P2.8 OVERVIEW OF THE ISNET DATA SET AND CONCLUSIONS AND RECOMMENDATIONS FROM A MARCH 2004 WORKSHOP TO REVIEW ISNET DATA

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1. INTRODUCTION

The continuous Infrasonic Network (ISNet) operation started 1 May 2003. During mid-summer, all three stations were operating and by late July, noise reducing eddy fences were installed at all network locations. Data obtained were analyzed from two perspectives. One compared infrasonic signal detections with Storm Data reports of tornadoes and funnels, sorting results by observatory and state. The other perspective reviewed all significant infrasonic signals (i.e. signals typically showing high signal-to-noise ratio, continuous energy, and long duration) and preliminary comparisons were made with the meteorology. Results from both these perspectives are reviewed. A workshop was held in late March 2004 to summarize the data and experiences with the ISNet operations. The conclusions and recommendations are reviewed, including those to continue operation for the 2004 severe weather season and to provide more display options.

The challenges involved with creating a demonstration network included the following:

- Installing the infrasonic systems and newly developed eddy fences at each of the observing sites.
- Providing data links to bring the processed infrasound information to Boulder, CO for use with a web display available to NWS forecast offices.
- Providing displays that could be readily interpreted and compared with other meteorological data sets.
- Designing a web display and integrating WSR-88D imaging.
- Providing familiarization to forecasters with an unfamiliar technology.
- Developing methodologies for characterizing infrasonic signals and comparing infrasonic data with storm reports and other observations.
- Developing paths to obtain feedback on the operation of the network and making recommendations based upon the 2003 results.

The workshop held during the spring of 2004 developed a set of recommendations based upon the operation of the network starting in May 2003. A key recommendation was that the operations continue through 2004. These recommendations are summarized in Appendix A. Our spirit in assessing the strengths and weaknesses of the system was to do a critical analysis of all phases of the operation. This is the first attempt at applying and assessing infrasound as an operational tool to severe weather detection and forecasting, and there were many lessons learned. Background on ISNet and the displays provided is reviewed by Bedard et al (2004).

2. ISNET DATA ANALYSIS AND DISPLAY

Figure 1 summarizes the data flow for the measurement sites, web displays, and after-the-fact analysis of data archived to CD. Figure 2 reviews processing options.

Processing and archiving is performed on a personal computer based system that ingests the signals from the four infrasonic sensors. There are options for displaying the time series (to monitor data quality) or the polar plots of data for the last hour, updated every 12.8 seconds. This display is also located in the operation rooms at Pueblo, CO and Goodland, KS.

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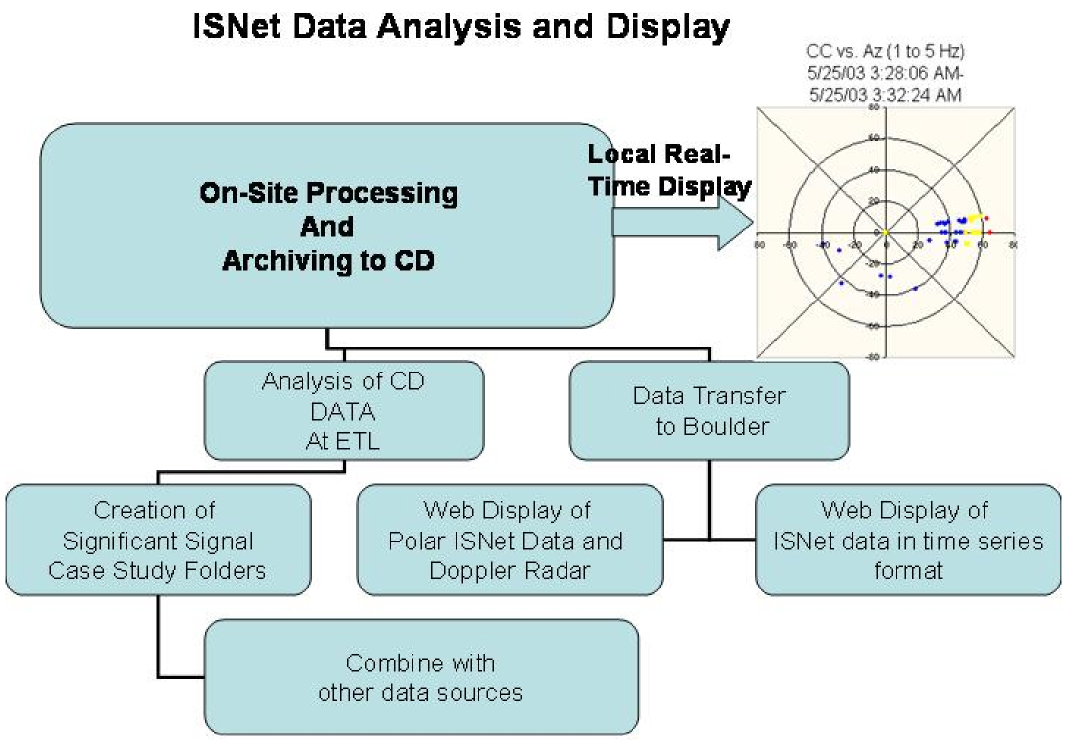

FIG. 1. ISNet analysis and display flow chart.

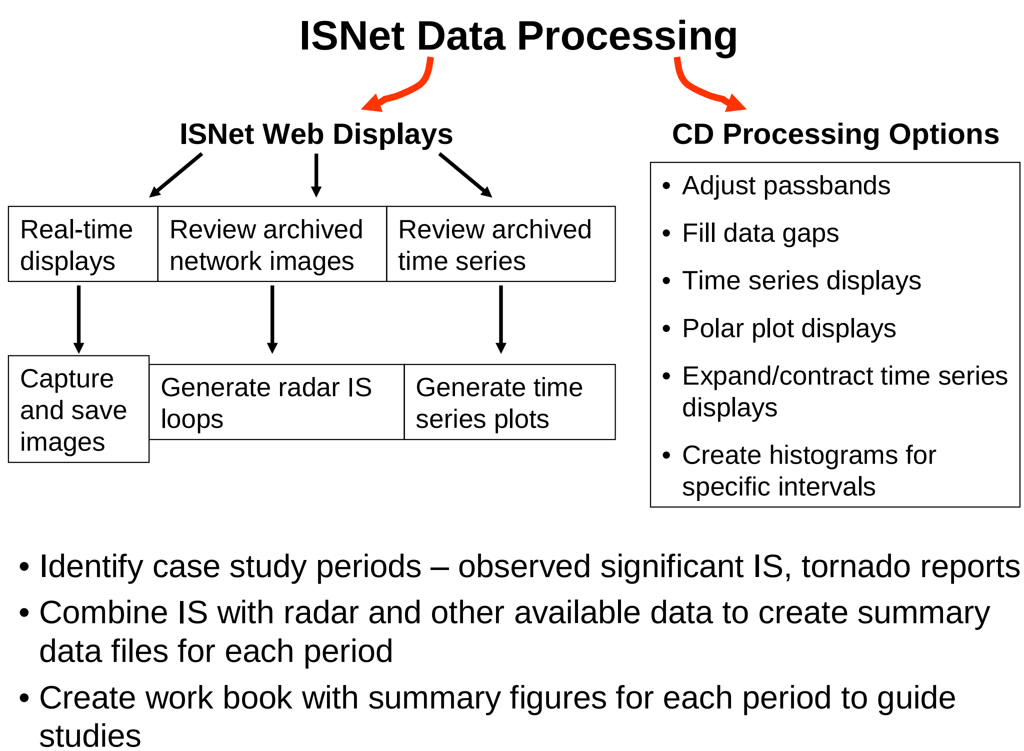

FIG. 2. Infrasonic processing options for web data and archived data.

3. ISNET ANALYSIS PERSPECTIVES

The continuous ISNet operations created a data set based upon 12.8 second processed data blocks focusing on the time period between 1 May and 30 September 2003. As the Pueblo and Goodland systems were added to the network, essentially continuous data became available from three stations with very few gaps. In addition, ISNet data used in forming web displays were archived, and raw infrasonic data at 40 Hz sample rates from the four sensors at each station were archived to CD. Whenever it was evident that interesting signals and/or weather was present; we saved WSR-88D Doppler radar images for comparison studies.

We have worked to develop approaches to summarize these extensive data sets to help guide assessments of the value of infrasonic observations for tornado detection and warning. These data are analyzed from two different perspectives (Figure 3).

ISNet Analysis Perspectives

Storm Data Reports

- **Were reported funnels and tornadoes detected?**
- **How often and under what conditions were tornadoes not detected?**
- **What were the impacts of the eddy fences?**
- **How did the network as a whole operate? Single stations?**
- **What were the times of the tornado reports relative to infrasound signals observed times?**

Significant Infrasonic Signals

- **How many significant signals corresponded to storm reports?**
- **How many signals associated with weather were not related to storm reports of funnels or tornadoes?**
- **How many signals not related to weather could have caused false alarms?**
- **What signal characteristics could lead to further improvements in detection algorithms and displays?**

FIG. 3. Contrasting two analysis perspectives.

From one perspective, Storm Data are used to create tables listing reports of tornadoes and funnels aloft for the 1 May through 30 September period and whether infrasonic signals were detected. These are summarized by state using plots of range to each station from reported tornado or funnel locations as a function of Julian calendar day. Symbols on the plots indicate signal detection, no signal detection, wind noise masking, and no data available. In some cases, the existence of more local masking infrasonic signals is noted.

From the other perspective, all significant infrasonic signals were listed, whether or not they corresponded to reports of tornadoes or funnels. Significant signals were characterized by high signal-to-noise ratios, duration (usually longer than several minutes), and persistence (not sporadic, intermittent bursts of energy). Thus, we took quite different approaches in analyzing the data set, and to a large extent, these were independent of each other.

