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Initial Results of a New Technique for Investigating Sferic Activity [1,2]

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A technique for the measurement of sferics on a massive scale has been developed. The technique pertains largely to spectral and directional measurements. Representative samples of data are presented and discussed. The data samples include:

1. Diurnal variations in sferic rates as a function of the 10.5, 40, and 100 kc/s component amplitudes.
2. Sferic rates as a function of triggering level.
3. Directional measurement of sferic rates.
4. Correlation of directional sferic rates with weather reports.
5. Sferic amplitude distributions at 10.5, 40, and 100 kc/s.
6. Comparison of the distribution of amplitudes of the sferics from two different storm areas.

Recommendations for future measurements are made.

1. Introduction

1.1. Background

A "sferic" [3] is the electromagnetic energy radiated from a lightning discharge and propagated between the earth and the ionosphere. The spectral components of this radiation are variable in both phase and amplitude depending on the nature of the discharge [1].[4] Electromagnetic energy is radiated at frequencies ranging from a few cycles per second up into the megacycle range [2, 3]. As the sferic is propagated its original form is modified as a result of propagation characteristics [3 to 7].

When sferic waveforms are observed on an oscilloscope the end result of all propagation factors is seen, but the analysis of these same factors is by no means self-evident [8]. Certain spectral components whose amplitude and phase cannot be resolved with broadband waveforms can be separated out and recorded at measurable levels through the use of properly designed restricted band techniques.

1.2. Instrumentation

Sferics were observed with a system devloped for the automatic measurement of the complex spectral characteristics and for the automatic high-speed processing of statistical data. These observations are potentially useful in many applications such as propagation studies, distance measurements, thunderstorm location and tracking, and ground conductivity determinations. In these applications, however, only a minute fraction of the total number of sferics is of interest or value. Therefore, in order to make practical use of the few desired sferics it is necessary to eliminate the undesired signals immediately to avoid a prohibitive waste of time in analyzing the data. Such a scheme permits data handling on a scale which is statistically meaningful. Analysis techniques which were previously impractical can be applied since manual data processing is substantially reduced.

The system performs the following functions: Azimuthal detection, complex spectrum measurement, data storage, data selection, and recording.

The azimuthal detection portion of the system has been designated E–Φ (Ephi) because the bearing of the transient signal is determined from the relative phase of the vertical electric field at spaced antennas (three antennas were used for these measurements). The system minimizes siting and polarization errors A directional code is generated upon reception of each signal. This code is ideally suited for subsequent logical operations.

Pulses are derived from the sferics in certain portions of the spectrum. These pulses are formed by band-pass filters of such characteristics that the pulses rise as rapidly as possible but still maintain a shape nearly independent of the characteristics of the sferic waveform. Information on the relative phase and amplitude of these spectral components is obtained by comparing filter outputs.

These intrinsic characteristics of the signals, along with data from Ephi are used to distinguish desired from undesired signals. The data selection is accomplished by logical "and" and "or" circuitry in

[1] Contribution from Central Radio Propagation Laboratory, National Bureau of Standards, Boulder, Colo.
[2] Portions of this paper were originally presented to the spring URSI meeting in Washington, D.C., May 1959, in two papers entitled: "Observations of Some Spectral Components of Sferics" by R. F. Linfield, and "Observed Time and Direction Variations of Sferic Activity" by R. H. Doherty.
[3] The authors feel that the use of sferic or sferics as defined above is more suitable than atmospheric or atmospherics because of the more general connotation of these latter terms. For example: Nagoya University's Research Institute of "Atmospherics" studies all electromagnetic phenomena of natural origin, and a National Institute for "Atmospheric" Research proposed for the United States would study all phases of the physics of the atmosphere.
[4] Figures in brackets indicate the literature references at the end of this paper.

accordance with a preset program. Data are stored while these logic circuits perform their respective functions. These circuits make the decision to record or disregard the data in about 500 μsec.

Special techniques which overcome some of the difficulties of recording and timing randomly occurring transient signals have been developed. Electronic counters are used to indicate summation of sferics selected with respect to certain parameters.

Oscilloscope photographs are taken not only of the broadband sferic waveform but also of the various pulses derived from the different portions of the spectrum. A high-speed intermittent-action camera was developed for this purpose and is so arranged that, if desired, pictures are taken only of sferics which have particular values of certain parameters. The time of arrival of the sferic is recorded on each photograph in digital form [9].

1.3. Data Interpretation

Sferic rates are most meaningful when they are related to a certain area. Sferic density is defined as sferics per second per square mile, and this type of information would be directly available from two directional systems recording and correlating sferics. The data that are presented in this paper were observed at only one point and, therefore, the azimuthal rates only indicate the direction of the activity. Weather reports were the only available independent data and, in general, it was difficult to determine whether the activity was concentrated or diffused within the sector.

In order to compare different sets of measurements the observed rates must be standardized with respect to time and the sector width. Sector rates are, therefore, expressed as the number of sferics per second per degree.

The data presented in this paper are in most cases relatively small samples and are intended primarily to illustrate some of the simpler types of measurements that might be made on a systematic long-term basis.

2. Omnidirectional Data

2.1. Diurnal Variations of Sferic Rates

In many cases it is convenient to describe sferic activity by the rate of occurrence with respect to one or more parameters. For example, the number of sferics per second which exceed a specified field strength or the number per second which come from a given direction with amplitudes[5] within specified limits.

