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EXPLORATORY MEETING ON ATMOSPHERIC ELECTRICITY AND SEVERE STORMS

The summary of a meeting held April 10-11, 1978,
at NASA/Marshall Space Flight Center

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ACKNOWLEDGMENTS

The interest and initiative of the participants in the meeting and its potential are gratefully acknowledged. The support of Mr. Jim Hughes, Office of Naval Research, which permitted the attendance of several participants is also acknowledged,

I. INTRODUCTION

This document summarizes the Exploratory Meeting on Atmospheric Electricity and Severe Storms which was held April 10-11, 1978. The motivation for this exploratory meeting on atmospheric electricity and its relationship to severe storm development, growth, and intensity resulted from the recently developed goals and objectives of the Severe Storms Research Program of NASA's Office of Space and Terrestrial Application. The applicable goals and objectives of NASA's Severe Storms Research Program will be restated to set the frame of reference for this report. It is within this framework that the future courses of action relative to the development of space technology for observation and measurement of atmospheric electrical phenomena will be developed for support and sponsorship by the Severe Storms Research Program,

The goal of the Severe Storms Research Program is: "to aid the responsible storm forecasting agencies in improving the accuracy and timeliness of severe storms forecasts and warnings through research and development that combines aeronautical and space-related techniques and observations with other key indicators of severe storm development." This will be accomplished through the sponsorship of severe storms research and development to improve the basic understanding, instrument development, data interpretation technique development, and forecast model development. Atmospheric electricity is an integral part of severe storms and the meteorological phenomena associated with their development, growth, and intensity. Electric and electromagnetic signals (sferics) are nature's best indicators for remote sensing of severe storms. Thus, the study of atmospheric electricity provides the opportunity to help accomplish the program objectives associated with the conduct of applied research for understanding storm development, development of new space technology storm severity indicators, demonstration of utility of analysis and interpretation techniques, and development of severe storms models to enable improvement of storm forecasting and lightning hazard warning capabilities.

The exploratory meeting was initiated as a result of the interest created in part by (1) a proposal by Dr. B. Vonnegut [1] and the subsequent selection of a lightning survey experiment for flight on an early Space Shuttle mission, (2) data acquired from the OSO and DMSP satellites [2,3], (3) NASA workshop discussions in the solar-terrestrial area [4] which implicate atmospheric electricity as a potentially significant

coupling mechanism, (4) a brief paper (Appendix A) by Dr. Be Vonnegut concerning the need for satellite observations of lightning, and (5) NASA's desire to explore the relationship between atmospheric electricity and severe storms in more depth. Accordingly, this meeting was arranged to discuss atmospheric electricity and its relationship to severe storms, the feasibility of developing a set of instruments for either a Space Shuttle or an unmanned satellite, and the scientific rationale which would warrant further in-depth assessment, involvement and development of supporting activities by NASA. The subject of atmospheric electricity involves a large number of applied and basic scientific interests among many investigations. This meeting was of an exploratory type because of the limitations on resources and time. NASA plans to sponsor a more extensive workshop. Fortunately, several of the leading investigators in the area of atmospheric electricity and severe storms were able to attend and contribute to the meeting. They included:

Dr. Marx Brook, New Mexico Institute of Mining
and Technology

Dr. Heinz Kasemir, NOAA/Atmospheric Physics and
Chemistry Laboratory

Dr. Richard Orville, State University of New York
at Albany

Dr. David Rust, NOAA/National Severe Storms Laboratory

Dr. Patrick Squires, NCAR/Convective Storms Division

Dr. Bernard Vonnegut, State University of New York
at Albany

The agenda for the meeting and a list of attendees are included as Appendix B.

II. DISCUSSION

Many of the fundamental questions in atmospheric electricity remain unanswered. These were reviewed by the participants, and a list was developed to provide a basis for future discussions and development of space technology applications. The application of information on atmospheric electricity and its associated phenomena, based upon satellite

observations, to the identification of severe storm development, growth, and intensity depends on our ability to relate the atmospheric electricity measurements as key indicators. Some of the questions which are important for a satellite sensor system, whether based on sferics in the radio frequency region or on optical or other observations from photometers, etc., involve the following topics:

- (1) Lightning flashing density determination
- (2) Lightning flashing rate determination
- (3) Discrimination between signals, received by sensor
- (4) Cloud-to-ground and intracloud discharges
- (5) Amplitude versus frequency--spectroscopic signatures
- (6) Applicability of radio frequency data received at satellite altitude due to ionospheric critical frequency constraints
- (7) Ability to accomplish essentially real-time data management, discrimination, and transmission
- (8) Relationship of measurable atmospheric electricity characteristics to severe storm development, etc.
- (9) Spatial and temporal resolution of observed characteristics
- (10) Ability to provide correlative field experiments and associated data
- (11) Applicability of measured parameters to model developments and applications
- (12) Need for answering fundamental problems in atmospheric electricity before meaningful application of observations can be made

Obviously, these topics need to be explored in more detail, better defined, and, where possible, addressed in terms of their importance for application to a meaningful severe storms atmospheric electricity satellite measurement project. However, all participants agreed that a better knowledge of

atmospheric electricity and its role in the development of severe storms would result from the application of space technology.

