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METEOROLOGICAL SATELLITE LABORATORY
REPORT NO. 13

Conference on Sferics Measurements from Satellites

WASHINGTON, D. C.
OCTOBER 1962

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METEOROLOGICAL SATELLITE LABORATORY

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CONFERENCE ON SFERICS MEASUREMENTS FROM SATELLITES

Edited by
Stanley D. Soules

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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PREFACE

This report presents the transcript of the Conference on Sferics Measurements from Satellites held on April 27, 1962 in Washington, D. C. and sponsored by the National Weather Satellite Center of the United States Weather Bureau.

A group of scientists from the fields of meteorology and atmospheric electricity were invited to present their thoughts and ideas on how the collection and study of world-wide sferics data from a satellite could assist the meteorologist in his understanding of the behavior of the atmosphere.

Five speakers gave short talks on how sferics measurements might be made and how these data could be utilized. Their comments formed the basis for a general discussion among the other participants of the conference which was under the chairmanship of Dr. Sigmund Fritz.

These proceedings are being distributed to bring to scientists in meteorology and closely allied fields the ideas and comments set forth at this meeting with the hope that interest will be stimulated in others to suggest new ways for using sferics data gathered from satellites.

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AGENDA

I. Introduction - S. Fritz

II. Meteorological requirements for world-wide sferics measurements from satellites

Why are world-wide sferics measurements needed? What can be learned about the atmosphere from them?

A. Electrical properties of atmosphere - E. J. Workman (20 minutes)

B. Meteorological implications - H. Riehl (20 minutes)

III. Instruments and auxiliary observations

What should (and can) be done to fulfill these needs?

A. Additional surface observations - R. E. Hallgren (10 minutes)

B. Practical satellite measurements - what compromises must be made between theoretical demands and practical instrument characteristics? What spectral interval, spatial resolution, instrument characteristics, etc. can be achieved - V. E. Suomi (20 minutes).
(Given by D. T. Hilleary in Dr. Suomi's absence due to illness)

IV. Interpretation of practical satellite data and significance for meteorology

What meteorological information can be inferred from count of strokes, sferics energy spectrum, etc? - R. E. Holzer (20 minutes).

V. Discussion of questions raised by speakers and participants

VI. Recommendations for future action

CONFERENCE ON SFERICS MEASUREMENTS FROM SATELLITES

Dr. Fritz: I should say a little about the need for this meeting. First of all, why do we want to measure anything from satellites? We can measure sferics characteristics, for example, in the United States or probably at any single spot, fairly well from the ground, If, however, one wants world-wide observations, then that almost necessarily implies the use of a satellite because very few things that are of interest to meteorologists can be measured on a world-wide basis from the ground.

From time to time, we hear about and receive proposals regarding the desirability of measuring sferics from satellites. In the field of sferics, as in other fields, there are people who have great capability in designing instruments for measuring sferics. There are other people whose prime interest is not so much in instruments but rather in getting the data from instruments that somebody else has designed, and then studying those data to get some basic information about the atmosphere. The ideal arrangement is to have those two groups closely allied. In this room, there are some people who have both of those interests.

Nevertheless, there are also people who have predominant interests in one or the other of those two aspects of the problem. I think it is very important before anything major is done that we get the views of these two types of people. One is the group that is going to use the data. What type of data do they want? What will they do with the data? Then, we have to ask what can be done to fulfill the needs that they foresee. Some of the things, then, which I hope we will talk about here are the reasons why we want to measure sferics on a world-wide basis.

We have arranged the program more or less around the outline that I have just mentioned. Namely, that we will first talk about the need for world-wide sferics, if such a need really exists. The need would be expressed probably in terms of what we can learn about the atmosphere, or some parts of it or the whole of it, from a study of the sferics data which could be obtained later.

There may be several different types of information about the atmosphere which one can get from sferics; one type of information may be useful in studies of the electrical properties of the atmosphere. It has been suggested that thunderstorm activity, which gives rise to sferics, may be one of the elements which determine the gross electrical properties of the atmosphere.

There may be other meteorological implications. For example, Dr. Riehl and Dr. Malkus, in their studies of the "hot towers", investigated the transfer of properties between the surface and the atmosphere, and saw other implications about global meteorology.

So perhaps we should start the first part of the meeting with Dr. Workman, who has offered to tell us something about the electrical properties of the atmosphere.

Dr. Workman: I have heard something about this title, and I assumed from the title that I was not expected to know very much about satellites.

Dr. Fritz: This is altogether correct. I think that what we would like to have now is not a discussion of satellite measurements, but rather, if one had world-wide measurements of sferics, by whatever means obtained, what implications would this have for the studies of the electrical properties of the atmosphere.

Dr. Workman: I might say that your effort to explain why we are here is well understood. I feel that I am a little bit out of place here because actually, I do not know much about satellites.

I have, however, a considerable interest in what can be found out about certain problems in atmospheric electricity. One of the interesting things to me about the general subject of atmospheric electricity is that, due to distinguished colleagues around the table here and other people who have gone before them, classical atmospheric electricity seems to be a fairly well-behaved subject. Our descriptions are reasonably consistent with the known facts. Many things about the subject are sufficiently well understood so that one can now use the atmospheric electrical manifestations as a tool to learn other things about the atmosphere.

Anomalies in atmospheric ion populations as well as radioactive particle distribution near the surface and in the circulating atmosphere can be very useful in finding out something about the behavior of the atmosphere with respect to circulation.

There is one thing that looks almost as if it should be done now -- maybe it will have to be done by satellites -- and that is to find out more definitely about thunderstorm frequency over the earth.

I don't know how one should go about this, whether one should observe this with sferics or whether one should use some sort of a photometric device. Either method, I suspect, will have considerable shortcomings in indicating reliably the average number of thunderstorms that we have.

Unfortunately, a large part of the earth where we expect high thunderstorm occurrence is not very well reported, places like the island of Bali, for example, and over much of the tropical regions there seem to be inadequate thunderstorm reporting systems.

One would like to know (certainly our staff would like to know) how abundant thunderstorms are. I would like to know how abundant thunderstorms are over the plains of Texas. It is rather important to find out, for example, how much atmospheric space is required to develop and to sustain a good thunderstorm activity.

Perhaps one could devise some sort of photo-multiplier recorder whereby equipment-limited rates of rise of pulse would serve to discriminate reliably lightning strokes as seen from outside the atmosphere. If this could be done, I think by observing the electromagnetic radiation, perhaps this method might be easier.

We have been dealing for a long time with some magic number of 1800 storms at one time over the earth. I certainly would like to know whether this is even approximately right. One needs to know this to make some assessment of energy transfer in order to do some bookkeeping on the vertical heat flow problem.

There is another subject in the general field of atmospheric electricity that I should like to see studied. This is the shape of the (what you might call) "equalizing layer of layers" of high conductivity at the top of the atmosphere. How do thunderstorm fields influence the "shape" of such regions? I think this should be very important for better understanding of what possible connection there is between thunderstorm electricity and the maintenance of the earth's electric field. Also, it is important, I believe, for evaluating the many thunderstorm electrification mechanism which have been proposed. I don't know how one should do this. It probably would not be done with a satellite. I sometimes think, Bob (referring to R. E. Holzer), that perhaps we should have had a little bit more concern with this problem when we were measuring field changes to infer charge transfers. Certainly, the lower part of the conducting layers must be distorted very considerably by the presence of very high positive charges in thunderstorms. In our part of the country one sees lightning strokes which go into the very peripheral regions at the top of clouds. I suspect they go there because this is where the conductivity is limited.

Coming to the earth, we are making measurements now of the behavior of the electrical field and the constitution of the atmosphere with respect to ions within about 10 centimeters of the surface. It turns out that this is an extremely interesting way to investigate the diffusion problems at the surface of the ground. It has been suggested that perhaps our radioactivity measurements that are being made there might be extremely useful in carrying out an analogous transfer problem; i.e., a way of getting at the water vapor diffusion at or near the surface for dry climates such as ours.

I have one other suggestion that is only of general interest. A great variety of ways have been promulgated for generating thunderstorm electricity. One who studies thunderstorms is considered very remiss, indeed, if he is not the author of a system for generating thunderstorm electricity. So I have one way of doing this. At least I have a partnership interest in a way of doing it. Since this is in the general field of atmospheric electricity it is interesting to point out something that seems to have escaped attention for some time. This is that every coulomb of electricity that is involved in thunderstorm activity must involve necessarily, according to our picture, the electrolysis of so much water, perhaps twice as much. This will have a significant bearing upon the hydrogen balance of the atmosphere.

It is of interest to observe the lack of homogeneity in space charge which results from thunderstorm fields at the bottom of the atmosphere. One very rapidly sweeps out charged radioactive products and takes them up at the rate of as much as one meter per second toward the base of the storm. This leads to a heterogeneous composition of the atmosphere with respect to radioactive products.

I think that is about all that I am prepared to say as an opening

statement.

Dr. Fritz: Thank you very much. You have raised several interesting points.

One of the things you mentioned was that you would like to have some idea of abundance in the distribution of the world pattern of thunderstorms. I presume that the importance of this would have something to do with the determination of, say, the magnitude or the horizontal variations of the electrical field in time and space. You may want to comment on that point.

Another thing you said is that you would like to know the thunderstorm distribution in Texas. Isn't it possible to do that much better from the ground than from any satellite?

Dr. Workman: I probably would not suggest doing this from a satellite. I was just saying that I would like to know this. I'm concerned about the energy transfer and, therefore, I need to know how much room a thunderstorm needs.

Dr. Fritz: I think there is another point. Regarding the diffusion of water vapor from the surface, is there any likelihood that we would be able to determine on a world-wide basis, the distribution of diffusion from the ocean surface to the air by observation of sferics?

Dr. Workman: I don't know how. I think we have seen numbers quoted, but I imagine that these are based upon uncertain calculations on the amount of rainfall. I heard someone report yesterday that the rainfall on the continents probably gets cycled as rain three or four times. These are things that we need to know.

Dr. Fritz: The question is whether we could determine it from sferics observations.

Dr. Workman: I don't know how. There are probably other ways to go about it, but I think that the atmospheric electrical approach is fairly good, because it gives you numbers with which to work.

Dr. Jones: Many, many times in Oklahoma we have had plenty of warm, moist air on the surface. We had the cold, dry air overhead which would come down and replace it if proper "triggering" existed. The cold air goes overhead and goes on east. The warm, moist air goes on someplace else. Unless there is a thunderstorm, you will not have any sferics. Many times I have sat out there at my laboratory for 24 hours, just hoping that a thunderstorm would take place.

Dr. Fritz: What kind of a thunderstorm?

Dr. Jones: Triggering thunderstorm. What I call a triggering thunderstorm. Once you have a thunderstorm formed, you will have many meteorological conditions that could form a tornado or a thunderstorm and it just doesn't happen.

If the cold air stays at 35,000 feet and the warm, moist air is 500 feet above the surface, and if they do get together with one little triggering

thunderstorm, you will have probably a very severe storm. Maybe even a tornado.

Unless the diffusion comes up sufficiently to trigger off the first thunderstorm, nothing will happen. That is why I say that I doubt very much if the sferics would be any indication of the amount of evaporation either over the ocean or over the continent.

Dr. Fritz: Does anyone else want to comment on Dr. Workman's remarks?

Dr. Nordberg: I would like to make one comment on the many interesting points that Dr. Workman mentioned. It occurs to me that probably only one would really lend itself to be studied by a sferics satellite. This is just to determine the number or the frequency of thunderstorms. On the others, I see very little possibility of using sferics satellites.

On the first one, I would like to raise a question, because I am sure in the ensuing presentations and discussions probably most of it will center on that point.

The question I want to raise is, have we really or has somebody established a correspondence or relation between sferics produced in a certain band of the spectrum and the thunderstorm occurrence itself?

Dr. Workman: I doubt whether they have been studied from the outside.

Dr. Nordberg: Well, even from the ground, what is the statistical basis? Dr. Fritz, is this going to come up in some of the presentations scheduled, or should we take this up in a discussion?

Dr. Fritz: We have no very formal agenda. We can discuss it for a few minutes.

Dr. Workman: I think that my assignment here is more or less general, because of my lack of knowledge of sferics. What I have to report would not be too intimately connected with this modern sferics program. Concerning sferics, I would like to yield to my distinguished colleague, on the left, who has studied sferics much further. [Referring to Dr. R. E. Holzer] .

Dr. Fritz: Well, Dr. Holzer has a chance a little later, so if you don't mind - - -

Dr. Byers: I'd like to make a comment before this gets too far. You use the word thunderstorm. I would like to know what is meant by this. How do you define thunderstorm? I don't think it has any real definition.

A thunderstorm as such doesn't have an entity. I think what we are really talking about, at least in the context of sferics, are centers of electrical activity.

