- ## AE11A: Thunderstorm Electrification and Lightning I
- **Monday, 10 December 2018**
- **08:00 - 10:00**

The recent availability of high-quality broadband VHF interferometric data shows the stepping is basically a two-stage process. After being initiated by a fast breakdown event, negative-polarity breakdown develops relatively slowly upward for several hundred meters or so, at which point an energetic, faster IBP occurs that produces a step-like, similar altitude increase.

The New Mexico Tech VHF Broadband Interferometer was operational at the El Reno Regional Airport in Oklahoma between April 27 and June 30 of 2018. This location coincided with the northwest side of the central Oklahoma 3D Lightning Mapping Array. The interferometer utilized three 13-inch flat plate VHF antennas (15-87 MHz bandwidth) arranged in an equilateral triangle with 80 meter baselines. A fast antenna was simultaneously sampled with the VHF at 180 MHz and 16-bit depth. A total of 36 TB of interferometer data was collected from over 24,000 lightning flashes.

Occasional brief and small electric discharges in thunderstorms have been observed before with radio frequency lightning mapping systems. These discharges may last from a few hundred microseconds to a few milliseconds and may show some small spatial extent. In this presentation, we report detailed BIMAP observations of such mini-discharges. BIMAP is deployed at the High Altitude Water Cherenkov (HAWC) gamma-ray observatory in Mexico at 4.1-km altitude, and is significantly closer to lightning activities for overhead thunderstorms as compared to sea-level observations. In a May 20, 2018 storm, numerous mini-discharges have been observed, together with very intermittent inverted intra-cloud (IC) discharges. The mini-discharges typically last a few hundred microseconds to about a millisecond. Detailed interferometric mapping shows that the mini-discharges propagate either upward or downward, apparently due to the local electric field structure for a specific event. Correlated polarization observations show that the mini-discharges start with fast breakdown in the direction of the local electric field and gradually slow down and stop where the electric field diminishes or changes direction. Despite the briefness and small spatial extent, the mini-discharges are similar to the initiating process of otherwise normal lightning discharges.

The FengYun-4A (FY-4A) geostationary meteorological satellite was launched on December 11th, 2016. The Lightning Mapping Imager (LMI) was equipped on FY-4A for total lightning (cloud-to-cloud and cloud-to-ground flashes) observation. It operates at a wavelength of 777.4 nm with 1.875 ms integrated time. The LMI could observe lightning activity continuously day and night with spatial resolution of 7.8 km (sub satellite point) over China region. The product algorithm of LMI was consisted of false signal filtering and clustering analysis.

An asymmetric mesoscale convective system organized and moved through the Severe Thunderstorm Electrification and Precipitation Study observation area in northwest Kansas, USA, on 11 June 2000. This storm has been analyzed by Lang and Rutledge (2006) using radar and lightning mapping array observations. We review *in situ*meteorological and electrical observations from an instrumented armored aircraft that passed northwestward through the convective region and then far out into the trailing stratiform region, reversed course, and returned southeastward back through the stratiform region and out through the convective leading edge. We analyze the microphysical and electrical characteristics of a sloping positive charge layer encountered by the aircraft that extended outward into the trailing stratiform region and reached down as far as the 6km MSL (~-10 C) level. The dominant hydrometeor types in the stratiform region included graupel and rimed aggregates. The ambient electric charge concentration was ~4 nC m^{-3}. Additional observations will be presented at the meeting, along with a discussion of electrification in trailing stratiform regions.

The first two Geostationary Lightning Mappers (GLMs) provide valuable new observations that directly impact operational weather forecast environments. The GLM captures 500 images per second to report lightning occurrence and characteristics throughout the GOES field of view. Both sensors detect intra-cloud (IC) and cloud-to-ground (CG) lightning, but this fundamental difference (radio versus optical) influences the application of these data.
As part of the GOES-16 Post Launch Product Test (PLPT) phase, the Geostationary Lightning Mapper (GLM) data has been rigorously validated by independent reference datasets, and the GLM data quality is now acceptable for supporting the National Climate Assessment (NCA) program. The NASA Marshall Space Flight Center NCA Lightning Analysis Tool (LAT) has been enhanced to ingest GLM L2 data in order to examine the space-based observations of lightning over the continental US.
The long-term goal is on investigating the inter-relationships between lightning and climate, whereas the main focus of this initial study is on making unique GLM-based estimates of lightning nitrogen oxides (LNOx). Greenhouse gas concentrations that influence climate, such as ozone, are affected by LNOx. Conversely, changes in climate, from any causes, can affect the characteristics of lightning (e.g., frequency, current amplitudes, multiplicity, polarity, cloud-top optical amplitude and areal extent, and LNOx production itself). These changes in lightning characteristics, inferred from the US ground-based National Lightning Detection Network™ (NLDN) and from the continuous observations afforded by GLM, can in turn help monitor lightning-caused impacts to humans (e.g., fatalities, injuries, crop/property damage, wildfires, power outages, airport delays, changes in air quality).