The discussion at the meeting encompassed several on-going NASA programs which might have immediate applications and utility to atmospheric electricity. In addition to the experiment on nighttime/daytime optical survey of lightning [1] by Dr. B. Vonnegut (State University of New York at Albany) and Mr. O. H. Vaughan (NASA/Marshall Space Flight Center) scheduled for an early Space Shuttle flight, a planned Space Shuttle/Spacelab 1 flight experiment involving a low-light-level TV sensor and entitled "The Atmospheric Emission Photometric Imaging (AEPI) Experiment" was presented by Dr. David L. Reasoner, NASA/Marshall Space Flight Center. The planned tethered satellite concept for flight on a future Space Shuttle was reviewed by Dr. C. Lundquist, NASA/Marshall Space Flight Center, and follow-up discussions were held on this subject. As a result, Dr. Heinz Kasemir, NOAA/Atmospheric Physics and Chemistry Laboratory, participated in the Tethered Satellite Workshop held May 2-3, 1978, in Huntsville, Alabama, under sponsorship of NASA and the University of Alabama in Huntsville.

The discussion section of this report has been organized to provide (1) a summary of some primary scientific questions on atmospheric electricity identified at the meeting and (2) the comments received from the principal scientific participants for inclusion in this report.

A, Primary Scientific Questions

The two main scientific areas of atmospheric electricity are the global circuit and the generator aspects. Several of the primary scientific questions of concern within each of these areas were identified.

1. Global Circuit.

- (1) Are thunderstorms the generators?
- (2) What is current flow in the ionosphere?
- (3) What is the coupling between the lightning electromagnetic field and the whistler mode?

- (4) At high altitudes can the effects of the thunderstorm on the electric field be distinguished from other effects; for example, the influence of changes in the magnetosphere?
- (5) What are the inputs to circuit from other sources?
- (6) What is the role of the fair weather field with respect to charge generation in thunderstorms?

2. Generator.

- (1) Where is negative charge located in a cloud, and how did it get there? How does a cloud produce electricity (cloud dynamics, circulation, precipitation mechanisms, etc.)?
- (2) Is charge carried on precipitation particles or well distributed on smaller cloud particles?
- (3) What are the interactions between electric fields and hydrodynamic processes? What is the role of electricity as a triggering mechanism in storm development and in cloud physics?
- (4) What are the details and mechanisms of lightning (for example, why the difference between discrete and hybrid stroke, warm cloud lightning phenomena)?
- (5) What is the relation of the (physical) character of lightning to meteorological parameters (convection, etc.)?
- (6) What are the charging and discharging mechanisms?
- (7) What are the characteristics of positive ground discharges, and why do they occur?
- (8) What are the electrical characteristics of severe storms (tornadoes, hurricanes, etc.), and are there unique signatures--system versus component parts?

(9) What happens to the charge particle population when there is a discharge? What are the microphysical processes?

(10) What is the land-ocean ratio **of** lightning?

The consensus was that the first five items listed in the "Global Circuit" area were more appropriate for space platform sensor measurements. The opinion was that item **5** in the "Generator" area would be helped by the Orbital Flight Test **2** (OFT-2) experiment by Vonnegut and Vaughan and that items **1, 2, 5, 6, 8,** and **10** in the "Generator" area could be significantly helped by further space sensor application; i.e., lightning survey instruments, etc.

B, Contributed Comments by Participants

The remainder of this section consists of six brief commentaries by some of the principal participants in the meeting. The individual contributions remain essentially in the form furnished by the originators for inclusion in this report.

Heinz W. Kasemir
NOAA/Atmospheric Physics and Chemistry Laboratory

Research areas of atmospheric electricity that could be explored from the Shuttle or the tethered satellite:

The generally accepted model of the atmospheric electric global circuit is that of a leaky spherical capacitor (Israel, 1966), given in Figure 1 (Fischer and Mühleisen, 1968).