Data contained in this paper, with one exception, were recorded in Gold Beach, Oreg., during the summer of 1958. One set of measurements was made in Boulder, Colo., in November 1958. A typical sample of the summer sferic activity recorded at Gold Beach is shown in figures 1, 2, and 3. Data from figures 1 and 3 are related in that the times of observation were essentially the same. Additional 10.5 kc/s data were obtained during July and August, but plots of the average of all 10.5 kc/s data were so similar to figure 1 that an additional figure of these data was not included. Therefore, figure 1 may be considered representative of summer sferic

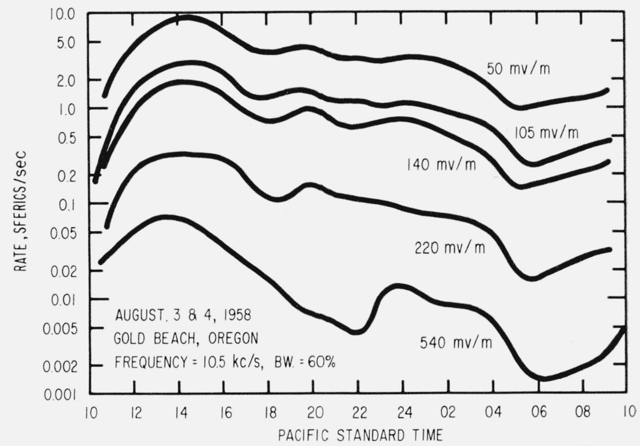

FIGURE 1. *Diurnal sferic rates, 10.5 kc/s.*

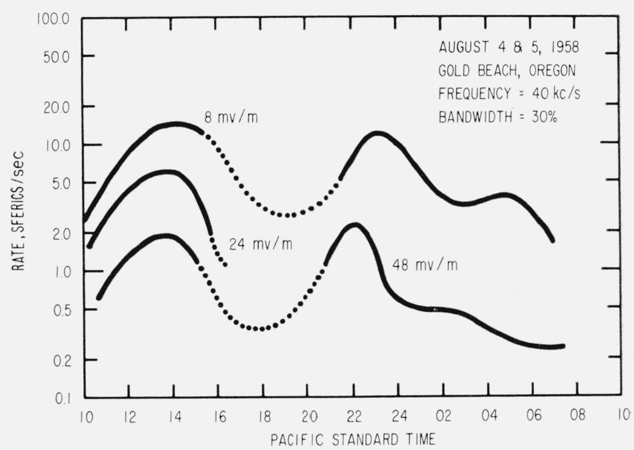

FIGURE 2. *Diurnal sferic rates, 40 kc/s.*

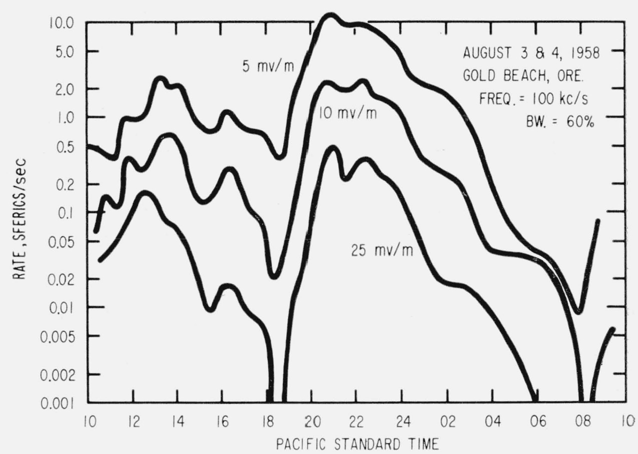

FIGURE 3. *Diurnal sferic rates, 100 kc/s.*

[5] In this paper all amplitudes or triggering levels presented in millivolts or volts per meter represent peak-to-peak values of an equivalent cw signal centered in the pass band of the filter.

rates recorded at Gold Beach. These data were obtained using band-pass filters with center frequencies of 10.5, 40, and 100 kc/s and bandwidths of 60, 30, 30 percent respectively. The amplitude of the 10.5 kc/s component is usually about one-half the amplitude of the broadband waveform and, therefore, the approximate broadband rates may be determined from figure 1. This ratio, however, varies somewhat from sferic to sferic depending on the spectral distribution of the energy [3].

Figure 1 also shows that the sferic activity was greatest in the early afternoon and least in the vicinity of sunrise. These times of day correspond to the usual daily cycle of thunderstorm activity. During the summer months a major part of the thunderstorms in continental United States occurs in the mountains and central part of the country. The peak occurring between 1200 and 1600 correlates well with sferic activity in the mountainous regious. The smaller peak at 2000 and the sustained activity throughout the night probably reflect the storms in the central plains and Gulf regions (see fig. 4). Since fewer sferics from a particular storm will exceed a given threshold level at the receiver as the distance to the storm is increased, it may be assumed that these measurements are weighted heavily by the relatively nearby thunderstorm activity in the mountains.

In comparing the 10.5 kc/s (fig. 1) and 100 kc/s (fig. 3) records, the early afternoon peaks correspond rather closely but, in contrast, the 100 kc/s record shows a minimum at sunset and a large peak around 2100 hr. Part of the data from figures 1 and 3 are replotted in figure 5 to show the nighttime peak more clearly. The daytime minimum and the rapid increase shortly after sunset is evidently the result of an ionospheric effect at sunset and the subsequently enhanced ionospheric propagation thereafter. The peak at 2100 correlates with the activity in the plains region as shown in figure 4, but the comparison of the rates at 10 and 100 kc/s after 2100 is not understood.

Although part of the data are lacking for the 40-kc/s curves (fig. 2), the trends shown are not inconsistent with what might be expected at such an an intermediate frequency.

2.2. Variations in Sferic Rates

When the sferic rates were considered as a function of receiver sensitivity or triggering level, a nonlinear distribution was observed. Some examples are shown in figure 6. In these cases samples of data were obtained during brief periods of time so it could be assumed that the sferic activity remained essentially constant during an individual measurement period. Since the distributions are different, it seems obvious that the sferic activity had changed significantly between sets of measurements.

A number of samples of rate versus triggering level data, averaged over 4-hour periods, are shown in figure 7. The scattering of the points is a result of the mixture of diurnal and day-to-day variations in sferic activity. A smooth curve drawn through the mean of the points is seen to have an average slope of about −2.

