The A/D converter owns three channels, and can capture at most 2048 VHF pulses for one lightning flash with 200MHz sampling frequency. The time window for one VHF pulse is 2.5 microseconds, and it is sufficient to record VHF pulses radiated from lightning. They carried out field campaigns during summer thunderstorm seasons, and captured a lot of data. The location of 3D VHF radiation sources has been accomplished. Basically one VHF pulse in one time window gives us the continuous development image of lightning discharge. Two or three VHF pulses are eventually noticed in a 2.5 microseconds-window. Though we speculate it may be the evidence of the bi-directional leader concept, the interpretation in terms of the data analysis is not completed yet. They intend to compare VHF broadband interferometer observations with a Doppler radar data to confirm the performance of the system. They conclude tentatively that the function of the system is working well, and the VHF broadband interferometer for lightning monitoring is accomplished with high accuracy from the aspects of time and space.

AE22A-1117 1330h POSTER

Los Alamos Sferic Array 1998-2003: Results, Array Status, Data Processing and Calibration

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The Los Alamos Sferic Array (LASA) network of fast electric-field-change meters has operated in several configurations during the past five years. This presentation describes the array operations including calibration issues and methods. We will include a summary of 'lessons learned' from the array operations. The routine processing algorithms will be described in detail. Comparison of LASA lightning observations with other detection systems will be updated to cover the entire 5 years of data. The changes in the array operations which have been possible due to improvements in technology will be noted, and directions for future array improvements will be presented.

URL: http://edot.lanl.gov

AE22A-1118 1330h POSTER

Comparison Study of LIS and EDOT Lightning Detection

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LIS is a NASA space borne sensor that identifies the optical emissions of lightning emerging from the top of thunderstorm clouds. LIS data is organized into pulses and then into flashes to produce a product that measures total lightning. EDOT is a ground-based network of "fast antennas" that detect electric field changes. This network is owned and operated by Los Alamos National Lab and currently deployed primarily in Florida. EDOT uses time-of-flight measurements to calculate the source location, time, peak current, event-type classification and, in some cases, emission height. LIS and EDOT lightning parameters complement each other. The calculated instantaneous footprint of LIS defines a subset of EDOT events for Florida and the surrounding seas. Subsets of other available lightning data were also created for the LIS field of view. The subsets are cross-linked to match EDOT events to a specific LIS flash. EDOT events classified as cloud to ground lightning and narrow bipolar events are of particular interest. Both spatial-temporal correlations and anti-correlations will be presented.

AE22A-1119 1330h POSTER

Full Wave Analysis and Observation of Spherics Generated by Lightning

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We have developed a simple and cheap system with just a single VLF electromagnetic (EM) receiver to locate lightning discharges, which can determine both the direction and range of each lightning return stroke. With this system, we observe wave forms of two horizontal magnetic fields and of one vertical electric field of VLF spherics. The wave form of each VLF spheric usually consists of a couple of sequential pulses. The first pulse comes directly from a lightning return stroke, and is used for the direction finding of the stroke. The second and later pulses represent the multiple reflections of the first pulse between the ionosphere and the ground. The difference in the time-of-arrival of each set of adjacent pulses is determined by the difference in their multi-hop propagation path lengths in the Earth-ionosphere waveguide. By using the time-of-arrival differences between two or more pulses, we can inversely estimate both the reflection height of the ionosphere and the range of the lightning stroke. In this study, in order to quantitatively evaluate the observed spheric wave forms, we compute the propagation of the electromagnetic pulses (EMP) radiated by lightning current strokes by using the full wave method including the ionosphere and the ground, and compare their characteristics with the actual observations.

AE31A MCC: 3020 Wednesday 0800h

The Physics of Lightning and Storm Electrification II *(joint with A, NG)*

Presiding: **A R Jacobson,** Space and Atmospheric Sciences Group, Los Alamos National Laboratory**; L D Carey,** Texas A&M University

