500 KC./SEC. SFERICS ANALYSIS OF SEVERE WEATHER EVENTS

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ABSTRACT

The count rate of "sferics" monitored at 500 kc./sec. has been related to official severe weather events occurring within the detection area during a 48-day period. Sferics activity was always in evidence prior to and during severe weather occurrences. Few weather events occurred after the sferics count rate began to decrease. Radar evidence of "hard" echoes from the vicinity of a severe weather event occur prior to a rapid increase in sferics which immediately precedes the event.

1. INTRODUCTION

The electromagnetic radiation spectrum produced by lightning and other lightning-related discharges occurring during cumulonimbus cloud activity has been detected at monitor frequencies ranging from very low frequency (VLF) to microwave frequencies. An extensive attempt to relate VLF sferics data to severe weather was made by the U.S. Air Force [1, 2]. The results indicated that although no apparent correlation existed at 10 kc./sec., some indication was in evidence at higher frequencies in the VLF spectrum. This finding supported the view held by Jones [3] that a severe weather event such as a tornado produces identifying changes in sferics count rate at monitor frequencies near 150 kc./sec. Malan [4] showed that many more "sferics" pulses are detected by monitoring at medium and high frequencies than at VLF. The use of medium frequency monitoring between 400 and 500 kc./sec. has proven to be a good compromise between long detection range and good response to thunderstorm characteristics [5]. In addition to sferics count rate as a parameter, changes in the amplitude distribution of 500-kc./sec. sferics have been related to thunderstorm development and a tornado evolution [6].

The present study, conducted during a 48-day period (May 12–June 28, 1962) in Oklahoma,[1] was made by measuring the 500-kc./sec. sferics [2] count rate in a number of 5.6° azimuth sectors and relating this information to severe weather incidents. The sferics detection equipment [7] has a maximum range of 200 n. mi. and a fair weather or background count rate of zero. In addition, original 500-kc./sec. sferics detection equipments, used continuously for storm analysis since 1956, were employed in order to directly relate this study to all our prior field investigations.

Severe-weather data used were furnished by the U.S. Weather Bureau (Kansas City) in the form of date, time, location, kind of severe weather occurrence, and source of the report.

A WSR–57 radar at Oklahoma City, located 40 mi. from the sferics equipment, was used to obtain supplementary information for both field operations and data analysis.

2. OMNI-DIRECTIONAL RELATIONSHIPS

The detection area, which is quite similar in extent to the radar coverage area, includes about 180,000 mi. Thunderstorms occurring anywhere in the region contribute their respective sferics activity to the total or omnidirectional count rate as measured at the monitor point. The severe weather incidents which occurred within the same detection area were used for comparison with the sferics activity.

Out of a total of 1152 hr. of operation, there were 47 periods of sferics activity totaling 821 hr. This means that 72 percent of the time sferics activity was present and this is evident in the distribution of the number of sferics-hours per day, shown at the left of figure 1. The total number of sferics pulses detected per day shows a much greater variation and reflects considerable differences in count rate. Also shown in figure 1 are the severe weather events and their identification. The symbol T refers to tornado or funnel cloud, H refers to hail storm, and W refers to wind storm.

The severe storm classifications are distributed as shown in figure 2. The distribution is identical to that of all severe storms reported throughout the United States during the period and probably reflects some degree of psychological bias on the part of those reporting the weather incidents as well as of the classification definition. The data shown in figure 3 indicate a broad distribution

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[1] This study was done in cooperation with the National Severe Storms Project, under Weather Bureau contract Cwb-10346 and Project Agreement with Federal Aviation Agency, ARDS–A–176.

[2] The term "sferics" as used in this paper refers to the electromagnetic radiation produced by all forms of lightning-like discharges occurring near or within lightning-related regions of charge separation in thunderstorms.