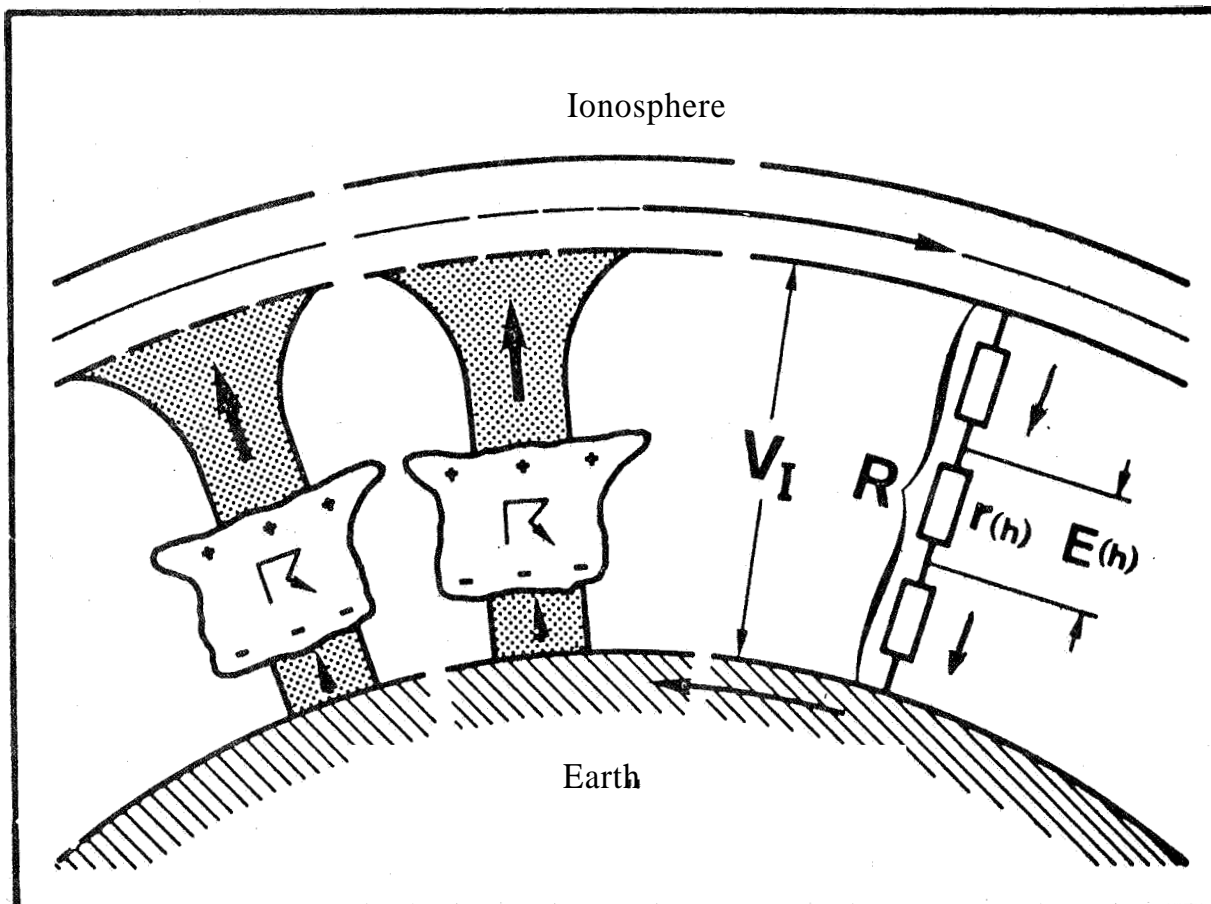


Fig. 1. Atmospheric electric global circuit. Current flow indicated by arrows.

Thunderstorms are assumed to be the generators of the atmospheric electric current flow. In the load circuit the current flows up from the positive charged top of the storm to

the ionosphere, spreads out horizontally in the ionosphere around the globe, flows down to earth in the fair weather regions and returns through the earth to the negative charged base of the storm. Hereby, it is assumed that the ionosphere is an equipotential layer with approximately infinite conductivity to insure horizontally homogeneous distribution of charge delivered by the thunderstorm.

The ionospheric part of the model is based on a physical misconception, To enforce a sideways spread of the charge or current--let's say at the lower boundary of the ionosphere--the ionosphere would have to be an extremely good insulator, not an extremely good conductor. Otherwise, the current will continue to flow radially outwards, It may even penetrate the ionosphere and enter interplanetary space. This has been repeatedly pointed out (Kasemir, 1971; Kasemir, 1977). The atmospheric electric current flow in the ionosphere is experimentally, as well as theoretically, an unexplored area of geophysics.

The Shuttle and especially the tethered satellite would give the first opportunity to make in-situ measurements of the electric current of thunderstorms reaching the ionosphere, of the influence of the earth's magnetic field on the current flow, and of a host of other related problems. Related problems are, for instance, the coupling of the electromagnetic field emitted by a lightning discharge to whistler mode propagation and monitoring the world lightning activity by ELF signals (Schuman resonances).