AE31A-01 0800h INVITED

Lightning Initiation by Runaway Air Breakdown

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The maximum macroscopic electric fields measured in thunderstorms are generally found to exceed the threshold for runaway breakdown and lie below the threshold for initiating conventional breakdown. In order for the conventional process that has been studied extensively in the laboratory to initiate lightning discharges it is necessary therefore to invoke the existence of field enhancements (e.g. around water droplets) in the thunderstorm electrical environment. On the other hand, the recent measurements of penetrating radiation in association with the leader activity that precedes a return stroke in natural lightning and triggered lightning have confirmed the importance of runaway breakdown in lightning discharge physics as a whole. In this talk we examine the potential role of runaway breakdown in initiating lightning. Several mechanisms are proposed including the initiation of an intra-cloud lightning discharge by an extensive energetic ($>10^{15}$ eV) cosmic ray shower (CRS). The results of first principles, fully electromagnetic, 2-D simulations of these various initiation mechanisms are presented. Conventional breakdown is found to develop in the field enhancement that occurs at the tip of a propagating positive streamer initiated by the combination of runaway breakdown and a CRS. The radio frequency emissions calculated for these discharges resemble the narrow bipolar pulses that have been associated with lightning initiation. The theory of runaway breakdown will be contrasted against conventional breakdown and the implications of our results for lightning initiation will be discussed.

AE31A-02 0830h

Observations of Runaway Breakdown in Thunderstorms: Where We've Been, Where We Are and Where We Need to Go

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The search for energetic electrons associated with thunderstorms began with C.T.R Wilson's original hypothesis in 1925. With varying degrees of success, numerous investigators have attempted to verify this hypothesis through ground-based measurements as well as *in-situ* measurements using balloons and aircraft. Over the past two decades, more advanced theories for energetic electron avalanches (Runaway Breakdown) have been proposed. Also during this time, more advanced measurement techniques have been applied in the effort to confirm or refute the presence of runaway breakdown in thunderstorms. These recent measurements indicate that energetic electrons indicative of runaway breakdown are present in lightning (step-leaders and dart-leaders) as well as near charge centers of thunderstorms. Since we have so few observations, additional measurements of energetic electron processes inside thunderstorms are certainly needed. However, this area of observational research appears to be ready to move beyond pure phenomenology and can begin to shape the next generation of runaway breakdown models. Conversely, we need to use current models to improve the next generations of observations.

AE31A-03 0845h

Laboratory Investigation of Positive Streamer Discharges From Simulated Ice Hydrometeors and Possible Relevance to the Problem of Lightning Initiation

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Observations have demonstrated that lightning can begin at very high altitudes at which environmental temperatures are well below -18°C, yet previous laboratory studies of positive streamer discharges from ice hydrometeors have been taken as evidence that ice hydrometeors at these cold temperatures likely do not contribute significantly to lightning initiation. The results of a new laboratory investigation indicate that simulated ice hydrometeors at temperatures as low as -38°C can initiate positive streamer discharges; however, relatively strong electric fields are required. Among many hypotheses for lightning initiation, we are concerned with two possibilities: 1) the hydrometeor-initiated intensifying positive streamer system, whereby a relatively weak (but still stronger than observed) background electric field can be locally intensified to levels believed sufficient for lightning leader formation, and 2) runaway breakdown, an alternative means of local electric-field enhancement that requires background electric-field strengths comparable with observational evidence. During the course of the laboratory investigation, a third possibility came to mind: perhaps reality is better explained by a combination of these two hypothesized processes. Perhaps an initial runaway electron avalanche need only result in a local electric-field enhancement sufficient to support initiation of positive streamer discharges from nearby hydrometeors. If so, any initial positive streamers should intensify rapidly and branch, resulting in significant electric-field enhancement at their origin. The positive feedback on the electric field should cause a succession of intensifying positive streamer systems, further enhancing the local electric field to strengths sufficient for the formation of a bipolar leader in a manner similar to that of the negative stepped-leader 'step'. Then perhaps this small bipolar leader could serve as

the embryonic lightning discharge, proceeding to develop in a bipolar fashion up to the scale of typically observed lightning flashes. This paper presents results of the laboratory investigations.

AE31A-04 0900h INVITED

The Severe Thunderstorm Electrification and Precipitation Study (STEPS)

