Title: Electrification in Winter Storms and The Analysis of Thunderstorm Overflight Data

N93-20087

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Background of the Investigation: We have been focusing our study of electrification in winter storms on the lightning initiation process, making inferences about the magnitude of the electric fields from the initial pulses associated with breakdown, i.e., with the formation of the initial streamers.The essence of the most significant findings is as follows: 1) Initial breakdown radiation pulses from stepped leaders prior to the first return stroke are very large, reaching values of 20-30 Volts/meter, comparable to return stroke radiation. 2) The duration of the stepped leader, from the initial detectable radiation pulse to the return stroke onset, is very short--ranging from a minimum 1.5 ms to a maximum of 4.5 ms. These values should be contrasted with the published durations of stepped leaders from summer storms which fall in the range from 6-20 ms. The difference in duration is significant in that the radiosonde soundings for summer and for winter storms show only a 20-30% difference in the height of the -10 degC to -20degC region which is where the lightning charge is found to accumulate. This difference in height cannot account for the difference in duration of the stepped leader (a factor of 2-3) between winter and summer storms. Obviously, the velocity of the leaders in winter storms must be greater by a factor of 2-3 than the leaders in summer storms.

This past summer (June-August of 1991) we participated in the CAPE program at the Kennedy Space Center in order to acquire data on stepped leaders in summer storms with the same equipment used to get the winter storm data. Our efforts were certainly worth while, because we discovered that the vigorous leaders seen in winter so frequently were present in summer storms, although not as large in amplitude and certainly not as frequent. The analysis of the large amplitude radiation pulses from these summer storms continues at this time, and the conclusions cited earlier with regard to the differences between summer and winter leaders remain unaltered.

It is reasonable to attribute the striking difference in the two types of leaders to the value of the breakdown electric field inside the cloud, i.e., the maximum value of the electric field which can be sustained without the initiation of a discharge. In looking for a different set of in-cloud conditions between summer and winter which might have a major role in influencing the breakdown field we are immediately drawn to the hypothesis that it is the precipitation mix that determines, almost exclusively, the value of the breakdown electric field. Many laboratory studies have been done on the influence of water drops on the breakdown field, and an elegant theoretical and laboratory study was published by G. I. Taylor in 1965. The size of water drops affects the breakdown electric field: larger drops lower the breakdown potential gradient; a factor of 2 increase is acheived in going from 2.4 mm rad drops to 1.2 mm rad. A temperature dependence, though less noticeable, is also present. Surface tension is a function of temperature, and increases with decreasing T.

Ice crystals, also present in the -10 degC to -20 degC region, are not as active in lowering the breakdown potential gradient. Although ice crystals may provide corona, their resistivity is too high to maintain the electric field at the tip after the emission of charge. In general, it has been found that ice crystals initiate breakdown at much higher fields than do water drops. The subject of the influence of ice crystals on the electric breakdown is far from complete and is in need of further study.

A check on the above hypothesis was possible for the Albany winter storm during which time a sounding was taken at the Albany Airport. We were able to determine that in the region of -10 degC to 20 degC the vapor pressure was saturated with respect to ice. Thus there was no liquid water present to lower the breakdown potential gradient; only the ice phase populated the charge accumulation region! This result has important implications related to electric charge separation in clouds, as well as implying that charge storage per unit volume in winter storms can exceed that possible in summer storms.

Significant Accomplishements of the Past Year: We have been able to strengthen our original hypothesis that electric fields in winter storms are higher than they are in summer storms by considering the influence of the precipitation environment in the region of electric charge accumulation. We have been able to propose a reasonable rationale for the observed fact that lightning strokes from winter storms are more destructive and carry larger currents than do the stokes in summer. Stronger fields imply greater charge density, and since the energy stored is proportional to the square of the electric field, we would expect more destructive currents. This result is completely consistent with both aircraft-triggered lightning-damage statistics, and with powerline-damage statistics.

