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ON THE OPERATIONAL USE OF THE AUDIO SPECTRUM ANALYZATION OF SFERICS IN RELATION TO SEVERE WEATHER: 530 KHZ

Mark E. Ewens
National Weather Service Office
Fargo, North Dakota

1. Introduction

The National Weather Service (NWS) uses a variety of techniques to forecast and detect severe thunderstorms and tornadoes; including RADAR, satellite, ground based and airborne spotters, and (with renewed interest) lightning detection (atmospherics - sferics). During the 1950's, the U.S. Air Force (USAF) operated an experimental lightning network. Yet, due to technological shortcomings, as well as the intense interest in conventional and Doppler RADAR, sferics became primarily a research tool.

A great deal of research has been performed by a variety of private and Governmental organizations, resulting in localized and regional lightning networks. During the 1970s, renewed interest in sferics as an operational tool was illustrated by Kohl and O'Malley (1975) and many others. (The reader is directed to the reference list) A review of published papers shows that most lightning research has been aimed at correlating the rate-of-change in the number of sferics pulses to the onset/occurrence of severe weather. (In this study, severe weather is defined using NWS guidelines as the occurrence of surface wind speeds greater than 58 mph, hail 3/4 inch or larger, tornado or funnel cloud.)

Lightning is blamed as the number one killer associated with thunderstorms (both severe and non-severe), and accounts for more deaths than all other meteorological events combined. Recently, the Bureau of Land Management (BLM), National Severe Storms Lab (NSSL), National Aeronautics and Space Administration (NASA), the National Severe Storms Forecast Center (NSSFC) as well as many others have shown interest in lightning detection. This is evidenced by the BLM's western U.S. lightning network, the NSSL network, and the University of New York (SUNY) network. Yet, operationally there exists a big gap between the knowledge and the use of sferics to detect/forecast severe weather. This paper presents a simple technique (developed at Weather Service Office (WSO) Fargo, North Dakota), which may be adopted locally, to help in the effort of severe weather warning.

2. Instrumentation and Operation

The sferics devices used in this study were two A.M. radios tuned to 530 kHz (Kohl, 1980; O'Malley, 1980; Ewens, 1986), a Leads/Northrup (L/N) chart recorder, and a commercially-available Audio Spectrum Analyzer (ASA).[1] Due to attenuation and other atmospheric factors, 530 Khz lends itself to a maximum range of about 200 nm (Isreal, 1980; Kohl 1980). The Audio Spectrum Analyzer (ASA) program runs on a Tandy Color Computer 2 (CoCo2). The ASA receives an audio signal (in this case from an A.M. radio) then breaks it down into 27 discrete frequencies from 31.5 Hz to 12500 Hz (Fig. 1). The computer references the highest received signal and automatically adjusts the other frequencies so that an accurate response curve (in reference to the strongest frequency) is maintained. The ASA program has the capability to respond in real time (instantaneously) or in a Root Mean Square response mode. Both peak power and "freeze" action are available; so it is possible to study the subtle changes that occur in the audio spectrum during the metamorphosis from a "garden variety" to a "severe" thunderstorm.

As with all omni-directional sferics equipment, the overall storm index is inferred from ASA data. Yet, unlike the L/N recorder, the automatic referencing of the ASA prevents saturation by nearby storms. Thus, the ASA will still react to a distant storm which is becoming severe even if convection nearby is producing a response.

3. This Study

The NWS uses several data gathering techniques to detect, then warn for, severe thunderstorms and tornadoes. For the past three decades, the primary tool has been conventional weather RADAR, specifically the WSR-57 and WSR-74 series. The quality of the NWS warning program had shown steady improvement during the past decade, but it has leveled off recently as techniques and technologies fully mature (Grenier, 1988) (Fig. 2). National and Central regional skill scores (Donaldson et al., 1975) are fairly consistent - False Alarm Ratio (FAR) .60/.63 (respectively); Probability of Detection (POD) .57/.59; Critical Success Index (CSI) .31/.30.

The scores could be higher, but effectiveness of warnings has been hampered by several factors; including the misuse and misunderstanding of RADAR data (Bogin, 1986), limitations of the RADAR itself (FMH-7, Chapters 1, 2, and 3), and a limited (but rapidly growing) understanding of storm scale and mesoscale factors (Doswell, 1985; numerous other authors). While the Doppler capability of NEXRAD (the WSR-88D) should improve these scores, the NEXRAD era will be several years in unfolding. Immediate, ready-to-use, tested, and reliable techniques should be employed in an attempt to more accurately fulfill the warning requirements.

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1 Disclaimer: Reference in this paper to any specific commercial product or manufacturer does not constitute or imply its endorsement, recommendation, or favoring by the United States Government.

Detailed breakdown of the 27 descrete audio frequencies

31.5Hz	
40.0Hz	
50.0Hz	
63.0Hz	Low
80.0Hz	
100.0Hz	
125.0Hz	
160.0Hz	
200.0Hz----------	
250.0Hz	
315.0Hz	
405.0Hz	
500.0Hz	Medium
630.0Hz	
800.0Hz	
1.0kHz	
1.25kHz	
1.6kHz----------	
2.0kHz	
2.5kHz	
3.15kHz	
4.0kHz	High
5.0kHz	
6.3kHz	
8.0kHz	
10.0kHz	
12.5kHz	

Fig. 1 A detailed breakdown of the 27 discrete audio frequencies as portrayed by the Audio Spectrum Analyzer.