Although I have spent many years working on thunderstorms, I wouldn't venture a definition of thunderstorms. I think rather than size, scope, or anything else, what we want to really measure are the processes which are

accomplished by thunderstorms, whether they be transfers of water in the atmosphere, or transfers of electricity, or transfers of heat. In the case of sferics we are trying to conclude an electrical transfer of some kind.

This, of course, is related to a general atmospheric disturbance which we call a thunderstorm, but which has no boundaries or limits, nor is it even easily defined.

Dr. Fritz: I think that's a very good point. It certainly is very important for us to consider that in this meeting because the thing that we are talking about measuring from a satellite is the world-wide distribution of a single quantity, namely sferics. The problem before us is, can this be of any use in determining anything else about the atmosphere? You pointed out very well, I think, that a thunderstorm has a great many different properties. If I understood all the remarks, not all of them give rise to sferics. Is that true or not?

Dr. Byers: Yes.

Dr. Fritz: Then the question is what do we learn from sferics?

Dr. Holzer: May I ask you one question? Wouldn't you be willing to say that because of the multiplicity of the phenomena association with the thunderstorm, that you might have a number of different definitions depending upon the particular group of phenomena that you were engaged in at the moment?

In other words, the boundaries of the thunderstorm would not necessarily be the same if you were looking at the electrical structure or if you were looking at such a phenomenon as the water transport of thermal transport or something of this sort.

Dr. Workman: It is difficult to have much of an electrical exhibition in a thunderstorm without transferring water and heat.

Dr. Byers: You can't quantitatively measure the amount of heat or water going up, except to say that if there is an electrical discharge, it represents a lot of water or something like that.

Dr. Fritz: I think we may want to come back to this. What we should do now is have Dr. Riehl tell us about his views of the meteorological implications as divorced from strictly electrical properties of the atmosphere. This was mentioned in the previous discussion, but I'm sure you'll have some additional points.

Dr. Riehl: I had hoped that before you finally got around to me there would be somebody talking about what world-wide observations would actually yield us. Since I didn't know what that would be, in preparing my notes, I sort of had to write my own ticket as to what we would get from the satellite.

Dr. Riehl: This might be pretty much in the dreaming classification. From the viewpoint of considering the general circulation, my interest in sferics is not in the electrical field. The satellite would be essentially a tool for general circulation calculations. It may also serve as a tool in the

immediate practical sense of aiding severe weather warnings. This may include such features as the equatorial trough zone and even cold fronts in our latitudes which even over the continents often are not too well described and which one tends to lose on the surface chart after they move into the subtropical oceans. Then, quite often, a new center of activity starts on the front and this may be picked up with the sferics method quite effectively.

In order to proceed with general circulation computations, we have to make several assumptions to decide whether sferics observations would be a useful measurement with which to operate. The most important assumptions are:

(1) The principal precipitation in the Tropics occurs in thunderstorm form where sferics would be measureable.

(2) The satellite is capable of giving at least a frequency-area indication of sferics occurrence.

These assumptions remain to be proven. I think the point has already been made here, that a sferics parameter must be assumed to be proportionate to precipitation. A series of experiments may be needed to establish whether such a connection can be established. It seems reasonable to me that a proportionality needs to be found if there is to be a useful input into general circulation by the sferics system.

We now consider some kind of a noise level and perhaps isolate the major part of the non-stationary portion of precipitation. This precipitation can be related to what has been referred to as the "hot tower hypothesis". Several years ago Dr. Malkus and I asked what kind of a heat flux is necessary in the Tropics across the 500-mb. surface in order to produce a heat flux large enough to give a heat balance in the upper part of the troposphere and have enough left over for the known heat export from the Tropics. It was postulated that this heat flux was carried by the large clouds extending to 30,000 - 50,000 feet. We then found from the dimension of cells, essentially obtained from empirical knowledge, that the number of large clouds must be of the order of 10^3. These are not individual cells, but rather large clouds with area from 10 to 100 square kilometers. This figure of 10^3 clouds applies to a 10° latitude band near the equator. The 10^3 cells would occupy on the order of one per mill of the area of the belt.

We suppose that the mass flowing into the Tropics from the higher latitudes ascends in these clouds, hence only in a very small fraction of the tropical area. The inflow extends from the surface to about 700 mb; the outflow from the Tropics centers near 200 mb.

If the air moving into the Tropics is heated to temperature characteristic of the equatorial zone over the oceans and has also acquired a corresponding moisture content, then ascent of this air to the high troposphere will account for very nearly all the vertical heat flux requirements, that is, within 15 - 20%. It is arguable whether this difference is due to uncertainty of observations or is due to existence of another essential mechanism, such as recirculation and heat transfer upwards by means

of downdraft air originating in thunderstorms which would come down to the ocean surface, pick up more heat and go up again. There are other possibilities. For instance, last year I had the opportunity to evaluate a number of infrared radiometer soundings which had been taken by Suomi in the Caribbean Sea. These showed that the infrared cooling between 500 mb. and 100 mb. was less than previously assumed. If I would use the new radiation data and assume validity throughout the Tropics (which may not be true), then the upward heat transfer from hot towers would be sufficient to give heat balance in the upper troposphere and account for the heat flux to higher latitudes without any further need for recycling of air vertically in the Tropics.

Dr. Workman has previously mentioned 2,000 thunderstorms going on at the same time. Here the same order of magnitude is obtained through quite different reasoning. This gives an interesting connection and at least some chance that the estimates are correct.

Assuming all of the foregoing is valid, the major precipitation occurs in large clouds; variations are related to variations of the general circulation and sferics measurements can pick up the large clouds and their distribution in time and space. We can now say what we might like to extract from this information as parameters for following changes of the general tropical circulation.

Here of course, the dreaming part comes in. We should have an intensity measurement of the large clouds, in order to measure the strength of the tropical heat source with the proposed equipment.

If you get a constant satellite monitoring system and have all areas constantly under observation we should get an integrated 24-hour tropical value, say for 10° latitude belts from 30°N. to 30°S., with frequency and intensity of large clouds as a function of time. Further, there can be regional breakdowns and also special coordinate systems, for instance attached to the equatorial trough, for summarization of the data.

Dr. Byers: I just wanted to ask about one point. You mentioned frequency and intensity. If you are going to make a determination of the heat process, or other dynamic process, don't you need duration in there also? In other words, you get it over a period of time, or do you prefer that this is included in your intensity frequency?

Dr. Riehl: I think that we should have a 24-hour accumulation to obtain integrated values.

Dr. Byers: One wonders if, for example, the atmosphere under certain conditions is capable of accomplishing a certain amount of total transport over a long period of time and over a large area versus over a short period of time of over a small area?

Dr. Fritz: I don't know whether you are thinking of a satellite in this case or not. Is your point that a satellite would be over a particular point for a short interval of time and wouldn't sample the effect of the whole thing?

Dr. Byers: I'm not thinking about satellites, particularly. Of course, the satellite would measure what I am talking about, I suppose, but unless the satellite can give you a time resolution by repeated measurements on something, you wouldn't get this integrated factor.

Dr. Riehl: I'm talking essentially in terms of a satellite series where eventually you would have all areas under observation continuously. However, even a single orbiting satellite will collect a large enough sample per day to yield one integrated value.

Dr. Workman: I should like to make one suggestion about the use of this information for determination of the heat flow. It might be a way to find this 15% which you mentioned.

One must necessarily involve the amount of precipitation here in order to make one's calculation. The important thing to notice is that not all precipitation from cloud bases gets to the ground, and that all precipitation-action does involve the transfer of heat.

This is variable over all parts of the earth. For example, in New Mexico, I would make sort of an educated guess that if you could define some kind of a moment by multiplying precipitation times the height that it falls, the total moment of precipitation that does not get to the ground would be greater than that which reaches rain gages.

This is left out of this calculation. In fact any involvement, any process of separation of hydrometeors by gravity does involve a heat transfer vertically. This unrecorded precipitation is very large in our belt of the country, and it must be considerable over all parts of the earth.

As for the vertical transfer of heat, precipitation which falls a short way and evaporates into warmer air having been condensed at a high altitude has a lot to do with heat transport that must be at least the 15% in your calculation, probably more.

Dr. Riehl: I have tried to make a calculation of this kind. Of course, you realize this was done for an equatorial zone, and a situation like New Mexico was not involved. Over the tropical oceans the depth of the sub-cloud layer is only 1600-2000 feet; the air is moist and there is little chance of evaporation.

The main purpose of the calculation was determination of the role of release of latent heat of fusion for vertical heat flow. With such release at high levels, the frozen matter drops and melts again at lower levels. This produces a heat flux upward. Lacking data we tried to make an estimate of the magnitude of the effect by taking a large quantity of water up, let it freeze and then fall down to the low troposphere. We find that the heat flux would account only for about 4% of the total required using very large values.

Dr. Byers: Might I remark that all precipitation is separated gravitationally and is evaporating regardless of where it is. You just see it more in New Mexico, because you have all of this space between the base and the cloud.

Dr. Fritz: You don't take account of it when you are measuring rainfall.

Dr. Riehl: You don't use rainfall in this type of calculation. Essentially you calculate the conversion of water vapor. This gives you the maximum amount of water available for condensation about the freezing level or higher. Let this water fall from the high levels and evaporate before it reaches the ground. This will reduce the precipitation at the surface and it will produce a transfer from sensible to latent heat within the lower atmosphere. A net change in the heat content of the lower atmosphere will not result, only a thermodynamic change. Some mechanism has been indicated for the redistribution of heat such as the downdraft which initiates vertical cycling of air. This mechanism was actually used by taking the downdraft to the surface permitting heat flow from the ocean to take place into the relatively cold air, both latent and sensible heat, until the mass became buoyant upward. This mechanism easily permits a 10-15% increase in upward heat flux.

Dr. Byers: I might just point out that the total precipitation, the precipitation measured at the ground, represents the total heat release to the atmosphere. The part that evaporates on the way down represents a redistribution of the heat within the atmosphere.

Dr. Fritz: Coming back to the question of whether or not we take into account some of the details of the vertical, can sferics tell us something about these things? In other words, if we had these sferics measurements over the oceanic Tropics, can we estimate any of these quantities?

Dr. Holzer: This bears on some remarks I had planned to make later in the meeting, but I would be glad to introduce the subject now.

Dr. Fritz: Perhaps for just a minute in case any other people have questions along this line. Why don't you do that and it may raise other questions.

Dr. Holzer: At the present time there is no completely satisfactory index of thunderstorm activity based upon sferics observations. There is not even a clear definition of the intensity of a thunderstorm, but I believe that most investigators interested in electrical phenomena would associate storm intensity with the power generated by the storm. There is, of course, a crude index of thunderstorm power in the frequency and intensity of the lightning strokes. This is due to the fact that the energy of charge separation in the storm (by whatever mechanism one may postulate) is supplied by the storm. Accordingly, the rate of dissipation of charge by lightning is directly related to storm power.

There have been a number of attempts to derive meteorological information from sferics measurements. One interesting attempt of this type is described by Brook and Kitagawa in the Journal of Geophysical Research about two years ago.

Dr. Fritz: Could you clarify what you mean by thunderstorm power or energy? Is this everything?

Dr. Holzer: I was thinking primarily of the rate of generation of mechanical

energy. Brook and Kitagawa tried to correlate stroke duration and frequency of occurence of strokes with meteorological parameters of the storm. They noted that stroke duration was related to the vertical distribution of charge in the cloud and, hence, to vertical convection. They found some evidence to indicate that stroke frequency was a measure of the horizontal aerial extent of the storm. This work offers some hope for obtaining significant meteorological information from electrical observations.

Work of this type should be extended in several ways. If the observations are to produce generalizations, measurements must be made in other geographical regions, particularly in the Tropics where more than half of all thunderstorms occur. It is also possible that additional types of measurements such as sferics amplitudes and spectral energy distributions could provide further insight into the problem of meteorological interpretation. Finally, if the results are to be applicable to satellite measurements, the character of the sferics signals at frequencies in excess of 20 megacycles/second must be explored more fully.

In short, there is now no neatly packaged answer to the question of how to interpret sferics records in terms of storm characteristics, but there is hope that some type of answer may be obtained.

Dr. Riehl: It would require a great deal of ingenuity and effort because one should look carefully at all the parameters that are likely to provide clues concerning storm characteristics.

Dr. Riehl: On the other hand, as long as 10 years ago, we discussed at some length the earth's charge measured from the ground including its variation from day to day, world-wide, and also directional with respect to certain areas. I don't know to what extent this has been carried further.

Dr. Holzer: It is true that the atmospheric electric field intensity or charge density at the surface of the earth and the air-to-earth current density are controlled primarily by world-wide thunderstorm activity. The difficulty lies in the fact that local meteorological conditions may produce perturbations in the records which may mask the world-wide effect. Use of atmospheric electrical measurements for determining the relative numbers of world thunderstorms would require ideal conditions not easily obtainable at most places on the surface of the earth and never obtainable at any one place all of the time.