Distinct energetic intra-cloud (IC) lightning discharges, including compact intra-cloud lightning discharges (CID) and energetic intra-cloud pulses (EIP), have been proposed to be associated with other severe weather phenomena such as heavy precipitation, hail, strong convection and high wind shear, and terrestrial gamma-ray flashes (TGF), all of which can be a significant hazard to public safety and can cause extensive property damage. Stronger relationships between these energetic lightning types and severe weather, as well as their prevalence in different storm environments, would improve our understanding of severe weather evolution and prediction. The Geostationary Lightning Mapper (GLM) onboard the GOES-East satellite already provides lightning detection from cloud-to-ground (CG) and IC flashes over the Americas, but it is not capable of differentiating between the many types of energetic lightning. In this research, we describe the training and validation of a machine-learned model for predicting energetic intra-cloud (IC) lightning discharges from GLM data not only for finding the prevalence of distinct energetic ICs in different environments, but also as a future tool in the research of severe weather evolution.

In order to build and validate an energetic IC lightning prediction model for GLM data, a truth data source is required. Given the known difference between CIDs, EIPs, and other ICs when observed by LF radio instruments, a database of matched LF and GLM flashes can be used as a truth source for the desired prediction model. A supervised machine-learning algorithm is employed to train the prediction model on GLM level 2 data, which includes area and intensity for flashes and their associated groups and events. The machine-learning solution provides key advantages over other methods for establishing a complex inverse model, such as fast run time once the model is trained, natural statistical representation at the output and robustness against noise. Data from the National Lightning Detection Network is used to remove CG lightning from the GLM data before and after the model training. Once the prediction model is trained, GLM data without CG lightning can be used with the trained model for a prediction of the statistical distribution of CIDs, EIPs, and other ICs for anywhere in the American sector.

The Lightning Mapping Imager (LMI) aboard FY-4A was launched on December 11 2016, one month after the launch of the GOES-16. The LMI was the first space borne lightning observation sensor developed by China. Here, we collect one year’s observation of LMI events and validate its performance with the Lightning Imaging Sensor (LIS) on International Space Sensor (ISS).

Storm-related static fields were significantly larger at both oceanic sites relative to land, due at least in-part to lesser screening by near-surface space charge. Time-evolution of the electrostatic field during storm development and propagation is suggestive of a weak or missing lower positive charge region in many of the storms that initiated over the deep ocean

Winter thunderstorms are characterized by higher production of very energetic lightning strokes and very fast pre-stroke processes indicating presence of strong main negative and weak lower positive charge centres in the thunderclouds

Using optical data obtained by the JEM-GLIMS mission and the ground-based lightning data provided by the JLDN, NLDN, WWLLN, and GEON, we have developed a new method to distinguish the lightning discharge type, *i.e.*, intracloud (IC) discharges, positive cloud-to-ground (+CG) discharges, and negative CG (-CG) discharges. We have analyzed a total of 8354 JEM-GLIMS lightning events and succeeded in identifying 4997 IC discharges, 767 +CG discharges, and 2590 -CG discharges. From this result, we further estimated the IC/CG ratio (Z-value) and clarified its latitudinal, regional, and seasonal dependences. It is found that the Z-value seems to be higher over the continent than the ocean, especially at the areas where the lightning activity is high, *i.e.,* Southeast Asia, Central Africa, and Central America. In addition, the average Z-values in the local summer season is higher than that in the local winter season.

A transient peak in the rainfall intensity was observed with an average time lag of around 2-4 minutes after all the lightning discharges considered in the present study. The corresponding Raindrop Size Distributions depicts presence of high concentration of larger drops after the discharges. Lag correlation analysis shows a correlation of r=0.75 between lightning frequency and rain intensity during a thunderstorm.

The present study suggested that lightning discharges can generate high concentration of ions producing high space charge density inside the cloud. These charges make the precipitation particles highly electrified thereby accelerating the growth mechanism of the liquid phase particles producing high intensity precipitation commonly known as rain gush. The current results provide a basis for parameterization of the electrical processes in rain formation mechanism in weather and climate models.