SOURCE: NSSFC Technical Memorandum 18

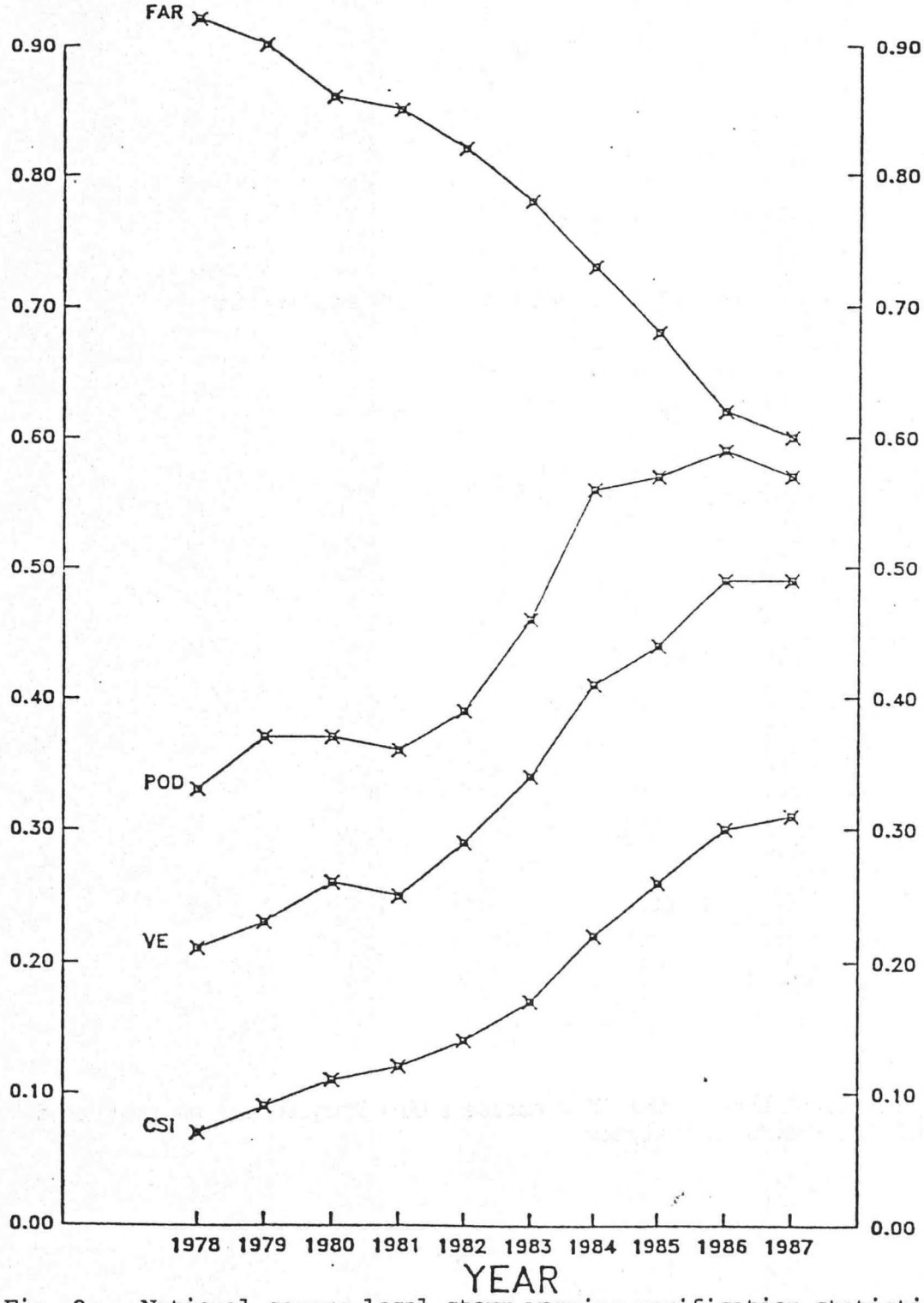

Fig. 2 National severe local storm warning verification statistics 1978-1987 (from NSSFC Technical Memorandum 18).

4. Results/Notes

A review of the 473 warnings issued by WSO Fargo during the period 1984-1988, showed that 165 warnings verified. The average POD was 0.63, FAR 0.65 and CSI 0.28 (Fig. 3). Since the late summer of 1986, studies have shown a strong correlation between certain [ASA] audio frequency response patterns and surface severe weather. The use of SFERICS in conjunction with the operational Lemon warning techniques (Lemon, 1980) could have greatly decreased the FAR and increased the POD and CSI (Fig. 4).

Over a three warm season study period (1986-1988), 152 events[2] were analyzed with the ASA technique, which is made up of three distinct parts: (1) the Lemon criteria, (2) the use of the L/N recorder trace, and (3) the CoCo2 based ASA output. It must be noted here, that due to the omni-directional nature of the receiving equipment, no hard statistical data on lead time is available. Thus, "lead times" are subjectively based on warning post mortems and the authors real time experience with the technique.

A. Generalized Non-Severe Storms

Typical ASA displays of developing thunderstorms are shown in Figs. 6a and 6b. Non-severe convection shows up with both random peaks (new/developing) and well defined curves (older/steady-state) generally centered between 800Hz and 1.6 Khz, audio. The peak power generally lies below +3B, but its magnitude depends on the frequency of lightning flashes and the proximity of the convection. As the storms intensify, a shift in audio response begins. The peak power generally moves to around 1.0 Khz audio, with peaks reaching +5dB. This is sometimes accompanied by a secondary (and much weaker) peak developing between 110 and 200 Hz audio.

B. Intensifying Storms/Storms in Transition (Non-Severe)

In intensifying convection that are beginning the metamorphosis from non-severe to severe, the secondary lower frequency peak begins to expand and increase in power response. While the primary audio response is in the 800 Hz to 6.3 Khz audio range, with a broad peak power response around 1.6 Khz (Fig. 7a), the second responsive band (in the 40 Hz to 800 Hz range) depends on the proximity and frequency with which sferics pulses are received. Storms that are "dry," with a great deal of in-cloud lightning, tend to evoke a lesser secondary response in the lower audio frequencies than "wet" storms with higher cloud-to-ground lightning. (Dry and wet are subjectively based on recorded sferics pulse rates versus precipitation output.)

The transition to a severe thunderstorm is indicated by a continued "widening" of the audio response in the middle and high range (600 Hz to 12.5 Khz). Also, more power over a larger area is received in the secondary peak around 160 Hz audio (Fig. 7b). This peak will generally exceed the -15 dB power level. Frequency response below 100 Hz tends to be suppressed as the automatic

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2 An event is defined as any one period of thunderstorm activity within recording range of the ASA/Leeds/Northrup counter (Fig. 5).

