTE Satellites

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The Tropical Rainfall Measuring Mission (TRMM) and Fast On-Orbit Recording of Transient Events (FORTE) missions have lightning sensing experiments. On occasion, both sets of instruments measure the properties of the same flash. This paper presents several examples of how the data sets are combined to detect, locate, map, classify and analyze a lightning flash in a remote storm location. The Lightning Imaging Sensor (LIS) on TRMM has the sensitivity to detect, locate, organize and map the spatial and temporal development of a flash. Because of the higher orbit, the FORTE instruments trigger their recordings on the largest events during a flash. Within the context of the LIS data, the high time resolution FORTE Photo Diode Detector and FORTE VHF data confirm the LIS detections and provide additional diagnostic information to classify strokes within a flash. The combined analysis, in some cases, can include altitude information about the VHF source to produce a two and a half-dimensional analysis of a flash. The remote locations of these oceanic storms illustrate how space based lightning observations can complement those made by fixed, ground based lightning detection networks.

AE21A-10 1135h

Characterization of the Initial Stage of Object-Initiated and Rocket-Triggered Lightning

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Upward discharges are initiated by a leader that originates from the object and propagates upward toward the charged cloud overhead. Upward discharges involve an initial stage that is characterized by a continuous current with a duration of some hundred milliseconds and an amplitude of some tens to some hundreds of amperes, often followed by one or more downward leader/upward return stroke sequences. Since direct current measurements are usually performed on towers that experience primarily upward discharges, there has been considerable interest lately in characterizing upward lightning flashes. Specifically, there is the question of whether current pulses occurring during the initial stage, that is, pulses superimposed on the long-lasting, low-level continuous current, are due to return strokes or due to an M-component-type lightning process.

The phenomenology of upward lightning is similar to that of rocket-triggered lightning. Wang et al. (1999b) have studied the characteristics of the current pulses in the initial stage (IS) of rocket-triggered lightning. In most cases the IS contained current pulses (initial continuous current (ICC) pulses) superimposed on the slowly varying continuous current. A statistical comparison between these pulses and the M-component pulses following return strokes in triggered lightning indicates that both types of pulses are due to similar physical processes.

In this international collaborative study, we compare the characteristics of the IS in rocket-triggered lightning in Florida with their counterparts in natural upward lightning as observed on (1) the Gaisberg tower (100 m, Austria), (2) the Peissenberg tower (160 m, Germany), and (3) the Fukui stack (200 m, Japan). All current records in Japan and some of the current records in Germany and Austria were obtained in winter, whereas all triggered-lightning data were obtained in summer. All lightning events effectively transported negative charge to ground. The geometric mean (GM) values of the overall characteristics of the IS, duration (T), charge transfer (Q), and average current (I), for rocket-triggered lightning (T = 305 ms, Q = 30.4 C, I = 99.6 A) are similar to their counterparts for Gaisberg-tower flashes (T = 235 ms, Q = 29.6 C, I = 126 A) and Peissenberg-tower flashes (T = 290 ms, Q = 38.5 C, I = 133 A), while the Fukui-stack flashes are characterized by a somewhat shorter GM initial-stage duration (T = 88.4 ms) and a larger average current (I = 496 A). The GM initial-stage charge transfer for the Fukui-stack flashes is 48.8 C. The observed differences in the IS duration and the average current are probably related to the differences in the lower current measurement limits: about 200 A for the Fukui data set vs. 15 to 20 A for the other three data sets. The characteristics of the ICC pulses in object-initiated (Gaisberg, Peissenberg, and Fukui) lightning are similar within a factor of two to three, but differ more significantly from their counterparts in rocket-triggered lightning. Specifically, the ICC pulses in object-initiated lightning exhibit larger peaks, shorter risetimes, and shorter half-peak widths than do the ICC pulses in rocket-triggered lightning. Possible reasons for the observed dissimilarities will be discussed.