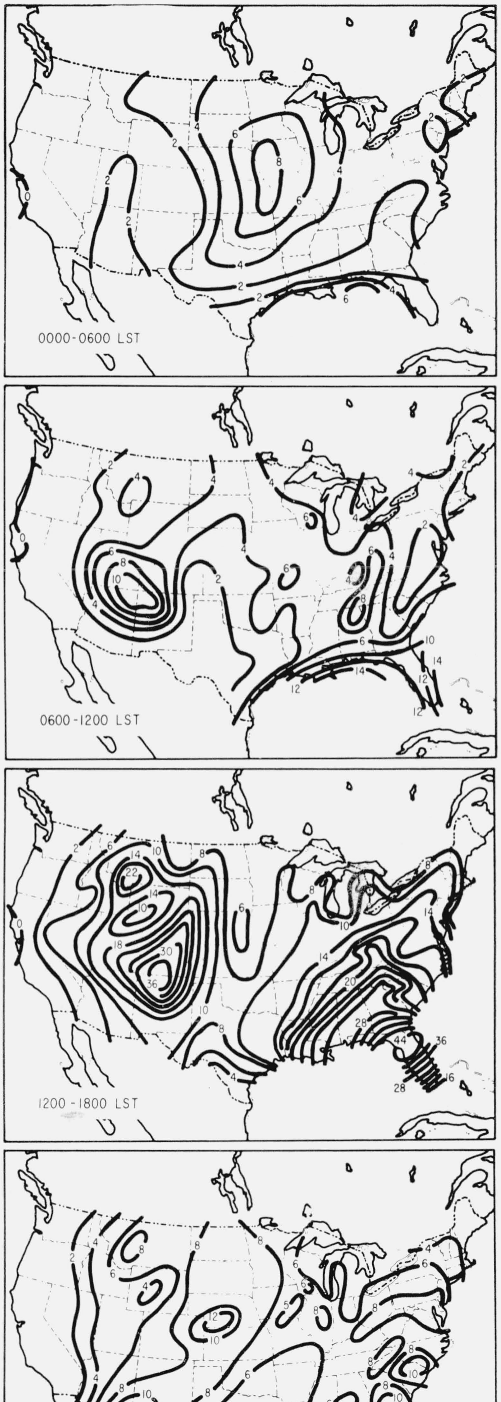

FIGURE 4. *Diurnal thunderstorm counts.*

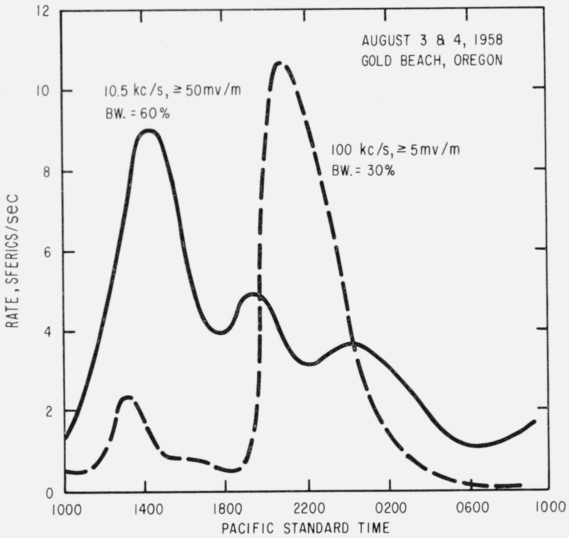

FIGURE 5. *Comparison of 10.5 and 100 kc/s rates.*

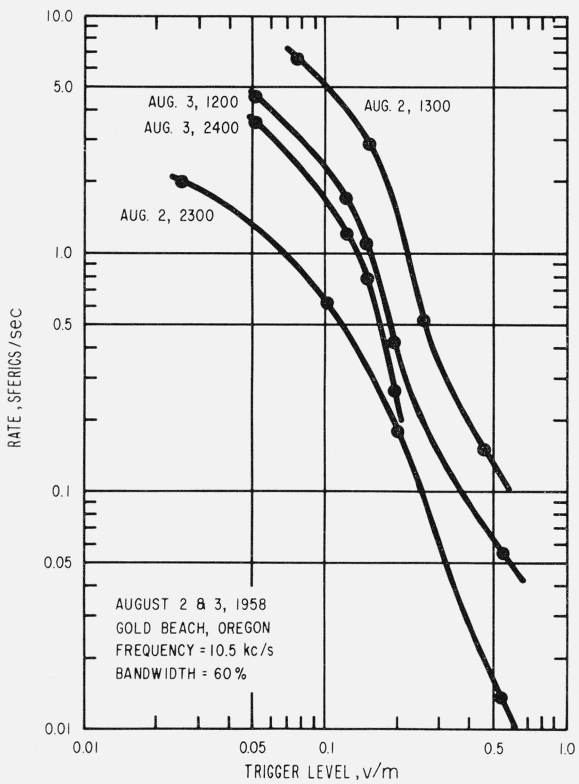

FIGURE 6. *Examples of sferic rate distributions as a function of triggering level.*

3. Directional Data

3.1. Correlation of Azimuthal Plots and Weather Data

The foregoing data provide no clue as to the direction from which the sferics came. The phenomenon being measured can be better explained by use of azimuthal scans of the sferic activity. Comparison