Another approach to the problem of assessing world-wide thunderstorm activity from a single location might be mentioned. Some years ago O.E. Deal and I did some work on extremely low frequency sferics. We found a nearly linear correlation between the diurnal variations of the integrated signal in the frequency range from 30 - 120 cycles/second and the diurnal variation of world thunderstorm activity. Such measurements would offer more hope of providing an index of the number of storms in progress, but aren't you also interested in the distribution of these storms over the surface of the earth?

Dr. Riehl: The first parameter I worked on was overall daily index.

Dr. Holzer: There is some hope of getting this information from extremely low frequency sferics although there are some difficulties here, too. Solar flares and other phenomena may affect the properties of the earth-ionosphere "wave guide" and thus affect signal attenuation.

Dr. Jones: May I ask what you mean by high frequency?

Dr. Holzer: When I spoke of "high frequencies" earlier, I was referring to signals in the megacycle range which would penetrate the ionosphere. A large fraction of the sferics measurements have been made in the very low frequency range between 3 and 30 kilocycles/second. My last remarks concerned the lower portion of the extremely low frequency range, particularly from 30 to 120 cycles/second.

Dr. Fritz: May I clarify one point you just made with regard to Dr. Riehl's request for the world-wide distribution? You implied that you could do this with low frequency, and this means the measurements from the ground? Is that what you mean?

Dr. Holzer: Yes, made on the ground.

Dr. Fritz: You mean, you think you can get world-wide distribution and average - -

Dr. Holzer: Let me qualify the statement. The results we obtained exhibited good correlation with average meteorological statistics on the diurnal variation of the numbers of thunderstorms in progress only during certain months of the year when there were relatively few thunderstorms nearby, that is, on the North American continent. The proportionality I spoke of can only be observed when the thunderstorms are at great distance. If this were to be done on a continuing basis one would need a polar station, probably in Antarctica, where the major thunderstorm centers are quite distant.

Dr. Fritz: And that one station would give you something of the order that Dr. Riehl wants?

Dr. Holzer: I pointed out also that there were some limitations associated with variations in the ionosphere. Since the causes of the important variations in the propagation of extremely low frequencies are in the lowest part of the ionosphere, especially the D region, I believe that the difficulties would not be too severe.

Dr. Riehl: I may say that things aren't quite as bad as Dr. Holzer pointed out. I think this is largely because radio engineers don't speak to meteorologists, and meteorologists don't speak to radio engineers.

Dr. Fritz: This is one reason why everybody is in the same room now.

Dr. Pierce: I would say that we now have a fairly good idea of the noise spectrum of frequency of a thunderstorm. We know it best, as Dr. Holzer points out, in the VLF range and at 10 kc/sec.; but there have been quite a lot of simultaneous VLF measurements at about 10 mc./sec., and there have also been other measurements but they are rather isolated ones. One can almost

define the spectrum as varying inversely with the frequency.

Dr. Holzer: Do you mean the amplitude or power spectrum?

Dr. Pierce: The power spectrum varying inversely with the frequency.

Dr. Holzer: I believe this is right and it is consistent with a theoretical study by Hill.

Dr. Fritz: Could you clarify what frequency is radar frequency?

Voice: Three centimeters, 10^{10} cycles/sec. I think. 10^4 mc./sec.

Dr. Fritz: I see. Measurements have been made up to 10^4 mc./sec.

Dr. Holzer: Let me clarify a statement that I made. I believe Dr. Pierce and I are not as far apart as one might assume. I am aware that considerable information has been gathered by radio engineers. Most of their work has been directed toward studying noise level. Such information, while useful in practical communications problems, tells little about the character of individual strokes or the distance of such strokes. If one is interested in meteorological interpretation one must use data different in kind from that gathered by radio engineers. It is not a matter of refusing to speak to the radio engineers; it is rather that their data is not in a form most suitable for the purpose at hand.

Dr. Pierce: We have two things here. We have the routine radio noise measurements of the radio engineer. We also have a few radio research engineers, who are getting VLF impulses and multimegacycle impulses.

Dr. Holzer: A good example of the type of work done by research engineers to which Dr. Pierce refers is that of Horner in Slough, England. He has made simultaneous measurements of sferics in narrow frequency bands centered at 11 mc./sec. and 6 kc./sec. He found that the high frequency and low frequency records do not correspond to each other in detail. For example, the return stroke which is the major source of electromagnetic radiation in the kilocycle range produces little radiation in the megacycle range. Horner was unable to make definite identification of the megacycle radiation with specific processes in the lightning stroke. Clearly more work needs to be done on this problem.

Studies of the type carried on by Horner and others are far more important to meteorological interpretation of satellite records than noise level measurements which are principally useful for the communications engineer.

Dr. Workman: May I ask Dr. Holzer a question? Wouldn't you say that even though you know the noise spectrum you still have the question of how to relate this to lightning strokes? Then once you have done that, you have another question of how to relate those to charge separation.

Dr. Holzer: We do not yet have enough information to do this. More correlated measurements are necessary. Unfortunately, most people who look at sferics records do not look at lightning and thunderstorms and vice versa.

Dr. Fritz: Dr. Jones wants to tell us something briefly.

Dr. Jones: Here are photographs that were taken at 4:00 o'clock last Friday morning of a cloud-to-cloud stroke in a rather minor thunderstorm. My area of observation is primarily 150 kc./sec.

We have four or five sferics sources. Of course one is the cloud-to-ground stroke with which you are all familiar that turns out a rich frequency content at 150 kc./sec., and we have a cloud-to-cloud stroke. In the photograph that is going around you'll notice there is one streamer in there that repeated itself five times.

This was taken with a film strip camera where the film is moving continuously past the lens. The little dots that you see on there are 1/10th second separations. The picture itself is about 1 second duration.

The third source is what Dr. Holzer tells me I should call the tornado pulse generator. I have been calling it the tornado oscillator. We believe that the tornado pulse generator is a vertical discharge ahout 1/2 mile in length at an altitude of some 15,000 feet. We need to know more about this phenomenon. The pulse generator hovers above the tornado funnel when the funnel is active and originally forms from a half hour to an hour before the tornado forms. During the existence of the funnel the discharge is often continuous.

This little device, the tornado pulse generator, appears as a glow on the side of the cloud. You can't actually see the discharge because it is way inside the cloud structure. It turns out frequencies, we find, above 125 kc./sec.

When this thing forms, the cloud-to-ground lightning almost ceases to exist. At a later time when the tornado actively ceases, and there is less energy generated, cloud-to-ground strokes and cloud-to-cloud strokes again become prevalent. During the tornado action, however, for certain types of tornadic storms, the oscillator absorbs a major percentage of the available energy.

The fourth type that I described, is the flare type discharge, which is quite rare and consists of a multitude of horizontal strokes overunning the cloud mass at 18,000 to 20,000 feet. This discharge is characterized by some 40 to 50 directional pips per second at 150 kc./sec.

Air Force men who have flown above it, say that when they look down on it, it's a sea of fire underneath about 10 miles wide. In other words if you look down on the thing, you will see a plane of horizontal discharges about 10 miles wide.

Once more, we don't have any measurements on this as yet except for the 150 kc./sec. df count. We do know that the 150 kc./sec. content is very strong, and that the 10 kc./sec. content is almost non-existent. That is why I am suggesting now, in this discussion that the 150 kc./sec. frequency be seriously considered in the satellite program. I think that this 150 kc./sec.

will propagate up to the satellite and really give you your best measurements.

Dr. Holzer: I would like to comment on Dr. Jones' remarks. One would have great difficulty in observing a sferics signal of 150 kc./sec. in a satellite. The hopeful aspect of his observations is that in the types of discharges to which he referred the power in high kilocycle range is much greater than in the low kilocycle range. If a corresponding increase of power were also found in the higher megacycle range which penetrates the ionosphere, it would be of importance in satellite observations.

Dr. Ligda: I think it is going to be quite difficult to justify a sferics satellite experiment on the basis of possible meteorological information which may be obtained at this stage of our knowledge.

We don't know enough about the relationship between the thunderstorm activity and other various phenomena in the general circulation. As Dr. Riehl pointed out, we have to make some rather bold assumptions to get on to this list. This is work which probably can much more readily and much less expensively be done with conventional surface observations.

I'm thinking, I'm afraid, in terms of the logistics of the satellite and which are quite serious. While we know the physical constraints on the experiment, for example, trying to locate a point on the earth, using the longer radio waves is going to be quite a trick to locate strokes with accuracy.

I wonder if we shouldn't be orienting our thinking more in terms of the geophysical experiment at this stage, and decide what we can do with a sferics detecting satellite that can't better be accomplished on the ground. Then, when we get one up there and see what we have, we can think more in terms of reshaping the experiment to get meteorological information.

Dr. Fritz: Right now we were talking about what we could do if we had no limitations placed upon us.

Dr. Ligda: We have very definite limitations. The satellite has to go out and around.

Dr. Fritz: These limitations are going to be discussed in due course.

Dr. Nordberg: I would like to look at both points that were made by Professor Riehl. The first was discussed very briefly and it came up here again. The second one was the general circulation.

The first one, I believe, was to use the satellite measurements for a severe storm warning, for instance. I would like to hear some discussion on what the advantages of a satellite would be in this respect over a ground based system. Aren't we talking about some rather limited areas very much in contrast to hurricanes where we were talking about very vast areas where we don't have any information?

If we are talking about areas such as, say, the southeast or any other part of the United States, or some other fairly populated areas where we

are interested in severe storm warning, would a ground based sferics system not do the same thing, and do it perhaps more efficiently with better coverage?

Dr. Riehl: In the first place, we are not just concerned here with a small area in a heavily populated country. Consider something quite different, for instance, the so-called equatorial trough zone which extends across the oceans. From the satellite you get some indication that there is such a zone.

Quite often there may be just a conglomeration of low clouds which do not amount to very much. But photographically from above the situation may look potent. From the viewpoint of operations the degree of intensity of convection would be a very useful thing to know. If you find that the radiation data are quite satisfactory in describing everything we want it is time to quit.

Dr. Fritz: You mean like the equatorial trough?

Dr. Riehl: I am thinking of possible consequences. With reference to the United States, there is often no information on things that happen outside the border. Storms may suddenly move in on the continent.

Dr. Fritz: You are talking about the development actually, rather than the warning of ships for example.

Dr. Riehl: Anything that has some relation to severe weather. You do now get a picture from the satellite. It may look very pretty. You may also get certain radiation data to tell you something about the height distribution of clouds. You made a comment on this. Do you think you have reached the end of the road as to what is needed for forecast operations? I'd like to get back to Dr. Ligda and ask just what do you have in mind for ground based sferics observations giving data for general circulation computations such as I have discussed? If ground based data would readily yield the information, we would be doing computations now on a daily basis, I assure you.

Dr. Hallgren: I'd like to comment on Dr. Riehl's statement. I was a forecaster for B-47 operations a number of years ago, and a majority of the flights were over the oceans where there are very few observations. The old fronts were always a major problem. One or several flights would go out one day and report the front had no thunderstorm activity associated with it. So, the best thing we could say was there was nothing there yesterday and probably nothing today. Then when he came back you had lost a friend, because during the 24-hour period things changed.

Dr. Fritz: What area was that?

Dr. Hallgren: I was at MacDill Air Force Base.

Dr. Fritz: No. I mean where were these fronts?

Dr. Hallgren: The fronts I referred to were over the Atlantic Ocean. Our flights went all the way to North Africa, Puerto Rico, Azores, and throughout that entire area. The principal parameter that worried the B-47 pilots was severe weather. They didn't mind flying through cirrus as long as it wasn't

for a major portion of the flight. While you were briefing them, they were rather uninterested until you mentioned thunderstorms. Then they were very concerned.

Dr. Riehl: This remains a problem for any air transportion.

Dr. Fritz: We have heard speculations with regard to what one would like to have. You really can't get what you want. For example, in the case of the heat transfer in the atmosphere which conceivably can be related to sferics measurements, there are many gaps in our knowledge. Even if we had sferics in whatever detail, or whatever form we would want, we would still have a problem with regard to any detailed interpretation in this context, but there is some hope of getting a sort of qualitative estimate. Putting aside these gaps in our knowledge, which would create certain difficulties if we had whatever measurements we even dream about, there are some practical limitations.

In the next few presentations, we would like to go into some of these questions. One question will relate to what is needed in the way of surface observations to bridge part of this gap that we were talking about. It may not do too much for the gap between a sferics measurement and interpretation in terms of heat transfer and water transfer, but it would apply to the question of what surface observations are needed before we try to get satellite measurements. Now we are getting more specific. For example, one thing mentioned was frequency range, as not all frequencies are applicable for satellite measurements.