AE21A-11 1150h

Submicrosecond Structure of the Electric Field Derivative During the Onset of First Return Strokes in Cloud-to-Ground Lightning

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Typically, the radiation field that is produced by the first return stroke in cloud-to-ground lightning begins with a slow front that lasts about four microseconds and that is followed by a fast transition to peak in tens to hundreds of nanoseconds. We have analyzed 132 digitized records of the dE/dt (100 MHz) and E (10MHz) fields that were radiated by first strokes in strikes to sea water under conditions where the lightning locations were known and there was minimal distortion of these fields due to propagation. A large fraction (64%) of the dE/dt signatures contained significant multiple peaks within a 5 μs interval near (4 μs before to 1 μs after) the dominant peak, and 38% had multiple peaks within 1 μs of the dominant peak. When the integral of dE/dt was computed and compared with E, the integrated waveforms exhibited considerable fine-structure that was not resolved by the 10 MHz digitizer. This structure includes fast pulses near the beginning of the slow front, large peaks and shoulders within the slow front and during the fast transition, and very narrow peaks in E. Examples of the dE/dt and E waveforms will be given together with statistics that suggest the lightning attachment process is more complex than is commonly assumed in the literature.

AE22A MC: 123 Tuesday 1330h

Thunderstorm Electrical Effects on the Middle and Upper Atmosphere and Ionosphere I

Presiding: **D D Sentman,** University of Alaska**; V P Pasko,** The Pennsylvania State University

AE22A-01 1330h INVITED

The Search for Upward Lightning

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Some of the reports about 'upward lightning' are over one hundred years old. Eyewitness reports became more numerous with the advent of night aviation operations. Early photographs of lightning, Nighttime-Daytime Optical Survey of Lightning Experiment (NOSL), in November 1981 produced interesting images of lightning as seen from Space Shuttle. Both civilian and military pilots had observed luminous phenomena occurring above thunderstorms, although they were reluctant to report them in official channels. Vaughan and Vonnegut collected and published some of these eye witness reports in 1982 and 1989. From 1985 into the 1990's the Mesoscale Lightning Experiment (MLE) gathered video images of lightning from the Space Shuttle platform. By 1989, the remotely operated low light video camera in the payload bay yielded many hours of lightning images. The breakthrough came in 1989 with the video evidence obtained by Franz, Nemzek and Winckler. This video clip provided hard evidence of the existence and duration of upward lightning. MLE investigators received a copy of the video for study. Many hours of Shuttle video were then reexamined to find these brief events that extended beyond the horizon as seen from space. The high oblique view provided a simultaneous view of the lightning in a storm cell and the sprite above. Within a few years investigators were in the field using a variety of sensors to measure and analyze sprite phenomena. The name 'sprite' replaced earlier names for upward lightning. Dr. Davis Sentman suggested it after he had observed them during the summer of 1994 from jet aircraft. The search for upward lightning led to the study of sprites, jets, elves and starters. Because sprites, jets and elves have appeared for millennia, their eventual discovery was inevitable. The Winckler contribution was the catalyst for major progress in this science.

AE22A-02 1355h INVITED

Electrical Discharges into the Stratosphere from the Tops of Intense Thunderstorms