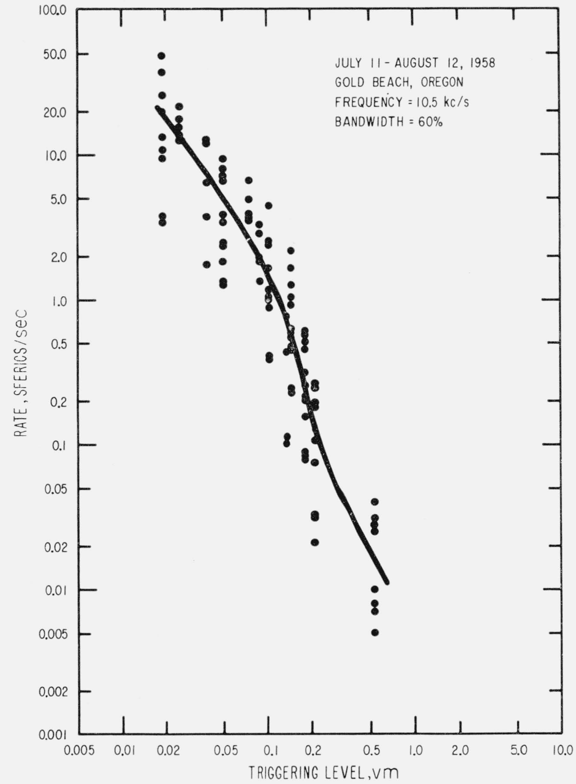

FIGURE 7. *Mean sferic rate distributions from period July 11 to August 12, 1958.*

of these scans with the occurrence of thunder or visible lightning reported by the U.S. Weather Bureau provides some further understanding of the subject. See also [10] and [11].

Figures 8 through 10 include a wide variety of thunderstorm conditions. Each symbol indicates that a weather station reported thunder or visible lightning at approximately the hour shown on the maps. Linear polar plots of sample sferic rates measured at Gold Beach, are superimposed to show the comparison with the reported lightning.

In figure 8, only three stations reported lightning. The azimuthal scan seems generally to agree with the reports, but does not show three distinct lobes in the expected directions. There are several factors which could explain the lack of agreement between such sferic measurements and available weather data. For example:

1. The available weather data are not complete. In the meteorological data used a number of weather stations had not reported.

2. Lightning is less obvious in daylight than at night. More distant lightning will probably be reported at night than during the daytime.

3. In the available reports no distinction was made between a single stroke of lightning and an intense electrical storm.

4. In some areas weather stations are so widely separated that thunderstorms and especially the visible lightning or audible thunder often escape observation.

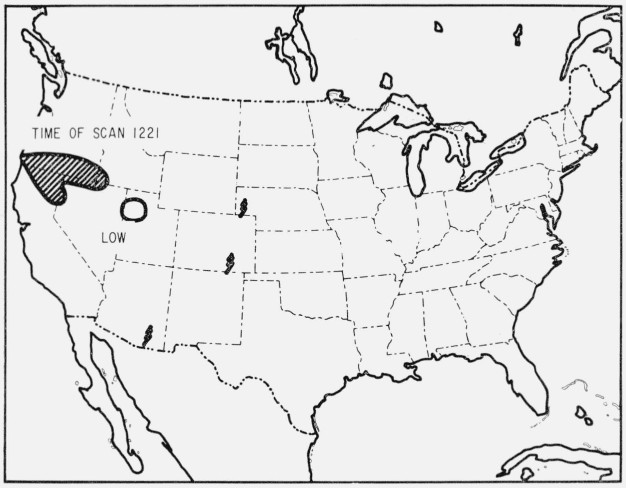

FIGURE 8. *Comparison of azimuthal scan with reported lightning, July 16, 1958.*

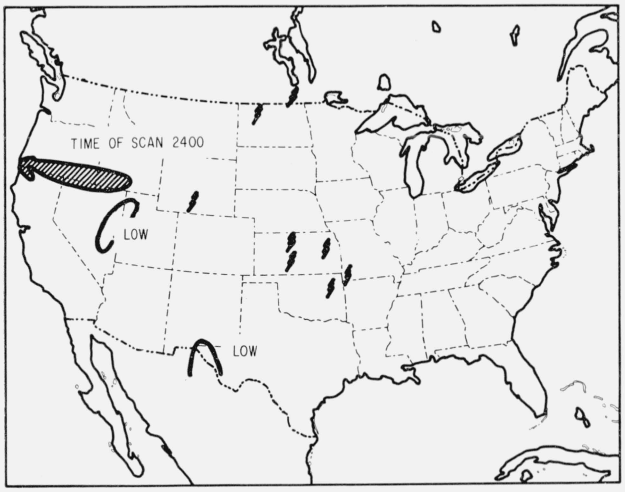

FIGURE 9. *Comparison of azimuthal scan with reported lightning, July 16, 1958.*

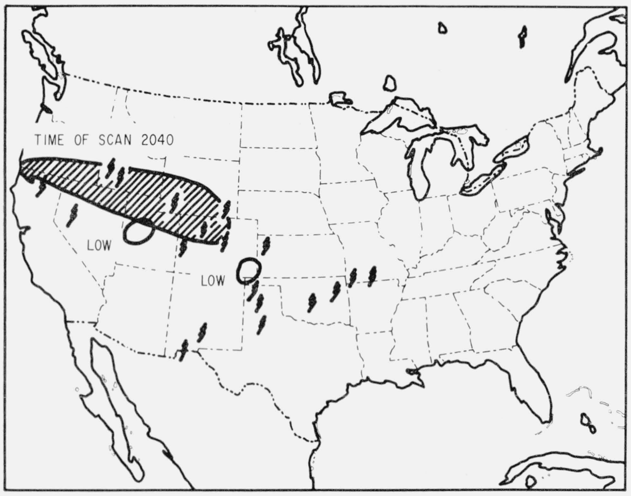

FIGURE 10. *Comparison of azimuthal scan with reported lightning, July 16, 1958.*

The correlation between the reported lightning and the azimuthal scan at 0100 (fig. 9) earlier the same day is somewhat better than at 1300 (fig. 8). The small lobe (fig. 9) to the north-east corresponds to the thunderstorm activity along the North Dakota-Manitoba border, while the large lobe to the east seems to be composed largely of sferics from the storm in south-central Wyoming. The lightning reported in Kansas, southwestern Missouri and northeastern Oklahoma is at roughly twice the range of the Wyoming storm. Correspondingly, a smaller percentage of sferics from the more distant storm would exceed the triggering level. The main lobe shows sferics from this direction, but the Wyoming storm appears predominant.