4. COMPARISON WITH STORM DATA RESULTS

All reported tornadoes from Storm Data that occurred in Colorado, Kansas, and Nebraska during May, June, July, and August of 2003 were included in this comparison. Separate plots were created for each observing system with the ordinate being the range to the tornado report location, and the abscissa the calendar day. Data points on the plots indicate detections, non-detections, and the presence of masking wind noise. The first set of plots deal with reported tornadoes in Colorado. The dates of wind noise reducing eddy fences installation are shown on these plots. These fences reduce wind noise so that infrasonic signals can be identified in the presence of winds greater than 30 ms^{-1}.

The symbol “no data” indicates that the observatory was not operating. The symbol “no signal” indicates that no signal from the direction of a reported tornado was detected. At times, there were other infrasonic signals present that could have masked signals related to tornadic activity.

4.1 *Storm Data Comparison for Colorado*

For Colorado during the period from 1 May to 30 September 2003, there were a total of twenty-four tornadoes and two funnels reported. Detection information is presented separately for each infrasonic observing system on plots of range from the reported tornado to the station as a function of calendar day. Information on the symbols indicating whether signals were detected appears on the plot legend.

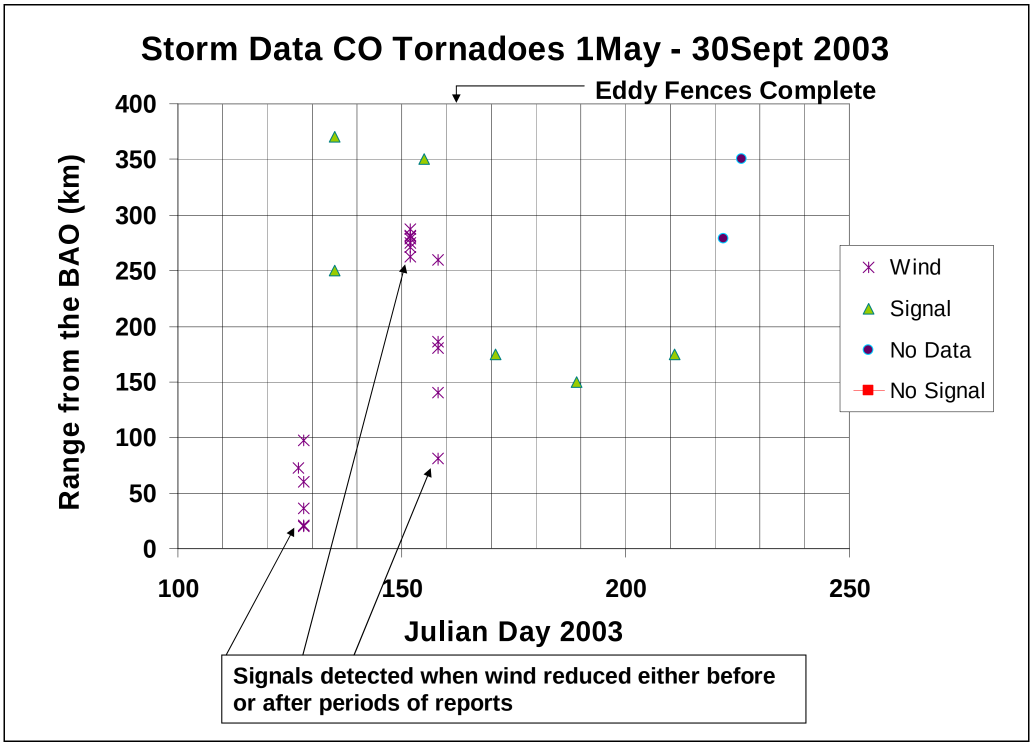

FIG. 4. BAO signal detection results for tornadoes reported in Colorado during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 400 km.

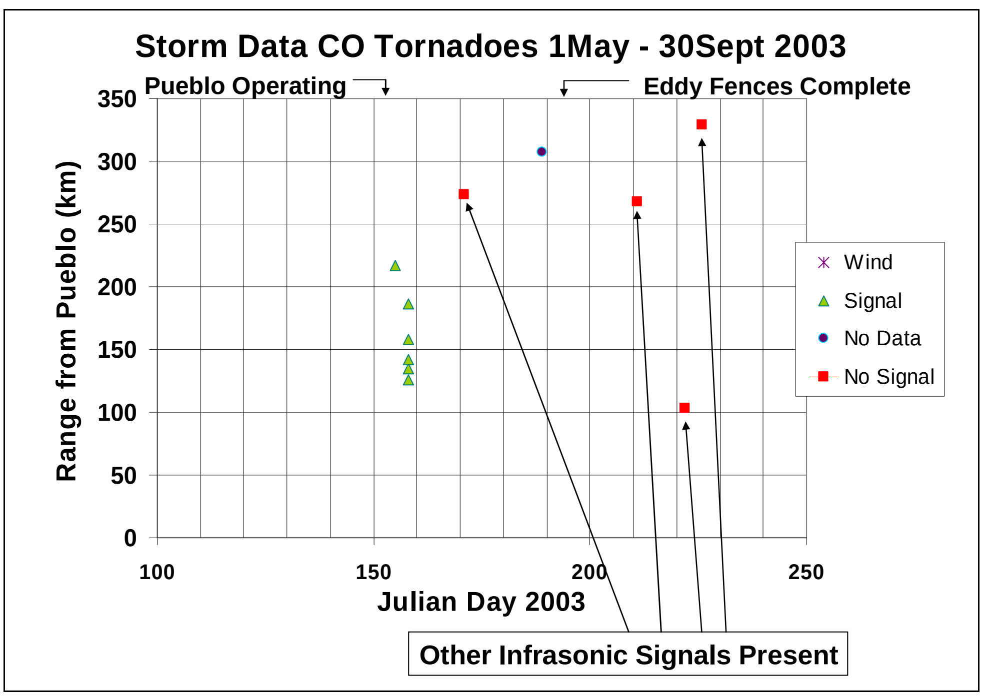

FIG. 5. Pueblo signal detection results for tornadoes reported in Colorado during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 350 km.

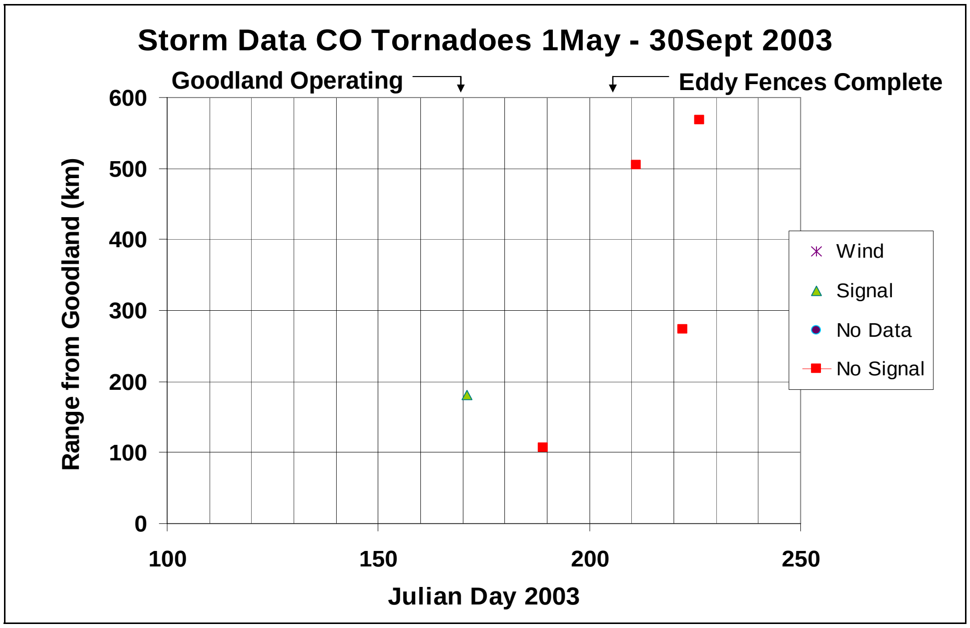

FIG. 6. Goodland signal detection results for tornadoes reported in Colorado during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 600 km.

The following points are indicated from the three figures for Colorado:

- At the BAO, many tornadoes were obscured by wind noise before the completion of the eddy fences.
- At Pueblo, signals could have been obscured by sources close to Pueblo that masked more distant signals. No signals were obscured by wind after Pueblo operations began.
- At Goodland, the ranges were relatively long for the three reports after the completion of the eddy fences. Also, west-to-east sound propagation is degraded during the summer months, while east-to-west propagation is enhanced at longer ranges (>150 km) by upper level winds (Jones et al, 2004).

4.2 *Storm Data Comparison for Kansas*

For Kansas during the period from 1 May to 30 September 2003, there were a total of eighty tornadoes and nine funnels reported. Multiple tornadoes occurring near each other during a relatively short time period are grouped together and listed as one data point on the plots.

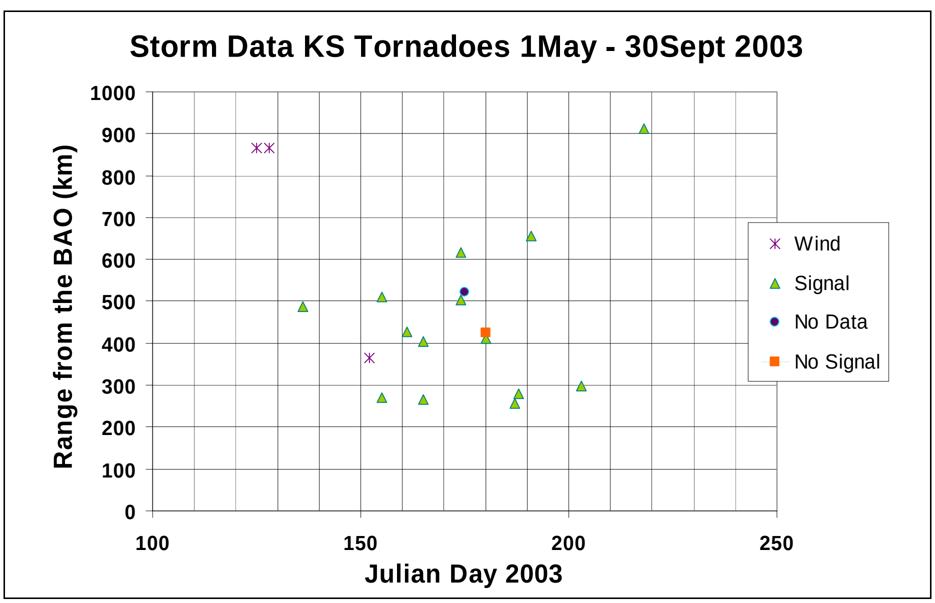

FIG. 7. BAO signal detection results for tornadoes reported in Kansas during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 1000 km.