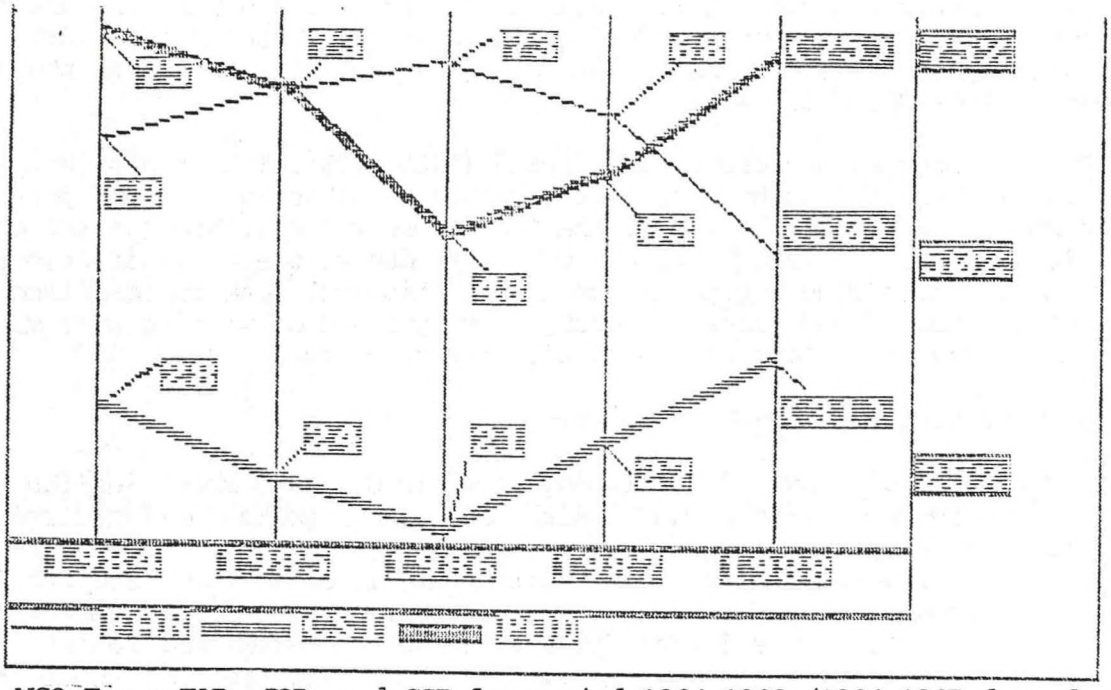


Fig. 3 WSO Fargo FAR, POD, and CSI for period 1984-1988 (1984-1987 data from NSSFC Technical Memoranda; 1988 data from (local and NSSFC) preliminary estimates).

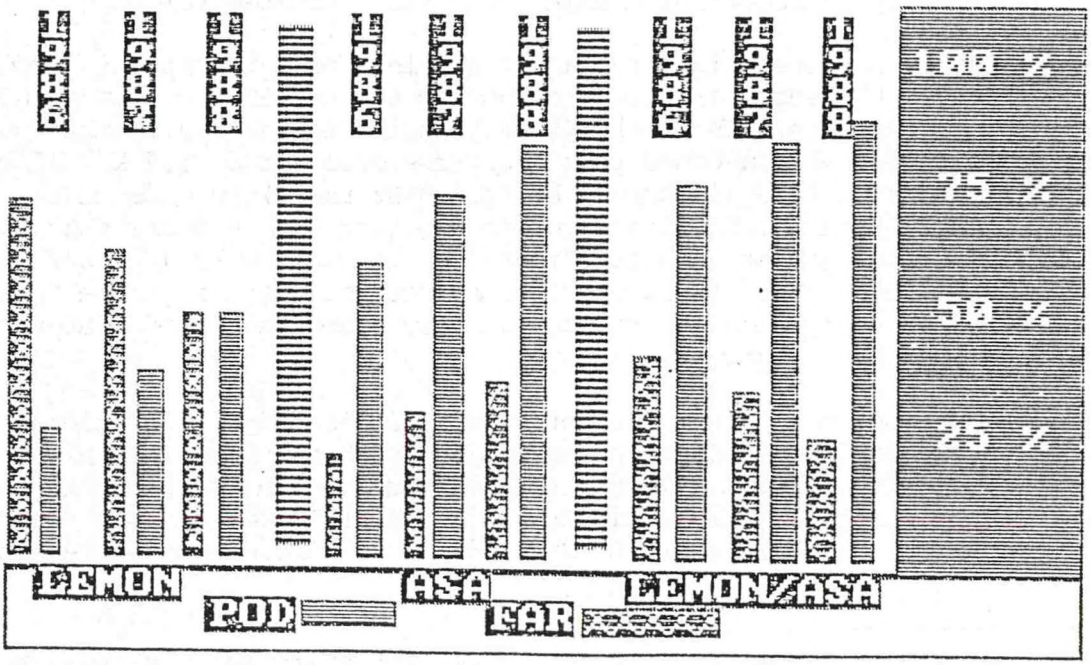


Fig. 4 Bar-graph breakdown of 1986-1988 severe weather warning verification using the Lemon technique only, ASA technique only, and Lemon/ASA techniques combined. Skill scores somewhat subjective based on post mortems as well as real time experience.