A small and somewhat irregular lobe to the southeast is rather conclusive evidence that lightning was occurring in that direction also. While no lightning was reported, two low-pressure areas in that direction are shown. It is entirely possible that unreported lightning was taking place in either or both of these areas. A further possibility is that a number of these sferics were of more distant origin, representing only the very large discharges from a storm in Central or South America.

By late evening that same day the thunderstorm activity was widespread throughout the Central and Western States (see fig. 10). This sferic rate plot is more consistent with the reported lightning.

A linear polar plot of sferic rates conveys immediately and simply a clear notion of the direction in which the bulk of the sferic activity exists. But frequently, significant amounts of sferic activity in some directions may represent a very small fraction of the maximum and cannot be successfully shown on a linear plot. A polar logarithmic plot overcomes this difficulty: however, it is impossible to define zero on such a plot and when no sferics are observed in a given direction there is a break in the curve. In many cases only one sferic may be counted in a particular direction during the course of a systematic set of measurements. The single sferic count can be reduced to a value of rate and plotted along with the rest of the data, but while correct dimensionally, statistically the sample is not adequate. In view of these limitations the logarithmic plots are more suitable for presenting averaged data (figs. 12 and 13) than data obtained during a single scan (fig. 11).

Figure 11 is a logarithmic polar plot of an azimuthal rate scan made July 30, 1958, between 1030 and 1130 P.s.t. A 6° sector was rotated clockwise in 6° increments. The sferics were counted for a period of exactly 1 min on each heading. In this case the triggering level was 50 mv/m and, therefore, more sferics from greater distances were recorded than shown in figures 8, 9, and 10 where the triggering level was 85 mv/m. The main lobe at 70° follows the general pattern of the other plots but in contrast, several storms in the western half of the azimuth circle were evident at that time.

A large number of azimuthal scans were averaged to provide a more representative measure of the sferic activity during July and August. The data

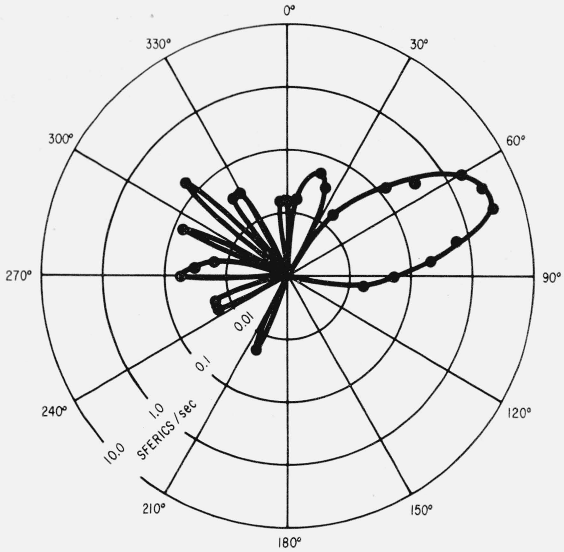

FIGURE 11. *Azimuthal scan of sferic rate, July 30, 1958: 1036 to 1135 P. s. t.*

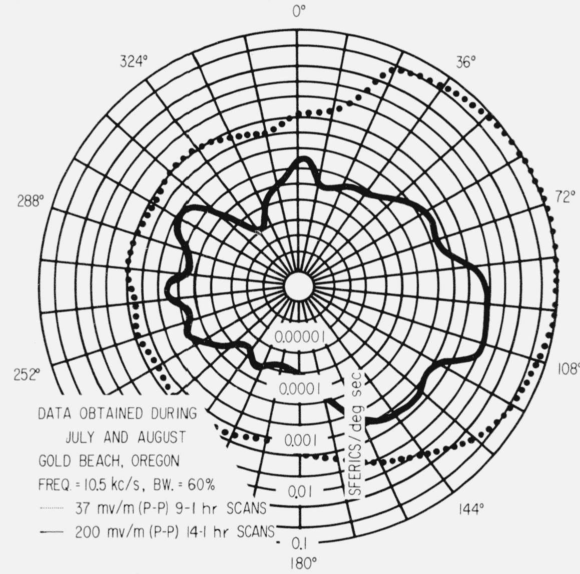

FIGURE 12. *Average sferic rate as a function of azimuth.*

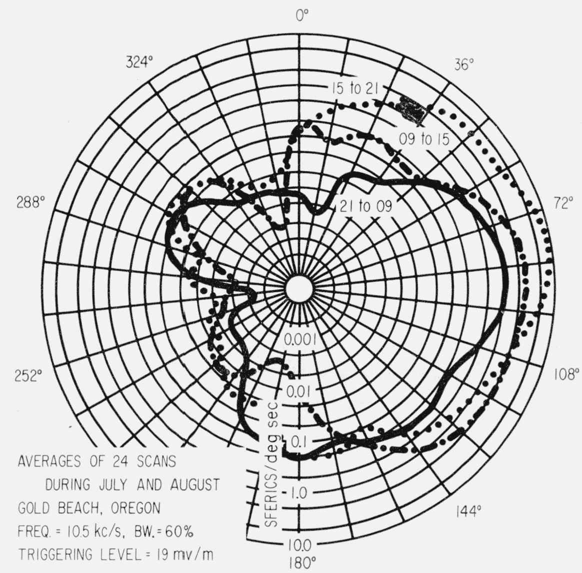

FIGURE 13. *Average rate over 24-hr period in three time blocks.*

were averaged in two ways: First by selecting scans which were well distributed over the diurnal cycle, and second by arranging the data in time blocks. These average values are plotted in figures 12 and 13, respectively.

It is evident that the two curves in figure 12 are generally similar but the 200-mv/m curve is much more variable. This variation is partly caused by the difference in triggering levels. The quantity of data (that is, the total number of sferics counted) in the 200-mv/m curve is considerably less than that in the 37-mv/m curve. The total amount of data, especially that at the 200-mv/m level, was evidently not great enough to average out completely the day-to-day variations on a statistical basis.