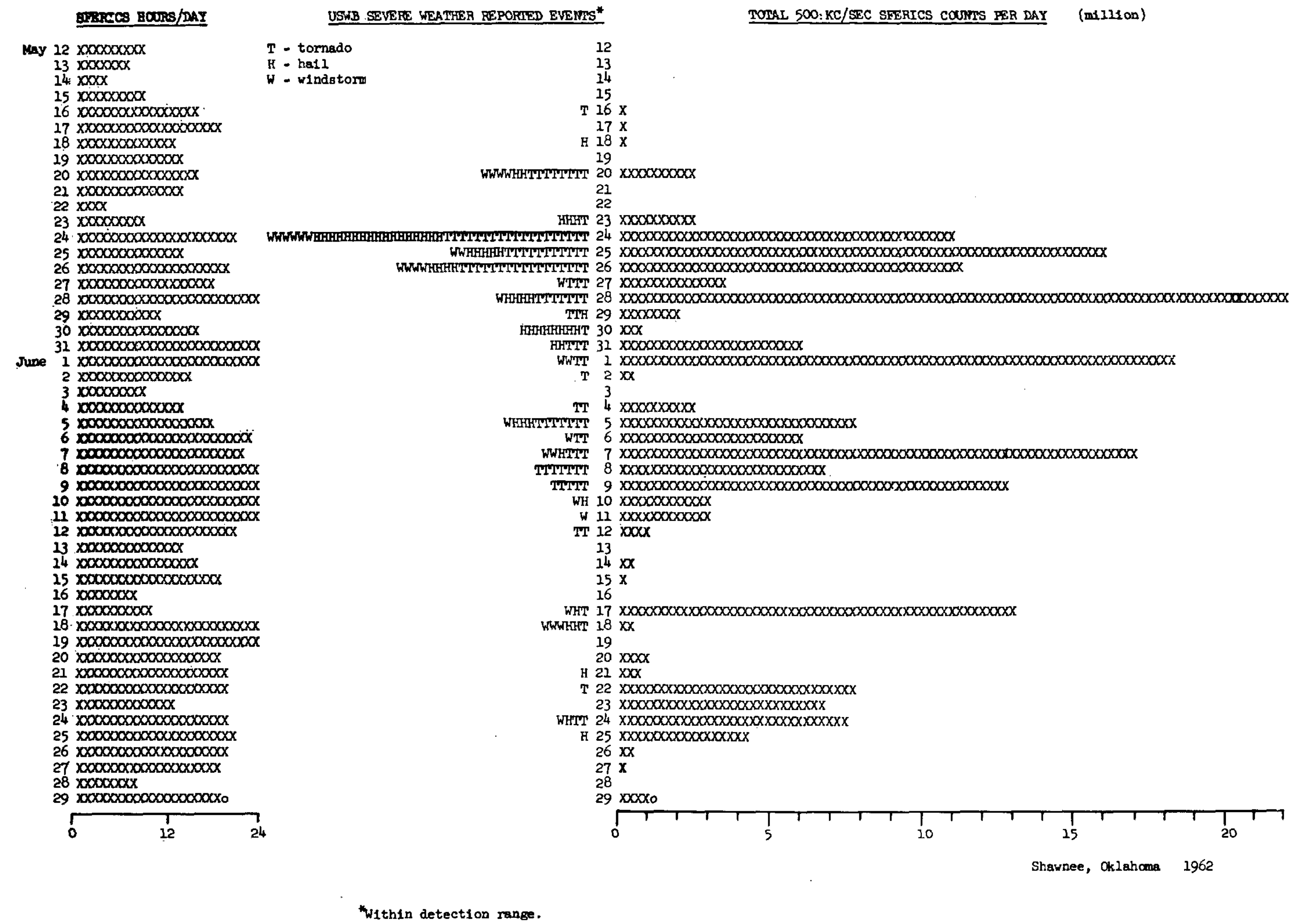

FIGURE 1.—500-kc./sec. sferics and severe weather summary.

in distance from the detection station to the severe weather event. The mean distance was 130 mi.

It is recognized that the reporting of severe weather incidents is imperfect; however, the number of severe weather events reported per day does have significance in the relationship with sferics activity. Based on the data found in figure 1, the following quantitative results (r=correlation coefficient) may be derived:

(A) Number of hours of sferics activity per day AND number of severe weather reports per day: $r=0.29$

(B) Total number of sferics detected per day quantized to 100,000 pulses AND number of severe weather reports per day: $r=0.49$

(C) Total number of sferics detected per day quantized to 1,000,000 pulses AND number of severe weather reports per day: $r=0.52$

(D) Number per day of sferics activity slopes exceeding $\pm 180{,}000$ pulses/hr.[2] AND number of severe weather reports per day: $r=0.50$

The latter correlation coefficient was derived to test the premise that the rate of change is more significant than the level of sferics activity. The onset is no more rapid than the cessation of sferics activity as shown by the distribution in figure 4. Thus the situation is evidently one in which, if the sferics count rate is large, the rates of change are also large.

The slope of the general trend of sferics activity is important in defining the maximum-level instant during a stormy period. A typical record of a sferics activity period is shown in figure 5. Note the rapid initial buildup of count rate from zero to over 15,000 counts/min. in less than 3 hr. The maximum activity (38,400 counts/min.) is well defined in the record, and the time of occurrence is indicated by the dashed line. The times of occurrence of severe weather are also indicated. Note that most of the severe weather occurred prior to the sferics activity maximum. This phenomenon was apparent in other storm periods also, as shown in table 1 which includes 67 severe weather events taken from the period of high incidence from May 23 to May 27, 1962.