Dr. Suomi was supposed to be here, but unfortunately he is ill. He was going to talk to us about other practical satellite limitations; about things like resolution, for example. In his absence, Mr. Hilleary has agreed to say a few words so we could open the discussion in some logical way. Before Mr. Hilleary talks, Dr. Hallgren agreed to tell us something about what he thinks is necessary in the way of additional surface observations in order to make a more logical approach toward satellite type of measurements.

Dr. Hallgren: A large part of what we (Mr. MacDonald and myself) had planned to present has already been stated or inferred in one way or another. The detection and location of lightning flashes has been carried out for many years with ground based sferics networks. These observations have proved quite useful in synoptic meteorology. However, the full potential has never been realized.

For the future, satellites potentially provide the means by which observations of sferics can be obtained on a global basis. Most of the ground based sferics networks utilize the signal emitted by a lightning flash in the 10 kc./sec. portion of the spectrum. However, due to the influence of the ionosphere on the low frequency signals, it seems reasonable to utilize the portion of the spectrum of radiation from a lightning flash above the critical frequency of the ionosphere for the detection of sferics from a satellite.

Figure 1 shows the manner in which a high frequency sferics sensor would observe the earth from an earth oriented satellite such as Nimbus. The antenna would have a fixed beam pattern and would monitor a "strip" of the earth's surface below the satellite orbit. A basic problem is whether the

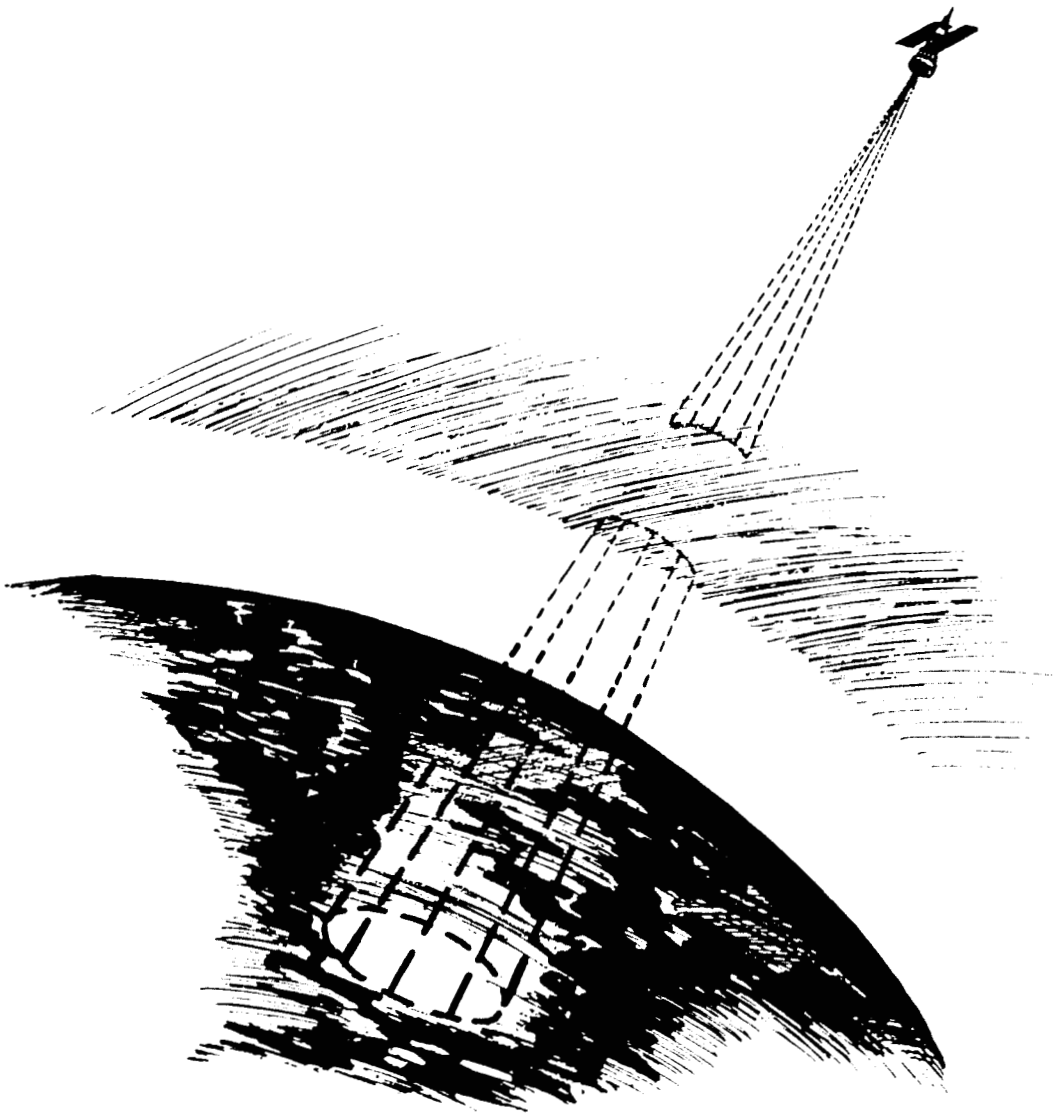

Figure 1. Antenna pattern for a sferics sensor.

characteristics of the sferics in the 100 to 500 mc./sec. frequency range are such that they can be both detected and identified as such in the presence of other noise at satellite heights.

The requirements to detect and identify imply a rather detailed knowledge of a number of parameters. Among these are:

(1) The characteristics of the signal emitted by a lightning flash in the 100 to 500 mc./sec. frequency range -- power, envelope duration, plus characteristics, etc.

(2) The noise of the environment -- terrestrial and extraterrestrial- and the propagation of the signal through the atmosphere and ionosphere.

(3) The climatological aspects of the density of thunderstorms to be expected within the pattern of the antenna and the frequency of flashes from a thunderstorm cell.

With a detailed knowledge of the above parameters, including the statistical distribution of each parameter, the feasibility of a sensor can be established and the design can be effected. It is difficult to delineate which parameters are most important in the design of a sensor. The design of each component of the sensor will depend to varying degrees on each of the parameters mentioned above.

Some of the uses of the various parameters in showing feasibility and designing the sensor are as follows:

Signal Strength -- The signal strength is important in the calculation of the signal-to-noise ratio to be expected at satellite altitudes, and therefore, will be important in selecting the center frequency at which the sensor would operate. From a knowledge of the statistical distribution of signal strengths emitted by lightning flashes at these frequencies, it will be possible to calculate what percentage of the flashes that occur will be detected within the pattern of the antenna.

Envelope Duration -- The envelope duration might be an important parameter by which sferics can be identified from the background noise. Furthermore, the envelope duration will be important in determining whether or not, or how frequently, the signal from various lightning flashes will overlap or become continuous which occur within the pattern of the antenna.

Pulse Characteristics -- The pulse characteristics of sferics in this frequency range might be used for the identification of the sferics signal.

The noise of the environment and propagation of the signal will be important in the calculation of the signal-to-noise ratio. The density of thunderstorms and frequency of flashes from a cell will be used in the calculation to determine whether or not sferics signals from flashes will overlap and whether a thunderstorm will be detected during the time it is monitored by the antenna.

The data presently available in the characteristics of sferics in the 100 to 500 mc./sec. frequency range is limited to a few investigations. Figure 2 shows a summary of the data available on the total duration of sferics at frequencies from 11 to 1,200 mc./sec. Malan reports at 12 mc. the signal duration to be approximated by the duration of the total flash. Hallgren and MacDonald report an average duration of about 20 msec. from each stroke at 30 mc./sec. and also indicate that they found no substantial decrease in the envelope duration up to 400 mc./sec. They also report that the maximum duration occasionally exceeded 200 msec. Hewitt reports signal duration of about 5 msec. preceding the first stroke and durations of about 1 msec. preceding the first stroke and durations of about 1 msec. preceding succeeding strokes. Hewitt also reports durations "of a few tens of milliseconds" for intracloud strokes. Atlas reports at 1,200 mc./sec. an average duration of about 500 microseconds with a maximum of 2.3 msec.

In general, the duration of the sferics signals decreases with increasing frequency above 10 mc./sec. However, the data that are presently available are insufficient to assign an average duration to any particular frequency, and the statistical distribution of durations needs further investigation. Furthermore, the difference in the durations of cloud-to ground, intracloud, and cloud-to-air flashes requires further investigation.

The most comprehensive data on the pulse characteristics of sferics signals above 10 mc./sec. are those of Atlas for 1200 mc./sec. and a bandwidth of 600 kc./sec. He reports that the median duration of the pulses was 20 microseconds with an average of 27.5 microseconds and that the duration of the pulses seldom exceeded 40 microseconds. Hewitt reports at 600 mc./sec. and a bandwidth of 1 mc./sec. that the duration of the pulses was only a few microseconds for an intracloud flash and was a general rise in the receiver noise for a cloud-to-ground flash. Hallgren and MacDonald report at 30 mc./sec. and a 5-kc./sec. bandwidth that the duration of about 50 percent of the pulses exceed the resolution of about 100 microseconds.

Figure 3 presents a summary of the data that are presently available on the signal strength at frequencies above 10 mc./sec. and represent the field in volts/meter normalized to a range of 1 statute mile and a bandwidth of 1 kc./sec. The solid line is an extrapolation of the spectrum for a stepped leader stroke proposed by Watt and Maxwell. The results of Horner and Clarke are based upon 25 sferics and those of Atlas on 9 sferics. Hewitt considers his value to be a conservative estimate of the field strength and according to Atlas, he considers that the field of the stronger sferics must have been 10 times greater than the value of 6.5×10^{-6} v./m. shown in figure 3. Atlas considers his value of field strength, 1.5×10^{-4} v./m. at 2800 mc./sec. to be representative of the field from "strong"sferics. Hallgren and MacDonald consider their values of field strength between 30 and 400 mc./sec. to be representative of "average" sferics. They report that their calculated field strengths decrease by a factor of three between 30 and 400 mc./sec. It is quite obvious that the data on signal strength are indeed scarce and not sufficient to determine whether or not the field strength falls off as 1/f in this frequency range.

The above discussion can lead to only one general conclusion. The information that is presently available on the signal strength, envelope

11 mc./sec.(Horner & Clarke)	- Range from 40-330 msec.
12 mc./sec.(Malan)	- Throughout period of flash.
30 mc./sec.(Hallgren & Mac Donald)	- Avg. 20 msec./stroke; Max. 200 msec. No substantial decrease in duration to 400 mc./sec.
600 mc./sec.(Hewitt)	- Up to 5 msec. first stroke, 0.5 to 1 msec. succeeding stroke (cloud to ground). Series of spikes for "few tens" of milliseconds (cloud).
1200 mc./sec. (Atlas)	- Avg. 0.5 msec./stroke Max. 2.3 msec.

Figure 2. Signal duration

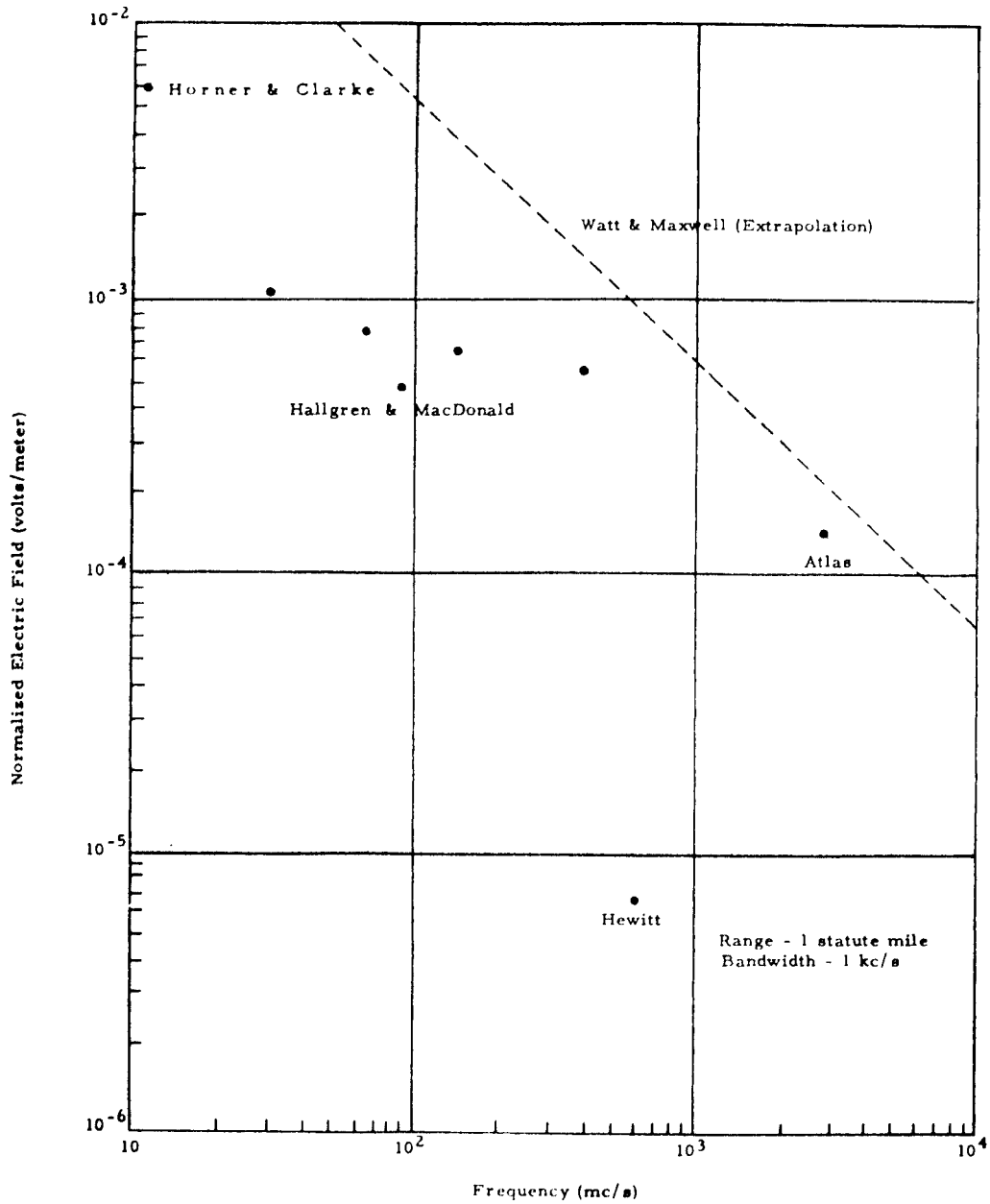

Figure 3. Normalized Electric Field vs. Frequency.