An additional factor is that the data for the two curves were not recorded simultaneously. Thunderstorms do not occur in the same places every day so the distance from the storms to the receiver was variable. In regions where storms occur frequently, an average value for such distances may be established within a few days but in regions where storms rarely occur, limited observations will not establish a reliable average.

Figures 12 and 13 may be compared with the U.S. Weather Bureau charts [12] of thunderstorm days shown in figure 14 and the summer thunderstorm diurnal storm counts shown in figure 4. A thunderstorm day is defined as a day on which thunder is heard. In counting thunderstorm days no distinction is made between a single clap of thunder and one or more intense electrical storms; however, in figure 4, the distinction is that each individual thunderstorm is reported separately. The average rate curves, figures 12 and 13, correlate well with known regions of intense activity indicated in both figures 4 and 14.

Figure 12 indicates an increase in sferic rate at the higher sensitivity (37 mv/m) from about 12° to 156°. These azimuths subtend both the mountains and the central plains. At the lower sensitivity (200 mv/m) the maximum has shifted southward and the greatest activity is found in the interval between 80° to 156°. The location of these storms were not established, but these azimuths include the Central Plains, the Gulf of Mexico, and South America. The ratio of the sferic rates for the two sensitivities at any given azimuth indicates the relative number of large sferics compared to the small ones. These ratios are approximately 12 to 1 toward the west (240° to 312°)

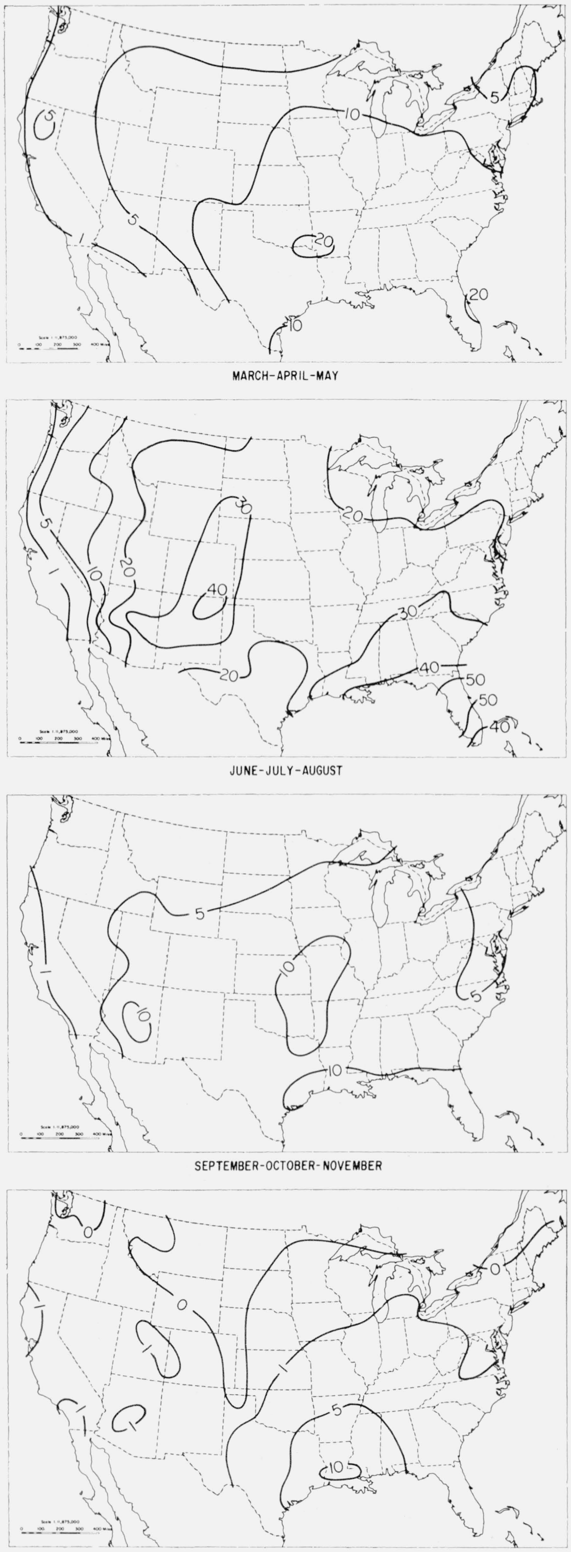

FIGURE 14. *Thunderstorm days in three-month periods.*

and toward the southeast (108° to 156°) but they increase to as high as 125 to 1 to the northeast and east (24° to 90°). These widely differing ratios may be related to source characteristics and propagation differences over land and sea paths.

In figure 13 the observed sferic rates were averaged and grouped in three time blocks. These curves may be compared with the average thunderstorm counts in figure 4. Unfortunately, different time blocks were chosen in the two figures, but they seem to be at least generally consistent. Data during the early morning hours, 0300 to 0900, was extremely sparse. In order to show the azimuthal relationship of sferic activity through a complete diurnal period this data was combined with the data from 2100 to 0300. Such grouping reduces the average rates below what they should have been from 2100 to 0300.

Small but rather pronounced peaks in all three time blocks are seen in the vicinity of 300° to 312°, and the diurnal variations in these peaks are small. Since these peaks are not evident in the curves at lower sensitivity (figure 12), it is presumed that these sferics are of distant origin (Japan, Philippines, or Borneo-Sumatra area) and that only the largest ones exceeded 19 mv/m at Gold Beach.

3.2. Comparison of Data From Two Storm Areas

When the sferics in a narrow sector are observed for an extended period of time (in contrast to the brief periods on each heading in the azimuthal scans), better statistical samples can be obtained. In this connection, the distribution of amplitudes is of particular interest because it would be desirable to associate such distributions with individual storms. However, there was no adequate independent verification that the sferics from a particular storm were isolated and, for that reason, positive conclusions from these data are not warranted. Nevertheless, the data are of interest and are presented with a possible explanation.