- ## TUESDAY, 11 DECEMBER 2018
  - ## AE24A: Energetic Radiation from Lightning and Thunderstorms I

- 16:00 - 18:00

Primary Convener Brant Carlson, Amitabh Nag, David Smith, Michael S Briggs

Nikolai Ostgraad, AE24A-01: First half year of TGF observations by ASIM (Invited)

The Atmosphere-Space Interactions Monitor (ASIM) was successfully launched to the International Space Station on April 2, 2018. The ASIM payload consists of two main instruments, the Modular X- and Gamma-ray Sensor (MXGS) for imaging and spectral analysis of terrestrial gamma-ray flashes (TGFs) and the Modular Multi-spectral Imaging Array (MMIA) for imaging and spectral analysis of transient luminous events (TLEs) and lightning. ASIM is the first space mission designed for observations of TLEs and TGFs. Since early June 2018, the MXGS has observed hundreds of TGFs. In this paper we present an overview of the TGF observations during the first half year in operation. Five TGF images are presented with discussion of the Source Location Capability, Source Error and associated deconvolution noise. TGF footprint on Earth surface is plotted together with the lightening data from the GLD360 and WWLLN networks and, optical MMIA lightening data when available. For the TGF images discussed, the average SLE is 1º and the Earth average surface position accuracy is 10 Km, pending on TGF fluency and position in the MXGS field of view. A new field in TGF science is open with the imaging capability of ASIM, accurate correlation between TGF ignition layers, lightening nearby events and thunderstorm cores is now possible.

- ## Teruaki Enoto, AE24A-05: High-Energy Radiation Phenomena from Winter Thunderstorms and Lightning in Japan (Invited)

Winter thunderstorms in Japan provide ideal observation environment for the high-energy atmospheric physics thanks to their low cloud altitude and frequent powerful lightning discharges. We started the Gamma-Ray Observation of Winter THundercloud (GROWTH) collaboration in 2006 at Kashiwazaki, the costal area along the Japan Sea. Since 2015 we have been coordinating multi-point mapping observation campaigns of atmospheric gamma rays at several cities in northern Japan. Newly designed portable radiation detectors are distributed and deployed at local high schools, university, museum, and private companies, with aiming to make our campaign a citizen supporting science project. We have detected 24 long-duration bursts (Tsuchiya et al., 2007 PRL) lasting for typically a minute, as known as gamma-ray glows or thunderstorm ground enhancements, and 14 short spiky events with a typical time scale of ~100 ms (Enoto et al., 2017, Nature). The former is bremsstrahlung gamma rays from relativistic electrons accelerated and multiplied in thunderstorm electric fields. The latter is recently revealed to be clear evidence for photonuclear reactions triggered by lightning discharges. We are constructing multi-wavelength observation site at Kanazawa and Komatsu combining radiation measurements, radio observations, and atmospheric electric field monitoring. I will review our up-to-date status of the project.

- ## Michael Cherry, AE24A-06B: The TETRA-II Experiment to Observe Terrestrial Gamma Flashes at Ground Level – Results from First Two Years of Observation

The TGF and Energetic Thunderstorm Rooftop Array (TETRA-II) consists of an array of gamma ray scintillators to detect bursts of energetic radiation from thunderstorms at ground level in four separate locations: the campus of Louisiana State University in Baton Rouge, Louisiana; the campus of the University of Puerto Rico at Utuado, Puerto Rico; the Centro Nacional de Metrologia de Panama (CENAMEP) in Panama City, Panama; and the Severe Weather Institute and Radar & Lightning Laboratories in Huntsville, Alabama. The original TETRA-I array of NaI scintillators at Louisiana State University detected 37 millisecond-scale bursts of gamma rays at energies 50 keV-2 MeV associated with nearby (< 8 km) thunderstorms. TETRA-II consists of between 11 and 59 BGO and high-resolution $LaBr_3$ scintillators at each site with approximately an order of magnitude greater sensitivity than TETRA-I. The ability to observe ground-level Terrestrial Gamma Flashes from close to the source allows a unique analysis of the storm cells producing these events. Since it began operation in May 2016, TETRA-II has now detected over thirty ground-level bursts. We describe the set of observed events, including the time history and energy spectra, correlation with local radar and radio data, connection with the associated thunderstorm characteristics, and presence of gamma ray lines including lines from nuclear decays and positron annihilation.