The data shown in figure 6, taken from the entire 48-day period, further illustrate the greater incidence of severe

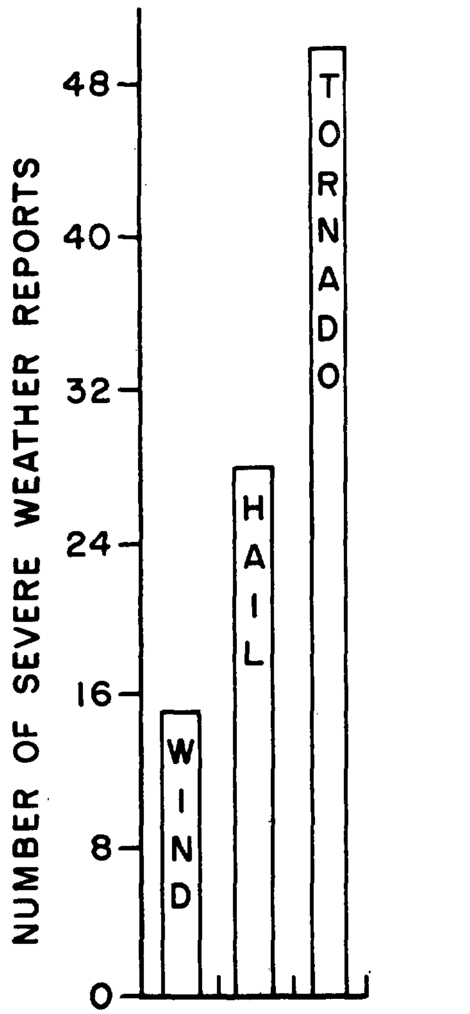

Figure 2.—Storm classification distribution, May 16–26, 1962.

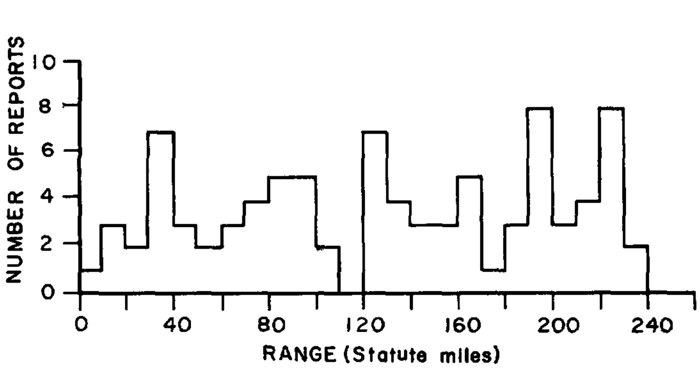

Figure 3.—Distribution of distance to severe weather locations, May 16–26, 1962. Number of reports is less 5 events which occurred when equipment was inoperative.

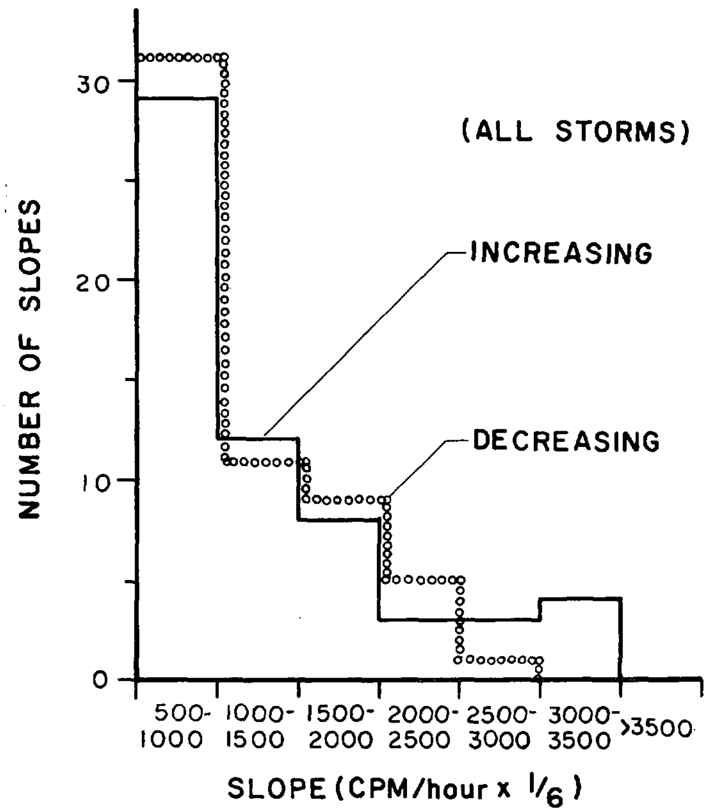

Figure 4.—Distribution of sferics activity rates of change, May 12–June 28, 1962.