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The serendipitous capture by John R. Winckler in July 1989 of the first low-light video of what are now called sprites launched a new era of middle atmospheric electrodynamic research. Since then, over 10,000 mesospheric sprites have been imaged by teams worldwide. Initially termed cloud-to-stratosphere (CS) lightning, this name was wisely abandoned because it implied more than was confirmed about the physics of the phenomenon. Sprites, almost exclusively associated with positive cloud-to-ground lightning (+CG) flashes possessing very large charge moments (500 C*km and up), occur within the stratiform regions of large mesoscale convective systems (MCS). In searching for sprites above MCS, other phenomena, now collectively termed transient luminous events (TLEs), were discovered, including elves, halos and trolls. The sprite, elve and halo optical emissions all occur well above the tops of even the tallest storms. The blue jet was the first TLE found that emerged from the top of the parent storm. The more recently discovered (red) trolls represent a faint discharge from or near the cloud tops returning up the channel of the previously intense sprites having unusually long tendrils. None of these TLEs could be termed true cloud-to-stratosphere lightning. Yet an examination of over a century of scientific literature frequently yields descriptions though while not matching any of the known TLEs would suggest a true CS event. Numerous eyewitness reports suggest long-lasting, brilliant lightning-like discharges can propagate from the tops of certain storm cells, at times to estimated heights of 35 km. Film images of 3 such events initially thought to be blue jets may represent the CS which we have tentatively given a new name, gnomes. On 22 July 2000, during the STEPS program, a GEN III ultra-blue extended imager at Yucca Ridge was monitoring distant sprites when a nearby supercellular storm entered the field of view. Distinctive discharges were detected on the cloud top. Several dozen appeared as bright, very small (sub 100 meter?) and very brief (sub 16ms) dots. Another dozen or more exhibited upward propagation on the order of 1- 2 km. While having certain features in common with blue jets, they were also optically much brighter and narrower. The gnomes occurred for 20 minutes at the base of an overshooting convective dome during the supercells growth stage. The gnomes were not associated with either CG or IC flashes. The storms IC and CG lightning flash temporal and spatial distribution statistics suggest atypical behavior.

URL: http://www.FMA-Research.com

AE22A-03 1420h

Results from the first conjugate sprite campaign

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While some theories for sprite generation predict the generation of relativistic electrons injected upward into the magnetosphere, observational evidence is incidental and relates to gamma-ray bursts from the atmosphere above thunderstorms observed from satellite. To address this important question, a ground campaign was undertaken in the summer of 2001 from two magnetically conjugate locations in Southern France and South Africa. The team in the northern hemisphere monitored the northern summer thunderstorm and sprite activity, while the team in the southern hemisphere looked for the optical and electromagnetic signatures of relativistic electron beams from the northern storms. The instrumentation in the south included an array of high time resolution photometers and VLF receivers. In the presentation we introduce the campaign, present the observations, and relate these to analytical predictions.

AE22A-04 1435h

Ground Observation of Sprites in Taiwan

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During the Sprites01 campaign, sprites were observed over thunderstorm systems in the southeast region of China and in the oceans around Taiwan. The observation location was on the Ali Mountain of Taiwans Central Ridge area with an altitude of 2413m and on the campus of National Cheng Kung University with an altitude of 50m. For the land sprites, 90% of them are either carrot or columniform sprites and 70% of the sprites occurring in groups. Their forms and occurrence frequency are very similar to those observed over the North American continent. For the oceanic sprites, carrot sprites account for 89% of the observed events, and 83% of the sprites occurring in singles. If one defines the thunderstorm, which continuously produces at least a sprite in 10 minutes interval to be a sprite active system. The active sprites generating periods for the observed thunderstorms are typically very short with an average time span around 30 minutes. The sprite production intensities for these Asian thunderstorms are estimated to be between I = 5.0 x10^{-4} sprites/km^2/$hrtoI = 1.2x10^{-3}$ sprites/km^2/hr.

AE22A-05 1450h

Mesospheric Energy Input Owing to Sprites and other TLE's and the Possible Effects Thereof

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This paper discusses the chemistry and energy balance implications of the results of the 1999 Sprites Balloon Campaign. A sprite at 0955:36.982 UTC on 21 August 1999 produced a vertical electric field perturbation of $\sim$ 0.275 V/m that was similar in time profile to the light emission. There was also a positive azimuthal magnetic pulse of $\sim$ 3 nT. These data suggest that the sprite itself carried an upward current of $\sim$ 6-11 kA, and that the light emission was the result of the deposition of $\sim$ -7 C of charge near 75-78 km altitude. This charge corrsponds to 50-100 MJ of electrostatic potential energy. All of the other 23 sprites observed by the balloon payload show similar signatures. No published model predicts the signatures observed in these data. Further investigation has discovered that virtually all large cloud to ground lighting strokes were followed 2-6 ms later by a delayed ELF pulse 2-4 ms long produced by D-region polarization and mesospheric charge deposition. Sprite halos produced by -CG's were 4-7 times as common as +CG events, which means that published event rates are serious underestimates. Sprites or halos occurred when the deposited charge moment was large enough to produce an electric field in the mesosphere that exceeded 65 V/m. The quantitative impact of these observations on our understanding of the chemistry and energy balance of the mesosphere will be discussed.