- ## Nini Berge, AE24A-07: Modeling Downward-Directed Terrestrial Gamma-Ray Flashes
  - Terrestrial gamma-ray flashes (TGFs) are bursts of high-energy photons originating in the electric fields of thunderclouds. They have been routinely observed by spaceborne instruments since their discovery by the Compton Gamma-ray Observatory in 1994. These TGFs have been shown to be associated with the propagation of upward intra-cloud lightning. Until recently, ground-based observations of TGFs were few and far between. The detections that were made happened in association with rocket triggered or cloud-to-ground lightning. The number of observations of downward-directed TGFs has now greatly increased, as cosmic ray observatories in Utah and Argentina have reported detections of high-energy particles correlated to lightning activity (Abbasi et al., 2017, 2018; Mussa & Colalillo, 2017).
  - The goal of the present work is to demonstrate how observations of TGFs on the ground pose a valuable addition to spaceborne detectors. The proximity to the event, as well as the possibility of observing the same event with several detectors, may reveal new information about the still elusive production mechanisms of TGFs.
  - We present a study of downward-directed TGFs using a Monte Carlo model to simulate photon transport through the atmosphere. In this way, we quantify how differences in timing, geometry, and spectrum of the initial burst would be reflected in ground-based observations. We also compare how time structures seen at ground level translate to observations made at satellite altitude. We show that simulations based on physical models can improve the interpretation of ground-based observational data, leading to a better understanding of TGFs and their production mechanisms.
  - References:

  - Abbasi, R. U., et al. (2017). The bursts of high energy events observed by the telescope array surface detector. Phys. Lett. A, 381(32), 2565–2572.
  - Abbasi, R. U. et al. (2018). Gamma ray showers observed at ground level in coincidence with downward lightning leaders. J. Geophys. Res.: Atmospheres, 123, in press.
  - Mussa, R., & Colalillo, R. (2017), Observation of high energy radiation in the Surface Detectors of the Pierre Auger Observatory in correspondance with lightning strikes. Abstract [AE31A-06] presented at 2017 Fall Meeting, AGU, New Orleans, LA, 11-15 Dec.

- ## MAttew Stanboro, AE24A-08: A Study of Consecutive Terrestrial Gamma-ray Flashes using the Gamma-ray Burst Monitor

The Fermi Gamma-ray Burst Monitor (GBM) has detected over 5000 intense, sub-ms flashes of gamma rays, known as Terrestrial Gamma-ray Flashes (TGFs). TGF pulses have been observed in pairs separated by less than a millisecond to several minutes. We present a study on these time separations. Based on a gap from 10 ms to 1 s in pair time separations, two sets of TGF pairs are found. Below 10 ms, we interpret that the pulses are due to an individual TGF. While after 1 s, the pulses represent distinct TGFs that are from the same thunderstorm system. The latter set may have pairs from individual thunderstorm cells, so a detailed analysis is performed. Using the World Wide Lightning Location Network (WWLLN) and the Earth Networks Total Lightning Network (ENTLN), sferics are identified with individual TGFs in a pair. 51 pairs are found in the data from Fermi-GBM that have an associated sferic from both members. The majority of these pairs have members originating from separate cells in a thunderstorm system, but 10 pairs have geolocations consistent with originating from the same cell. We present these 10 pairs, and the implications they have on their cells. Additionally, their time separations is analyzed to interpret the electric field recharge time based on large-scale electric field production models. An upper limit on the minimum electric field recharge time for a thunderstorm cell to produce an additional TGF is 10 s.

- **Wednesday, 12 December 2018**
- **08:00 - 10:00**
  - ## AE31A: Energetic Radiation from Lightning and Thunderstorms II

- ## Modeling and constraining a gamma-ray glow observed at 20 km altitude during the FEGS/ALOFT campaign

In the spring of 2017 the «GOES-R Validation Flight Campaign» was undertaken with an ER-2 aircraft over the continental United States. The plane, flying at a cruise altitude of 20km, had a scientific payload designed to detect optical signals, electric fields and gamma rays from thunderstorms. On May 8, 2017, the on-board gamma-ray spectrometers could detect a gamma-ray glow event lasting for about 4 minutes over Colorado. It was detected by several spectrometers, including three BGO-based detectors, similar to the ones on-board of the ASIM instrument docked to the international space station. The glow showed a gamma-ray count increase on top of the background of 10 to 40 %, which was rather unexpected from such high altitude (20 km). We present a detailed analysis and modeling of this glow event, by building a model based on the GEANT4 toolkit [1] (for particle propagation and detector simulation), associated with the PARMA code [2] (for cosmic ray generation). We evaluate two hypotheses for the glow generation:

- **A**: large scale (tens of kilometers) electric field starting from the top of the cloud (13 km) towards higher altitudes.