The atmospheric electric current (air-earth current density) and the electric field (passive antenna) have been measured from a balloon up to 30 km altitude with a vertical dipole antenna of 20 or 50 m length suspended from the balloon (Kasemir, 1960). A lightweight, low-power electrometer converts the input signal in the order of millivolts to frequency and modulates an ordinary meteorological radiosonde transmitter. The transmitted signal is then received and demodulated at the ground. This instrument and measuring principle may serve as a guideline for measuring the atmospheric electric field or current density in the ionosphere. Needless to say, conditions in the ionosphere are markedly different from those at 30 km altitude, It will be necessary to consider the tensor character of the conductivity, magnetically induced fields, the influence of other electromagnetic generators, etc. However, very crude estimates of signal-to-noise ratio, measuring capabilities, etc., indicate that measurements of thunderstorm

currents reaching the ionosphere should be possible from a tethered satellite using the suspending wire as an antenna,

I would like to propose this briefly sketched research for in-depth assessment and consideration for conducting these measurements from the tethered satellite.

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Richard Orville
State University of New York at Albany

I would like to point out the usefulness of pointing **the** Spacelab 1 low-light-level TV (LLLTV) system at thunderstorms when the time is available. It is my understanding that **the** 3914 Å, 4861 Å ($H\beta$), and 5577 Å filters, among others, will **be** available. The 3914 Å lightning emissions are generally weak in slitless spectra but apparently a strong feature in slit spectra. The 4861 Å $H\beta$ emissions are of moderate intensity in cloud-to-ground lightning and always present in lightning spectra.¹ The 5577 Å region in lightning spectra is primarily continuum. No spectra of lightning from space, to my knowledge, have been obtained. The potential significance of using the LLLTV experiment in lightning is that the time and spectral characteristics of lightning in the tops of clouds would be partially known for the first time. For example, **the** time characteristics of the neutral ($H\beta$) and molecular emissions (N_2^+ , 3914) would give us a clue to the electrical current characteristics of lightning in the upper portions of a cloud. We also strongly suspect that the spectral emissions from intracloud lightning are significantly different from cloud-to-ground discharges, but, to our surprise, no data have been obtained to check this,

Answering some of the above questions and hypotheses would primarily represent contributions to basic science, but would have the added advantage of supplying information upon which the design of a satellite lightning detector would partially depend., The LLLTV experiment appears to offer several scientific opportunities for which it was not designed, I hope we can take advantage of them,

1. Orville and Salanave, "Lightning Spectroscopy--Photographic Techniques," Applied Optics, **9**, August 1970, p. 1775.

David Rust
NOAA/National Severe Storms Laboratory

Many of the fundamental problems in atmospheric electricity have gone unanswered for decades. They include various aspects of the global circuit; i.e., is the thunderstorm-fine weather circuit responsible for maintaining the earth's electrical charge, and if so what are the currents that flow? With regard to the thunderstorm itself, the questions concerning charge generation mechanisms and the interrelationships between electricity and the dynamics and microphysics of the cloud are largely unanswered. Within these broad areas, there are several specific topics that lend themselves to, and in fact require, measurements over a regional or world-wide scale. (A list of these specifics was made at our meeting, and most of them will not be reported here.) Possible research topics relating to both large and severe storms will be briefly discussed,

Electrical activity associated with both large and severe thunderstorms is largely unknown. There are numerous parameters that need to be measured. One of these that is of particular interest is the lightning flash rate. The flashing rate of a thunderstorm is generally thought to be a few per minute. Intuitively, though, the impression is that the occurrence of lightning in large storms appears to range from frequent to nearly continuous. It may be that the flashing rate for a storm system is as high as several per second. The flashing rate may be indicative of convective activity and is, of course, related to the electrical energy of the storm. The proportion of intracloud and cloud-to-ground flashes is unknown. Another topic area where almost no data exist concerns the electrical activity and lightning associated with typhoons and hurricanes. In all the above, whether there is a significant variation in the flashing rate or other lightning characteristics as a function of storm severity is a question of interest in basic and applied science. For several engineering applications, the spatial density of flashes on a yearly basis is important; e.g., for the location of electrical power plants, especially those using nuclear power, etc.

It is beyond the scope of this memo to discuss technical details. However, much of the data needed can probably be obtained with optical flash detectors similar in principal to Dr. Vonnegut's device, which is scheduled for the second Shuttle (OFT 2). Additional measurements could possibly be made with

spherics-type receiving equipment, ranging from simple receivers to possibly a small network for determining lightning location. Whatever the type of measurements made, there will be the need for corroborative data to be collected on the same storm or storm system by sensors, including radar, at the surface **of** the earth. Comparison of these "ground truth" data with those obtained from space will facilitate the interpretation and determine the reliability of the data from space.