URL: http://www.uh.edu/research/spg/Sprites99.html

AE22A-06 1525h INVITED

Satellite Observations of Upper Atmospheric Discharges With the ISUAL Instrument on the ROCSAT-2 Satellite

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The Imager of Sprites and Upper Atmospheric Lightning (ISUAL) experiment on ROCSAT 2 satellite will make the first synoptic spacecraft based measurements of lightning induced luminous phenomena. Science objectives of the ISUAL instrument are the determination of the spatial, temporal and spectral properties of lightning induced upper atmospheric optical flash transients (sprites, elves, blue jets etc.) and the global (geographic/seasonal) distribution of upper atmospheric optical flash transients. The ISUAL instruments consist of a limb viewing low light level imager with a set of bore sighted photometers and a dual channel high time resolution array photometer. The ISUAL imager spectrophotometer and array photometer will measure the spectral content, the spatial and temporal intensity distribution of the optical flashes uninhibited by the effects of lower atmospheric absorption. Intensity ratios of the various emissions will be used to determine the energetics of the excitation processes. The investigation will take advantage of coordinated observations with ground based simultaneous measurements of electric fields and VLF waves and optical imaging and photometry. The ISUAL payload flying at 891 km altitude in a 1000-2200 local time near sun-synchronous near polar orbit will be able to provide the first unbiased survey of lightning induced optical flashes over the entire globe in the midnight sector. From such a survey we will be able to determine whether the occurrence frequency of sprites depend on factors other than the magnitude of the storms such as the prevailing tropospheric or mesospheric conditions.

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AE22A-07 1550h INVITED

In-situ Electrodynamics Over Sprite Producing Storms

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Direct measurements of electrical parameters in the atmosphere near Sprites have not been made. A new attempt to obtain such measurements will be conducted with support from the National Science Foundation (NSF) and the Instituto Nacional de Pesquisas Espaciais (INPE, Brazil). A series of up to four stratospheric balloon payloads will be flown in Brazil in 2001 with vector electric and magnetic field detectors to measure the EM pulse from lightning and Sprites, as well as a bremsstrahlung X-ray detector to search for evidence of runaway electrons. Airborne instrumentation will independently image the Sprites with a low light level CCD imager. The balloon payload will measure the transient electric fields with a sensitivity from microvolts per meter up to a kilovolt per meter. A new telemetry system will allow us to collect waveform data for all fields. Our plan is to use these data to help differentiate between various theories for the physical cause of Sprites.

AE22A-08 1615h

New Evidence for the Brightness and Ionization of Blue Starters and Blue Jets

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Blue jets and blue starters are partially ionized luminous cones of primarily blue light that propagate upward out of the top of thunderstorms at speeds of order 100 km s^{-1}. Blue jets propagate up ∼40 km, but blue starters, which resemble blue jets, terminate abruptly after only a few kilometers of upward travel. Theories on the origin of blue jets have proposed that they are due to either positive or negative streamers or runaway electrons. New analysis of multi-instrument observations of a blue starter from an aircraft during the Energetics of Upper Atmospheric Excitation by Lightning, 1998 (EXL98) campaign of July 1998, shows that the ionization accounts for ∼3% of the observed intensity. One of the Authors, P. Huet took a remarkable color photograph of a blue jet taken from Runion Island in the Indian Ocean. The jet occurred during a 2 minute exposure of a lightning storm over the ocean using 400 ISO Fujicolor film in a Zenith reflex camera with a 58 mm lens at f/4 or 5.6. We used the background corrected pixel counts of calibrated stars in the image for quantitative brightness calibration, and from the pixel counts in the blue separation of the jet image determined the minimum brightness and energy deposition. This analysis shows that the minimum optical energy deposition was ∼0.5 MJ. An inverted monochrome portion of the Runion Island photograph shows fine structure in the jet and eight streamers 50 to 100 m in diameter associated with the jet never before seen.