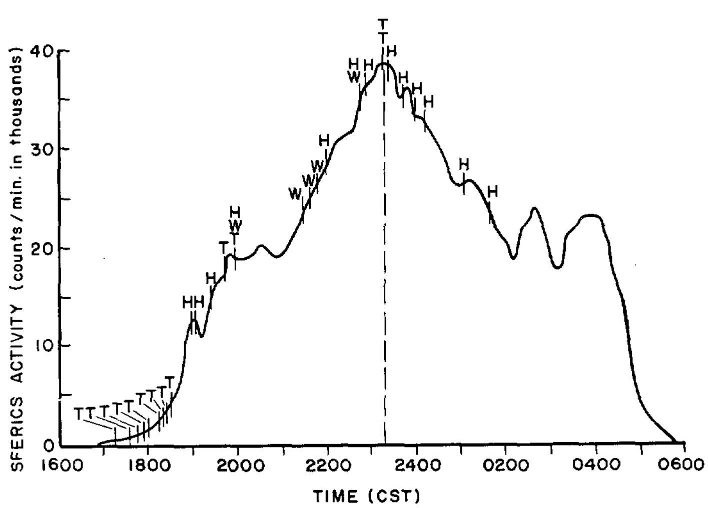

Figure 5.—Severe weather incidence and total sferics activity (May 24, 1962).

weather prior to the sferics period maximum. The frequency distribution shown at the top (fig. 6a) is of the times of occurrence of all the storm-sferics period maxima. The most frequent time of sferics activity maximum is the 2200–2300 CST period. The frequency of occurrence of the three severe weather categories, shown in parts b, c, d, of figure 6 is distributed such that 82 percent

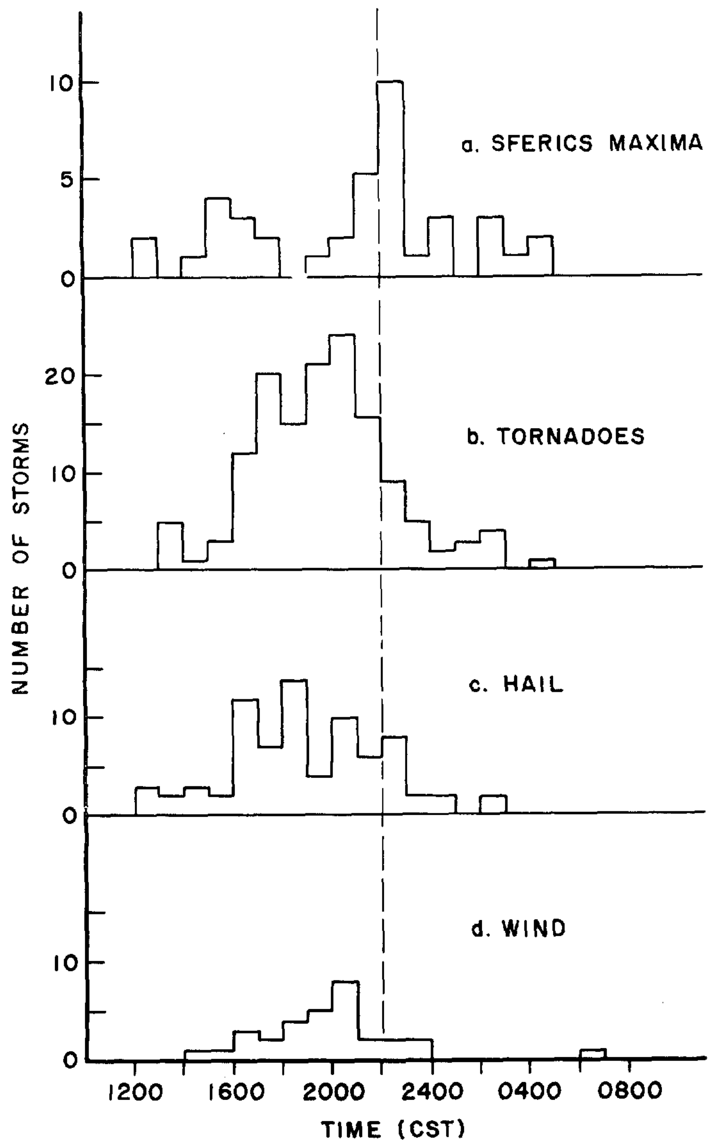

FIGURE 6.—Distribution of time of severe weather occurrence and sferics activity maxima, May 12–June 28, 1962.