duration, and pulse characteristics in this frequency range gives only an indication of the actual values to be expected. The statistical distribution of the various parameters is essentially unknown. Additional surface measurements of the above parameters are required in order to design a satellite sferics sensor. However, since a sensor system on a satellite will not view the radiation pattern of a lightning flash from the same angle as a ground based experiment, it is imperative that some data be collected in the future by an airborne experiment on U-2 aircraft or balloon.

Dr. Jones: Will any consideration be given to determine the location of the source, whereby you can tell exactly what angle the signal from the source arrives from?

Dr. Hallgren: In other words, can we pinpoint the location of the sferics signal in our surface experiment? We currently plan on obtaining the location of the thunderstorm from radar and visually the direction from which the flash originated.

Dr. Fritz: Are you finished with your presentation?

Dr. Hallgren: Yes.

Dr. Fritz: You indicated that we need more data of the same kind. It wasn't too clear to me why. The idea is to find out what we need to measure on the ground in order to decide, for example, what frequencies one should use on a satellite to see that there is enough power available in these frequencies. You said that you need more of this kind of information.

Dr. Hallgren: Yes. This is true. It is just like any measurement where you are not sure that the magnitude is accurately known. For example, Hewitt was studying radar echoes from lightning and he used the sferics signal to trigger his camera. Therefore, his signal strength measurements are just not very accurate. In addition, the statistical distribution of the parameter is extremely important. It is simply a fact that the data presently available at these frequencies are quite limited and although very encouraging, you just need more good, precise measurements. Does anybody want to say anything, or ask any questions in regard to this?

Voice: Isn't it possible that the duration was due to the fact that the sensitivity was down? I noticed, for example, that even in the very low frequency range that Kitagawa and Brook have increased the average duration of the pulse by increasing the sensitivity and increasing their frequency response. I am wondering if this type of thing might not also apply to the Atlas measurements?

Dr. Hallgren: No doubt, if you increase sensitivity you will increase the signal duration to some extent.

I'd like to add just one more slide. This will show you a photograph of sferics and then you can just draw your own conclusion.

Dr. Fritz: While you're getting that ready I'd like to ask a question. The

duration of these flashes is on the order of milliseconds. How long does the activity continue? At milliseconds you obviously don't have much time, so you have to have a lot of these going on all the time.

I wonder if this is related to the question of the lifetime of thunderstorms in a certain area. The satellite comes over, and in order for it to sense something this would have to be going on for some reasonable amount of time, hours I suppose, in order for a satellite to be there at the right time.

Dr. Holzer: The character of the satellite record will depend upon the size of the area from which signals can be received. The probability of receiving a signal will depend on the number of storms in progress in the area and the average interval between strokes in a single storm. Assume each storm produces a lightning stroke at 10-sec. intervals; if there are 10 storms in the area under surveillance, one would expect to receive one signal per second on the average.

Dr. Fritz: It would be one per second, but for how long? Would it be hours?

Dr. Holzer: The electrical life of a thunderstorm, that is, a single cell, is usually between 20 and 45 minutes. In the case of large storms which produce lightning over longer periods it is probable that the activity is produced by a succession of cells growing and decaying.

Dr. Hallgren: The upper trace on this photograph (figure 4) shows the amplitude of a sferics signal as a function of time. The center frequency being monitored was 30 mc./sec. with a 5 kc./sec. bandwidth. As you can see, there were two bursts of signal separated by approximately 70 msec. The first burst had a duration of approximately 20 msec., and the duration of the second burst was less than 1 msec. One possible interpretation of this sferic is that it originated from a multiple stroke flash. The longer burst of signal preceded the first return stroke and the second burst preceded the second return stroke. Any questions?

Dr. Holzer: This is quite instructive to see the original records. The duration of a stroke would be a matter of definition. The high frequency records certainly have less continuous activity than the low frequency records. A "stroke duration" might well be defined as the interval between the observed beginning of the first burst and the observed termination of the last burst.

Dr. Fritz: Yes. Is there general agreement on the idea expressed by Dr. Holzer that the numerical value of the amplitude versus frequency, which is one of the things discussed, is so uncertain that we need to have more of this in order to design an experiment to take advantage of the quantities?

Dr. Hallgren: I think our reported values of signal strength and duration are quite conservative. I wouldn't be surprised to see the magnitude of both parameters increase with a refined experiment.

Voice: I think your question about duration is very significant. We are talking about a phenomenon that lasts let's say (and I'm speaking very crudely

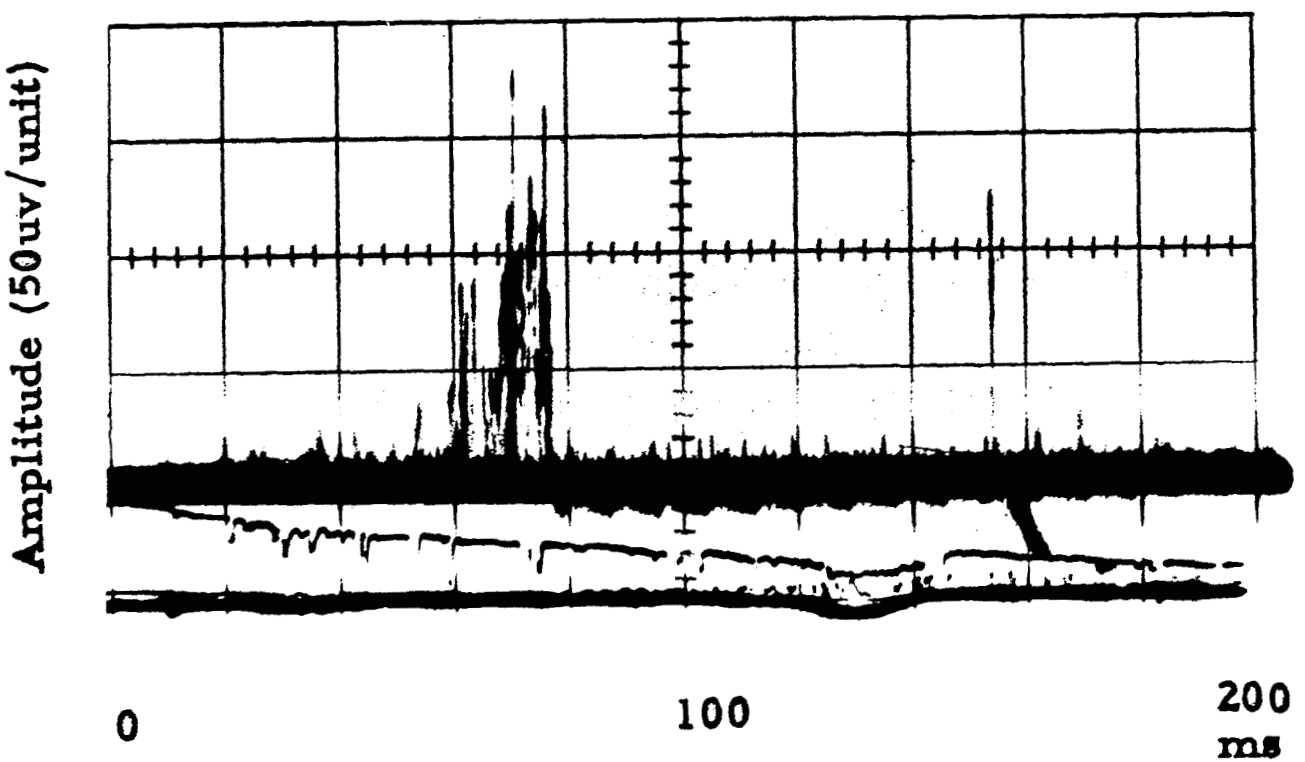

Figure 4. Sferics Signal, 30.3 megacycles/second at 5 kilocycles/second bandwidth.

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now in terms of order of the magnitude) for a length of time equivalent to about one orbit of a satellite and the pulses that you are attempting to measure, which come with a period of a fraction of a minute (10 seconds to more than a minute) and which have a duration of 1 to 100 msec. or perhaps 500 msec. I think these are important things to think about in the line of your field of vision, let us say.

Dr. Fritz: We should consider these very closely. It will tie in possibly with the frequency response of the instruments and how fast we have to be able to measure. These questions will come in, I suspect.

Do you want to say something?

Dr. Ligda: I might describe some of my observations. I think they demonstrate some of the uncertainty which attends the question of the amount of power which lightning radiates.

The nature of my experiment was to take a CPS-9 radar (10^4 mc./sec.), turn off the transmitter, and point the antenna toward an active thunderstorm from which I had already been observing lightning echoes for quite a few minutes to see what there was in the nature of radiated energy.

On the A-scope of the radar, which had a time base of about 4 msec., I got occasional indications of a number of little spikes like that which are written up in the final report which we made on that subject back in June 1958 on our Air Force contract AF19-(604)-1564.(See Appendix for reference to the report).

Each discharge produced a number of individual signal pulses, and the durations of the pulse envelopes were in fairly good agreement with the observations described here. If I recall correctly, about 3 or 4 msec; something on that order.

There would be something like 8 or 10 individual signal spikes in one of these signals and they appeared at any range on the scope.(The thunderstorm was about 60 miles away).

Then I turned the scope over from A and put it on R-scope. This, on a 5-mile range setting, would give a time base span of about 50 μ sec. This interval is smaller than the spacing between individual pulses or spikes so that it was only possible to observe one of them at a time.

Occasionally I would see a spike displayed which was of such short duration that it was clearly only one sweep. On any spike I was unable to see any separation at the baseline between the upward and the downward deflection of the indicator.

Now, I judge I could resolve on this scope something on the order of about a tenth of a mile. This would be about 1 μ sec. in time on the scope. These spikes probably were signals from a lightning discharge. I have no reason to suspect that they weren't, because they were the only transients which were appearing and they were showing up at intervals which would correspond

to lightning discharge activity in the storm itself. It means that the signals, which were emitted on a frequency of about 10,000 mc./sec., consisted of pulses of duration something less than a microsecond. What the power is in these I don't know. They looked like they were reasonably strong. This looks to be the sort of thing we have to cope with in "fine structure" of lightning signals. I think the kind of information which has to be gotten is of this type.

Dr. Hallgren: We are familiar with your work.

Dr. Ligda: I think that possibly the low frequencies have the same sort of a fine structure.

Dr. Hallgren: I think that this is indicated by Hewitt's measurements. At 600 mc./sec. he used a 1 mc./sec. bandwidth and reports the sferics contained pulses whose duration were of the order of 1 msec.

Dr. Ligda: I might add that these pulses are of such duration and frequency as to correspond very nicely with signals possibly emitted with the advance of the stepped leader.

Dr. Hallgren: Of course, down at the frequencies at which we were working (30 to 40 mc./sec.), the durations that we have measured are considerably longer than any average duration reported for a stepped leader. Therefore, sferics in this range of frequencies partially, at least, originate from the interstroke processes.

Dr. Fritz: I think we should proceed to the next point which Dr. Suomi was going to talk to us about.

We get to the question of what spectrum interval should you observe in order to measure something in this area from the satellite. The question is of spatial resolution and I think this needs to be discussed more. Mr. Hilleary has agreed to substitute on very short notice.