A 40-minute sample of data observed in three adjacent sectors gave the distributions shown in figures 15 through 18. The time indicated is G.m.t. which corresponds to P.s.t. of 1820 to 1900 on August 26. Available weather maps for this period indicated there were thunderstorms in the vicinity of the Nevada, Utah border and scattered thunderstorms in west Texas. The sectors were centered on 106°, 111°, and 116° true azimuth as shown in figure 19. The outer sectors were 6° wide and the center sector was 4°. The triggering level was 50 mv/m p-p.

The amplitude distributions of the broadband waveforms (1 to 150 kc/s) and components of the spectrum at frequencies of 10.5, 40, and 100 kc/s (30% bandwidth) are plotted in figures 15 to 18, respectively. The obvious characteristics of these distributions are: (1) The similarity between the 10.5- and 100-kc/s data, and (2) the lack of similarity between these data and the 40-kc/s data. It is suspected that the nature of these distributions is closely linked with the different types of lightning

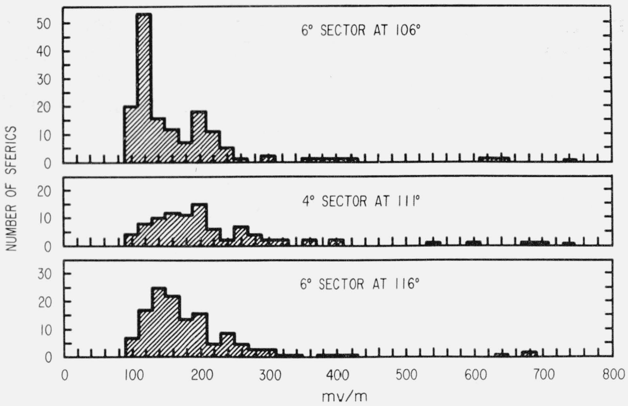

FIGURE 15. *Amplitude distribution of broadband waveforms, Gold Beach, Oregon: August 27, 1958, 0220 to 0300.*

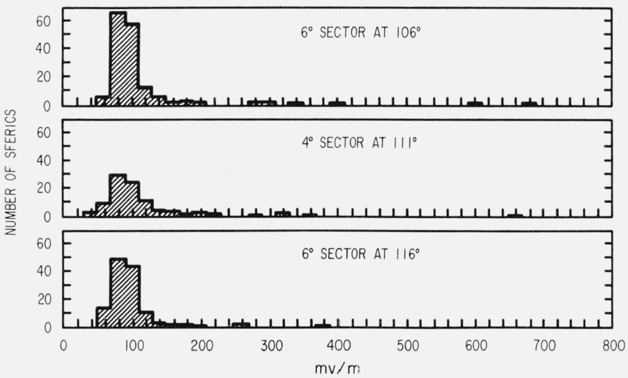

FIGURE 16. *Amplitude distribution of 10.5 kc/s component, Gold Beach, Oregon: August 27, 1958, 0220 to 0300.*

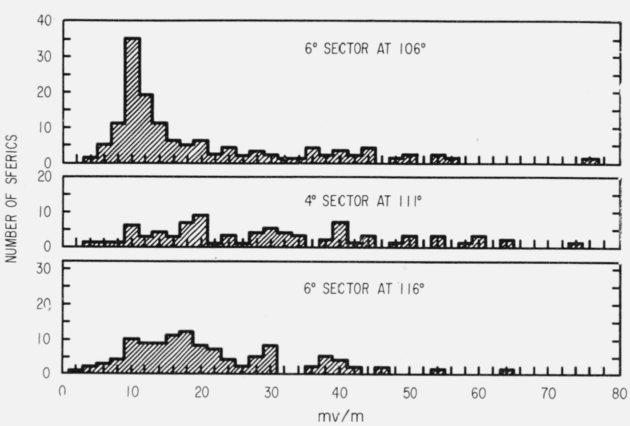

FIGURE 17. *Amplitude distribution of 40 kc/s component, Gold Beach, Oregon: August 27, 1958, 0220 to 0300.*

discharges [13] and propagation characteristics. The large sferics produced by the cloud-to-ground discharges probably account for the scattered large amplitudes in both the broadband and 10.5-kc/s distributions. The cloud-to-cloud and intracloud discharges probably account for the pronounced groupings at the lower amplitudes. The dissimilarity among the 40-kc/s distributions is not understood.

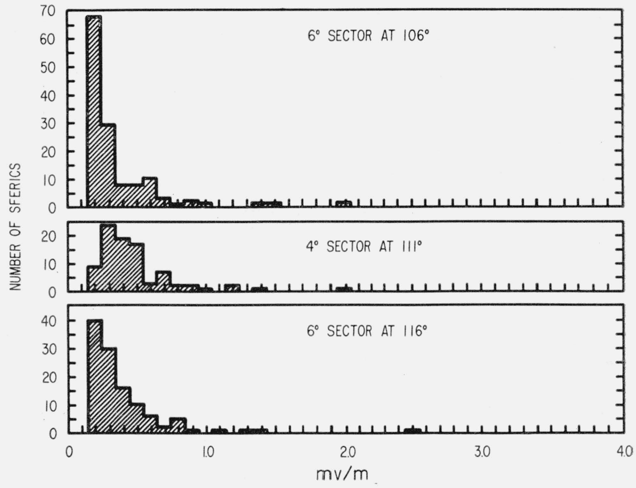

FIGURE 18. *Amplitude distribution of 100 kc/s component, Gold Beach, Oregon: August 27, 1958, 0220 to 0300.*

In November 1958, similar measurements were made at Boulder, Colo. During the course of the measurements the U.S. Weather Bureau reported a low-pressure area in the Gulf where thunderstorm conditions existed. The weather conditions between Boulder and the Gulf were such that the possibility of lightning occurring was extremely remote. The peak of the sferic activity as determined by an azimuthal scan correlated perfectly with the center of the reported low-pressure area (see fig. 19). The cumulative distribution of the 10.5-kc/s component of the sferic amplitudes from this direction are shown in figure 20 along with the cumulative distribution of the data from figure 16.