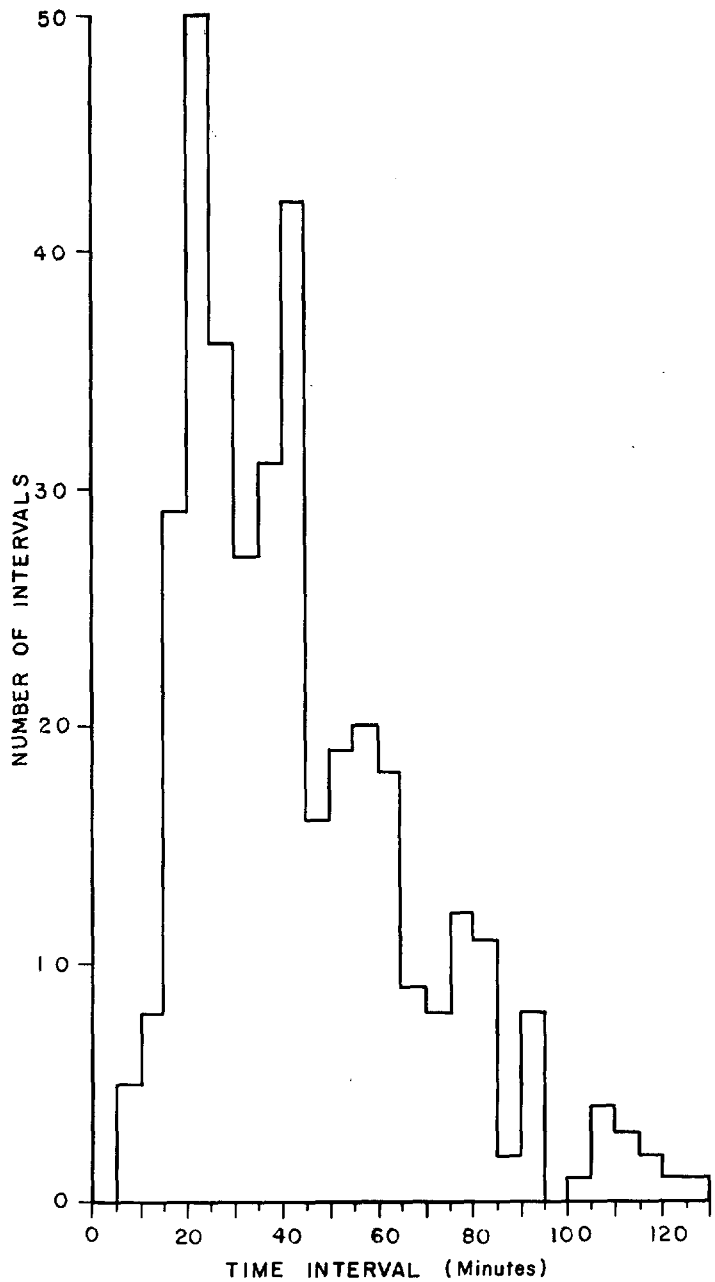

FIGURE 7.—Distribution of time interval between maxima of sferics count rate.

TABLE 1.—*Severe weather incidence related to total sferics activity*

Date and time of investigation 1962	(CST)	SW events occurring prior to S_T max.	SW events occurring after S_T max.	Total number of SW events
May 23 / May 24	1500– / 0600	4	0	4
May 24 / May 25	1600– / 0440	25	5	30
May 25 / May 26	1620– / 0800	14	5	19
May 26 / May 27	1500– / 0810	13	1	14
Total		56 84 percent	11 16 percent	67 100 percent

S_T is total omni-directional sferics count rate.
SW is official severe weather event.

of the events occur prior to the most frequent time of sferics activity maximum. Thus, during the entire period, which includes sferics activity periods without associated severe weather as well as very intense severe storm periods (see fig. 5), the sferics activity reflects a strong diurnal influence which undoubtedly is a predominant factor in the time of severe weather occurrence. The diurnal variation of storm incidence apparent in this series compares well with generally accepted data.

During the increasing and decreasing trends in total sferics activity there are frequent changes in slope, including short period reversals in sign, all of which describe a succession of minor maxima superimposed upon

TABLE 2.—*Severe weather indicator omni-directional sferics*

Co-factors	Incorrect	Correct	Percent correct
Days with SA and SW	XXXXXXXXXXXXXXXXXXXX	CCCCCCCCCCCCCCCCCCCCCCCCCCCC	58
Days with SA>100,000 pulses/day and SW	XXXXXXX	CCCCCCCCCCCCCCCCCCCCCCCCCCCCCØØØØØØØØØØØØ	85
Days with SA>1,000,000 p/day and SW	XXXXX	CCCCCCCCCCCCCCCCCCCCCCCØØØØØØØØØØØØØØØØØØØØ	90
Days with SA slope>180,000 p/hour/hour and SW	XXXXXXX	CCCCCCCCCCCCCCCCCCCCCCØØØØØØØØØØØØØØØØØØØ	85
Days with SA slope>1,000,000 p/hour/hour and SW	XXXXXXXXXXXXXXXXXXXX	CCCCØØØØØØØØØØØØØØØØØØØØØØØØ	56

C =severe weather predicted; based on sferics only
Ø =no severe weather predicted; based on sferics only
X =converse or error (severe weather predicted)
SA =sferics activity
SW=severe weather events documented
Explanation:
For example; relating days with SA greater than 100,000 pulses/day, we find 29 days in which SA did exceed this value *and* there was SW within the detection area. This is a correct prediction, C.
We also find that on 12 days the SA did not exceed 100,000 pulses/day *and* there was no SW reported. This is also a correct prediction, Ø.
In addition, there were 7 days during which the converse occurred. SA exceeded 100,000 pulses/day but there was no SW reported. This is an incorrect prediction, X.

the average slope or trend. It has been established that these minor fluctuations are due to large-area portions of different thunderstorm complexes undergoing simultaneous changes in activity as will be discussed in the next section concerned with directional sferics activity.