In summary, there is little doubt that meaningful measurements relating to fundamental and applied problems in atmospheric electricity can be conducted with instruments on space vehicles and satellites.

Patrick Squires
National Center for Atmospheric Research

The generally accepted explanation of the fair weather electric field envisages the solid earth and the upper atmosphere as forming two plates of a leaky spherical condenser which is kept charged by thunderstorms (pumping positive charge upwards and negative charge downwards). Many questions arise in connection with the electrical properties of the upper atmosphere and also concerning the mechanisms involved in the thunderstorm generator. On the one hand, these mechanisms obviously depend on the dynamics and microphysics of convective clouds, and, on the other, it is thought by some that electrical effects may exert a significant influence on precipitation formation and thereby influence in some degree the larger scale energetics of the atmosphere. It is probable that the measurement of electrical phenomena, especially by means of remote sensors, would provide a useful diagnostic tool in the study of convective storms, once a degree of understanding has been achieved of the interrelationships between electricity, dynamics, and microphysics.

Observation from space would seem well adapted to two major problems in atmospheric electricity:

(a) The global observational capability of satellites offers the opportunity to make large-scale surveys of the distribution of lightning discharges. Such surveys could help to improve the estimates which have been made of the mean generator current. If the accepted theory is correct, this must obviously match the leakage current which occurs over fair weather areas. It would also provide valuable data on the geographical distribution of lightning over continents and oceans, which appears to raise a number of challenging questions in relation to climatology of deep convection, and the dynamics and microphysics of clouds.

(b) If observations of lightning occurrences from space can be combined with high resolution imagery, it would probably be possible to gain improved understanding of the relationships between electrification and convection.

Bernard Vonnegut
State University of New York at Albany

Observations from Low Altitude Orbit

Advantages of observations made at the altitude of a few hundred kilometers, planned for the orbiting flights of the Space Shuttle, are that it will be easy to obtain high angular resolution and that, because of the relatively short distance they will have to travel, electromagnetic signals will be relatively easy to detect. A disadvantage of observations from this platform is that it will not be possible to observe phenomena for more than a minute or so.

With quite simple unmanned equipment it should be possible to obtain valuable data on the lightning processes from the vantage point of the low altitude orbiting satellite. A simple, wide-angle photoelectric optical system could be mounted on the satellite looking down so that it will record the lightning impulses occurring in an area beneath the vehicle of approximately one million square kilometers. The output of this apparatus, which would be a signal in the audio range, would be recorded continuously on magnetic tape aboard the spacecraft or it could be telemetered to ground and recorded there.

By subsequent analysis of the data, assuming of course that an associated time code was available, it would be possible to answer such questions as the following:

- (1) What is the relative frequency of lightning discharges over land and over sea?
- (2) How does the number of lightning strokes in lightning events at sea compare with those over land?
- (3) In the cases where the satellite observations coincide with severe weather phenomena, such as hurricanes and tornadoes, is there any association between the characteristics of the lightning discharges in this area and the severity of the storm system?

If two similar optical systems were to be used, which would require two channels for recording the data, it might be

possible **by** the use of optical filters to distinguish and characterize several varieties of electrical discharges,

If the equipment could be flown over a period of many weeks or months, sufficient data could be accumulated to derive information on lightning frequencies over various areas of the globe and average global lightning rates. Because the area under surveillance at any time would be only a few tenths of one percent of the area of the globe, these observations would probably not be of much value in answering questions concerning global atmospheric electrical processes.

Observations from Geosynchronous Satellite

The geosynchronous satellite offers the exciting opportunity of observing the lightning that is taking place over half the surface of the globe, and with several satellites it is conceivable that it will be possible to monitor the lightning activity over the entire earth. Whether it is possible to observe lightning successfully at this distance will of course depend on the sensitivity of the photo-optical systems that are available. It must of course be recognized that because of the greater distance of the satellite the signal from a lightning discharge will be four or five orders of magnitude smaller at the geosynchronous satellite than at the lower orbiting altitudes. To judge from Conrad's observation that at a distance of 25,000 miles he was able to see lightning discharges on the dark side of the earth, there seems little doubt that lightning could be monitored successfully from the geosynchronous satellite at night. The probability is good that equipment could be devised that would also work even when the earth's surface was brightly illuminated by the sun.

With equipment that monitored the lightning activity over a large fraction of the total area of the earth, sufficient data would be provided to answer the following questions:

- (1) What is the relationship between the global occurrence of lightning and the intensity of the fair weather atmospheric variables?
- (2) What is the extent of the variation of lightning activity on time scales ranging from tens of seconds to years?