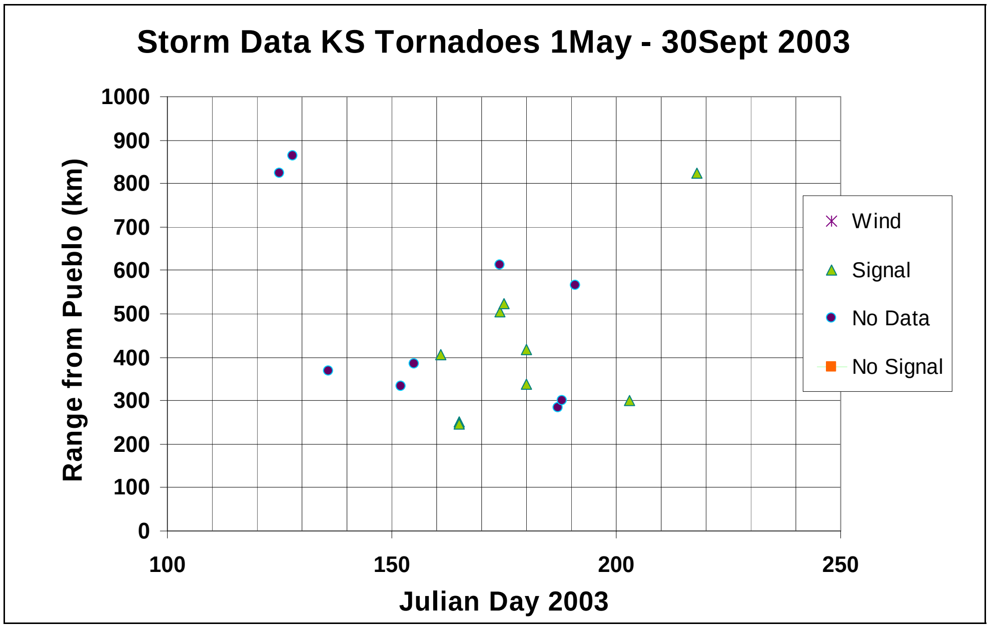

FIG. 8. Pueblo signal detection results for tornadoes reported in Kansas during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 1000 km.

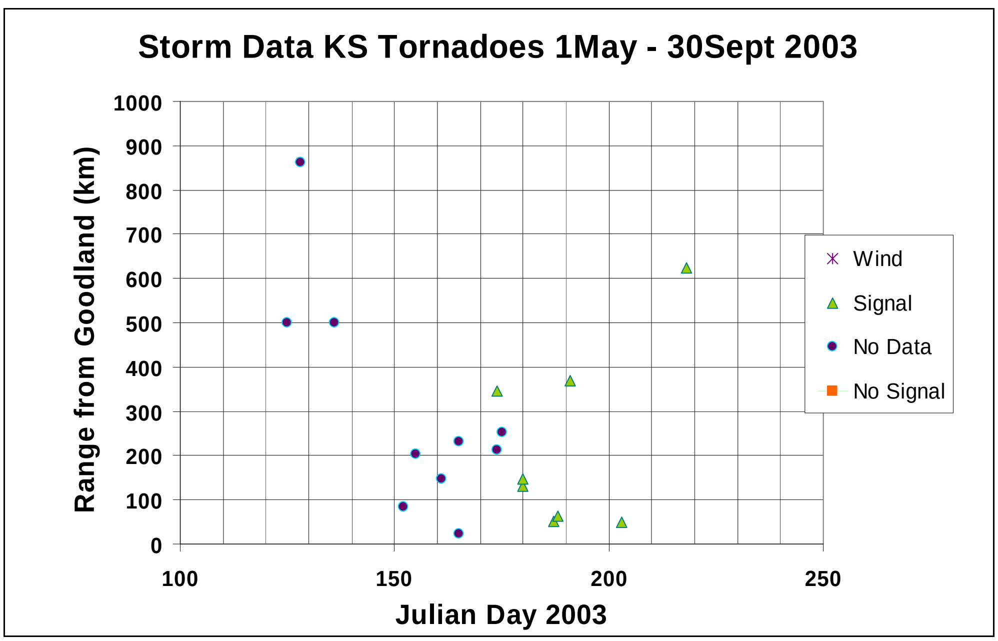

FIG. 9. Goodland signal detection results for tornadoes reported in Kansas during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 1000 km.

The following points are indicated from the three figures for Kansas:

- At the BAO, no tornadoes were obscured by wind noise after the completion of the eddy fences.
- At Pueblo, no signals were obscured by wind after operations began.
- At Goodland, no signals were obscured by wind after operations began.

4.3 *Storm Data Comparison for Nebraska*

For Nebraska during the period from 1 May to 30 September 2003, there were a total of seventy-three tornadoes and eight funnels reported. Multiple tornadoes occurring near each other during a relatively short time period are grouped together and listed as one data point on the plots.

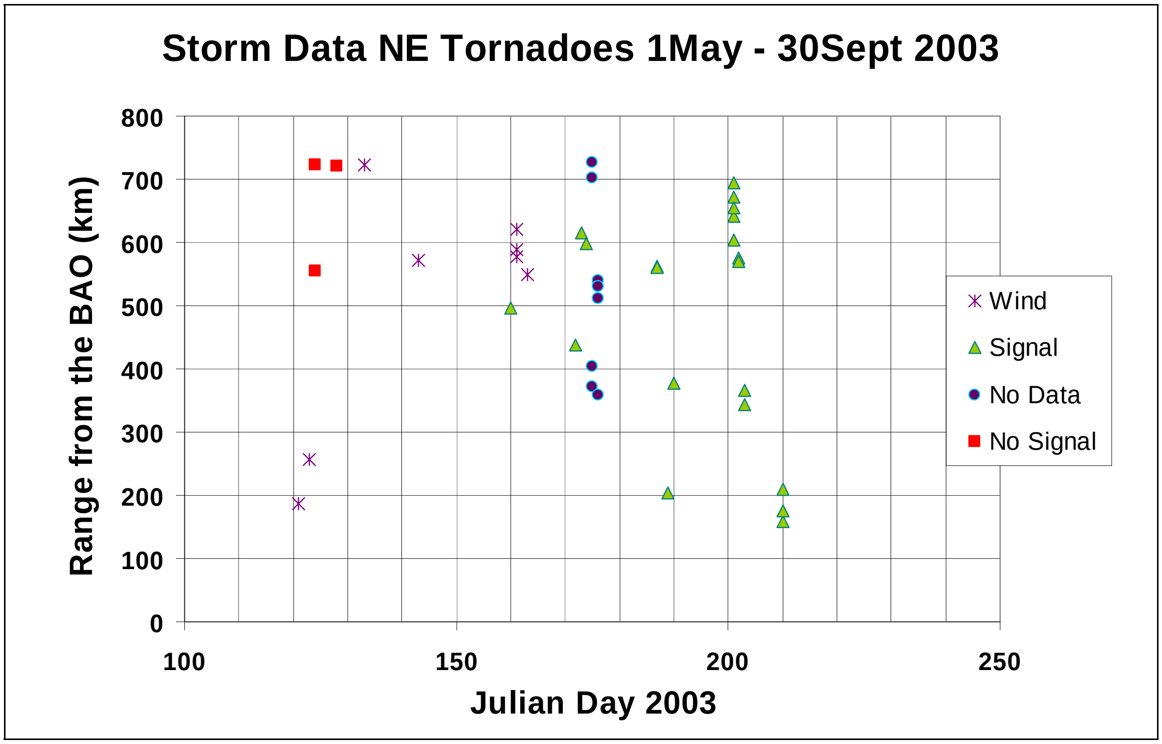

FIG. 10. BAO signal detection results for tornadoes reported in Nebraska during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 800 km.

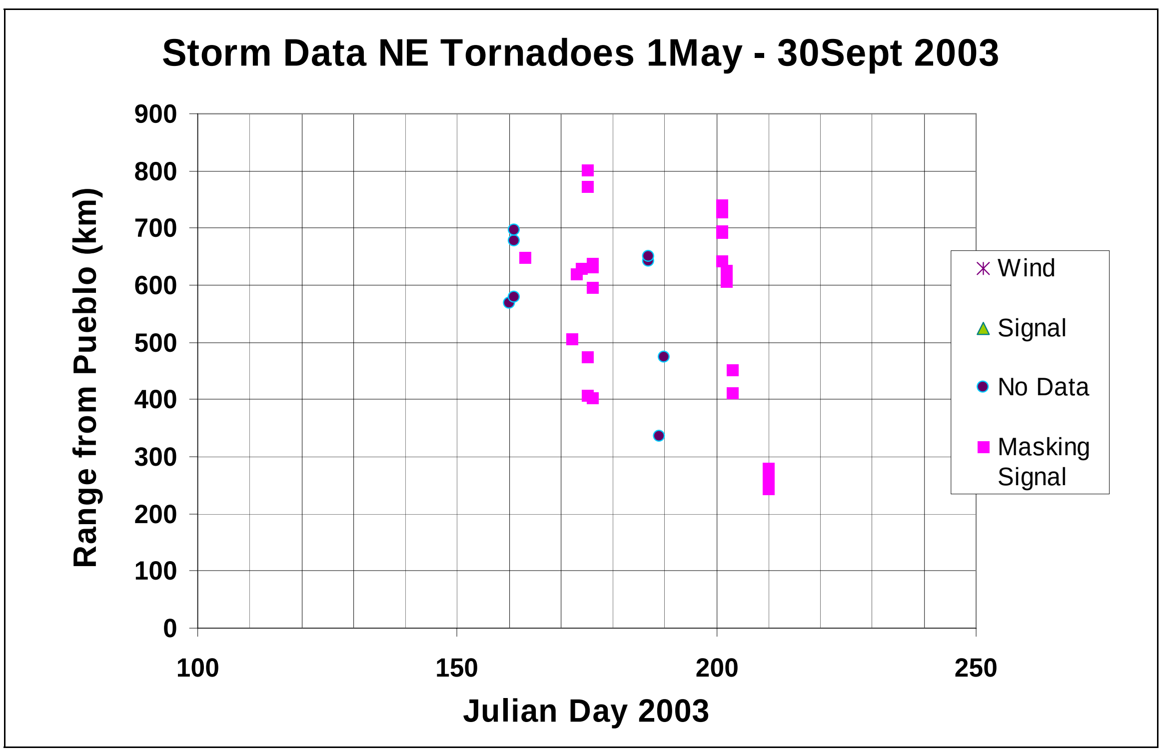

FIG. 11. Pueblo signal detection results for tornadoes reported in Nebraska during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 900 km.