The distribution of time intervals between maxima in the total sferics activity from all storms which occurred during the 48-day period is shown in figure 7. On the basis of the distribution it would be possible to predict that an overall storm period maximum has been attained. Observing 45 min. of the record would give 50 percent probability; 60 min. would give 75 percent probability; and 2 hr. would approach 98 percent probability of determining the correct trend.

An indicator of the end of the occurrence of severe weather, therefore, may approach an accuracy of 84 percent if the period maximum may be defined, and the accuracy in defining that maximum is dependent upon the observing interval. The time scale is considerably shortened when individual storm areas are observed as discussed in the next section.

Not enough data have been analyzed to derive estimates of performance of various sferics measurements when used without other meteorological data in predictor fashion. One intermediate step in the process is represented by the data in table 2.

The quantitative discrimination level for prediction does vary the success of the severe weather indication with a maximum accuracy of 90 percent obtained when the sferics activity exceeded 1,000,000 pulses per day. The indicator accuracies tabulated apply only to days with cumulonimbus activity existent. There is *no* instance of severe weather occurring during the entire 48-day period without the sferics activity exceeding 250,000 pulses per day. Sferics activity on an omni-directional basis thus appears to be a necessary but not sufficient parameter of a severe weather predictor.

3. DIRECTIONAL RELATIONSHIPS

The directional sferics activity distribution was measured by monitoring equipment which averaged the sferics count rate occurring in each of 32 azimuth sectors. The azimuth circle was quantized into 64 sectors, 5.6° wide, and with the aid of weather radar (PPI) the sources of storm activity were determined. The time and location of severe weather events were obtained from the severe weather log. Individual severe weather events were referred to the directional sferics recording at the time of occurrence by identifying the azimuth sector containing the direction line to the event location.

A sector comparison of 82 severe weather events and related sferics activity included severe weather occurring from May 16 to May 26 within detection range. Only 2 cases (2.4 percent) did not have sferics activity in the sector at the time of the severe weather event. These were both tornadoes located at extreme range. One occurred at 205 mi. on May 24 (1637 CST) near Hutchinson, Kans. However, it was noted that sectors adjacent to the one aligned with the location did have activity at that time. The other tornado occurred on May 26 (1915 CST) north of Emporia, Kans. at a range of 220 mi. The finding that 98 percent of the severe weather events

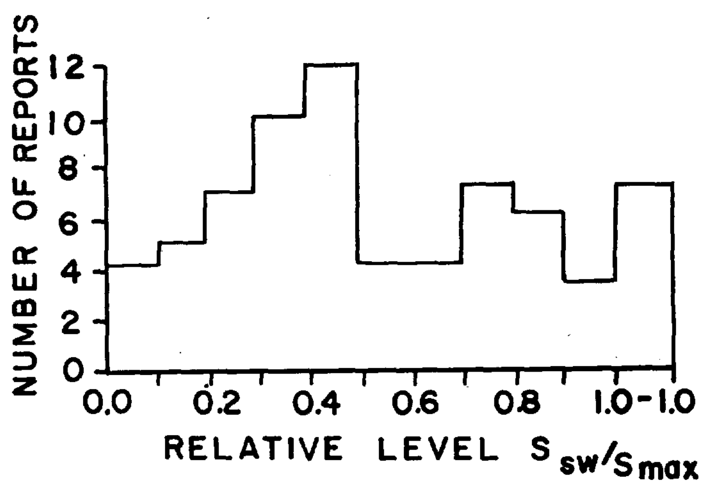

FIGURE 8.—Distribution of relative sferics levels at time of severe weather event.