- **B**: kilometer scale electric field inside the thundercloud (8 to 13 km altitude)

We conclude that type **B** configurations, with a strong enough potential difference placed inside a 9-11 km altitude range, give the best fits with the measurement in terms of photon flux increase, energy spectrum and consistency with other measurements (including E-field antennas).

Type **A** scenarios are not theoretically excluded, but require large electric fields that were not measured during the event.

- ## J.Dwyer, AE31A-02B: Ground-level terrestrial gamma-ray flashes produced by upward positive leaders

Terrestrial gamma-ray flashes (TGFs) are bright sub-millisecond bursts of gamma rays with energies extending to many tens of MeV. The vast majority of observed TGFs, measured by spacecraft in low-Earth orbit, are directed upwards and originate from between the main negative and positive charge centers of thunderstorms. In recent years, several downward directed TGF-like bursts of gamma rays have also been measured on the ground, presumably originating from below the main negative charge centers. These events have similar properties as the TGFs seen from space, including similar source luminosities, durations and energy spectra, suggesting the same mechanism(s) may be responsible for the production of the high-energy radiation. It is generally accepted that relativistic runaway electron avalanches (RREAs), accelerated in strong electric fields produced by thunderstorms and/or lightning leaders, are a key component of TGFs. However, RREAs require a large number of energetic seed electrons to be injected into the source region, and it is still not clear how and where these seed particles are generated. Two sources currently under investigation are the relativistic feedback and lightning leader mechanisms. For the former, energetic seed particles are produced by a positive feedback effect caused by backward propagating positrons and backscattered x-rays. For the latter, energetic seed particles are generated by the cold runaway electron mechanism in the very high fields associated with leaders and/or streamers. To investigate TGF produced by upward positive leaders initiated near the ground, a 3-D particle-in-cell (PIC) code is used to model the runaway electron and gamma ray production and propagation via the relativistic feedback and lightning leader mechanisms. Model results will be compared with ground-level TGF observations made at the International Center for Lightning Research and Testing.

- ## Sandra Miarecki, AE31A-07: TOTO-Cheyenne: ionizing radiation from thunderstorms on Cheyenne Mountain

Thunderstorms and accompanying lightning produce ionizing radiation on time scales from milliseconds to minutes. This radiation includes terrestrial gamma-ray flashes, hard X-rays from stepped leaders, gamma-ray glows, and thunderstorm ground enhancements. Recent measurements by Armenian and Japanese researchers indicate that getting up close and personal with the storms might produce more details about the complex processes inside. The US Rocky Mountains afford a unique opportunity to do just that by getting closer to the charge layers. The US Air Force Academy and the Naval Research Laboratory have begun a new project to study the ionizing radiation as lightning strikes near the antenna farm on the top of Cheyenne Mountain, near Colorado Springs CO. Our project is named TGFs On Top Of Cheyenne (TOTO-Cheyenne) and entered Phase I with a trial installation of a small gamma-ray and X-ray detection unit (NaI and plastic scintillators) during the Summer 2018. Phase II, which involves a larger detection unit, is scheduled for deployment during Summer 2019 in the same location. We present our results to-date, including a historical analysis of strikes in the Cheyenne Mountain area.

- ## Christopher Fazano, AE31A-08: Measurement of High Energy Particles (Photons and Neutrons) Produced by the Atmosphere in the American Midwest in Time and Space Using an Array of Detectors--and Connecting those Measurements to Meteorological and Physical Atmospheric Conditions.

Over recent years, researchers studying particle emission from storms have reported a number of astonishing results, including bursts of X-Rays attributed to lightning, sections of thunderclouds glowing in the gamma ray region (so called "gamma glow"), positron annihilation radiation, and even neutrons. These results are important because they provide us with a way of investigating the dynamical properties of a thunderstorm, including the electrification and discharge processes present. In addition, we wish to investigate the temporal and spatial development of atmospheric electricity as storms are born, live, and die. Similarly, we wish to conduct investigations of the dynamics of the atmosphere during weather events that do not usually produce lightning. To understand these and other atmospheric processes, we are in desperate and continuing need of data and analysis to continue our understanding of the dynamics of electricity in the atmosphere, (both inside and outside of storms) taken over a range of spatial locations and at many times. In this presentation, we report on the continuing measurement of atmospheric photons at energies of up to approximately 1500 keV using an array of detectors that are located from eastern Iowa through northern Illinois into north central Indiana. We also report on the development of the ability to measure of neutrons via a specially designed passive detection system that uses the activation of a custom designed aluminum shield that we refer to as a "neutron gamma radiator". We will present the detection of photons from the detector showing its spatial characteristics and we will present preliminary result from our neutron detection. We will connect both of these results to measured meteorological parameters. We discuss experimental challenges, future plans for expansion of our array, additional data needed, modeling needs, and using our array as an outreach tool to connect with high school teachers and students.