- (3) Does any correlation exist between global lightning activity and solar activity or the earth's position in the environment created by solar magnetic fields and solar winds?

If a small angle photoelectric optical sensor covering an area of perhaps 10^5 km² were installed on a geosynchronous platform that could be directed to any region on the surface of the earth, it would be possible to monitor lightning frequencies during the development of mesoscale severe **storm** areas. If lightning frequency can be related to the development and the severity of storm systems, such an apparatus might prove useful in detecting and predicting the outbreak of dangerous weather situations.

Comments by Dr. Orville, State University of New York at Albany

"In addition to the previous comments, **it** should be noted that a satellite would be ideal for recording lightning in warm clouds; that is, clouds with tops below the melting level. The satellite detector would isolate the lightning on the surface, and simultaneously geosynchronous satellites with infrared sensitivity would determine the cloud top temperatures.

A second opportunity to consider is the following. A lightning satellite detector in an earth orbit would also work in orbit around another planet. Therefore, we would be able to answer the fundamental question of whether lightning occurs on other planets, for example on Venus or Jupiter."

E. T. Pierce (Deceased)
Formerly with Stanford Research Institute

[Unfortunately, Dr. Pierce's untimely death prevented his participation in the meeting. However, it seems appropriate to include his remarks on satellite techniques relative to sferics (radio signals) which he prepared approximately 10 years earlier as part of his contribution to Volume 2, "Proceedings of the Scientific Meetings of the Panel on Remote Atmospheric Probing, April 18-20 and May 16-17, 1968," of the report on Atmospheric Exploration by Remote Probes under the sponsorship of the National Academy of Sciences, National Research Council, Dr. Heinz Kasemir's comments on this aspect of Dr. Pierce's paper are also included for completeness.]

Sferic measurements in satellites have great apparent attractions, but a little consideration soon reveals their very real limitations. The radio signals that contain most information about the lightning source are those at the lower frequencies (especially in the VLF band); it is these frequencies that are most influenced by the propagation through the ionosphere, so that much of the source information is lost. For signals at frequencies (above perhaps 100 MHz) that are relatively unaffected in their passage through the ionosphere, the original radiation is of low amplitude and contains only crude information on the lightning flash.

The flashing characteristics of a cell impose severe restrictions on the effectiveness of the surveillance of individual thunderstorms by low-altitude (say 1000 km) sferics satellites. For such satellites the orbital speed is about 7 km/s; thus with an antenna system resolving a cloud area comparable with that of a thunderstorm cell the area is only monitored for about a second. Since the interval between flashes is typically 20 s, 1 s is a time quite insufficient for a cloud to be identified as thundery or not.

High-altitude--stationary would be 37,000 km--orbit in conjunction with elaborate antenna scanning systems might enable fairly small areas of the earth's surface to be examined. However, at 37,000 km sferics signals must be identified within a framework of strong background noise. There may be advantages in using optical ($H\alpha$) sensors, but the discussion of these is beyond the scope of this report.

In summary, sferics satellites seem incapable of yielding useful information on individual lightning flashes or thunderstorms. They can monitor large areas (diameter ~ 1000 km) and hence determine approximately the degree of thundery activity within these areas. Thus the main potential use of sferics satellites **is** in improving our knowledge of temporal variations in the strengths and positions of the main global thunderstorm regions,

Sferics sensors in satellites might operate either **at** VLF, HF, or VHF. At VLF the source radiation is strong, **but** propagation is by the whistler mode so that the received sferic penetrates the ionosphere along the geomagnetic field line through the satellite position; before entry into the ionosphere the sferic propagates, from the originating lightning discharge, below the ionosphere in the earth-ionosphere quasi-waveguide. This complicated path entails difficulties in identifying the location of the lightning flash generating the sferic. The geomagnetic path control has some remarkable implications; for example, a satellite 1000 km above the equator would tend to receive **VLF** signals from equatorial thunderstorms via a path below the ionosphere as far as latitude 20° N or S, and then through the ionosphere along the appropriate field line.

At NF the sferics signals received in satellites above the ionosphere are well above the ambient background in strength. The ionosphere itself defines the area upon the surface of the earth that is being monitored. If several narrow-band receivers tuned to various frequencies within the NF band are employed, then the recorded noise can be associated with different areas and the value of the results enhanced. A multifrequency experiment of this kind, presently being carried on the Ariel 111 satellite, is already yielding useful data [Bent, 1968]. One aspect of HF sferics sensors is that the results are equally revealing upon the characteristics of the ionosphere as upon those **of** the thundery activity beneath. Indeed, **if** the latter information is to be deduced, then the ionospheric effects must first be reliably estimated,

The main drawback to using sensors at frequencies (greater than, say, 100 MHz) essentially unaffected by passage through the ionosphere is the **low** ratio of sferics signal to other noise. This other noise can be of cosmic, solar, terrestrial (thermal), **or** man-made (including receiver) origin. Pierce [1967] has estimated that for a satellite at an altitude of 1000 km the signal/noise ratio deteriorates from

about 10/1 at 100 MHz to perhaps 2/1 at 600 MHz; this decrease is principally due to the drop in the lightning signal as frequency increases. If the satellite altitude becomes greater, the signal/noise ratio becomes less; this is because, at best, the sferics signal varies inversely with distance, while several noise sources (cosmic, solar, receiver) are independent of distance.