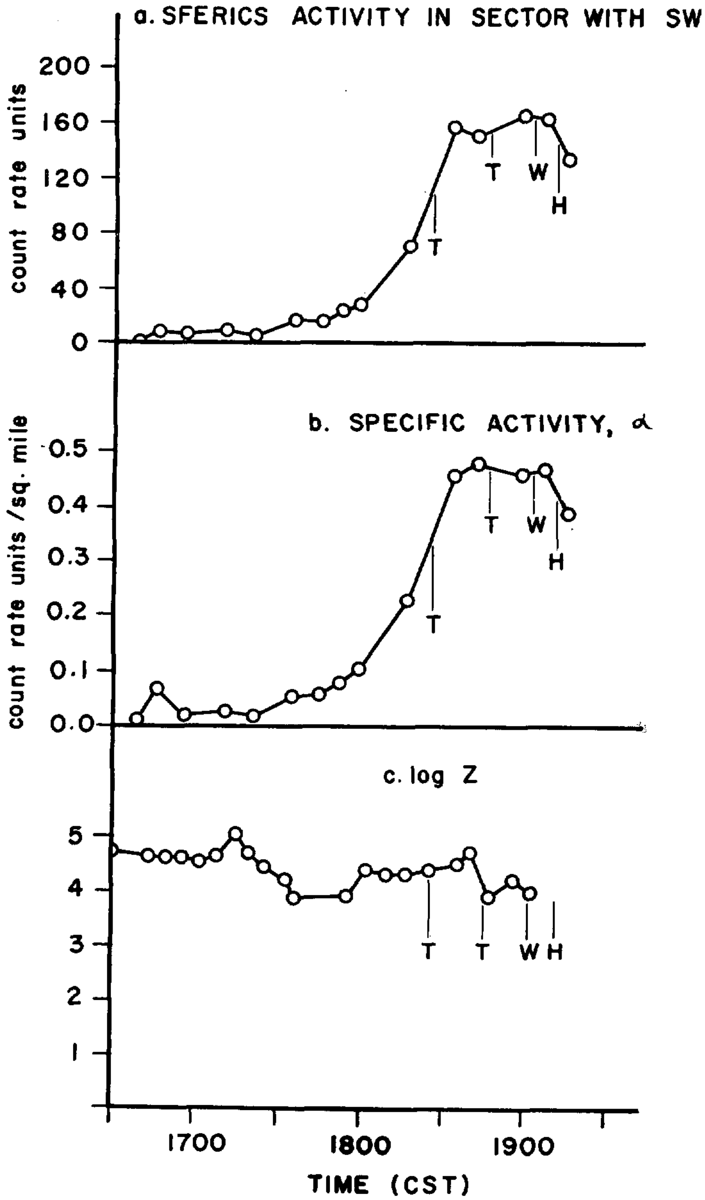

FIGURE 9.—Sferics record from the vicinity of severe weather occurrence, May 25, 1962.

produced sferics activity in the immediate vicinity is considered typical because the data were obtained from a period of high severe weather incidence.

Most of the severe weather events did not occur coincidently so a measure of the significance of the sferics level in the sector containing the event location is derived by relating it to the sferics level in the azimuth sector observed to contain the maximum level at the time of occurrence. These data are shown in figure 8 in the form of a fractional activity level distribution. Although the sferics activity may be appreciable in the vicinity of the severe weather location it is not large enough to permit reliable identification in the great variety of storm configurations and evolutions that occur. This is in part due to the fact that different storms are in various stages of maturity and dissipation and thus, as will be discussed later, the individual history of activity within each sector is an important parameter.

Figure 9a shows a typical history [3] of the sferics activity in a sector in which severe weather occurs. The time and kind of each event is indicated on the graph. It is important to note that documented evidence of severe weather does not exist prior to the period of rapid sferics activity increase. This effect is also apparent for overall activity from all storms in the region as detected on the omni-directional basis previously mentioned.

Figure 9b shows the history of specific activity, α, (counts min.^{-1} mi.^{-2}) for the same period. The specific activity is a sferics activity normalization based on the maximum sensitivity radar cloud echo area intersected by the sector. The specific activity also shows a rapid increase during the period of severe weather occurrence. The rapid rise in α is an indication that the sferics count rate is increasing much more rapidly than the cloud area. (See also fig. 11.)

The typical situation depicted in figure 9 occurs in an area where storm development has progressed to the extent of forming "hard" echoes in the radar display. Figure 9c shows the log Z (absolute reflectance) history of the hard echo at an altitude of 6,000 ft.

The sector aligned with the location of the hard echo and the sector containing the maximum sferics activity for the cloud were at all times either coincident or adjacent to each other. This was found to be the situation during the increasing storm trend periods of the storms analyzed.

During representative thunderstorm periods selected from the 48-day study a total of 2,840 sectors which contained maximum sensitivity radar echoes was examined. Of this total 42 percent were producing sferics at the time of comparison. However, of those sectors which were producing sferics activity, 91 percent also contained radar echoes. The sources of sferics are related to developing portions of storms which are definable by radar and comprise less than half the total storm area.

The data shown in figure 10 were obtained from a selected single storm complex located such that all sectors represent sections through the storm about 10 mi. wide and of uniform length. The times at which various sectors showed individual short term maxima in sferics count rate are indicated as well as the times at which the total storm sferics activity showed maxima. At 1445, for example, nearly 60 mi. of storm showed a simultaneous change in activity extending over a common area larger than 680 mi.^2 This situation is illustrated in the composite radar and sferics activity record of figure 11. The length of the sectors is proportional to sferics count rate and represents the distribution of sferics activity at the particular time of simultaneous change. These sferics fluctuations in areas very large compared to a radar-defined cell, further substantiate the important

[3] This storm is one of several chosen for detailed analysis as part of routine NSSP operations.

SECTOR NUMBER

23	24	25	26	27	28	29	30	31	32	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	TOTAL
1205	1205																											1205
				1215																								
	1250		1250																									1250
1325	1320																											1320
	1405					1410																						1355
								1445	1445	1445	1445	1445	1445	1445	1440													1450
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																					1710							1705
																				1735		1735						
																					1800		1800					
																							1930	1930	1930			1930
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Figure 10.—Identification of the sources of sferics level maxima, June 12, 1962.