AE22A-09 1630h

Three-dimensional modeling of blue jets and blue starters

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Blue jets are narrow cones of blue light propagating upward from the apparent cloud tops at speeds of the order of 100 km/s to a terminal altitude of about 40 km [Wescott et al., GRL, 22, 1209, 1995]. Blue starters are distinguished from blue jets by a much lower terminal altitude. They protrude upward from the cloud top (17-18 km) to a maximum 25.5 km in altitude [Wescott et al., GRL, 23, 2153, 1996]. It has recently been suggested that blue jets correspond qualitatively to the development of the streamer zone of a positive leader and therefore should be filled with a branching structure of streamer channels [Petrov and Petrova, Tech. Phys., 44, 472, 1999]. In our talk we will discuss the physical concept proposed by Petrov and Petrova [1999] as well as will demonstrate a role of blue jets and blue starters in the large-scale atmospheric electric circuit. We will also discuss specific physical reasons and required circumstances for occurrence of blue jets and starters above thundercloud tops and will support our arguments with results from a new three-dimensional model. The model simulates the propagation of branching streamer channels constituting blue jets and starters as a three dimensional growth of fractal trees in a self-consistent electric field created by thundercloud charges. The model is based on a phenomenological probabilistic approach proposed in [Niemeyer et al., IEEE Trans. Electr. Insul., 24, 309, 1989] and is a straightforward expansion of the previously developed two-dimensional version [Pasko et al., GRL, 27, 497, 2000]. The model results indicate that blue jets and starters can be formed by a fast (∼1 sec) accumulation of 110-150 C of positive thundercloud charge distributed in a volume with effective radius 3 km near the cloud top at 15 km. The obtained results closely resemble characteristics of blue jets and blue starters observed by Wescott et al. [1995; 1996] in terms of their altitude extents, transverse dimensions and conical structure, and support the suggestion of Wescott et al. [1996] that blue starters are related to the initial phases of blue jets.

AE22A-10 1645h

The Connection Between Delayed Sprites and Continuing Currents

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A substantial fraction (40% or more) of sprites initiate significantly after (tens to hundreds of milliseconds) the apparently causal lightning return stroke. Recent work [Cummer and Fuellekrug, GRL, 28, 495, 2001] has shown that, in at least a few cases, unusually intense continuing lightning currents are responsible for triggering these so-called delayed sprites. These continuing currents can be detected and analyzed through a quasi-static ULF magnetic field signature that is detectable much farther from the source than most other continuing current signatures. Quantitative analysis showed in one case that the continuing current carried more than 800 C of charge to ground. Beyond their initial detection, many important questions remain regarding the connection of continuing currents and sprites. For example, it is not known whether all delayed sprites are connected to a return stroke through continuing currents. These delayed sprites also provide a unique opportunity to quantitatively test, under extreme circumstances, theoretical predictions of the relationship between lightning charge moment change and sprite initiation. We have quantitatively analyzed high time resolution multi-station ULF magnetic field data recorded in the summer of 1998 for delayed and not-delayed sprites, and we will address these and other issues regarding the connection between these unusually large continuing currents and sprite initiation.

AE22A-11 1700h

Electron energies, densities, and electric fields in sprites from aircraft based optical observations*

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During the EXL98 aircraft mission, sprites were observed by cameras with narrow band filters to measure the N_2^+ 1NG (0,1) band at 4278Å and the N_2 2PG (0,0) band at 3370Å. We discuss the observations, instrumental and atmospheric corrections, and altitude profiles of ionized (1NG) and neutral (2PG) emission observed during a specific sprite. The ratio of ionized-to-neutral emission indicates a relative enhancement of ion emission at altitudes below 55 km. Electron energies are derived from these emission ratios using excitation rates based on both Maxwell-Boltzmann electron energy distributions and the results of a steady state electric field model that solves the Boltzmann equation. The resulting electron energies range from 1.3 to 2.2 eV with the minimum energy near 60 km. In addition, electric field profiles and column electron density profiles have been derived for this sprite. The average electric field above ∼55 km is well below the breakdown field for the atmosphere but below this altitude the electric field follows the breakdown field nearly exactly. The column density shows a broad peak between 59-62 km and drops significantly below 58 km to values ∼100 times less than the peak value. These observations indicate that while ionization appears to be a more significant process at altitudes below ∼55 km, a large amount of energy deposition occurs above 55km.