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During May-July 2000, the Severe Thunderstorm Electrification and Precipitation Study (STEPS) was conducted in the High Plains, near the Colorado-Kansas border, in order to achieve a better understanding of the interactions between kinematics, precipitation, and electrification in severe thunderstorms. Specific scientific objectives included: 1) understanding the apparent major differences in precipitation output from supercells that have led to them being classified as low-precipitation (LP), classic or medium-precipitation, and high-precipitation; 2) understanding lightning formation and behavior in storms, and how lightning differs among storm types, particularly to better understand the mechanisms by which storms produce predominantly positive cloud-to-ground (CG) lightning; and 3) to verify and improve microphysical interpretations from polarimetric radar. The project involved the use of a multiple-Doppler and polarimetric radar network, as well as a time-of-arrival VHF lightning mapping system, the T-28 armored research aircraft, electric field meters carried on balloons, mobile mesonet vehicles, instruments to detect and classify transient luminous events over thunderstorms (TLEs; e.g., sprites and blue jets), and mobile atmospheric sounding equipment. The project was a major success, gathering unprecedented data on a wealth of diverse cases, including LP storms, supercells, and mesoscale convective systems, among others. Many of the storms produced mostly positive CG lightning during their lifetimes, and also exhibited unusual electrical structures such as a possibly inverted dipole. The 29 June supercell case has received considerable study to date including the analysis of polarimetric radar data to demonstrate couplings between storm dynamics and the formation of hail and graupel, which lead to formation of significant positive charge in the mid-levels and copious amounts of positive cloud-to-ground lightning. The charge structure in the 29 June case, along with several other STEPS cases, contained charge structures that deviated from the standard tripole charge arrangement. Work is also under way to analyze the MCS event on 11 June, in particular, to better understand the mechanisms leading to positive CG lightning in the trailing stratiform region.

AE31A-05 0930h

Positive cloud-to-ground and other horizontally propagating lightning in the convective line and stratiform rain regions of a MCS observed during STEPS

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We report on an asymmetric mesoscale convective system (MCS) that occurred on 11 June 2000 during the Severe Thunderstorm Electrification and Precipitation Study (STEPS), which took place along the Colorado-Kansas border. This system passed through both dual-Doppler lobes of the CSU-CHILL and S-POL polarimetric radars, and produced a large number of lightning flashes (up to 1 flash per second), which were observed by the New Mexico Tech Lightning Mapping Array (LMA) and the National Lightning Detection Network (NLDN). Many of these were positive cloud-to-ground lightning flashes (+CGs) that came to ground in both the leading convective line and trailing stratiform rain region of the MCS. A significant percentage of these +CGs propagated over large horizontal distances (10s of km) within the stratiform region. However, great variety was observed within this subset, including +CGs that came to ground in the stratiform after initiating in the convective line, +CGs that initiated and came to ground in the convective line but tapped large charge reservoirs in the stratiform, and +CGs that initiated and came to ground within the stratiform region alone. There also were a number of intracloud flashes that propagated over long distances within the stratiform region. Polarimetric and dual-Doppler data from the two radars are used to characterize the kinematic and microphysical structure of the MCS, including the charge reservoirs tapped by these horizontally propagating lightning flashes. Results are compared to present MCS electrification theory.

URL: http://radarmet.atmos.colostate.edu/~tlang/11jun00/

AE31A-06 0945h

Lightning Modes in Thunderstorms

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The Lightning Mapping Array (LMA) shows the complete sequence of lightning discharges in convective storms and has expanded our understanding of the types of lightning discharges that can occur in the storms. In addition to the intracloud (IC) and cloud-to-ground (CG) discharges of normal-polarity storms, which occur between the mid-level negative and upper positive charge regions, and between the negative charge and ground, the LMA data show with surprising clarity the presence of lower positive charge in the storm, with some CG flashes discharging lower positive charge on their way to ground and others going straight to ground. In addition, the data also show the occurrence of 'low-altitude' ICs between the mid-level negative and lower positive charges, that do not go to ground. Finally, the observations delineate the mechanism of 'bolt from the blue' type flashes, which begin as normal-polarity upward-developing IC discharges in which the upper positive charge appears to be weak in comparison to the mid-level negative charge, resulting in the negative breakdown exiting the side of the cloud (through apparent positive screening charge along the radar cloud boundary) and going to ground as a -CG up to 5 or 10 km away from the storm center. Such discharges are surprisingly common and are even sometimes the dominant CG lightning type of a storm. The above behaviors of the lightning can be explained in terms of the relative amounts of the positive and negative charges in the different parts of the storm. The question as to what types of discharges will be occurring can be explained in terms of the energy of the storm charge distribution and how the energy would be changed by the different types of discharges, with the discharge types tending to be the most energetically preferred ones as time progresses. In addition to the above 'normal-polarity' lightning types, the LMA observations show where positive CG (+CG) discharges originate and how they develop inside a storm. They have also revealed the surprising occurrence of inverted-polarity IC discharges between main mid-level positive charge and upper negative charge. Inverted polarity ICs are the dominant lightning type in anomalously electrified storms and provide a good indicator of the anomalous electrification. The anomalous storms tend to be supercell or severe storms, but not all such storms are anomalously electrified. The discharges sometimes indicate a complex, rapidly evolving, multilayer charge structure but often indicate simple, inverted-type dipolar structures in which relatively shallow negative charge is above a dominant, deeper positive charge. The anomalous storms can go for long periods of time (or for their entire lifetime) without producing CG discharges, something that does not occur in normally electrified storms. The inverted polarity ICs can be bi-level in nature or can propagate large vertical distances downward through the storm precipitation, something never seen in normal-polarity ICs. Finally, the LMA has provided greatly expanded observations of short-duration (sub-ms) discharges in storms. The short duration discharges are temporally isolated and can occur as precursor events to full-fledged lightning or as spatially limited or attempted breakdown events. They occur much more commonly in anomalous than in normally electrified storms, and are associated with the upper negative charge region and convective surges in the anomalous storms. A more complete understanding of the short-duration discharges should provide important clues about the processes by which lightning is initiated in storms.