- ## AE33A: Energetic Radiation from Lightning and Thunderstorms III Posters

  - **Wednesday, 12 December 2018**
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  - **13:40 - 18:00**

- ## Yuuki Wada, AE33A-3397: Lightning-triggered termination of a gamma-ray glow in a Japanese winter thunderstorm

Gamma-ray glows, referred to as long bursts and thunderstorm ground enhancements, are bremsstrahlung emission of electrons accelerated and amplified in strong electric field inside a thundercloud. Although a lot of such phenomena have been observed by airborne, mountain-top and sea-level experiments, spatial structure and time evolution of the electron acceleration in thunderstorm are poorly understood. Winter thunderstorms along the Japan Sea are an ideal target to investigate gamma-ray glows because low altitude of winter thunderclouds enables us to detect glows at sea level. On 2017 February 11th, our radiation detectors, installed at the northern tip of Noto Peninsula in Japan, recorded a gamma-ray glow lasting for a minute. An atmospheric electric-field monitor suggested that the base of the gamma-ray emitting cloud is negatively charged. The glow was then abruptly terminated by an intercloud/intracloud discharge (IC). A lightning mapping system in the low-frequency band detected a leader development of the IC lasting for ~300 ms and extending up to 60 km wide. The timing of the gamma-ray termination is consistent with the moment when one of the leader passed 0.7 km far from the radiation detectors. This result is interpreted as destruction of the mechanism of electron acceleration in thundercloud by an IC leader . We confirmed that simaltaneous observation of high-energy radiation, atmospheric electric field and radio band is essential for gamma-ray glow studies.

- ## Bagrat Mailyan, AE33A-3398: Spectral analysis of individual Terrestrial Gamma-ray Flashes using Fermi Gamma-ray Burst Monitor data and lightning leader models

Due to high photon rates and low number of counts, studying individual Terrestrial Gamma-ray Flashes (TGFs) can be challenging. Gamma-ray Burst Monitor (GBM) onboard Fermi spacecraft has observed tens of sufficiently bright events, which are suitable for the individual analysis. *Mailyan et al.,* [JGR, 121, 11346, *2016*] for the first time fit individual, bright TGFs with Relativistic Runaway Electron Avalanche (RREA) models [*Dwyer, GRL, 30, 2055, 2003*]. RREA models assume that the TGF-producing electron acceleration takes place in a large-scale electric field in thunderclouds. Alternatively, lightning leader models consider the acceleration of the electrons at smaller spatial scales, at the tips of lightning leaders [*Celestin et al., JGR, 120, 10712, 2015*]. The predictions of the latter models for the TGF beaming geometry show some differences from estimations of the RREA models in homogeneous fields. In this work, we will analyze a large sample of bright Fermi-GBM TGFs in the framework of lightning leader models, making comparisons with previous results from the homogeneous-field RREA models. In addition, we will introduce more precise corrections for the instrumental effects caused by pulse pileup by considering a variable photon rate.

- ## Rasha Abassi, AE33A-3400: Ground-Level Detection of Gamma Ray Flashes from Downward Lightning Leaders