*The work at NRL was supported by Office of Naval Research and NASA.

AE31A MC: Hall D Wednesday 0830h

Thunderstorm Electrical Effects on the Middle and Upper Atmosphere and Ionosphere II

Presiding: **D D Sentman,** University of Alaska**; V P Pasko,** The Pennsylvania State University

AE31A-0060 0830h POSTER

Terrestrial Gamma-ray Flashes After CGRO: Prospects From HESSI

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Brief (1–5 ms) flashes of gamma-rays coming from the direction of Earth's atmosphere were discovered by the BATSE instrument aboard the Compton Gamma Ray Observatory (CGRO) in 1994. CGRO was deorbited in June 2000, but during its lifetime 75 Terrestrial Gamma-ray Flashes (TGFs) were observed. The source of the photons is generally assumed to lie at atmospheric altitudes of 60–70 km, and to consist of bremmstrahlung radiation from highly relativistic electrons energized by strong mesospheric electric fields overlying thunderstorms.

Because of the high altitude and upward-directed nature of this radiation, neither the gamma-rays nor the assumed causative runaway electron beams can be directly observed except by satellite. To date, no clear optical or in situ electron data exist to shed light on this phenomenon. Since CGRO's demise, there is no longer an orbiting gamma-ray instrument that is well suited for detecting TGF's. We describe the prospects for detecting TGFs with the High Energy Solar Spectroscopic Imager (HESSI), whose launch is imminent. While the BATSE main detectors had an upper energy band of 300 keV – ∼1 MeV, which was too low to resolve the hard (>1 MeV) TGF spectrum, the nine HESSI rear germanium detectors have spectral resolution of 0.1% – 3% up to >10 MeV. In addition, BATSE's triggering circuitry integrated for at least 64 ms (much longer than the duration of a TGF) while the HESSI spacecraft records and telemeters the energy and time of arrival of each photon event. On the other hand, the geometric factor for the HESSI detectors is small compared with that of BATSE. Altogether, we expect a comparable TGF detection rate from HESSI but superior spectral (and temporal) information, which may provide key new evidence for the underlying mechanisms behind TGFs.

URL: http://sprg.ssl.berkeley.edu/∼cpbl/tgf

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Spectral Evidence for Ionization in Air-Filled Glow Discharge Tubes: Application to Sprites

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The question of ionization in sprites and the evidence for VLF backscatter from sprites has motivated a quantitative spectral analysis of the various (classical) regions of the glow discharge tube under DC excitation and at air densities appropriate for sprites in the mesosphere. A PR-650 colorimeter (Photo Research, Inc.) has enabled calibrated irradiance measurements for localized zones along the axis of the discharge tube–in the dominantly blue negative glow, in the Faraday dark space and in the red/pink positive column. Consistent with historical nomenclature, nitrogen first and second positive emission is dominant in the positive column (associated with neutral N_2), and nitrogen first negative emission, with a prominent peak at 4278 A, is dominant in the blue negative glow (associated with ionized $N_2{}^+$). Whereas nitrogen first and second positive emission are also detected in the negative glow, no spectral evidence for ionization (no 4279, no 3914, no Meinel) is found in the red/pink positive column. This negative result is attributed not to an absence of ionization in the positive column, but rather to a sparse population of $N_2{}^+$ relative to neutral nitrogen in this region, and to the prominent emission in the blue part of the spectrum due to nitrogen second positive. A similar interpretation may be appropriate for the time-integrated spectra from the red body of sprites, also lacking direct evidence for ionization.

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Parental thunderclouds of sprites and elves in winter Japan

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