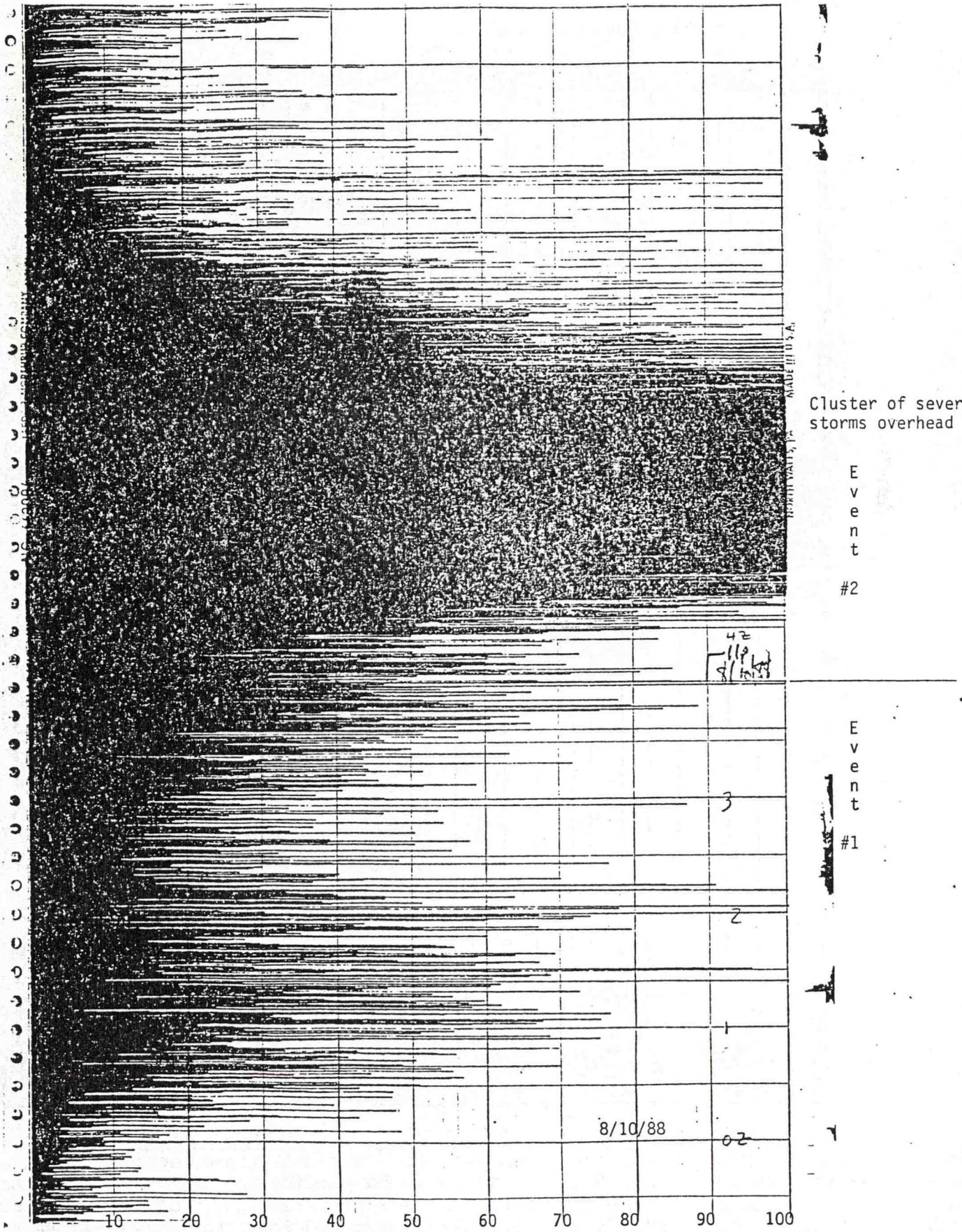


Fig. 5 Reproduction of the Leeds/Northrup Model-H recorder output. Vertical ordinates are in 1/2 hour increments. Two "events" are shown, one centered around 01Z to 02Z as convection passed 75-100 miles northwest of WSO Fargo; the second event (severe) between 04Z and 07Z as convection passed through the WSO Fargo immediate area.