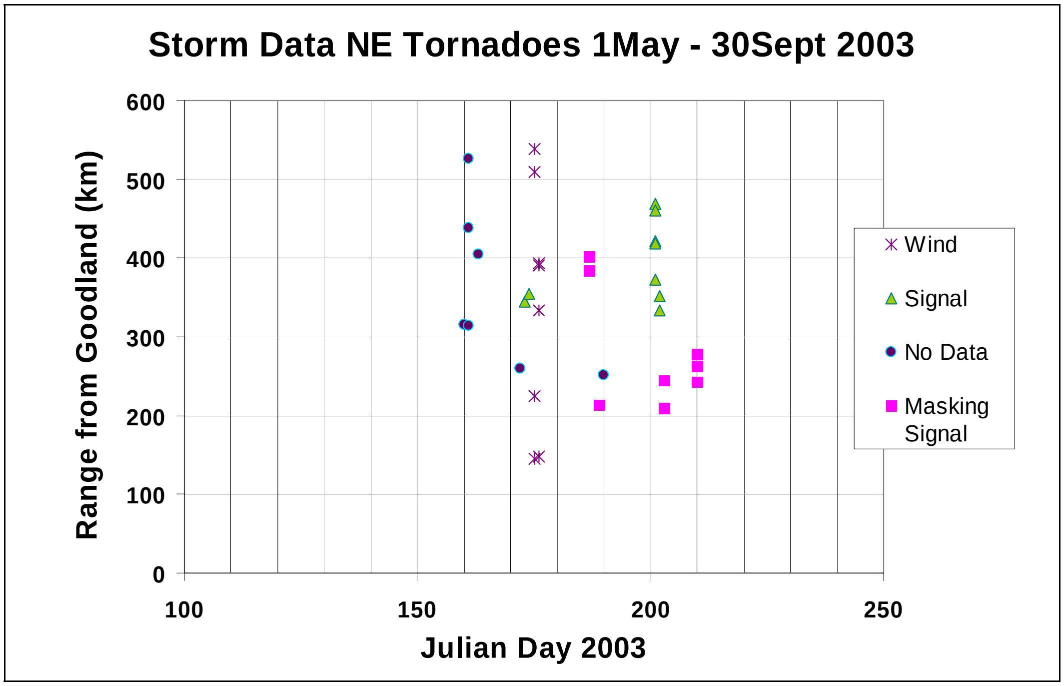

FIG. 12. Goodland signal detection results for tornadoes reported in Nebraska during the period from 1 May to 30 September 2003. The maximum range shown on the plot is 600 km.

The following points are indicated from the three figures for Nebraska:

- At the BAO, no tornadoes were obscured by wind noise after the completion of the eddy fences in spite of the long ranges involved.
- At Pueblo, signals could have been obscured by sources close to Pueblo that masked more distant signals. No signals were obscured by wind after Pueblo operations began.
- At Goodland, a number of signals were obscured by wind before the installation of the eddy fences.

4.4 *Wyoming Tornadoes*

There were three tornadoes (all F0) and five funnel reports for Wyoming between 1 May and 30 September 2003. No signals were detected at the Boulder observatory associated with two of these tornado reports. No data was available for one tornado and three of the funnel cloud reports, and masking signals were present at the times of the other two funnel reports.

4.5 *New Mexico Tornadoes*

There were six tornadoes (all F0) and ten funnel clouds reported for New Mexico between 1 May and 30 September 2003. Pueblo was not operating for the times of the tornadoes and did not show a significant signal for the time of the one funnel report where data was available.

4.6 *Some Implications of These Results*

Table 1 provides a chronology of ISNet key installation dates during 2003. One important result from the set of Storm Data comparisons was that there were no signals obscured by wind noise after the installation of the eddy fences.

General comments for the three sites for Colorado, Kansas, and Nebraska reports:

- No intervals corresponding to reports of tornadoes or funnels were affected by wind noise after the installation of eddy fences. The eddy fences are described in the paper by Bedard et al. (2004).
- For signals from longer ranges (usually >> 200 km), closer sources could have masked these more distant sources.

Table 2 summarizes the results from figures 4 through 12. There are several features of the data that are noteworthy. There were a total of thirty-five signals masked by wind noise. All of these cases were prior to the installation of eddy fences. Pueblo encountered the largest number of cases where signals were not detected because of the presence of more local signals masking more distant sources. There were twenty-three cases for Nebraska and four for Colorado. This large number of missed detections is probably caused by a combination of longer ranges and the fact that Pueblo frequently detects sources from northeast New Mexico.

BAO	Pueblo	Goodland
1 May – BAO operating		
	2 June – Pueblo operating	
	12 June – real time data transfer	
		18 June – Goodland operating
13 June – eddy fences complete		
	20 June – tests for tone source at Pueblo	
		7 July – real time data transfer
	10 July – eddy fences complete	
		25 July – eddy fences complete
	30 July – access to Goodrich plant to identify tone	

TABLE 1. ISNet chronology from May 2003.

State	Station	Signals Detected	Signals Not Detected (Wind)	Signals Not Detected (Masking Signals)	Signals Not Detected (Propagation? No signal radiated?)	No Data
CO	BAO	6	15			2
	Pueblo	6		4		1
	Goodland	1			4	
KS	BAO	13	3		1	1
	Pueblo	8				9
	Goodland	8				10
NE	BAO	18	9		3	7
	Pueblo			17		6
	Goodland	7	8	8		6

TABLE 2. Time periods of ISNet observations compared with Storm Data reports of tornadoes or funnels after stations started operating.

4.7 *Comparisons Between Tornado Report Times and Infrasound Detection Times*

Next, a sub-set of signals was identified where the start time of the infrasound was clearly defined. These were cases during which local wind noise did not obscure infrasonic signals and masking acoustic signals from other sources were not present.

That is, this set of signals with well-defined start times:

- Did not emerge from local wind noise, preventing identification of the start time with confidence.
- Did not emerge after a masking infrasonic signal ceased, preventing identification of the start time with confidence.
- Are of high enough quality that the onset time and detected azimuths are clear

For this sub-set of signals the distances from the reports to the infrasonic observatories were computed, along with the expected arrival times of signals based upon the report time predicted. These predicted times were than compared with the observed infrasonic signal start times.

In the next series of plots, the azimuth is plotted as a function of time for six-hour intervals. The times of tornado reports are indicated by solid arrows along the timeline base and the tornado azimuth from the station indicated by dashed arrows on the right hand side of the plot. Some of these reports are at long ranges from the stations, and this data will be summarized after the series of plots are presented. These figures show some interesting observations. While some infrasonic signals occurred quite near the times of tornado observations at the expected azimuths, other cases show infrasound occurring prior to the report times. Also, there were cases in which multiple discrete azimuths occurred over an interval after the time of the last reported tornado time. All signals in the sub-set chosen for closer examination had been classified as significant, independent of their being compared with the final set of Storm Data reports. All times are UTC.

The first case in this category was a tornado in Kansas at a range of 405 km from the BAO on 13 June 2003 (day 165). For this case, there is a broad sector of azimuths that includes the tornado azimuth. There is a trend of azimuthal progression towards the southeast. Two discrete azimuths near 90 and 100 degrees continue throughout the interval (Figure 13).

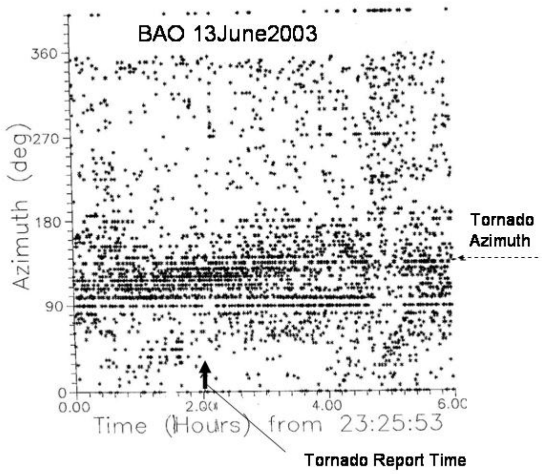

FIG. 13. Azimuthal data points for a 6-hour interval starting at 2325 on 13 June 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

The second case in this category involved tornadoes in Nebraska at a range of about 354 km from the Goodland observatory on 22 June 2003 (day 174). This case displays data at higher correlation coefficients (>42) and shows sporadic energy from two azimuths. There was no signal evident after the time of the last reported tornado (Figure 14).