We participated in the analysis of an unusual video photograph (Boeck,et.al.1992) taken from the space shuttle at night which shows an enhancement in the luminosity of the airglow layer directly above a lightning flash which occurred simultaneously within the uncertainty of a video frame. This is the only observed occurence of apparent ionospheric ionization produced by thunderstorm activity 100 km below the airglow layer. If it is not spurious, it demonstrates the existance of an energy coupling mechanism from the troposphere to the ionosphere. We were able to show that the enhancement did not result from return stroke radiation but more likely from one of the horizontally oriented vigorously radiating stepped leaders discussed earlier in this report.

At KSC we also recorded lightning flashes as ground truth for the ER-2 and the Lear jet aircraft doing cloud overflights as part of the CAPE program. As a result of the large amount of good electrical data we obtained it will be possible to get good correlations with the New Mexico Tech Wideband Noise and Coherent Radar and with the NCAR CP-2 Radar. The NMTech interferometer was also operated at the same time, making these data an unusual set for the analysis of electrical-precipitation interactions. All of the 7500 lightning flashes have now been plotted for cursory examination. We are also in the process of looking at the triggered lightning data, correlating that set with the excellent streak camera photographs of Dr. Vincent Idone of the State University of New York at Albany.

Focus of Current Research and Plans for Next Year: If funding is forthcoming, we plan to continue with several activities already in progress.

1) continue the analysis of both winter and summer initial leader data to further clarify the role of precipitation in limiting the maximum value of electric field strength in clouds. We should also like to collaborate with John Latham of the University of Manchester and with Alan Blythe of NMTech in designing laboratory experiments to study the role of ice crystals in in initiating electrical breakdown in clouds.

2) We plan to correlate our lightning measurements with the NMTech Radar and Interferometer data. A particular question of interest to be addressed is: How does a lightning discharge in a volume seen by the radar and the interferometer affect precipitation growth? This is an important question which can now finally be addressed with our dual polarization radar. This radar sees the ionized lightning channels without significant precipitation background clutter in the crosspolar channel, while the copolar channel sees the precipitation echo as normal. We have seen the growth of an echo after lightning, and with circular polarization it has been possible to watch the crystals align with the electric field (induced dipoles) and to see them disalign after lightning. We have not yet put all the data together to see whether electric fields provide enhanced forces for accelerated coalescence of droplets, thus promoting droplet growth. We intend to use these data to study this question.

3) As a result of a workshop discussing the possible role of lightning measurements in the TOGA-COARE program in the South Pacific, we are preparing one of our instrumental systems for use in Kavieng, New Guinea in conjunction with a 3 or 4 station array of LLP direction finders. The direction finders will be modified by LLP to higher sensitivity for use up to distances of 900-1000 km. I have prepared lightning waveforms recorded from those approximate distances to test the modified instruments. We shall be working with Drs. E. Phillip Krider and Charles Weidman to synchronize time between the direction finders and my waveform recorder. Although the instrumentation is NASA funded, a proposal for travel expenses and some analysis has been submitted to NSF by Drs. Ed Zipser and Dick Orville of Texas A&M. I have agreed to donate about three weeks time to setting up the instruments in Kavieng and training a student to operate them.

4) Finally, we want to return to finish the study of the origin of the 'slow tails' to identify the type of lightning flash which produces them. This requires 2 stations, and we hope to operate a pair in either Albany or Socorro with a station in Huntsville. The slow tails may be a unique identifier of continuing current lightning which is estimated to start about 95% of all forest fires.

Publications

1) A paper entitled "Electric Fields in Winter Storms" was given at a US-JAPAN workshop on 'Lightning in Winter Storms' and will be published in "Letters in Atmospheric Electricity, a Japanese journal.

2) A paper entitled "Breakdown Electric Fields in Summer and Winter Storm-Clouds: Inferences Based on Initial Lightning Leader Waveforms" has been submitted for presentation at the St. Petersburg International Conference on Atmospheric Electricity. It will be presented for me by Dr. John Latham. The paper is being expanded to include additional work on the role of precipitation in breakdown and to include better statistics of summer-storm stepped leaders.

3) Boeck,W.L.,O.H.Vaughan,Jr., R. Blakeslee, B. Vonnegut, and M. Brook, Lightning Induced Brightening in the Airglow Layer, Geophys. Res. Lett., 19, 99-102,1992.