  - Terrestrial Gamma Flashes (TGFs) consist of high-fluence bursts of gamma rays lasting up to a few milliseconds. To date, TGFs have primarily been detected with overhead satellites. The observations have increasingly shown that upward TGFs are generated in the upward-propagating negative leaders of intracloud lightning. Recently, we reported the first evidence that downward gamma ray showers are also produced at the beginning of downward negative cloud-to-ground (-CG) lightning (Abbasi et al., 2018; doi:10.1029/2017JD027931). The observed showers are evidently low-fluence TGFs, thus they provide new information about TGFs near their initiation threshold.
  - The observations were obtained through the unique synergy of the large-area Telescope Array cosmic ray Surface Detector (TASD) with a 3-D VHF lightning mapping array (LMA) and slow antennas (SA) recording changes in the ground-level electric field. The TASD covers 700 square kilometers in southwestern Utah, and currently consists of 507 three square meter scintillators on a 1.2 km grid. Three or more scintillators are required to fire within 8 microseconds in order to trigger readout by the TASD data acquisition system. To date, a total of at least 23 gamma flashes have been identified in bursts of several TASD triggers within a millisecond, and roughly 40 single TASD triggers have been observed in coincidence with LMA, SA or National Lightning Detection Network (NLDN) lightning events.
  - Offline analysis clearly shows that the triggers are caused by gamma radiation produced during the initial breakdown stage of fast, downward propagating, negative lightning leaders. The timing and duration of the TGFs is consistent with the gamma rays being produced by "initial breakdown pulses" (IBPs) at the beginning of intracloud and cloud-to-ground lightning.
  - An expansion by a factor of four in the coverage area of TASD is underway. Also, we recently added fast field-change antennas and a high-speed broadband interferometer to the instrumentation for improved coverage of the expanded TASD, which will enable us to demonstrate conclusively the correspondence of TGFs with IBPs and thus constrain models of TGF production.

- ## AMAhdi Bagheri, E33A-3401: Balloon-Borne Instrumentation for Detection of Gamma-ray Glows from Lightning

Gamma-ray glows are emissions of gamma rays that last from seconds to minutes and are produced by runaway electrons in high-field regions of thunderclouds. The lightning group at the University of New Hampshire in collaboration with the Florida Institute of Technology has designed balloon-based instrumentation for flying into thunderstorms with the aim of detecting such radiation. The instrumentation includes one BGO scintillator coupled to a Sensl J-series Silicone Photomultiplier, two Geiger-Muller tubes, and a low-power lightweight electric field mill, designed and calibrated to measure both polarity and amplitude of the vertical electric field inside the thunderstorm region. The current configuration is capable of measuring gamma rays and charged particles with energies from 100 KeV up to 6 MeV. The insertion of scintillator between GM tubes helps us to differentiate between gamma rays and charged particles. Additionally, with polarity information from field mill, runaway electrons could be differentiated from positrons. We have conducted several test flights of this system during the summer of 2018. In this work, we will present an overview of the instrumentation and discuss preliminary results from the test flights.

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Washington, D.C. | 10–14 Dec 2018

- **William Blaine**, Los-Alamos

- ## AE33A-3402: Simulating Electric Field Effects on Cosmic Ray Particle and Radio Frequency Observations

The presence of over-head electric fields associated with thunderclouds change the energy of passing cosmic ray secondary particles, impacting the responses of ground particle and radio frequency (RF) detectors to cosmic rays. In this work, we use Monte Carlo simulations to examine the particle flux and RF signatures produced by high energy cosmic ray showers propagating to the ground through both clear-weather and storm conditions. We further investigate how the High Altitude Water Cherenkov gamma ray observatory (HAWC) and the Los Alamos Broadband Interferometric Mapping and Polarization observation system (BIMAP), both co-located in central Mexico, would respond to such modifications of cosmic ray shower signatures. With an understanding on these responses, cosmic ray shower co-observations by HAWC, a large particle detector, and BIMAP, with its simultaneous detailed RF frequency and polarization observations, can help probe the electric field properties of over-head thunderclouds.

David Smith, AE33A-3403: The Possibility of the Ground Based Detection of Gamma Rays from the Reverse Positron Beam of a TGF

Some of the gamma rays in a terrestrial gamma-ray flash (TGF) must produce positrons via pair production, which then get accelerated downward through the same field region and create bremsstrahlung gammas of their own. Because the positrons do not multiply themselves by avalanching the way electrons do, there are fewer of them but their average energy is higher; the majority of electrons are introduced near the end of the avalanche region while virtually all of the positrons are accelerated along the entire region. The reverse beam is therefore dimmer but more penetrating, and may be detectable from Earth especially when viewed from elevation.

In 2015 Bowers et al. (2018; JGR 123, 4977) detected a TGF in Hurricane Patricia from an aircraft flying at 2.6km through what they believed to be the downward positron beam. This paper uses the energy spectrum for gamma rays produced by the positrons of a relativistic runaway electron avalanche as simulated by the REAM code, propagated through a model of the Earth's atmosphere in Geant4 (US Standard Atmosphere 1976) to examine the feasibility of detecting a typical upward TGF through its reverse positron beam at various altitudes on the ground. We find that, with patience, modest-sized scintillators on mountains at least as low as 2 km should be able to observe the same TGFs seen from spacecraft.