AUDIO FREQUENCIES IN HERTZ

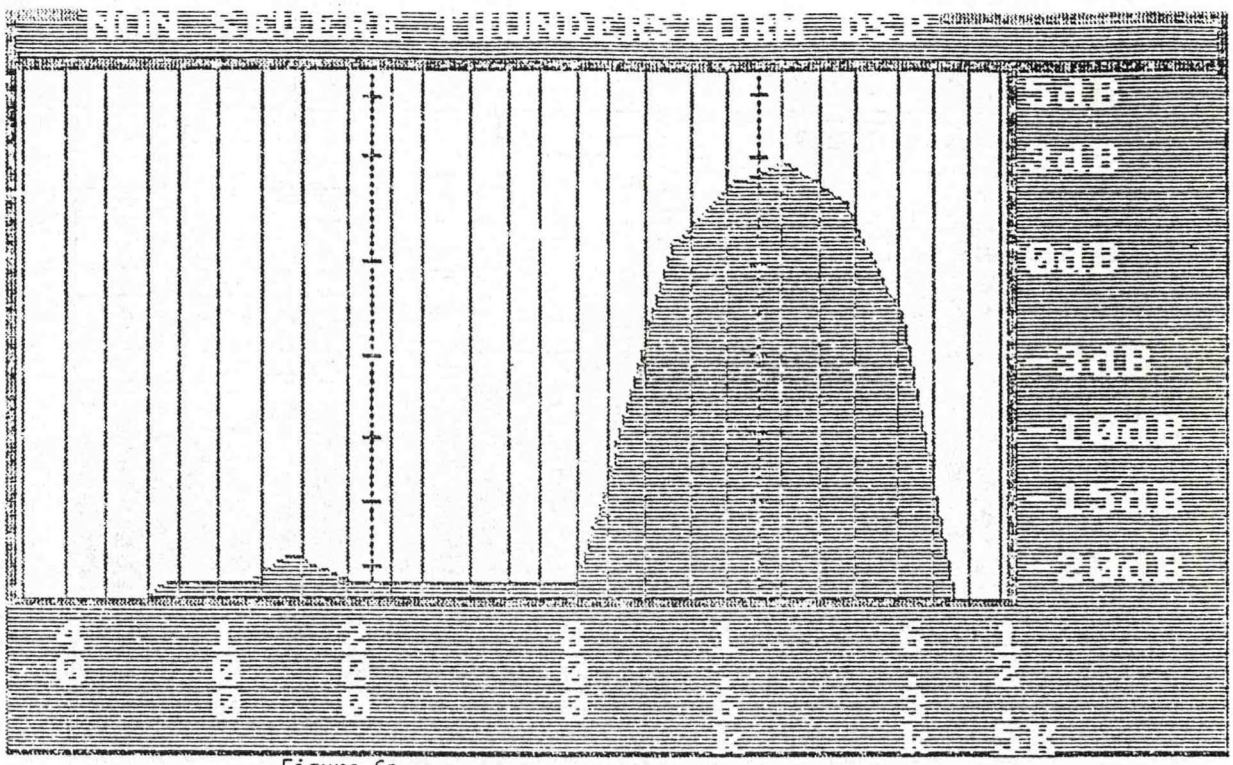


Figure 6a

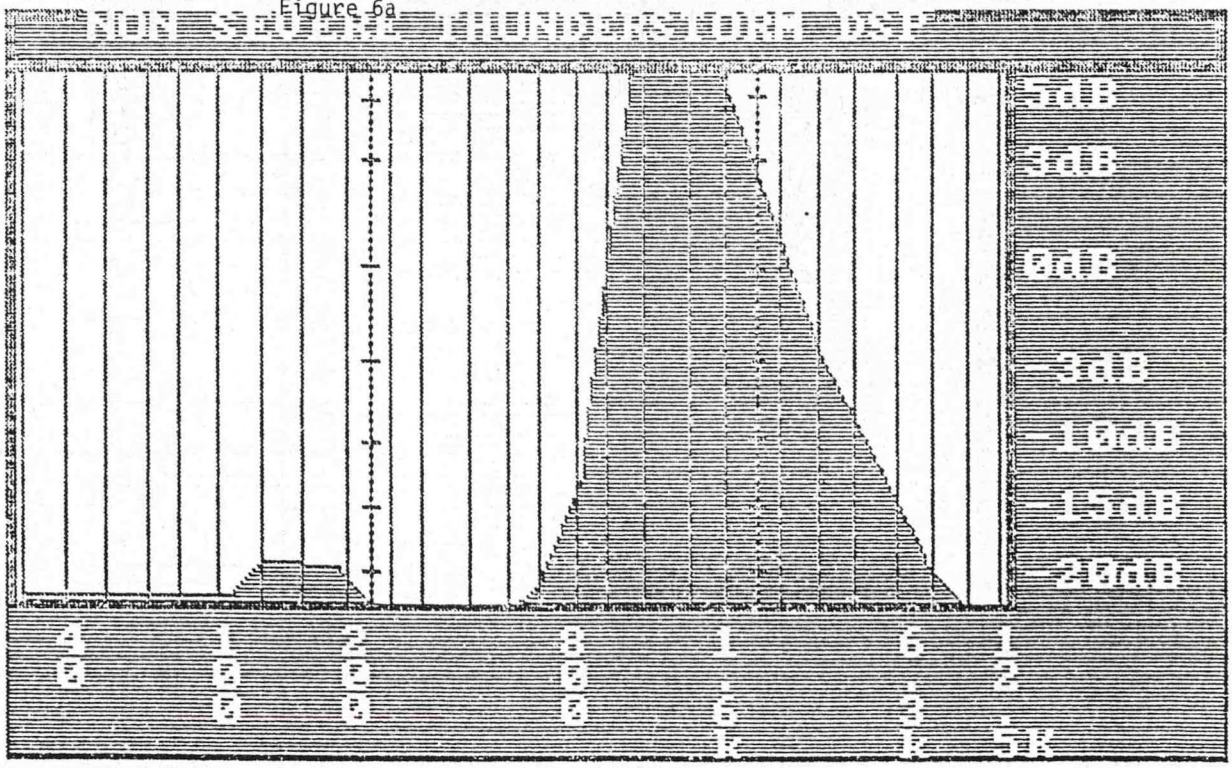
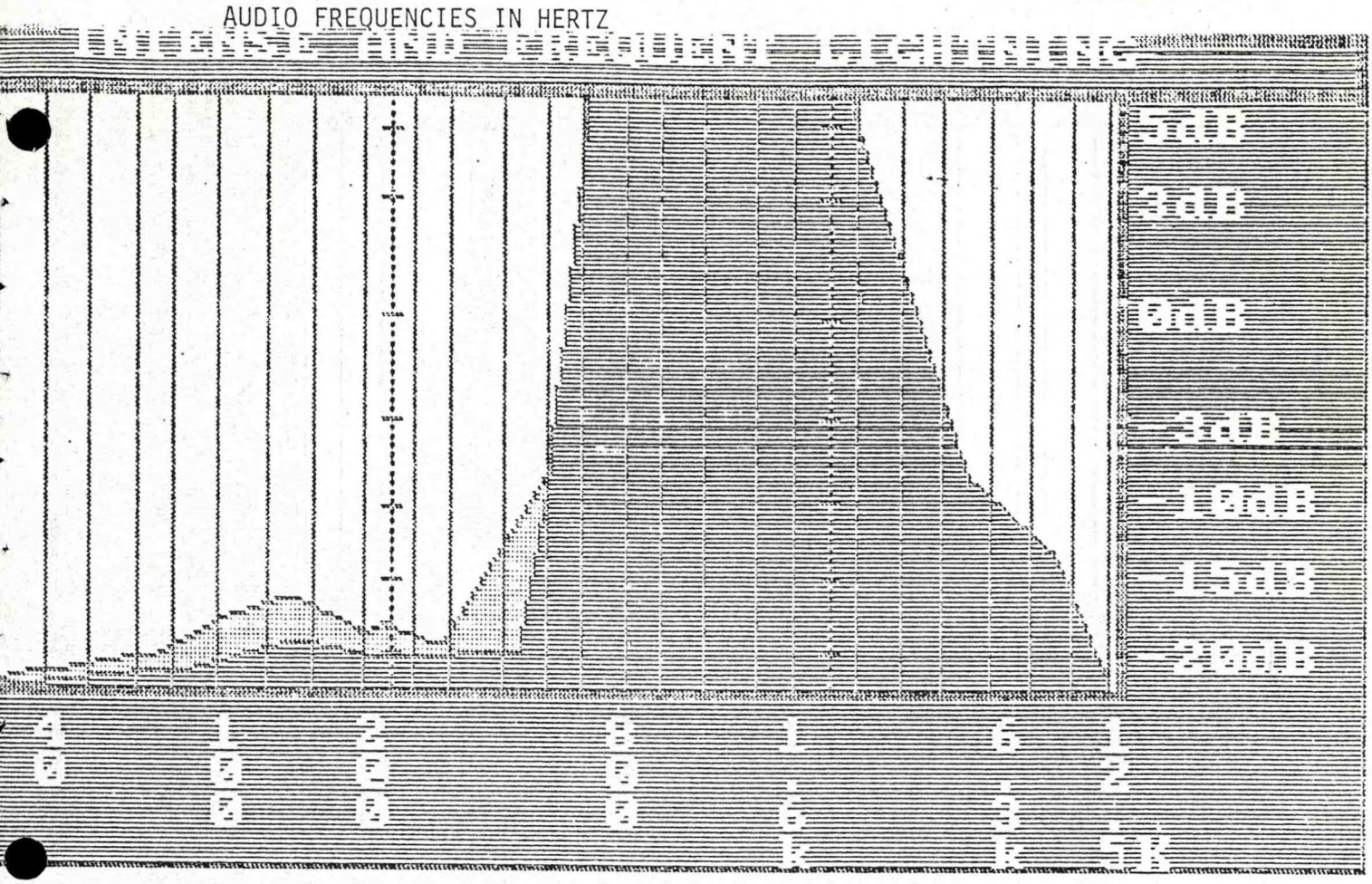