It is perhaps appropriate in this section to query whether sferics satellites are really necessary since the information they can supply is possibly already being obtained by other satellite experiments. For example, there are indications that large-scale thunderstorms with massive convection can be identified from cloud-photographing satellites. This identification might become more positive if comparisons were made between the cloud photographs and the considerable amount of sferics data that has already been obtained in satellites (Lofti, Ogo, Alouette, Ariel, etc.). Certainly this comparison should be performed before elaborate schemes for specialized sferics satellites are considered.

Comments by Dr. Kasemir, NOAA/Atmospheric Physics and Chemistry Laboratory

"Even considering the limitations of the satellite (such as lack of resolving power to pinpoint individual storms and the loss of a faithful reproduction of the sferics signal by frequency cutoff by the ionosphere), the one task the satellite can do very well, namely scanning rapidly the large thundery areas of the globe, would be an important achievement and worthwhile effort. It is true that the same result could be obtained by a world-wide sferics network, but the satellite would be independent of international organization of such a network and its political ramifications."

Additional Comments by Dr. Kasemir (1978)

"There are two new, important facts introduced by the tethered satellite (Space Shuttle) that may drastically improve the marginal signal-to-noise ratio in the VLF and LF range; namely the low altitude and the long necessary antenna of the tethered satellite. This may eliminate E. T. Pierce's objections."

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III, SUMMARY REMARKS

The meeting produced the following viewpoints:

(1) Application of space technology to the solution of the principal scientific questions in atmospheric electricity offers considerable promise for providing a better understanding of lightning phenomena and its relationship to severe storms.

(2) Priority should be given to the development of a lightning survey instrument to provide a synoptic observational capability from an orbiting platform, with ultimate emphasis on a geostationary continuous sensing capability.

(3) Efforts should be made to exploit the space technology opportunities associated with currently approved flight instruments such as the Shuttle/Spacelab 1 experiment, "The Atmospheric Emission Photometric Imaging (AEPI) Experiment," and the Shuttle/OFT-2 experiment, "Nighttime/ Daytime Optical Survey of Lightning." Also, the potential application of the tethered satellite and geostationary platform for research into atmospheric electricity should be encouraged.

(4) Both the atmospheric electric global circuit and the generator concept need increased interdisciplinary research and experimental program emphasis.

(5) The assessment of requirements for in-depth research and experiments should be sponsored for making measurements from satellites that will increase the basic understanding of atmospheric electricity and, in particular, the potential for application to lightning hazard monitorship and severe storm forecasting and warning.

(6) Correlative "ground truth" experiments should be accomplished to better define the electrical activity associated with thunderstorm development, growth, and intensity, with emphasis on those parameters which lend themselves to space technology applications.

(7) The microphysics of cloud physics and atmospheric electricity needs to be better defined to provide an understanding of the interrelationships between electricity, dynamics, and microphysics. Observations from a space platform seem well adapted to several major problems in atmospheric electricity associated with these interrelationships,

(8) The planned OFT-2 Space Shuttle lightning survey experiment should be improved and flown at every opportunity to acquire experimental data applicable to the design of a future synoptic lightning survey sensor,

(9) Sensor development research needs to be conducted relative to atmospheric electricity measurement requirements to establish the optimum components and technology for application to space-based instruments.

(10) Although RF (radio frequency or sferics) measurements from a space-based platform appear to have significant limitation for application as severe storms growth and intensity indicators, they do offer the potential for scanning rapidly the large thunderstorm areas of the globe and should be considered within this context for further research studies,

(11) There is ample evidence of potentially significant contributions from a better understanding of atmospheric electricity, using space-based observations, to the goal and objectives of the NASA Severe Storms Research Program to warrant conducting a more in-depth workshop on the subject in the near future, sponsoring selected research and experimental investigations, and conducting a space flight sensors system(s) feasibility study to better define the requirements, technology needs, and system potential.

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APPENDIX A

NEED FOR SATELLITE OBSERVATIONS OF LIGHTNING

B. Vonnegut

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It is of practical and scientific importance that surveillance of thunderstorms from satellites should include observations of lightning. The following list summarizes some of the ways that cloud electrification is intimately related to various cloud physical processes and how lightning imposes significant hazards on human activities.