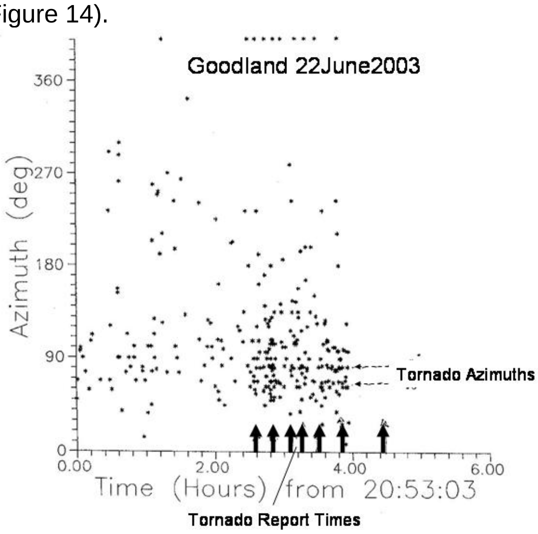

FIG. 14. Azimuthal data points for a 6-hour interval starting at 2053 on 22 June 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise. In this case only higher correlation coefficient data points are plotted.

The next case in this category was a tornado in Kansas at a range of 412 km from the BAO on 28 June 2003 (day 180). For this case, only signals at higher correlations (>44) are shown. Signals come sporadically from the direction of the reported tornado, and two other discrete directions also appear, from slightly further to the east (Figure 15).

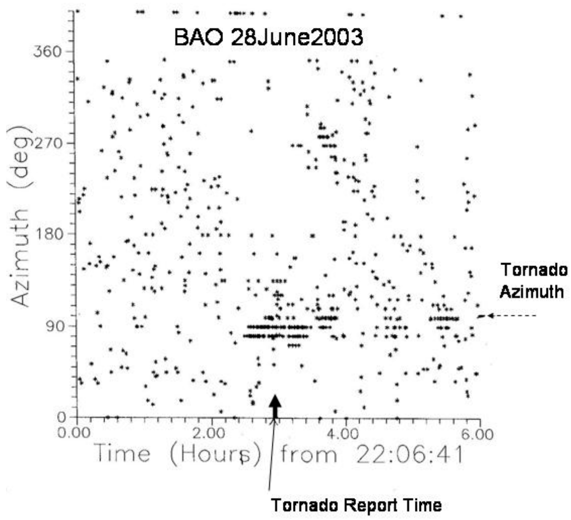

FIG. 15. Azimuthal data points for a 6-hour interval starting at 2206 on 28 June 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise. In this case, only higher correlation coefficient data points are plotted.

The next case in this category concerns two tornadoes in Nebraska at a range of about 560 km from the BAO on 5 July 2003 (day 187). In this instance, signals are present from several discrete azimuths for most of the period. Possibly, these signals are originating from more distant activity. Near the time of the tornado reports, energy is arriving from a more northeasterly direction that better corresponds to the azimuth of the reported tornado (Figure 16).

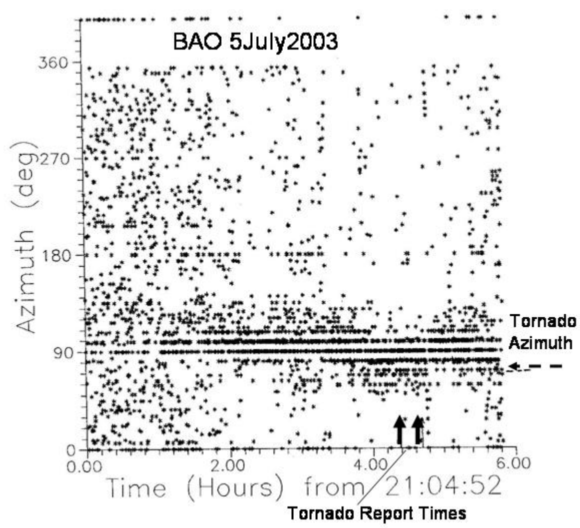

FIG. 16. Azimuthal data points for a 6-hour interval starting at 2104 on 5 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise. There are a number of discrete azimuths evident. Such observations are often associated with bow echoes.

The case of 7 July 2003 (day 189) was a tornado in Colorado at a range of 150 km from the BAO. The BAO detected several increases in signal activity. Signals from the northeast occurred near the time of the reported tornado. A second tornado was reported for the interval starting on 7 July 2003 (day 189) in Nebraska at a range of 204 km from the BAO. The bearing was essentially identical to the Colorado tornado report (Figure 17).

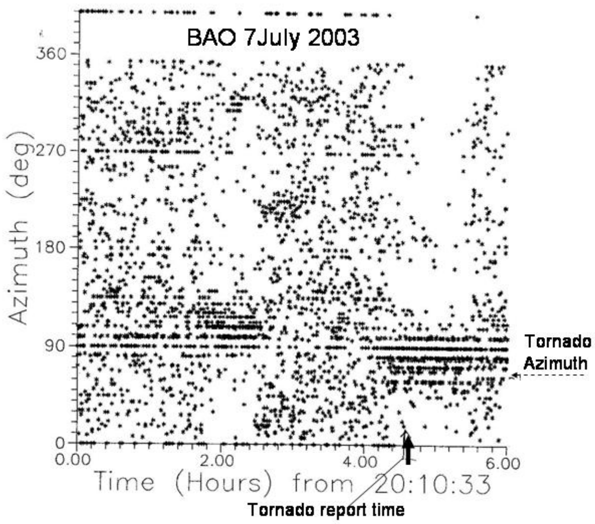

FIG. 17. Azimuthal data points for a 6-hour interval starting at 2010 on 7 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise. There are a number of discrete azimuths evident. Such observations are often associated with bow echoes.

The case for the interval starting on 8 July 2003 (day 190) was a tornado in Nebraska at a range of about 380 km from the BAO (Figure 18).

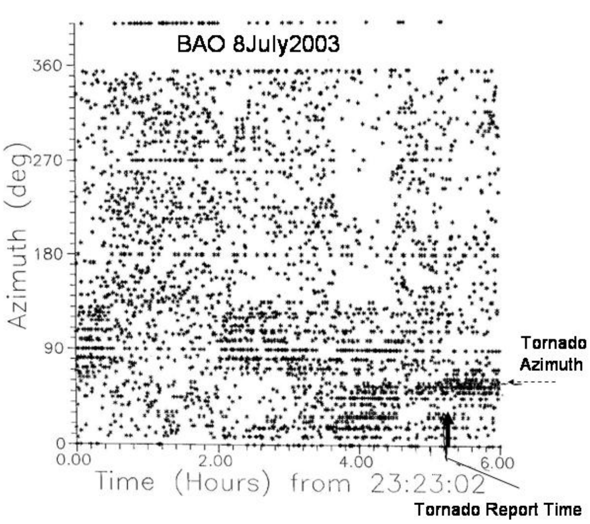

FIG. 18. Azimuthal data points for a 6-hour interval starting at 2323 on 8 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

The case for the interval starting on 9 July 2003 (day 191) was a series of reported tornadoes in Kansas at a range of about 400 km from the BAO (Figure 19). This case is interesting because of the series of discrete azimuths detected and the observation that energy continued for hours after the last tornado reported. Figure 20 for Goodland for the same set of tornado reports shows a difference in character. At Goodland, there are not a set of well defined, discrete azimuths. The range from Goodland is approximately 370 km.

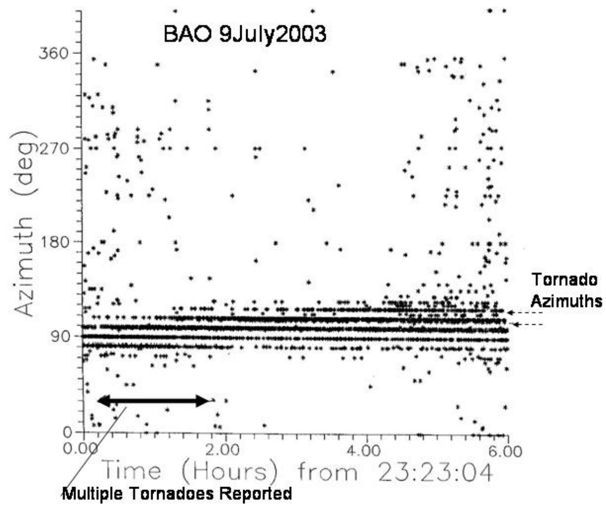

FIG. 19. Azimuthal data points for a 6-hour interval starting at 2323 on 9 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

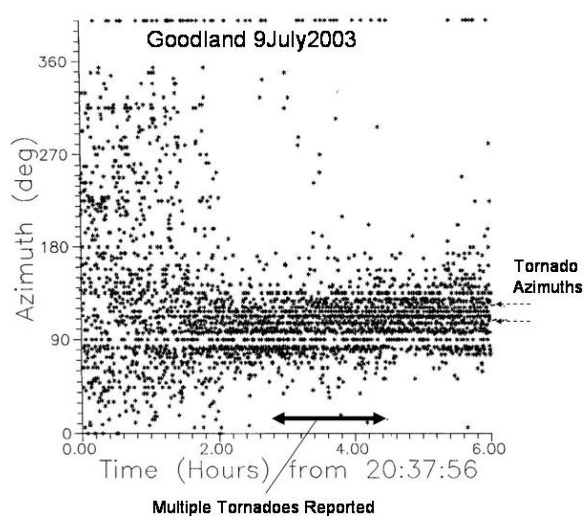

FIG. 20. Azimuthal data points for a 6-hour interval starting at 2037 on 9 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

The case for the interval starting on 20 July 2003 (day 201) was a series of tornado reports in Nebraska at a range of about 600 km from the BAO. The plot is for correlation coefficients >50. Energy continued for several hours after the last reported tornado (Figure 21).