Figure 6B

Fig. 6 Schematic representation of the ASA output. Horizontal lines represent the 27 discrete audio frequencies as detailed in Fig. 1. "Primary" frequencies are listed along the bottom; relative power in decibels from -20dB to +5dB are shown on the right side. Curve within the shaded areas represent the upper limits of observed received power for each discrete frequency. (a) ASA display during generalized weak/developing convection. Shaded area represents the cap of the most active area, in both audio frequency response and power, during this period. Minor secondary peak between 100 and 200 Hz not always visible. (b) Well developed non-severe convection.



THIS SPORIOS SIGNATURE IS ASSOCIATED WITH INTENSIFYING NON SEVERE STORMS AS WELL AS STEADY STATE NON SEVERE STORMS.

FIGURE 7A

Fig. 7a As in Fig. 6, except for well developed "steady state" and intensifying convection. Darker shading represents the upper limits during "intense" steady state convection. Lighter shading below 800Hertz signifies the beginning of transition to severe storm development.

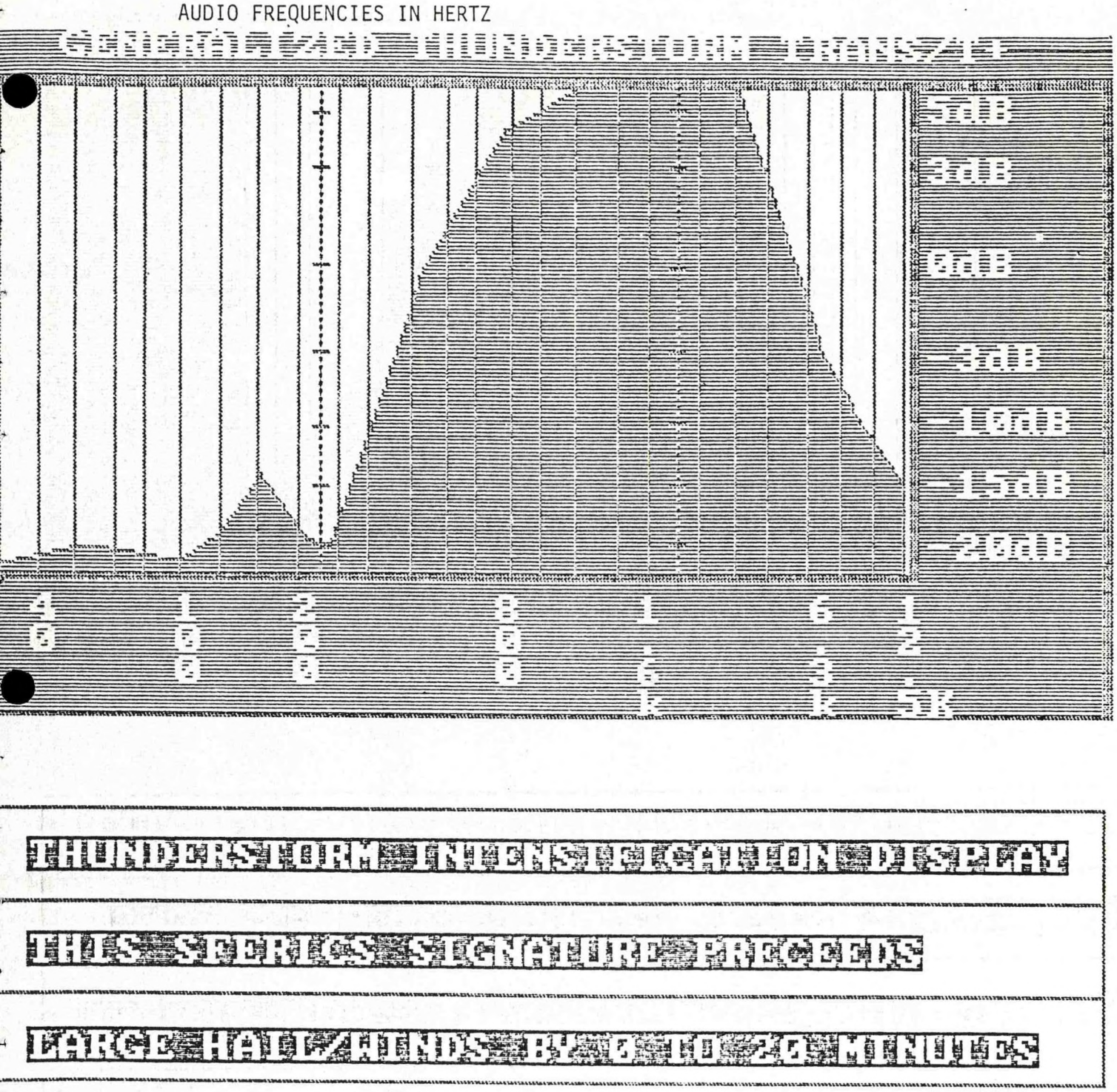


FIGURE 7B

Fig. 7b As in Fig. 6, except for well developed "steady state" and intensi fying convection. Thunderstorms as they become severe. Note how much of the upper 2/3rds of the display is involved with a broad peak between 1Khz and 3Khz. Note well defined secondary peak emerging around 160Hz.

referencing circuit keys in on the increase near 160 Hz. The signature of Fig. 7b often precedes the observation of hail greater than 3/4 inch and winds over 50 kts, an apparent average of 10 to 15 minutes.