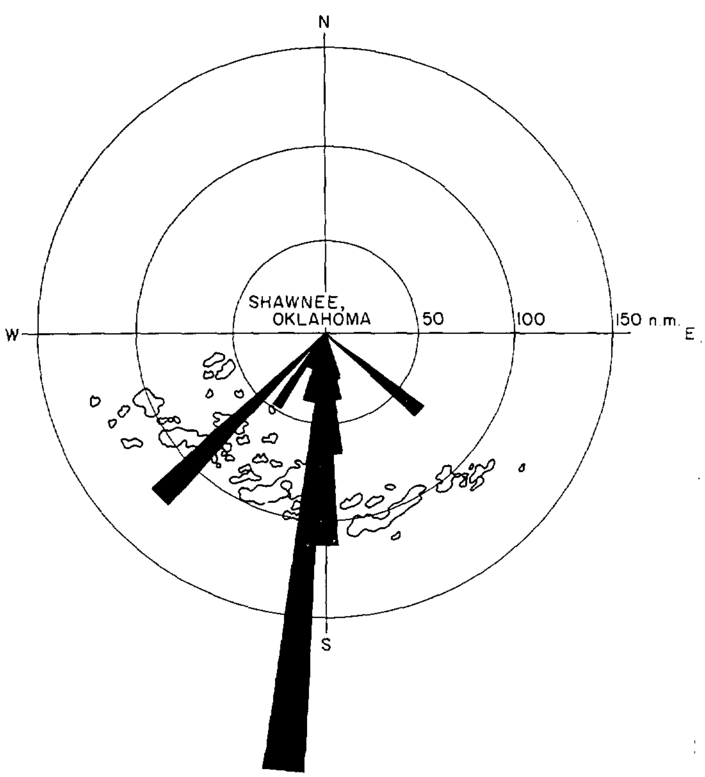

Figure 11.—Radar and 500-kc./sec. sferics record, 1445 cst (June 12, 1962).

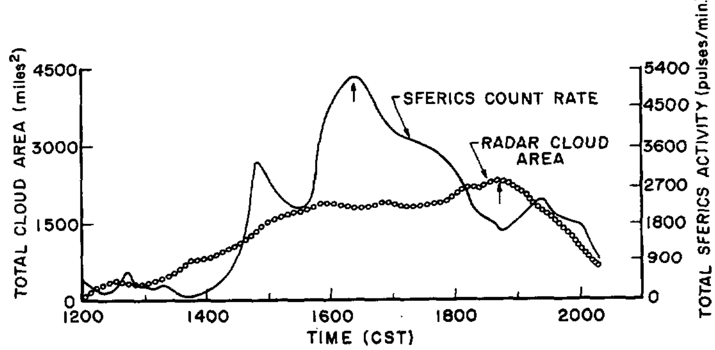

Figure 12.—Storm history of total sferics activity and total radar cloud area (June 12, 1962).

conclusion that the thunderstorm complex is more than a localized phenomenon.

Figure 12 shows a history of total sferics activity and total radar cloud area for a typical storm. Large increases in sferics count rate during a gradual increase in total cloud cover, as displayed in the figure, occur frequently in many storms. This is a period of increase in specific activity. It is also important to note that the decreasing trend in sferics activity precedes the general dissipation of cloud cover. This is evident in the time displacement between the respective storm period maxima (see arrows).

4. SUMMARY AND CONCLUSIONS

Previous investigations [5, 6] showed that monitoring sferics on 500 kc./sec. results in a detection system which has a well defined maximum range and zero fair weather response. The use of this frequency in the study of severe weather associated with thunderstorms has verified the intimate relationship between the electrification processes and dynamics of severe storms.

The 500-kc./sec. sferics activity was always produced in the vicinity of severe weather events. Even though radar evaluation may indicate storm maturity to the level of the formation of hard echoes, severe weather events do not occur until the sferics activity from the cloud shows an initial rapid increase. Further, most severe weather events occur during the overall increase in sferics activity and prior to the storm period maximum. Finally, a decreasing sferics trend precedes the storm dissipation trend.

Cloud evidences of sferics origin are well defined by weather radar. It was observed that large areas within a storm complex show simultaneous changes in sferics activity without variation in total cloud echo area. This phenomenon was found associated with the occurrence of severe weather events as well as other changes in storm configuration; e.g., the formation of a squall line. This effect was also previously reported associated with an isolated tornado measured at 500 kc./sec. [6].

The scope of this study has been limited to only a small fraction of the data available from a comprehensive analysis of the storms undertaken as part of the National Severe Storms Project during the period. With sferics analysis it has been possible to measure remotely the electrical activity of individual storms, in total or in part, and follow their progress from origin to dissipation. An attempt to define specific severe weather predictors is premature. However, some of the relationships appear to be of immediate interest in applied meteorology.

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