Mr. Hilleary: The very few remarks I'm going to make have already been touched upon in other discussions. Most of our preliminary thinking has been in terms of the Nimbus satellite system which will be a polar orbiting vehicle stabilized with respect to the earth and the sun, so that orientation of fixed antennas will be no particular problem. The bottom of the satellite will be always level with the surface of the earth and one side of it will be forward at all times.

We have considered for this type of a satellite three possible sferics systems. One has very little directional sensitivity and might be useful for hemispheric electricity studies or, perhaps, some "thunderstorm bookkeeping" measurements.

We have also thought in terms of a system with a broad-beam directional antenna, as suggested by Dr. Hallgren, directed to cover an area immediately below the satellite. The area monitored would coincide roughly with the area of cloud picture. This might be of operational use to meteorologists because

it would show if there was sferics activity associated with each cloud picture.

Voice: What area?

Mr. Hilleary: I think it is about 500 miles on each side.

Dr. Suomi wanted to talk about the third system possibility employing radio direction finder techniques. I would like to turn over this part of the discussion to someone who knows more about radio direction finders than I do. One of the basic considerations in direction finding would be the signal-to-noise ratio. We would need knowledge of the strength of the signals to be expected and the noise at the satellite level in order to judge the resolution of such systems.

The experiment and system designers will need to know the things that the research people here want to know about the sferics signals. The research workers want to know the "signature," the essential characteristics of the signal as might be revealed by spectral analysis, so that they can interpret it in terms of the physics of the problem. The system designer would want to know precisely these same things, so that he can design an optimum system. These are the particular points that I wished to mention. They have already been brought out more than adequately.

One important question would be (and perhaps Dr. Riehl would like to start this off), what resolution on the earth's surface would be of use for various meteorological purposes? How can we relate resolution and usefulness for each type of measurement?

Dr. Fritz: You probably want the best resolution you can get.

Mr. Hilleary: Not necessarily.

Dr. Fritz: There is one question that I would like to discuss now. It's the question of the spectral interval. This morning some people had mentioned 50 kc./sec., and I had the impression that you said that 10 mc./sec. was ---

Dr. Holzer: Above 10 mc./sec., that is, above the average critical frequency of the F_2 region. There would be difficulty in using signals near 10 mc./sec. because cosmic noise absorption measurements show great variability in this region, from 2 to 15 db. I believe that in the range you were speaking of, Dr. Hallgren, you avoided this difficulty.

Dr. Nordberg: Wouldn't you have to be quite a considerable amount higher than the F_2 critical frequency, because you also have to consider satellite geometry? You will not always be looking straight down. As a matter of fact, a lot of your measurements, if you want to get any statistics whatsoever, would have to come from a fairly wide cone of observation.

Dr. Holzer: I should like to ask Dr. Hallgren what the total ionospheric absorption was in the frequency range of his measurements.

Dr. Frtiz: Is it from 100 to 300?

Dr. Hallgren: 100 to 300 mc./sec.

Dr. Rossby is much more familiar with this and could give a more precise answer to the question.

Dr. Rossby: Well, no. Really, my work has been primarily concerned with the propagation of VLF signals and I have some figures on that. Of course, this is an entirely different spectral region. All I can recall now are the figures of signal-to-noise ratio that you gave.

Dr. Hallgren: Well, let me go back and say that when GE was designing the top side sounder experiment, they studied the attenuation rather closely. I think Dr. Schemerling of Penn State was consulted by GE and did the work in which he has quoted at 15 mc./sec. an attenuation of approximately 1 db. At 500 mc./sec the attenuation is essentially negligible.

Dr. Holzer: Attenuation at 15 mc./sec. is a function of latitude. You get more obstruction in the Tropics, for example, and this will be very critically related to the F_2 critical frequency. I was asking whether you consider it probably quite negligible at 100 mc./sec.?

Dr. Nordberg: Above 100 mc./sec. it ought to be.

Dr. Pierce: I think the fact that 100 mc./sec. is largely unaffected in passage through the ionosphere comes from satellite observations.

Dr. Nordberg: Even in measuring ionospheric density we are quite content using say 50 or 48 mc./sec. signals as a reference. This means that these frequencies go through virtually unattenuated.

The F_2 critical frequency is very rarely above 12 even in the Tropics, but this is, of course, vertical propagation and you have to allow for the cosine law. I believe that anything above 100 mc./sec. is practically not even refracted.

Dr. Vonnegut: Shouldn't we consider the possibility of using visible light which would permit fine resolution with very simple apparatus? Has anybody had a look at the dark side of the earth with existing equipment to see what it looks like?

Mr. Soules: John Glenn did.

Dr. Vonnegut: It seems to me that you run into quite a lot of hardware if you use radio frequency direction finding techniques. I think that there is certainly a chance of getting a nice overall picture just by using ordinary optics.

Dr. Fritz: Professor Suomi, if he were here, would probably have talked about it because he had some ideas about mounting a photomultiplier on a TIROS satellite and triggering it somehow with light. I wonder about the relation between the visual signal and the sferics signal. Is there a one-to-one relation? Is there always a visual signal when you get a sferics signal?

Voice: You always get a radio noise when you get a spark.

Dr. Fritz: Does that mean that the sferics will be more frequent than the visual one?

Dr. Byers: The visual one is attenuated more in the cloud.

Dr. Fritz: I mean from the satellite level you would get a sferics one more often than you would a visual one. This doesn't mean that Dr. Vonnegut's suggestion shouldn't be followed up, because it may supply a check and be so much simpler to do.

Voice: From what I have heard in the discussion here today, the difficulty of actually identifying a sferics signal, in the visible may not be any greater or even very comparable to identifying it at a low frequency signal.

Dr. Workman: The important thing to note is that the direction finding is very simple. Of course, there are going to be strokes that would not send very good signals. If there is a high cirrus cover, you won't see very much photometrically.

Dr. Hallgren: I would like to hear Dr. Pierce discuss how he would utilize such data in your research.

Dr. Pierce: What data is that?

Dr. Hallgren: VHF sferics measurements obtained from a satellite.

Dr. Pierce: How one would use them?

Dr. Hallgren: Yes. I wonder if you would want to comment.

Dr. Pierce: This seems to me to be the whole general subject of the meeting.

Dr. Hallgren: I would like to hear it from you specifically, respecting your outstanding background and experience.

Dr. Pierce: I would regard it as giving information:

A. On radio noise.
B. As a means of locating thunderstorms.
C. Having located sferics sources, how does one translate that location into the kind of convective interchange Dr. Riehl has been talking about?

You have three definite stages there. The first one is really not a meteorological thing at all. It's just an interest in the radio noise. Then we have to fix the location and translate it into information relating to the general circulation.

Dr. Rossby: Do you, Dr. Pierce, and/or Dr. Hallgren, have a feeling now for the kind of average basis that the radiation pattern of a sferics source might

look like?

Dr. Pierce: Depending on frequency, the pattern as viewed from above the ionosphere could be very different from that occurring below. One thing just crossed my mind regarding the differences mentioned between horizontal and vertical flashes and I'm going to throw it out now. Would there be an appreciable change of a state of polarization?

Dr. Nordberg: There is considerable rotating even at 100 mc./sec.

Voice: That technique has been used for measuring total electron content of the ionosphere.

Dr. Fritz: What would be the significance of it?

Dr. Pierce: I imagine that it means that it would be rather difficult to relate a received orientation of signal to orientation of lightning.

Dr. Fritz: In other words, you wouldn't be able to locate the specific source.

Dr. Nordberg: No, it means you wouldn't be able to locate the orientation of the stroke to tell whether it was a horizontal stroke, vertical stroke, or whatever angle the stroke was at. Is this desirable information for the atmospheric physicist and the meteorologist?

Dr. Fritz: Let's see if I understand. If you had an antenna which had a limited angle, it might see a thunderstorm occurring somewhere else?

Dr. Nordberg: No, just that its polarization has rotated.

Dr. Fritz: It would still mean that the thunderstorm was underneath the satellite.

Dr. Holzer: This information is desirable, but it certainly isn't essential for the sort of things we have been talking about this morning.

Dr. Fritz: Does anybody want to say anything more about resolution problems?

Dr. Byers: I thought we might go back to the question that Mr. Hilleary asked. He directed it to Professor Riehl, which apparently disqualified me. In the TIROS-Nimbus system, for example, we can very well find the effective radiating temperature of the upper surfaces of clouds. In that way we can find out their altitudes.

As you look at the results of these surveys, you find that there are obviously regions where there is a great deal of thunderstorm activity, that will show up quite well. Many of them have cirrus at the tops which spread for some cases 100 miles or more, covering a very large area.

It is impossible to tell from these photographs to what extent this is cirrus alone or has thunderstorm activity imbedded underneath it. Sferics could tell very well where the lightning activity cuts off. So much of this cirrus is still extremely dense even some distance away from the center of

activity. So, the resolution would have to be good enough to tell where within 10 miles the lightning activity cuts off under these cirrus fields.

Dr. Fritz: In other words, you would be asking for a resolution for something like 10 miles.

Dr. Byers: Yes.

Dr. Fritz: Is this practical?

Mr. Hilleary: In considering radar systems, we found that it is utterly hopeless to consider getting anything like a good resolution and full coverage between orbits.

Dr. Fritz: You might satisfy Dr. Byers' requirements without going all the way to the horizon. In other words, say you have 500 miles in area. Within that area, could you have a 10-mile resolution to avoid the question of looking out to the horizon?

Dr. Riehl: Once you have an area of this type, you also have the cloud pictures to fall back on.

Dr. Fritz: Yes, but Dr. Byers pointed out that the cirrus would overlap the area so that you couldn't tell much.

Mr. Hubert: If you want to look at the intertropical convergence zone in the eastern Pacific, you can find it on a map as a yellow line a degree wide, but it appears on pictures 5° wide. I'm sure that the real active convection is not 5° wide, but if it's dense, it is dense almost all the way through its width of 300 miles.

Dr. Vonnegut: It seems to me that one might be able to tell what was going on underneath the cirrus by observing the orientation of the ice crystals caused by the electric field produced by the storm.

I was wondering whether any of the satellite pictures that are obtained of these cirrus shields ever show the reflection of the sun. Frequently, from an aircraft you can look down and see a bright image of the sun on the horizontal ice crystals.

In the case of an electrified storm, I would imagine that there would be a displacement of this bright zone. The sunlight would no longer be reflecting off the horizontal surfaces for the ice crystals would be tipped by the electric field. It may be that you can gain some evidence of electrical activity going on underneath by looking at the reflectivity of the cirrus shield. Has this been tried?

Mr. Hubert: We had a quick look at this, but we weren't aiming at this at all. We looked for the bright sun spot in reflecting clouds and they didn't appear to be exactly in the right place. We attributed this probably to the forward scattering of droplets rather than the orientation of ice crystals. You have to take these two factors into account.

We have looked at some of the things that Carl Erickson did. We checked this and didn't seem to find the brightest spot necessarily -- it was along the plane of the sun, but not at the right spot. The brightness measurements in the photographs are so crude that I'm not even sure this a a firm result. This is the impression.

Dr. Fritz: I guess I spoke out of turn before when I said that nobody had done this. Dr. Byers says that Dr. Fujita has. Do you want to say something?

Dr. Byers: He detects differences in the reflectivity. He is not sure of his interpretation. He feels that he has distinguished between water and ice without any difficulty. As to whether or not he can get the orientation of the crystals, I just wouldn't know. I'll suggest this to him and see if he can figure it out.

Dr. Fritz: Dr. Jones?

Dr. Jones: I was just going to ask a question of the last gentleman.

Dr. Fritz: That was Mr. Hubert.

Dr. Jones: I haven't been able to isolate or detect any lightning reflection. Have you?

Mr. Hubert: No.

Dr. Jones: Would there be an opportunity to?

Mr. Hubert: Dr. Wark tried to find the moon on TIROS pictures. Maybe he has looked into this brightness thing a little more. I don't know. Did you do any brightness calculations on what the vidicon was capable of seeing in your search for the moon?

Dr. Wark: In the case of the moon, we were very near the noise limit of the system. The moon was so small anyway that it was only about two scan lines wide. We examined many pictures and there were so many little flaws on the pictures that we couldn't decide which one might be the moon and what might be just a bit of dust or something else.

Voice: How about lightning flashes?

Dr. Wark: We have never taken any pictures that I know of.

Dr. Nordberg: There have been pictures taken of the earth in the dark. I think some people looked for the lights of Los Angeles or the lights of large metropolitan areas. We have looked hard but we could not detect anything.

Dr. Wark: I think it is a matter of brightness in this case. Cities are simply not very bright in comparison with a cloud illuminated by sunlight.

Dr. Fritz: Let's see now. There are many other instrument characteristics that we could discuss.