C. Hailstorms and RWXX

With further intensification, the ASA response curve begins to narrow down. The primary peak is in the 1.0 Khz range, frequently with +5dB power (Fig. 8). The secondary peak remains around 160 Khz, but often equals or exceeds -10 dB power. The remaining lower frequencies below 160 Hz become increasingly prevalent. At this point the synoptic scale meteorological conditions must be considered carefully. Intense rainfall events, sometimes exceeding two inches in one half hour will achieve the same response in the ASA as severe hailstorms. However, if synoptic scale conditions are such that mid and low level moisture availability is "high," then the risk of severe weather is somewhat diminished while the risk of flooding is increased. This is one of the weaknesses of the technique. The atmospheric process which create intense rainfalls may also produce intense, frequent lightning strokes. This particular signature often precedes large hail and damaging winds by about 10 minutes.

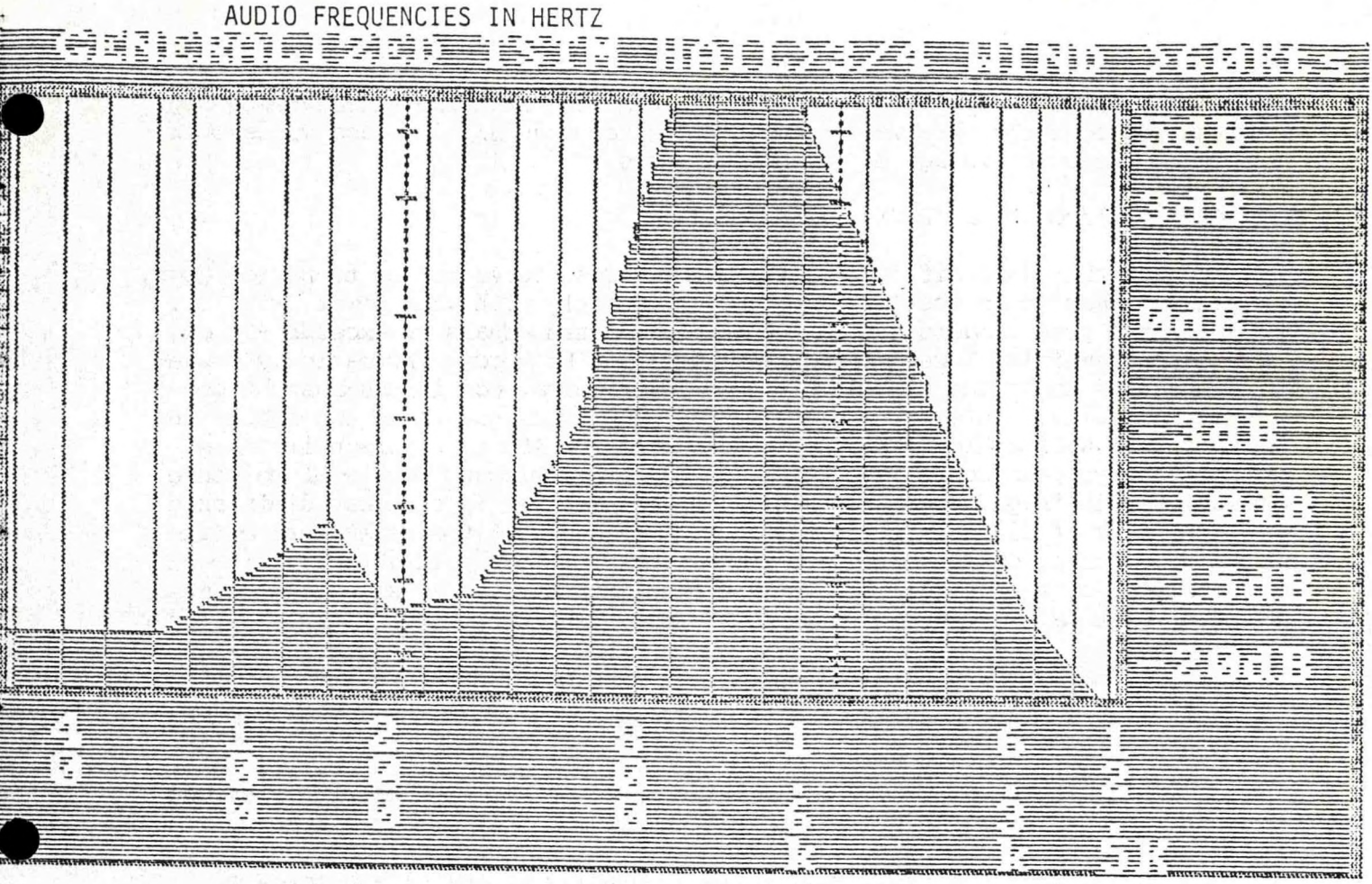
D. Tornadic/Tornadic Signature Storms/Wind Storms

The event least often viewed is the tornadic signature. The characteristic ASA response is fairly dramatic and unmistakable (top half, Fig. 9). A downward shift in the primary peak to between 800 Hz and 1.0Khz, with a strong secondary peak in the 125-200 Hz range (often breaching 0 dB) develops and broadens. In the strongest tornadic storms, this peak exceeds 0 dB. While the 31.5-250 Hz range is well involved, there is usually a lack of any activity above 6.3 Khz. This signature precedes the conventional RADAR tornado signature (when visible) by five to 20 minutes with a 10 minute (subjective) mean. However, since only 11 tornadic storms have been observed with this technique, meaningful statistics cannot be ascertained.

Wind storms (surface winds greater than 80 kts) evoke a response similar to tornadic storms. The difference is illustrated in the bottom half of Fig. 9. Generally, all frequencies are involved, but the peak in the 125-200 Hz range is lower in amplitude (0 to -3dB) than observed in tornadic storms.