In obtaining the data the receiver triggering level was varied in steps over a wide range beginning at 10 mv/m. The sferic rate was determined at each step. It is of special interest to note that the slope of the curve rapidly approaches zero below 20 mv/m, indicating that virtually all the sferics in that sector exceeded the threshold sensitivity.

The data for the other curve (Nevada storm) were obtained by operating the receiver at a fixed threshold sensitivity of 40 mv/m, while the amplitudes were scaled from film recordings. In that case virtually all the sferics exceeded a field strength of 60 mv/m, again indicating that all the sferics from that sector were received.

These results would be expected if a single storm area existed in the sector and if the receiver sensitivity were increased sufficiently to detect all the sferics from that storm area. Evidently the storm areas established from the independent weather reports accounted for the observed activity within the sector.

Entirely similar results were published by Horner [14] where he found that all the sferics from a storm at a distance of 500 km exceeded 1.6 mv/m (300-c/s bandwidth). The greatest sensitivity used was 0.4 mv/m. The smaller sferics from two other storms

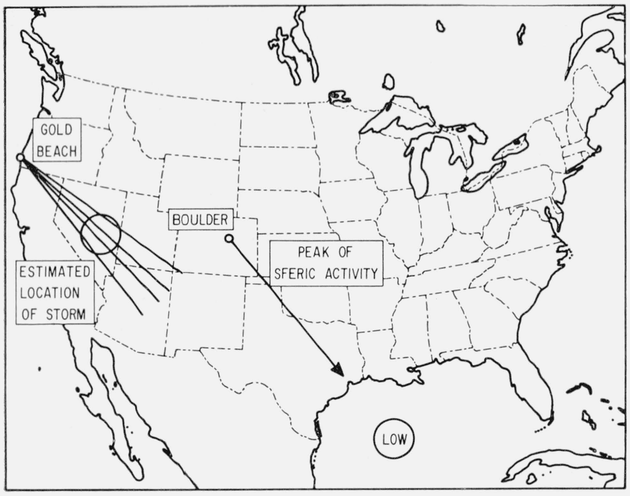

FIGURE 19. *Nevada and Gulf storms.*

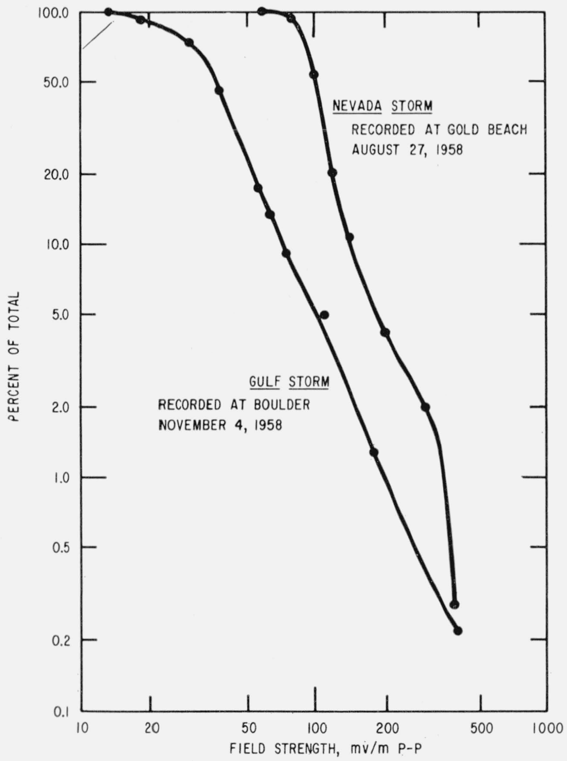

FIGURE 20. *Cumulative distributions of Nevada and Gulf storms.*

at 5,000 and 8,000 km did not exceed the 0.4-mv/m threshold, but it is presumed that similar lower limits existed.

The narrow bandwidths commonly used restrict the lower level at which individual sferics can be resolved because of the ringing effect of the higher Q circuits. The measurements reported herein were made with wide-band filters (30 to 60%) to provide substantially better resolution at higher sensitivities.

At the lower sensitivities the curves in figure 20 appear relatively straight, but with different slopes. Since one storm area was evidently over sea water and the other over mountainous area, it is suspected that the differences are related to the topography. The generally steeper slope of the distribution from the land area indicates that there were relatively fewer large sferics in this storm area. This, along with the other data that indicated larger sferics over sea water, might be explained by the higher conductivity on the sea water which might permit a greater surge of discharge current to flow.

4. Future Measurements

Measurements made from a single location do not provide fix information which is necessary for a more complete analysis of the data. In any future measurement program a minimum of two sets of equipment should be located in a configuration that would yield good fixes in the areas of interest. A third set of equipment appropriately located would further enhance the scope and usefulness of the data.

With two or more sferic stations linked together with telephone lines, instantaneous fix data could be obtained. Such data would give a current indication of thunderstorm activity and should be valuable to air navigation, weather reporting and forecasting, and other purposes.

Future long-term measurements could provide statistical data on the location and frequency of occurrence of thunderstorms and statistical classification of sferic characteristics as they relate to meteorological phenomena throughout the different seasons. Such statistical data would aid prediction services and should eventually yield a better understanding of thunderstorm activity in general.

Additional measurements should also stimulate the development of mathematical models of sferic activity. Such models should take into account explicitly the physical factors that determine the mechanism by which sferics originate. In the formulation of these models, the effect of topographical and meteorological factors should be carefully studied. The achievement of these models can result only from a closely coordinated effort in both the theoretical and experimental fields.

Sferics may be used as tools for evaluating the physical properties of propagation paths. For example, observation of the groundwave component of one or more sferics occurring on the extension of a line joining two stations provides the necessary data from which the ground conductivity of the path can be deduced [15].

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