Dr. Hallgren: I wanted to come back for one second to Dr. Byers' question on the 10-mile resolution.

If a forecaster had TIROS photographs in which cirrus clouds extended over a relatively large area, he still would have no information about the thunderstorm activity. However, if the forecaster had measurements indicating the number of flashes of lightning that occurred underneath the cirrus, this would be most significant to aircraft operations. Whether the thunderstorms are at 21° or 22° latitude really doesn't make much difference to the pilots. The important thing is will he cross a line of severe thunderstorm activity.

Therefore, I think there is information that can be gained from such data although resolution does not pinpoint the location of the thunderstorm.

Dr. Fritz: You think that resolution of 500 miles by 500 would still be useful.

Dr. Hallgren: Certainly.

Dr. Ligda: Our studies of radar echoes from lightning can detect the greater echo inside the precipitation area. They often occur in isolated thunderstorms at distances of 20 to 25 miles away from the rain core. So you get a great deal of electrical activity going on in the cirrus shield outside the rain core. Besides, I wonder if a 10-mile resolution would help to pin these down.

Dr. Nordberg: Can't we safely summarize, considering Dr. Ligda's remark and many of the other instrumental problems, that to look for any finer resolution with presently conceivable satellite sferics systems is just impossible?

I would like to say this. The fact that we cannot see lightning flashes, or cities with TIROS cameras is simply due to the TIROS system itself. You can have cameras that can observe these things. They exist.

Voice: Perhaps the area would be limited.

Voice: We could actually pick out a city or a lightning flash, particularly if we had a longer exposure.

Dr. Nordberg: But I was talking about the limited resolution. I was not talking about an optical system. I think you can very easily, well not easily, but with an optical system and a visual system you can certainly achieve great resolution.

You can also achieve the intensity level. As a matter of fact, I think that because Glenn saw lightning but didn't see noctilucent clouds or air glow, and since we have instruments that can even see noctilucent clouds and air glow from these altitudes, indicates that you can build an instrument that would optically see the lightning.

There are other problems that have come up here, such as what do you do if the lightning is obscured by overlying cirrus. You will probably get more indication or larger statistical samples if you look at the radio wave frequencies.

Can we talk about antenna problems and hardware problems like this of pinpointing 100 or 500 or 1000 mc./sec. signals within a 10-mile area from the satellite?

Dr. Fritz: Do you want to talk about this? I think it is an important point. I don't know the answer.

(Dr. Riehl made some calculations on the blackboard).

Dr. Fritz: This is very good.

I wonder if Dr. Stampfl would tell us about his views on what is practical in the way of resolution. What is the lowest resolution that is practical?

Dr. Stampfl: Well, I hate to do this in the presence of so many experts who have used sferics equipment with which I am not familiar.

In general, a static antenna on the satellite can look at the area underneath. If you want resolution within elements of this area that the satellite sees, one has to go to a scanning system. Scanning of a mechanical nature in satellites is extremely difficult and it is virtually impossible to design for any kind of practical lifetime. So one is limited to either dishes and reflectors and scanning electronically, or to large area arrays and obtain your resolution by proper phasing.

Studies that have been done by Mr. Hilleary and other people showed that to obtain beam resolution within the order of a fraction of a degree involves a high amount of complexity and very large weight. One figure to keep in mind I think, is 40 miles from the Nimbus satellite altitude requires roughly a 3° beam. If one wants to do this at a 500 mc./sec. frequency, the reflector size is on the order of hundreds of feet.

To quote a specific example from memory, we had calculated that a 20-foot dish diameter is roughly the practical limit, assuming 1/10 of a wavelength droop at a 3-cm. wavelength. So, if one wants to go to dishes on the order of hundreds of feet, a completely different satellite concept than those presently available will have to be devised, both mechanically and electrically.

One cannot discuss sferics measurements with that kind of resolution on existing satellites. I think the only conclusion that could be reached would be to design a satellite which is only oriented towards the measurement of sferic signals. This is a personal view on the subject. It is only supported by those few facts that I was able to present without doing a study on the subject.

Dr. Fritz: What do you consider practical with the present satellites?

Dr. Stampfl: I think it would only be practical to consider static type antennas to view the sferics activity underneath the satellite area. The satellite sees the earth as a 122° disc. Whatever can be received from this 122° area can be recorded. I think this would be a practical limit.

Voice: No smaller resolution than horizon to horizon is practical?

Dr. Stampfl: Let's not say that. When you can get down to the size of one Nimbus type picture on the order of 500 miles, you may be right. This might be possible, but I cannot say what order of magnitude in weight would be required.

Dr. Fritz: In other words, it seems like the practicalities of the system for anything that is going to be available soon, like Nimbus, limits us to essentially horizon-to-horizon with not too much chance of getting anything finer. Say you have a static angle underneath the satellite. What is the smallest size you can get?

Dr. Stampfl: I think 45° is just about the smallest you can get.

Dr. Fritz: That's the size of one picture, more or less.

Dr. Stampfl: It's on that order.

Dr. Fritz: We can do something like looking straight down. You can get something comparable to the size of the picture on Nimbus when the camera is also looking straight down.

Dr. Stampfl: You have to keep in mind that the figure you quote is a theoretical or half power point on the 45° beam. As far as my knowledge goes, the variation in signal strength will be more than the factor 10 at the satellite; probably considerably more than a factor of 10. Consequently, what does the 3-db. point mean?

Mr. Hilleary: Dr. Stampfl's point is well taken. This is a half power point. The stronger strokes near the horizons may appear just exactly as would weaker strokes beneath the satellite.

Dr. Nordberg: A point was raised here whether we are back to the suggestion on optical techniques. I think there are two kinds of approaches here that could be traded against each other. Should you have a higher resolution and a rather limited number of observations? Or, would you rather have as large a number of observations as possible with more tolerance on your resolution?

I gained the impression from the discussion that you would rather have a larger number of observations. There are some cases where you would like to have a lot of resolution, but it seems to me that on these circulation schemes that Dr. Riehl has mentioned, provided that you can get all of the other assumptions fulfilled, you would like to have just counts more than anything else.

Even in the severe storm detection I think the point that received a lot of emphasis, perhaps most of the emphasis here, was whether old fronts contain electrical acticity or if they don't.

I think in most of these cases, even if you can't orient the electrical signal very well, if you have photographic coverage from the same satellite you can still say that over such and such an area I received a larger amount of counts than anywhere else and I see a front going through here. So, those

counts must be associated with that front. Of course, there still will be many cases left where you would like to have resolution.

Dr. Fritz: Yes. I think that last was a good point. In other words, if we end with a resolution of something like 500 miles on a side when we have pictures, the resolution would essentially be limited to something a little better. This is because the clouds won't cover the whole area. The clouds will be confined to a portion of the area and that will be the radiating source. So you may have a smaller spatial resolution.

Dr. Stampfl: Yes, but again modified by the point that I was trying to bring out before. In the second picture in the Nimbus sequence that you don't see yet, there might be a severe thunderstorm which you now associate with a possible weak thunderstorm located in the same front picture. I think you always have to consider at least three picture widths.

Dr. Fritz: Actually your basic resolution element would always be 122°.

Dr. Stampfl: 122° coverage. That you only get when you stay in frequencies well above 100 mc./sec., because otherwise you go beyond the horizon.

Dr. Fritz: So by this system it looks like you would be limited to something like the last thing Dr. Riehl mentioned.

Dr. Stampfl: I think the information rate that has been quoted here is not excessive. The television picture is a tremendous information source compared to that.

Voice: Mr. Chairman, looking at the next point here I think we have just about covered what meteorological information can be inferred by counter stroke.

Dr. Fritz: We have been talking about the resolution and the spectral interval. There are other types of information.

Dr. Holzer: I was originally scheduled to speak on the last subject in the agenda. Since most of the material has already been injected into the discussion in piecemeal fashion, I would like to summarize it. The simplest use of sferics signals to derive meteorological information is the measurement of the frequency of occurrence of sferics (lightning strokes) from a given area. This should provide a rough measure of thunderstorm power in the area and may provide a measure of the thunderstorms' effectiveness as a vertical transport mechanism.

If the area which a satellite has under surveillance is large and contains an important thunderstorm center, the stroke frequency may be sufficiently high that the resulting sferics signals overlap. In such a case an integrated signal could be used instead of a stroke count. A decision of this kind could be made when the altitude of the orbit was determined.

More refined methods of interpreting sferics signal such as observation of the spectral distribution of energy, duration of the signal, etc., offer hope of providing more detailed information concerning thunderstorms in the future. They are not yet sufficiently well developed to guarantee highly useful results in the first satellite which measures sferics.

If measurements are made on the ground with a view to providing information of particular use in a satellite program, special emphasis should be placed on observations in the high megacycle region of the spectrum and the correlation of these measurements with lower frequency observations. It would be particularly advantageous to make these measurements in the Tropics. Perhaps the Indian workers could be encouraged to undertake such measurements.

Dr. Fritz: Would Florida be a good place?

Dr. Holzer: Yes. It would, in fact, be desirable to get the information at more than one location.

Dr. Fritz: About that last point you made that we need a correlation between the emission in the low frequency and the high frequency, and then you said something about correlating with other things. You talked earlier about convection. Is that what you meant?

Dr. Holzer: It would be highly desirable to correlate sferics measurements with direct observations on the thunderstorms themselves, for example, cloud dimensions and rate of growth. Such measurements might be very significant in attempting to study the storm as a vertical transport mechanism, mentioned earlier in the discussion.

Mr. Hubert: You might do an observation program something like Anderson at GRD did on his cloud, where you pick out your storm and photograph it with time lapse and derive a good idea of the geometry and the time rate of growth of the storm.

Dr. Holzer: Dr. Workman just now suggested that one should also use radar to study storm precipitation.

Dr. Byers: Does this mean that you should orbit the satellite to those areas where these facilities are available?

Dr. Holzer: Well, this would be desirable. The satellite has one very important advantage, and that is it samples the whole world. This is the only thing. Other than this, all these should be done on the ground.

Dr. Nordberg: Would you say, Dr. Holzer, that these measurements actually should be made beforehand? That one should really have these measurements as a prerequisite to satellite observation?

Dr. Holzer: This is a matter of judgement and circumstance. I believe that if there were an opportunity to get simple equipment on a satellite, not necessarily designed as a sferics satellite, but one with a low latitude orbit, one should go ahead with a stroke counting program. I believe that even this simple measurement would be useful in providing world-wide information on thunderstorm distribution and would also be useful in planning a more elaborate sferics satellite. However, before one goes into an elaborate plan for a special sferics satellite, more ground measurements are desirable.

Dr. Fritz: In other words, if I understand your remark, you might go along something like this. Make the horizon-to-horizon type of sferics measurement

which I understand would be relatively simple. At the same time we should make a ground study to pin things down. Perhaps then plan for a more elaborate satellite program.

Dr. Riehl: You could do quite a few experiments on the ground.

Dr. Holzer: Yes. I believe that it would be desirable to encourage interested workers at various locations over the world to make correlated thunderstorm and sferics measurements in order to get a good sampling of data.

Dr. Fritz: I wonder how Dr. Riehl and Dr. Byers would feel about this, in view of what has been said, about the utilization of measurements which had no spatial resolution except that it sees in many instances from horizon-to-horizon. The spatial resolution in that framework is determined by the satellite. In other words, you see the whole world but you don't see anything smaller than an area that is covered from horizon-to-horizon which is on the order of 3,000 miles. In other words, a circle of 3,000 miles in diameter. I suppose you can do this as often as you please. More or less continuously you see 3,000- mile circles.

Dr. Byers: I would say let's not think only about what you might call the descriptive meteorological aspects of this thing. I think Bob has brought up some points suggesting that this kind of study is interesting in itself. That is, we want to find out a little more about the spectrum of these things; a little more about the energies involved.

I think that people who use and are studying sferics shouldn't always be looking around to find meteorologists who will pat them on the back and say, "This is going to solve our problems." I think there are things within the measurements themselves that are very much worthwhile. This is getting a little bit out of my field of competence. Therefore, perhaps I'm allowed to ask a few stupid questions.

For example, would this sort of thing tell us anything about emissions coming from the earth as a planet contrasted with some other planet? What about the signals from Jupiter? It seems to me that there are a lot of almost astrophysical problems here that have nothing to do with Herbert Riehl's problem or cloud physics or anything else.

Dr. Holzer: Well, Horace, I am not really arguing for purely a practical approach.

Dr. Byers: I know.

Dr. Holzer: It has been my experience that one never gets enough correlated measurements in a geophysical investigation. No matter what one's immediate reason for taking correlated measurements may be, one usually gets some additional scientific value from them. For example, if one makes correlated measurements on sferics, cloud growth, and development of precipitation sheets it may help Dr. Workman evaluate a theory of thunderstorm charge separation.