AE31B MCC: 3020 Wednesday 1020h

Advances in Lightning and Atmospheric Electricity Remote Sensing Systems and Algorithms II

(joint with A)

Presiding: **M Murphy,** Vaisala, Inc.**;** **D J Boccippio,** NASA Marshall Space Flight Center

AE31B-01 1020h INVITED

Overview of Current Lightning Detection Systems

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We give an overview of the techniques that are currently used in both ground-based (e.g. NLDN, LDAR/LMA, SAFIR) and satellite-based (e.g. OTD, LIS, FORTE) lightning detection systems, the key performance parameters (e.g. Detection-Efficiency, Location-Accuracy, and False Reports), and the algorithms that each system uses to time-tag lightning "events" and count "flashes" and "strokes."

AE31B-02 1040h INVITED

Improving Regional and National Weather Operations with New Lightning Mapping Technologies

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Technology now provides several options for mapping lightning over large regions. The present U.S. National Lightning Detection Network (NLDN) maps lightning ground strike points over continental distance scales, including substantial distances over oceans, and its capabilities are being expanded to map some cloud flashes. VHF time-of-arrival or interferometer networks map all lightning in considerable detail to a range of roughly two few hundred kilometers and are capable of countrywide coverage. VLF networks have demonstrated ability to map lightning globally, including over all oceans. And the demonstrated capability of satellite lightning mappers also could provide global coverage. A major application of these systems at present is thunderstorm detection to help mitigate effects of the lightning hazard itself and of other storm hazards. Thunderstorm detection is particularly valuable in the large regions where radar coverage is poor and not feasible, such as over oceanic and mountainous regions and in impoverished or sparsely populated countries. Though some mapping technologies, such as VLF systems and the present NLDN, are capable of detecting only one or a few points per flash and have a strong bias toward cloud-to-ground flashes, all mapping systems detect thunderstorms adequately for many purposes, including simple data assimilation into numerical weather forecast models. However, storms can be delineated much more quickly, reliably, and clearly by technologies that map all types of lightning and map several pixels or many points per flash. Such mapping systems reveal storm structure comparable in many ways to the structure provided by conventional radars. Depending on the storm and on the technology used, it is possible to map storm features such as overshooting storm tops, rising concentrations of lightning activity apparently reflecting rising updrafts, v-structures at storm top caused by flow around the obstacle presented by strong storm updrafts, sparse-lightning holes in the updraft cores of supercell storms, cores of large lightning density resembling the reflectivity cores of cells, and the maturation of the stratiform precipitation region of mesoscale convective systems, which produce much of the rainfall and flooding in the central United States. However, it is relatively difficult for weather forecasters to incorporate much information from lightning data into their forecasts when using only raw, real-time lightning locations. More research is needed to help extract or summarize information from the lightning data and present it in a form easier for forecasters to digest. Another area in which lightning data can contribute is data assimilation into numerical weather models to improve their forecasts. Research has demonstrated that lightning data can be assimilated into forecast models in much the same way as radar data are, but lightning data could readily be available over large regions of the globe where obtaining radar data is not feasible. Besides improving the initialization of the model by improving the location and extent of storms when the model begins its forecast cycle, a process that itself still can be improved, lightning data could be