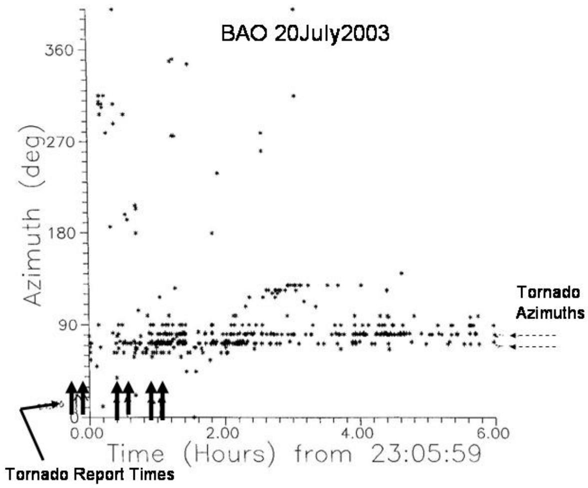

Fig. 21. Azimuthal data points for a 6-hour interval starting at 2325 on 13 June 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise. In this case, only higher correlation coefficient data points are plotted.

The case for the interval starting on 21 July 2003 (day 202) was a tornado in Kansas at a range of about 297 km from the BAO (Figure 22). This case also shows multiple discrete azimuths continuing for hours after the last reported tornado. For the same time period, two tornadoes were reported for Nebraska at ranges of 575 and 345 km (Figure 23).

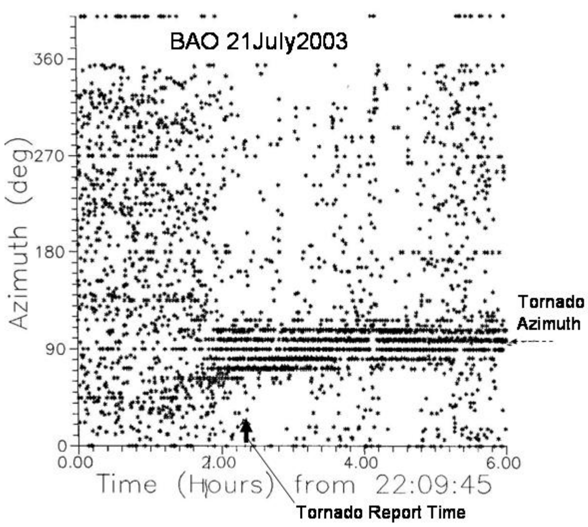

FIG. 22. Azimuthal data points for a 6-hour interval starting at 2209 on 21 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

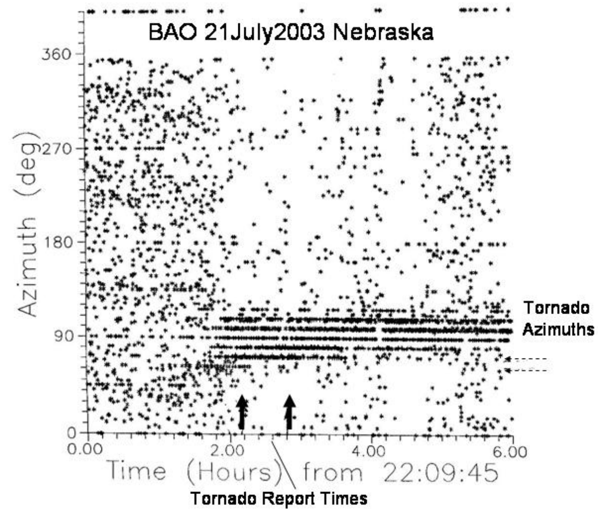

FIG. 23. Azimuthal data points for a 6-hour interval starting at 2209 on 21 July 2003. Each 12.8 second data point is plotted. The dark, repetitive groups of points represent consistent signal activity. The random, scattered points indicate noise.

4.8 *Histograms Summarizing Tornado Report Times, Predicted Infrasound Arrival Times, and Range information*

The following histograms (Figures 24, 25, & 26) summarize differences between tornado report times and infrasonic signal start times, differences between predicted arrival times and infrasonic signal start times, and the ranges from the report location to the infrasonic station. In these histograms, positive values of time indicate that infrasonic signals were detected before the report time or predicted arrival time. These summaries indicate that infrasound is frequently detected prior to the times of tornado reports.

Some cautionary comments are in order on this result. Especially when only one station is detecting energy, there is the possibility that a more distant, earlier storm is being detected along the same bearing. Alternatively, there could be other sound generating processes active not related to coherent regions of rotation within the storm. On the other hand, the result that infrasound can originate from storms prior to tornado reports is consistent with many of our past observations.

The next plot compares the difference between the tornado report times and the time-of-detection of infrasound. These are presented in histogram form with the positive time differences indicating that infrasound was detected prior to the tornado report.

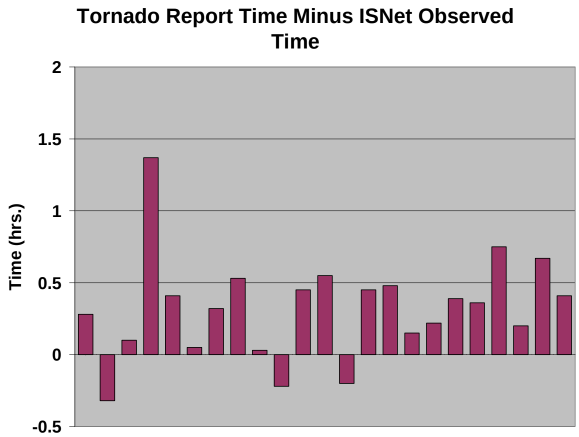

FIG. 24. Histogram of the difference between tornado report times and the start times of infrasonic detection.

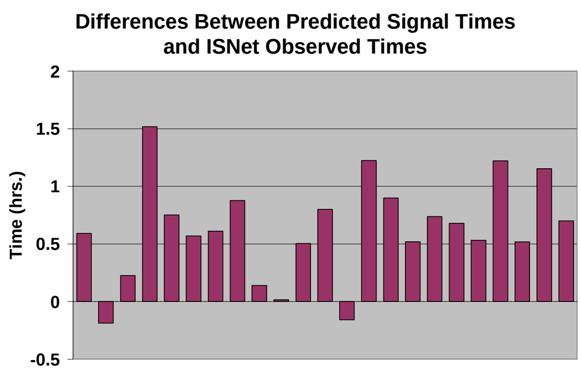

FIG. 25. Histogram of the difference between predicted acoustic signal arrival times and the start times of infrasonic detection. This figure indicates that infrasound is usually produced well prior to reports of tornadoes.

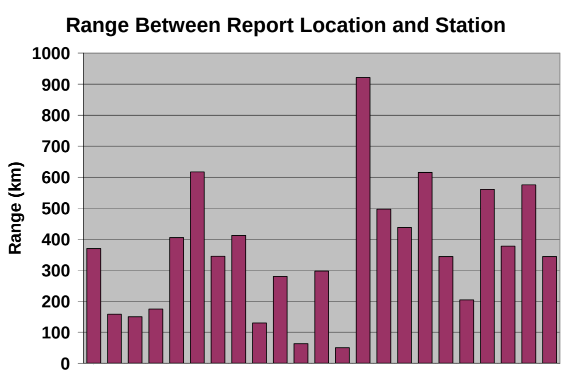

FIG. 26. Histogram showing the ranges to the tornado report location from the infrasound observing locations for the cases studied.

5. RESULTS OF STUDIES OF SIGNIFICANT INFRASONIC SIGNALS

We created a directory of significant infrasonic signals. This directory is intended as a resource for guiding choices of signals for further analysis and assessing ISNet operation. This directory includes the dates and times of significant signals. A significant signal has the characteristics of quality, persistence, and duration to be potentially associated with tornadic activity based upon our past measurements. Also included are periods identified as particularly interesting (e.g. when observations by chase teams are available). A file exists for each of these signals. For example, we have tried to save limited WSR-88D data when an interesting event occurred. Also, more detailed analyses and plots in various formats have been created for ISNet significant signal periods.

We analyzed data from the archives in parallel with data that was collected and archived over the remote links. When there has been a local processing failure, we still can analyze the groups of raw data files that are saved but not analyzed on site. Early on at Pueblo, when data was contaminated by a local tone, we also re-processed to eliminate the tone. Thus, the data sets are essentially complete with only a few gaps for the entire test period.

There were a great variety of signal types and detection situations, and over one hundred case study files have been created. At, times all three observatories detected signals. In other cases, only one station detected infrasound from a more local source. The case of 9 August 2003 is an example of a good signal detection from a nearby severe weather system. Between 0000 UTC and 0115 UTC, the BAO detected infrasound from the direction of a cell moving from the northwest to the south over the interval. Figure 27 shows a time series plot of azimuth that illustrates a shift from 300 to 180 degrees. Figure 28 is an ISNet image at 0011 UTC showing a cell appearing to the northwest of the BAO with strong infrasonic signals evident. At 0054, the Denver WSR-88D reflectivity image shows a cell to the south of the BAO (Figure 29), and the radial velocity is shown in Figure 30. Between 0000 and 0115 UTC, rotation was observed in the lower level clouds near southwest Boulder, CO and near the end of the interval, police officers in the Denver area reported funnels aloft.