5. Conclusions

The Audio Spectrum Analyzation of a sferics (lightning) signal and the relationship to severe weather has been examined. The equipment used for this study was a simple omni-directional radio, which reduced the ability to accurately quantify the results. The observed, though non-statistical, data strongly suggest a good relationship between low audio responses (100-300 Hz) and surface severe weather. The value of this technique is that it allows for the RADAR operator to more fully utilize the existing RADAR technique(s), thereby enhancing the warn/no warn decision.



THUNDERSTORM INTENSIFICATION DISPLAY

THIS SPECTRAL SIGNATURE PRECEEDS

LARGE HAIL/DAMAGING WINDS BY GENERALLY

LESS THAN 60 MINUTES

Fig. 8 As in Fig. 6. The well organized severe thunderstorm generally shows a narrowing of the peak responsive frequencies as well as a well defined and growing peak around 160Hz. Both intense rain showers and storms with large hail can evoke this response.

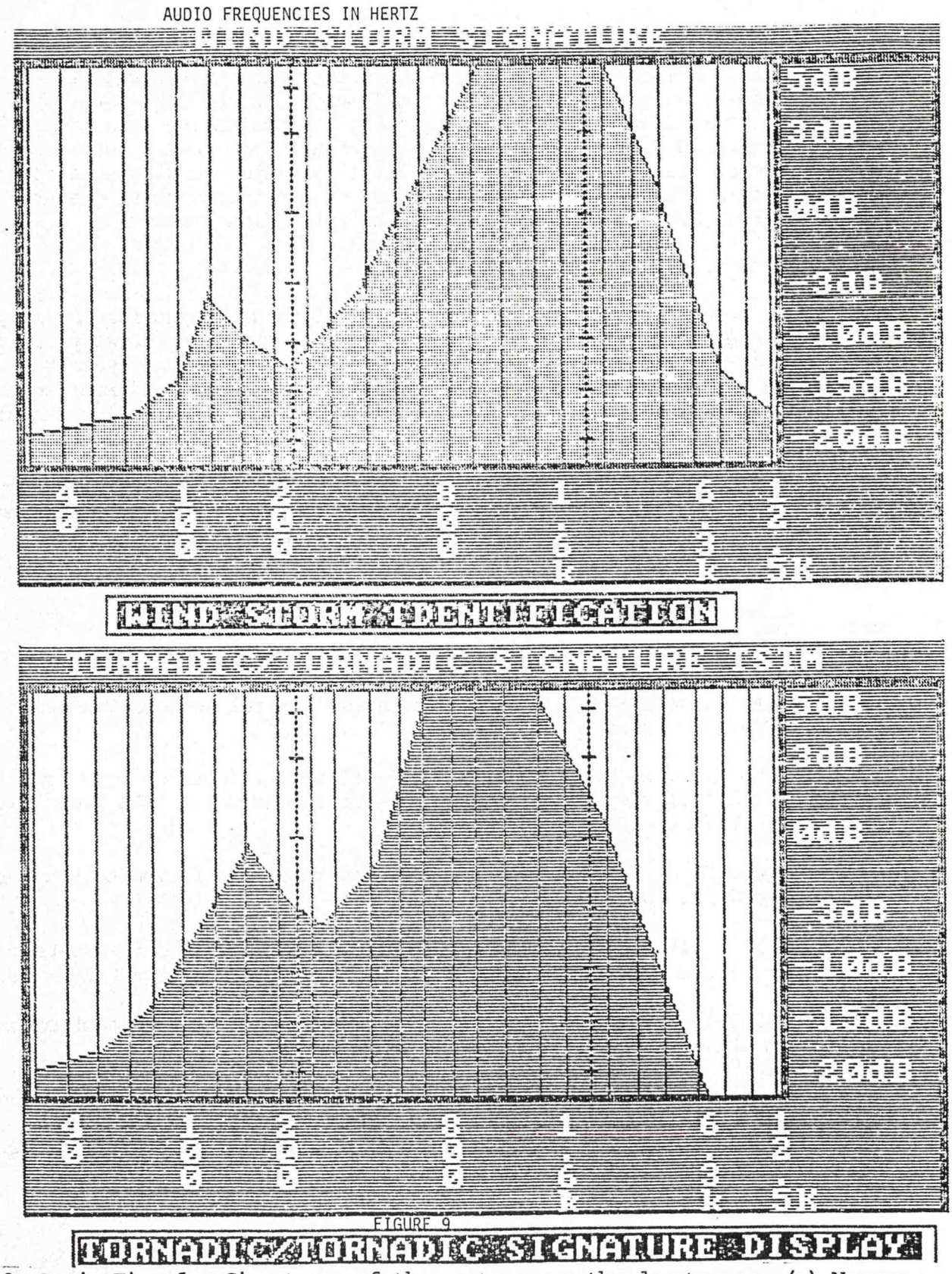


Fig. 9 As in Fig. 6. Signatures of the most severe thunderstorms. (a) Narrow peak, as well as a shift towards the lower frequencies. The secondary peak around 160 Hz grows dramatically. (b) Represents the wind storm signature, which is very similar to the tornadic signature.

6. Further Research

A directional sferics unit, with high sensitivity and better signal quality, has been developed and deployed at WSO Fargo for the 1989 severe weather season. This allows single cell tracking and monitoring as a storm develops, matures, and dissipates. Preliminary results show excellent sensitivity and directional discrimination, and initial single storm analysis is consistent with omni-directional results. Also, plans to adapt this technique at WSO Montgomery, Alabama are under way as part of the validation process.

7. Acknowledgements

The author wishes to extend thanks to the staff of WSO Fargo for the many hours of tolerance and assistance while this technique was being developed. The RADAR room is not a fun place to be during severe weather episodes, yet the staff helped in the evaluation of the sferics counter, especially during severe weather episodes. Much appreciation is given to those at NOAA's Environmental Research Laboratory and National Severe Storms Laboratory, in particular, who were willing to discuss different lightning detection techniques; Leo Grenier at the National Severe Storms Forecast Center's Techniques Development Unit, for his explanation on how verification statistics are compiled; and the assistance of Duane O'Malley, currently at WSO Rochester, Minnesota. Don Haworth, who designed and built the directional SFERICS unit, has provided invaluable input to this effort.

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