Dr. Byers: What I meant was not so much the taking of the observations, but the receiving of them. In other words, why should we think of ourselves as

doing this for Herbert Riehl? (laughter) That's not exactly what I meant to say.

Dr. Nordberg: Certainly a requirement is that you must have a rather well defined objective. That objective might be to determine the earth's electromagnetic spectrum. This might be valid, but one would have to define the objectives, and see that the objective can be met with the instrumentational constraints that would be placed on the experiment.

I think this is really what we are trying to do here. I think it is reasonable to assume that a sferics experiment would be a great contribution to meteorology. If there are any other contributions, we certainly want to hear them just as much and want to pursue them just as much.

The same condition would hold. You would have to define, and you have to know what you are after, and you have to know that what you are after can really be accomplished.

Dr. Holzer: Sferics information in the high frequency region is still very meager. A study of this portion of the sferics spectrum, which is important for sferics satellite work because these signals penetrate the ionosphere, would also contribute to the question of the origin of the signals from Jupiter. After a study of the high frequency sferics signals we would be in a better position to assess the possibility that the signals from Jupiter are produced by lightning.

Dr. Fritz: I think from the point of view of the astronomical type of thing that you just mentioned, the horizon-to-horizon measurement would be one that could lend some evidence to that question.

I didn't hear from Herbert Riehl as to what he thinks of the horizon-to-horizon measurement independent of Jupiter.

Dr. Riehl: I think that I would probably agree with you that serious measurements undertaken in this manner can lead to all kinds of consequences. My understanding had been that this would be a contribution to weather analysis and forecasting. From this viewpoint the horizon-to-horizon scanning would be a contribution. I quite agree with Horace.

Dr. Fritz: Do you want to say something, Dr. Pierce?

Dr. Pierce: I notice that Dr. Holzer omitted saying anything about EOGO noise satellite, in which he has an experiment. (laughter)

Dr. Holzer: I omitted mention of the experiment because I doubt that the results of our EOGO measurements will be of great importance to the particular subject under discussion here. As I view the problem there are three spectral regions in which sferics signals may penetrate the ionosphere in order to reach a satellite. First, there is the high frequency region, substantially above 10 mc./sec. which we have discussed at some length this morning. Second, there is the whistler mode region. Most of the energy in whistler modes appears to lie in the low kilocycle range. Third, there is the ELF region, especially the low audio and sub-audio frequencies, in which penetration of the ionosphere may

occur. The two spectral regions which we have not discussed are interesting in their own right but are not likely to contribute as much meteorological information as the megacycle region on which we have concentrated our attention.

The whistler mode sferics are not well adapted to a meteorological study because they may propagate a considerable distance in the earth-ionosphere "wave guide" before penetration of the ionosphere in the magneto-ionic whistler mode. Thus, information on the geographical origin of such a signal observed at a satellite is very meager. Further, since the signals travel great distances in the dispersive medium, their wave forms are very different from the signals which travel only in the earth-ionosphere wave guide and which have been studied extensively at the surface of the earth. The spectral energy distribution of the two types of signals is probably the only legitimate basis of comparison. Dr. Helliwell has an experiment on EOGO which will cover the whistler mode frequencies and in approximately two years he may have valuable data on these matters.

In the ELF range there is as yet no direct information on the penetration of the ionosphere. Our experiment is designed to explore the time variation of the magnetic vector of either electromagnetic or hydromagnetic waves in the frequency range from 1,000 cycles/sec. to 0.01 cycles/sec. While some of the signal power in the spectral region may have its origin in the low atmosphere it is more probable that most of the power will be associated with signals originating in the magnetosphere, at its boundaries, or beyond. We hope to have some answers in approximately two years.

At the momemt it does not appear that the lower frequency ranges will be as useful to the immediate problem under discussion as the high frequency range. Perhaps Dr. Pierce has another view on this matter.

Dr. Pierce: I am just thinking in reference to geophysical experiments and noise from Jupiter and other such extra-terrestrial sources. If we have a satellite monitoring sferics noise from the earth, it can also receive noise from space which does not normally penetrate the ionosphere. From a geophysical point of view this is just as interesting as the sferics noise. I think noise at all frequencies below about 10 mc./sec., coming from extra-terrestrial sources which we don't know anything about from observations on the surface of the earth is worth study.

Mr. Hubert: It seems that one of the things among the things that aren't known, perhaps because there haven't been enough measurements taken, is the effect of the variability of the critical frequency of the F2 layer on the signals that we are talking about.

Maybe one of the things that could be done is to put a piggy-back experiment on one of our meteorological satellites. A little typical sferics generator that would run the whole spectrum gamut. Then you sit on the ground and when it passes over at different zenith angles you can attempt to read these signals and thereby get some idea of the variability of time and space and the angle of these particular things.

Voice: What you are suggesting is really an experiment to study the ionosphere.

Dr. Fritz: Maybe this should be discussed afterwards.

Dr. Nordberg: I do not think that you would get much information on the ionosphere that you couldn't get by other means.

Dr. Fritz: We probably should call this meeting to a close. We have discussed pretty much what we set out to do, namely, at least some people would like to have very severe limitations. We have almost settled on the frequency range, except for this last possibility that Dr. Holzer mentioned.

We have decided that it is important to get some information in this frequency range, and also to get other associated types of information about the clouds so that one could extrapolate later when the satellite measurements become available.

As far as recommendations for the future are concerned, I think we more or less agree, at least there were no serious objections, on the idea that we should perhaps try a very simple sferics experiment from the satellite as soon as it can be made available. Not only the horizon-to-horizon measurment should be made from a satellite, but we should go ahead simultaneously with the ground studies which Dr. Holzer outlined.

Also we should be thinking of a more sophisticated satellite experiment for sferics when and if the data obtained in the first programs warrant it.

Dr. Stampfl: A 45° beam angle, taking all facts into account will probably get you knowledge from horizon-to-horizon.

Dr. Fritz: I thought that you were advocating an instrument which didn't have any 45° angle.

Dr. Stampfl: I am advocating an instrument which has an antenna beam as good as we can make it. A static antenna beam, be it 45° or 30° or something on that order of magnitude. Due to the tremendous range in power levels of lightning strokes, you will not know where the activity came from.

Dr. Fritz: I understand that, but I didn't realize that was your point.

Dr. Stampfl: There is one point that I think got lost in the discussion on resolution. This is the point on indication of the signals. There seem to be many spikes associated with one stroke and a stroke counter may give you false readings. Do we really have sufficient information to identify all these counts as lightning strokes? Maybe we will get many more counts than the 1,500 that Professor Riehl has put on the blackboard.

Dr. Riehl: This is just an estimate.

Dr. Stampfl: From what I have seen from the scope presentations that you showed in your slides, it occurs to me that an analog transmission would be most useful. This would satisfy both the meteorologist, who is only interested in average figures and counts, and the researcher who wants to see the actual wave shape.

Dr. Fritz: Meteorologists are also in research.(laughter)

Dr. Stampfl: With the figures that you have presented, it would be fairly simple to implement such an experiment within approximately 30 pounds of weight and a reasonable power figure. I wonder if Dr. Ligda has a comment there?

Dr. Ligda: I think that there is a possibility the area coverage is about comparable to what the satellite would be seeing.

Dr. Nordberg: This means you couldn't have any satellite observations without the sferics network.

Dr. Fritz: In this problem, does it help to measure at more than one frequency?

Dr. Ligda: There is a possibility that some advantage might be made of the effect of the intervening ionosphere on different frequencies.

Dr. Nordberg: Would you have to do more of a waveform analysis in order to resolve this? Is there sufficient information at the present?

Dr. Fritz: Does somebody want to answer this question?

Dr. Rossby: How many sources do you suppose there are of broadband noise that would appear simultaneously at two or more frequencies?

Dr. Nordberg: I wonder if the emphasis is really on simultaneity.

Dr. Pierce: Wouldn't you just examine structure? This would be the first approach to attempting to distinguish between sferics noise, man-made noise, and cosmic noise at a given frequency.

Dr. Nordberg: I suppose you would make such a study. There is quite a magnitude of work involved in such a study. I am really asking whether such a study has been made.

Dr. Hallgren: I would say that the noise has been studied in various areas. Certainly people have studied the cosmic noise and know many of the characteristics. It's a matter of summarizing and applying existing information and extending it to the degree necessary.

Dr. Fritz: In the case of man-made noise, wouldn't that affect your measurements on the ground just as well as it would the satellite instrument?

Dr. Nordberg: Yes, but on a quite different scale.

Dr. Fritz: Dr. Hallgren apparently is going to continue his measurements up in New York State and it might well be that another group down in Florida might do additional work there.

Dr. Hallgren: I'll do that in the winter. (laughter)

Dr. Fritz: In the winter you might have to go to Buenos Aires or something like that. (laughter)

Are there any other things? As far as I can see, we have discussed what we set out to. We have some recommendations for the future which are fairly definite and clear cut. At least we know where we want to go. Unless there are any other comments, questions, or suggestions, I would like to thank you very sincerely for what I think is a very fruitful meeting.

(The conference was called to an end at 1:15 p.m.)

APPENDIX

Participants were invited to submit any post-conference remarks they wished to make. Their replies follow:

Dr. Pierce: When I returned from the conference, I made a brief digest of my immediate reactions largely for my own benefit. However, since this also represents my present opinion you may care to incorporate it in the appendix to the conference proceedings.

I. Purpose

The immediate objective of a sferics satellite would be to monitor continuously and to locate all the active thunderstorm areas upon the surface of the earth. Several satellites would be required for full coverage, but valuable sampling and climatological data would be supplied by even one satellite.

II. Use of Information

There are very many ways -- both meteorological and otherwise -- in which the data could be employed. Examples are:

(a) Improvements in forecasting both from a direct and from a climatological use of the data.

(b) Translation of the results into solving problems associated with the general circulation. This assumes (Dr. Riehl) that areas of high sferic activity are also centers of convection.

(c) Application of the information to the sferics noise problems always present in terrestrial radio communication.

III. Present Position

The general opinion seemed to be that it would be premature at the present time to design an elaborate sferics satellite. This was largely because of the lack of some fundamental information upon which to base the design, notably the poor knowledge of the power-frequency relation for the noise from a thunderstorm.

However, it was considered that valuable information could be presently obtained even by a crude system. A satellite giving no better spatial resolution than horizon-to-horizon coverage would be useful. It would be interesting to relate the results obtained with those from a surface sferics network. A frequency of the order of 100 mc./sec. should give adequate power and be largely unaffected by the ionosphere.

IV. Subsidiary Investigations

It was evident that before optimizing any sferics satellite system, some information best obtained by observations at the surface of the earth was necessary. This included:

(a) An examination of the noise power of a thunderstorm as a function of frequency for all wavelengths in the radiofrequency spectrum. Observations should not be confined to certain spot frequencies as had been largely the case hitherto. The information should enable the optimum operating frequency of a sferics satellite to be selected.

(b) Tests whether major convective areas in the world do coincide with the chief sferics regions; hence whether the application of sferics data to general circulation problems can be made.

(c) Estimation of the noise emitted from the earth but not having an origin in sferics, at frequencies likely to be used in a sferics satellite. This would include man-made noise and, possibly, reflected cosmic noise. Such estimates would be necessary in order to determine what proportion of the noise measured in a satellite was really due to sferics.

Dr. Ligda: This is an extract from the original report which might be included as a footnote (to page 26). "The Synoptic Analysis and Forecasting Applications of Radar Weather Observations", Final Report Under Contract AF 19 (604) - 1564

"This observation is most satisfactorily accomplished using the A-R scope, with the antenna pointed in the direction of a thunderstorm. The manifestation of the signal using the 400-mile range setting is the sudden appearance of (usually) saturation-strength "spikes" for one sweep only along perhaps half the length of the base line. The spikes are usually of the order of 50 miles range separation and flick in and out again so rapidly that photography has not been attempted. When the scope is put on the 5-mile setting, the chances that any one of these individual spikes will appear in the gate is perhaps of the order of about one in six or seven, so a bit of waiting before one appears is usually necessary. Some have been observed, and it is interesting to note that the signals are so short in duration that no horizontal displacement of the trace during the time it rises from, and returns to, the baseline could be discerned. In other words, the signals appear as single vertical lines rising from the baseline. This means that the individual signals are something less than 1 microsecond in duration and recur at about intervals of very roughly 400 microseconds for a period of several milliseconds. The short duration of the individual signal strongly suggests that it is only produced when current is flowing or during successive advances of the stepped leader preliminary to formation of the ionized successive advances of the stepped leader preliminary to formation of the ionozed channel from which the much-longer-duration radar echoes are received. Since the electrons producing the signal could only move, at the most, about 1,000 ft. in one microsecond, it is also hypothesized that they do not travel back and forth between the tip of the advancing leader stroke and the charge center each time an advance occurs. Rather (it appears) they move only in one direction at intervals and in steps determined by conditions in the electrostatic complex."