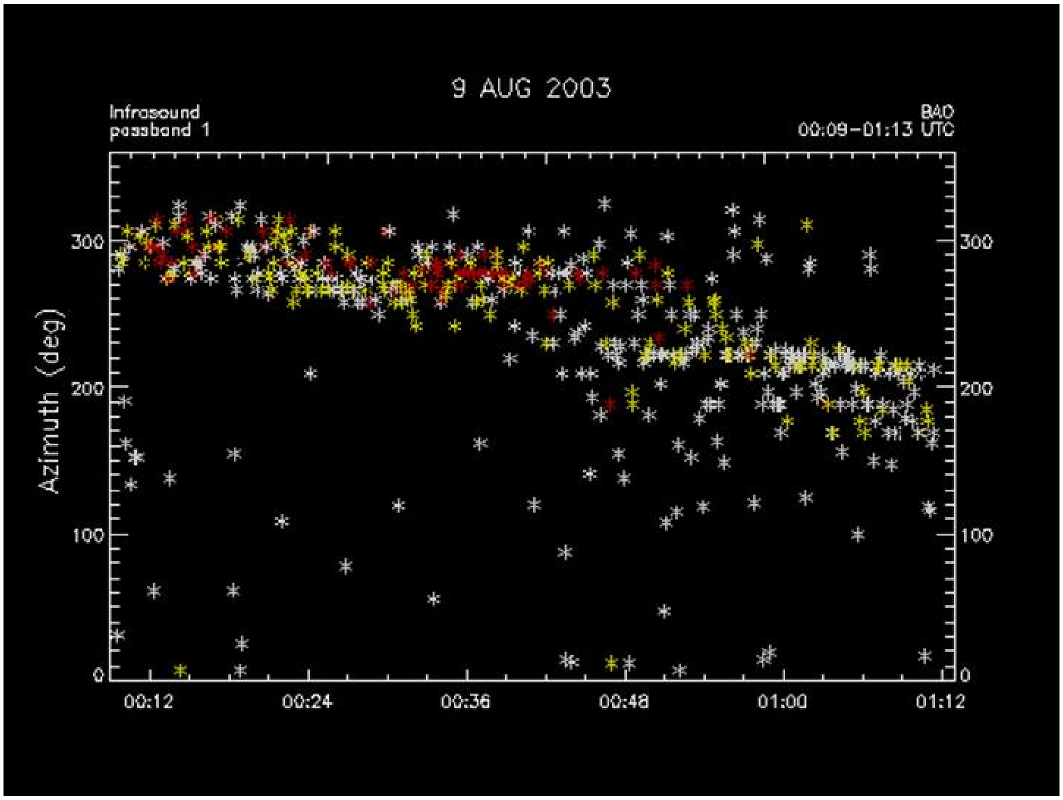

FIG. 27. A time series plot of azimuth for the BAO showing the direction from which the signal was originating and the progressive azimuthal shift as a function of time.

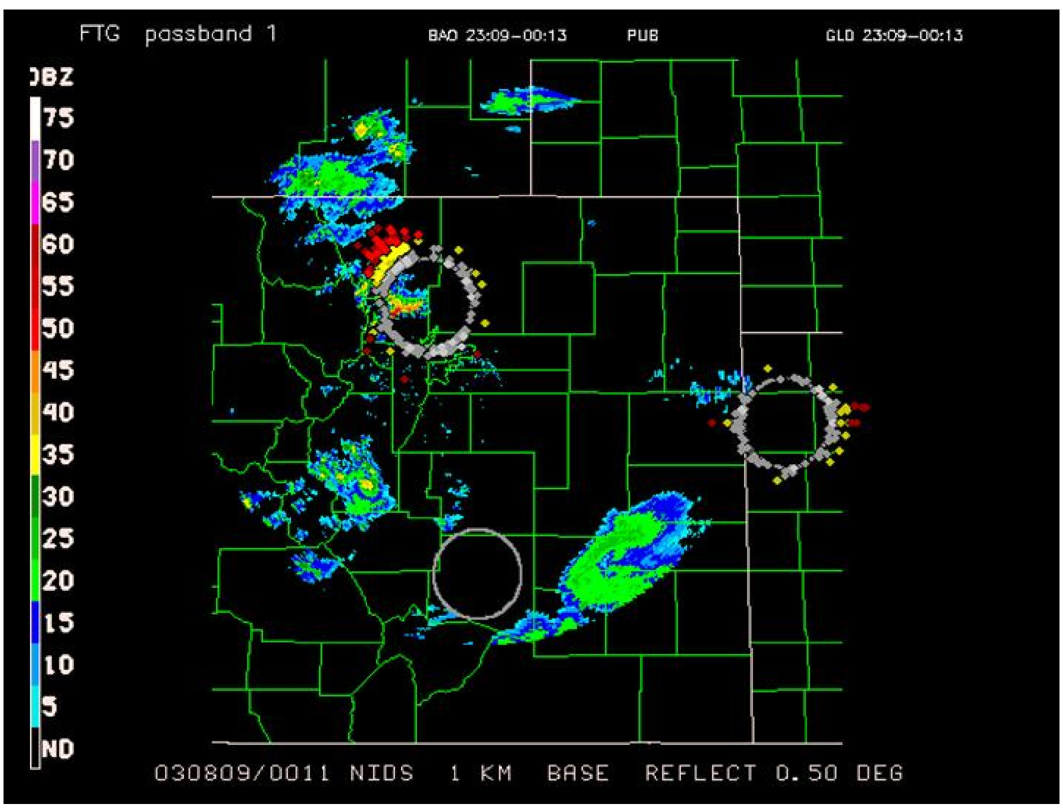

FIG. 28. ISNet image showing the strong infrasonic signal at the BAO at 0011 UTC on 9 August 2003.

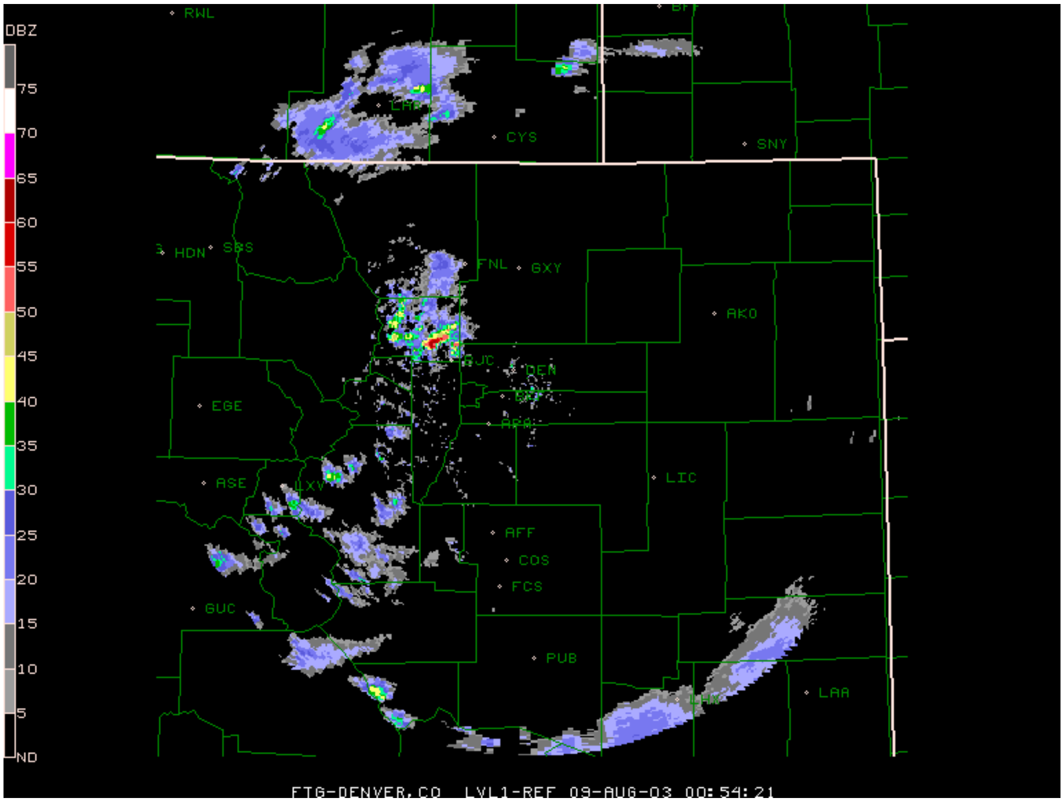

FIG. 29. Denver WSR-88D reflectivity image at 0054 UTC on 9 August 2003.

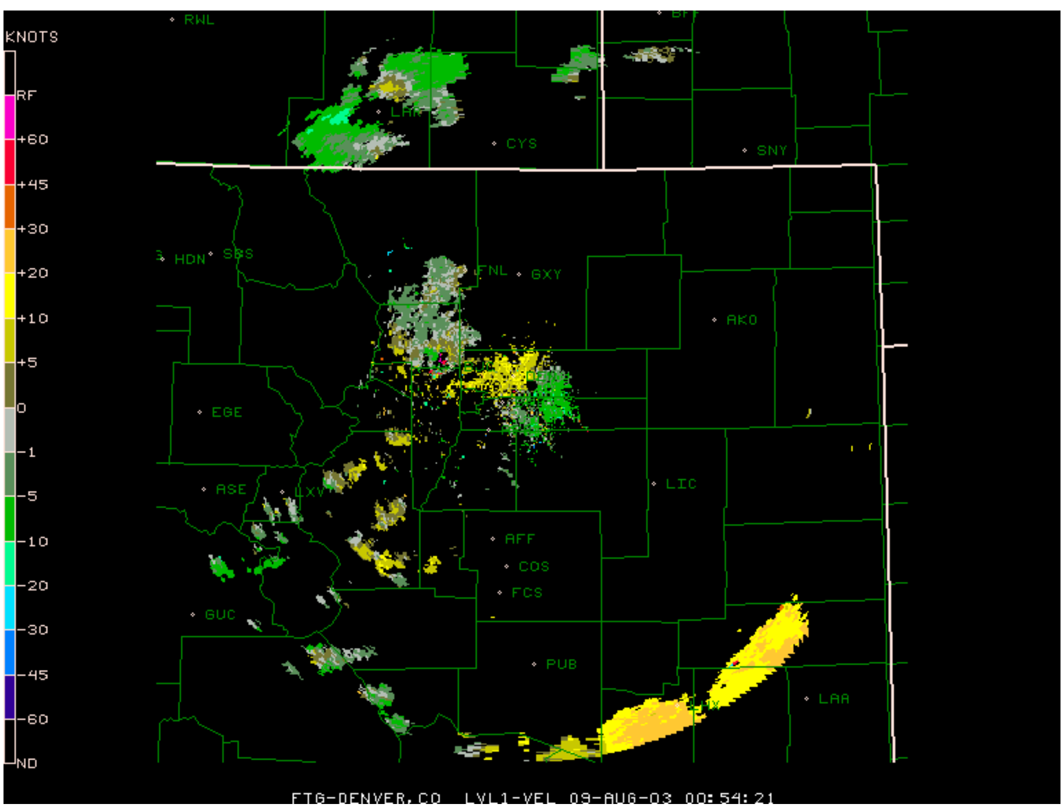

FIG. 30. Denver WSR-88D radial velocity image at 0054 UTC on 9 August 2003.