1, Convective Activity

Since it is known that strong updrafts are required to produce the intense electrification necessary for lightning (Workman, 1949), frequent lightning is a useful indication of strong convective activity.

2. Precipitation

The occurrence of lightning is intimately related to precipitation. It is generally recognized that rain and hail contribute to the generation of the electric fields responsible for lightning (Mason, 1953), and there is evidence that precipitation particles are often the initiator of lightning discharges. In some circumstances lightning and electrical forces can accelerate the formation of rain (Rayleigh, 1879; Moore, et al., 1964). Under other conditions electrical interactions may inhibit the formation or the fall of rain (Levin and Ziv, 1974).

3. Tornadoes

Evidence from eye-witness observations (Peltier, 1840) and sferics (Jones, 1951) and satellite measurements (Orville and Vonnegut, 1975) shows that tornadoes are frequently associated with exceptionally frequent lightning discharges. If continuous satellite observations of lightning

by day and night were available, they could provide an indication of the probability or existence of the intensely electrified storms that produce tornadoes,

4. Cloud Electro-Optical Effects

Electrical dipoles induced on ice crystals in the top of thunderclouds will cause plate and needle-shaped cirriform crystals to become oriented in the direction of the electric field (Vonnegut, 1965). As a consequence, when lightning occurs, there may be abrupt changes in optical properties of the cloud as the electric field suddenly changes in magnitude or direction. Satellite instrumentation capable of detecting the occurrence of lightning can be helpful in identifying situations in which satellite optical observations may be subject to the influence of changing strong electrical fields,

5. Lightning Hazard

Lightning not only can electrocute people and livestock and ignite forest fires, but also menace rocket launchings, aircraft flights, and the transfer of fuel and explosives. If information on lightning were available from satellites, it would be helpful in filling civilian and military needs for warnings of intense electrical activity,

The best technique for determining from a satellite when and where lightning is occurring involves detecting electromagnetic radiation that is produced by the lightning discharge. This radiation ranges from radio frequency spherics with wavelengths of kilometers to light in the ultraviolet portion of the spectrum. A variety of options is therefore available in the design of the apparatus. The use of detectors in the short wave region appears attractive in view of the much smaller apparatus that is required to give sufficient directional information to identify electrically active clouds. The use of longer wavelengths will probably afford greater sensitivity in the detection of lightning during daylight hours,

The **DMSP** satellite, during the period of the jumbo tornado outbreak of April 3, 1974, showed lightning observations. These observations were serendipitous in nature and obtained with instrumentation designed for another purpose. Satellite

instrumentation specifically designed for indicating the presence of lightning both day and night should be of value in forecasting severe storms and in providing new basic scientific information on lightning and its role in meteorological processes.

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APPENDIX B

Exploratory Meeting on Atmospheric Electricity and Severe Storms, April 10-11, 1978

Agenda

- I Meeting Frame of Reference and Introductions
- II Severe Storms and Atmospheric Electricity,
Relationship to Growth and Development, Evidence from
Past Research Applicable to Satellite Technology,
Scientific Rationale
- III Atmospheric Electricity as Part of Overall Earth's
Energy Budget
- IV Atmospheric Electricity Coupling Mechanisms
- V Shuttle/Spacelab Planned and Proposed Sensor and
Experiment Concept Applicability to Atmospheric
Electricity Research
- VI Future Actions

Attendees

- Dr. Marx Brook, New Mexico Institute of Mining and Technology
- Dr. James C. Dodge, NASA Hq, Office of Space and Terrestrial
Applications
- Dr. William G. Johnson, NASA/MSFC Space Sciences Laboratory
- Dr. Charles A. Lundquist, NASA/MSFC Space Sciences Laboratory
- Dr. Heinz W. Kasemir, NOAA Atmospheric Physics & Chemistry
Laboratory
- Dr. Richard Orville, State University of New York at Albany
- Dr. David L. Reasoner, NASA/MSFC Space Sciences Laboratory
- Dr. David Rust, NOAA National Severe Storms Laboratory
- Dr. Patrick Squires, NCAR Convective Storms Division
- Dr. Robert E. Turner, NASA/MSFC Space Sciences Laboratory
- Mr. Otha H. Vaughan, Jr., NASA/MSFC Space Sciences Laboratory
- Dr. William W. Vaughan, NASA/MSFC Space Sciences Laboratory
- Dr. Bernard Vonnegut, State University of New York at Albany

APPROVAL

EXPLORATORY MEETING ON ATMOSPHERIC ELECTRICITY
AND SEVERE STORMS

Edited by William W. Vaughan

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