- ## AE33A-3404: A summary of high-energy radiation events from recent observing campaigns at ground-based sites in Japan, Mexico, and Canada
  - During the peak lightning seasons of 2017 and 2018, the Gamma-ray Observations During Overhead Thunderstorms (GODOT) instrument, an array of scintillators, was deployed in Japan on the western coast during the winter thunderstorm seasons and on Mt. Fuji in the summer. A smaller set of detectors was placed in Toronto, near the CN tower (a frequent source of upward lightning) in the summer of 2017 and as of this writing is in the process of being deployed for the 2018 season. Another pair of detectors is being deployed for the summer 2018 season to the High Altitude Water Cherenkov (HAWC) array in at the top of Sierra Negra Mexico, which also hosted GODOT in the summer of 2015.
  - Due to the low cloud altitude (1-2 km) and frequent lightning discharges of winter thunderstorms on the Japanese coastline, and the high altitude of the HAWC array (4 km), both sites are ideal for ground-based observations of fast Terrestrial Gamma-ray Flashes (TGFs) and the longer timescale gamma-ray events referred to as glows. We will present highlights of the observed high energy radiation events, as well as meaningful upper limits on TGFs from lightning, from the deployments listed above.

- ## Gregory Bowers, AE33A-3410: Co-Observations of Thunderstorm Ground Enhancements by the High Altitude Water Cherenkov (HAWC) array and the Gamma-ray Observations During Overhead Thunderstorms (GODOT) instrument

Overhead thunderstorms can produce significant increases in the background radiation count-rate that can last 10s of seconds to minutes. These count rate enhancements or 'glows' can consist of two components; the always present modification of the incident cosmic ray background spectrum (termed the Modification of Spectrum (MOS) glow), and in the case of sufficiently high field strength, the production of bremsstrahlung gamma-rays from relativistic runaway electron avalanches (termed an RREA glow). We present simultaneous glow observations from both the High Altitude Water Cherenkov (HAWC) array in Mexico, and the co-located Gamma-ray Observations During Overhead Thunderstorms (GODOT) instrument. This is the first observation of a glow by a Cherenkov-Type detector. Both instrument observations are compared to Monte Carlo simulations of cosmic-ray showers propagating through thunderstorm electric fields.

- ## David Smith, AE33A-3413: Is there a thundercloud electric field threshold for terrestrial gamma-ray flash production?

Two lines of evidence suggest that terrestrial gamma-ray flashes (TGFs) may be an "all-or-nothing" affair: the lack of weak TGFs seen from nearby lightning from aircraft and from the ground, and the stacking analysis of RHESSI spacecraft data during times of passage over lightning, which showed a surprisingly weak signal, mostly from TGFs that were radially distant.

The only event seen from the ground that is as bright as the TGFs seen from space and has a well-characterized time history shows a very smooth profile consistent with the catastrophic onset of relativistic feedback. Other, much more common events seen from the ground that appear to associate bursts of gamma-rays with individual leader steps, even those with very high average photon energies like those at the Telescope Array in Utah, are much fainter than TGFs seen from space.

Together, these observations suggest that "true" (bright, smooth) TGFs are a threshold phenomenon based on the onset of feedback, and a rare one, while a fainter class of event, using only seeds generated by the leader with varying degrees of runaway acceleration and avalanching, but without significant feedback, is a common phenomenon.

We present data from two very similar upward lightning flashes initiated from a tower in Uchinada, Japan, during winter thunderstorms on 2015 December 3. One produced a fully bright TGF, while the second produced no gamma-rays at all, with an upper limit 10,000,000 times fainter than the derived brightness of the other flash. This alone suggests that TGFs are a threshold phenomenon. Even more significantly, in the event with a TGF, the upward positive leader approached a thundercloud producing a gamma-ray glow, while for the event without a TGF, no glow was in progress. This suggests that it may be the thundercloud field being above the feedback threshold, and no particular characteristic of the leader, that predicts whether a TGF takes place.

As these were positive leaders, it is not clear how they would go about injecting seed electrons into the thundercloud, which is more natural for "ordinary" upward TGFs seen from space, where the leader is negative. Since upward positive leaders have no difficulty producing bright TGFs, this may be another point in favor of a feedback-dominated model, which has no similar asymmetry with the sign of the leader charge.

Primary Convener

- Timothy J Lang
  - *NASA Marshall Space Flight Center*

Wednesday, 12 December 2018

16:00 - 18:00

- AE34A: High-Resolution Observations and Modeling of Physical Phenomena Involved in Cloud Electrification and Lightning eLightning