The signals have been separated into a set of nine categories as listed below.

1. Distant tornadic storms / severe weather complexes
2. Regional tornadic storms or those with indications of rotation
3. Landspouts / gustnadoes
4. Single observatory detections from nearby sources
5. Single observatory detections from regional sources
6. Probably sprite-related
7. Signals not related to weather or of unknown origin
8. Turbulence / windshear-related
9. Meteors

For some of these signal categories, the signal characteristics are quite different from those related to severe weather and are unlikely to cause false alarms (e.g. sprite-related, turbulence/wind shear-related, and meteors). These were included in the directory because they help define the background of signals recorded by ISNet operations to date.

A list of the numbers of signals in each category appears in table 3.

The numbers listed in the table are summarized in two pie charts (Figures 31 & 32). The first lists all the nine categories by percentages. The second combines the categories that are unlikely to cause false alarms together (no false alarms) and the single observatory detections both nearby and regional detections together (other WX). Two well-documented cases of landspouts that were not detected and three cases of landspout / gustnado detection are listed.

Category	**# of Signals**	**Comments**
Distant tornadic storms / severe weather complexes	12	6 related to observed tornadoes, 4 to bow echoes
Regional tornadic storms or those with indications of rotation	22	11 related to observed tornadoes
Landspouts / gustnadoes	5	3 signals detected
Single observatory detections from nearby sources	26	
Single observatory detections from regional sources	15	Pueblo detected 10 cases from the directions of cells in New Mexico or Arizona
Probably sprite-related	1	Originates from large areas of weaker reflectivity
Signals not related to weather or of unknown origin	10	Most would not cause false alarms because of their characteristics or the lack of significant weather
Turbulence / windshear-related	21	11 signals occurring prior to October 2003 were short sporadic bursts of energy and should not cause false alarms
Meteors	2	Very short impulses and would not cause false alarms
Totals	114	33 would not cause false alarms

TABLE 3. Summary of significant signals detected by category.

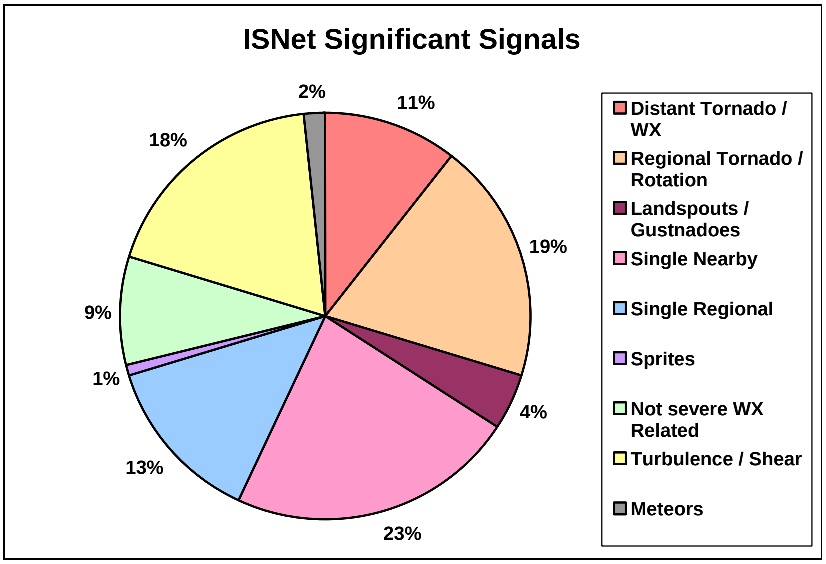

FIG. 31. Pie chart showing the percentages of signals detected in the various categories.

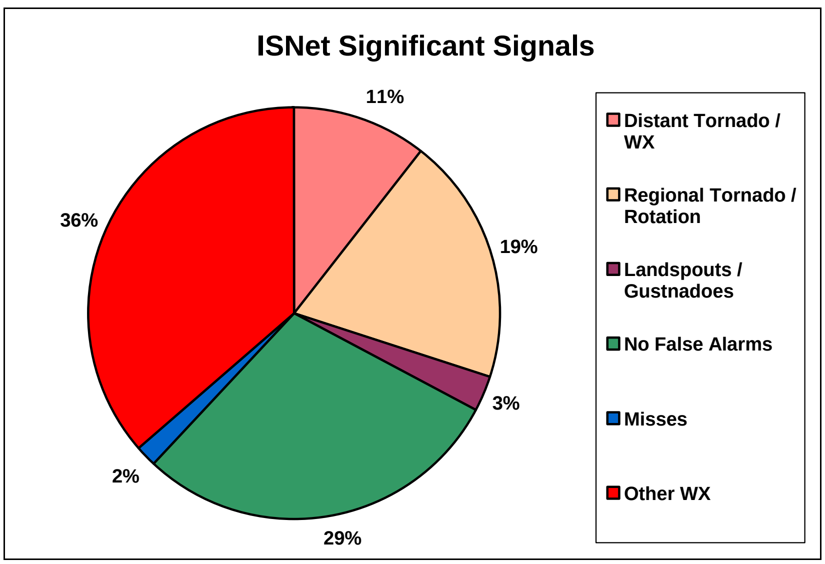

FIG. 32. Pie chart showing the percentages of signals detected in the various categories.

These charts only provide a preliminary overview of the signal statistics. As more detailed analyses are made in the context of archived weather data, the numbers in various categories could change in important ways. The directory is intended as a guide to the extensive data set and will hopefully help identify important cases that deserve more analysis.

The following comments address some of the more important implications of these statistics.

- 29% of the signals would not represent false alarms because of short durations, sporadic/rapid changes, or unique characteristics (e.g. meteors showing progressive large changes in azimuth, elevation angle, and frequency).
- 33% of the signals were related to distant or regional storms with tornadoes, funnels, or rotation, and landspouts.
- 36% of the signals were related to severe weather with no observations of tornadoes, funnels, or rotation. It is this set of signals that represents an important potential false alarm challenge. Many of these storms were in remote areas at long ranges (e.g. >150 km) from the closest radar, and we have no means of eliminating these as false alarms. This emphasizes the need for verification, defining as many of the details of the storm dynamics as possible in evaluating network operation.

6. CONCLUDING REMARKS

In spite of the relatively few tornadoes in Colorado during 2003, we learned a great deal about ISNet design and operation. Appendix A reviews feedback concerning a broad range of issues from web displays to ray tracing to source modeling. Many of the issues raised are addressed in a series of papers presented at this conference (Bedard et al., 2004, Jones et al., 2004, Szoke et al., 2004, Hodanish 2004, Nicholls et al., 2004). For example, a paper summarizing ray trace model work (Jones et al., 2004) has important implications for network design.

The following remarks, which concern several areas of ISNet operation, are important to note:

- The infrasonic sensors have operated continuously at the three stations for more than a year with no problems.
- The eddy fences were constructed using local contractors and the construction details differ for the three sites. The fences at Goodland are more susceptible to wind damage and need to be reinforced and the design modified. We now have a new fence design which is more rugged and easier to install.
- We have a software problem with the processing computer which requires archiving data every three days. This causes inconvenience and has resulted is some loss of data. We are working to solve this.
- The year 2004 provided a large number of tornado cases, and these are currently being analyzed.
- There is a need for additional means of verification, especially in remote areas. It would be ideal to integrate infrasonic network stations as a component of future field campaigns.
- We are currently working on alternate displays and processing algorithms in response to workshop recommendations outlined in Appendix A.
- Local displays provide infrasonic data with no delay at both Pueblo and Goodland. The Denver/Boulder WFO currently receives data only through a web site that involves a delay of approximately six minutes. We are working to reduce this delay.

7. REFERENCES

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Szoke, E. J., A. J. Bedard, Jr., E. Thaler, and R. Glancy (2004). A comparison of ISNet data with radar data for tornadic and potentially tornadic storms in Northeast Colorado. Proceedings 22nd Conference on Severe Local Storms, 4-8 October 2004, Hyannis, MA, Sponsored by the Amer. Meteorol. Soc., Boston, MA.

8. ACKNOWLEDGMENTS

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Appendix A
Feedback on ISNet Issues

Participants in this project combine to form an Inter-Line Office NOAA Collaborative Project for Technology Transfer involving ETL, FSL, and three Weather Service WFOs. This summary provides comments and recommendations from a one and a half day workshop held in Boulder on 31March and 1 April 2004.

Ray trace program: background fields for land spout, supercell infrasound propagation simulations

Comments: The basic studies are currently supported by another program. Support will be needed to apply this work to more complex situations.

Recommendations:

- Obtain wind and temperature profiles for a typical supercell environment and model propagation to stations located at different ranges and azimuths.
- Obtain wind and temperature profiles for a typical landspout environment and model propagation to stations located at different ranges and azimuths.
- There were also comments about the value of adding terrain effects.

Training

Recommendations:
Keep training on the "light side." Use web sites and loops prepared on CDs.

Hardware: changes, problems

Our current use of Windows 98 was necessitated by the fact that we did not have the time to get the complex array of sub-routines to operate under more recent versions of Windows. This has caused problems that require archiving every three days.

Recommendations:
Work to solve this problem and replace current computers with new ones after the problem is solved. Under the current mode of operation, archive prior to expected severe weather.

Verification

Recommendations:
Make use of WFO logs to expand data available for comparisons. Consider offering bonuses to storm chasers for documentation of certain events (e.g. landspout cases). Issues of administration and legal issues need to be addressed.

More timely BAO data to Denver/Boulder WFO

Recommendations: Work to develop a data path that will provide more timely data to the Denver/Boulder WFO. The Pueblo and Goodland WFO's rely in large part on the local displays which are essentially in real time.

False alarms and signals that make displays more complex

Recommendations:
False alarms are not an issue outside of storm situations. "Not a big headache." No change needed at present.

Data visualization, web displays, feedback

Comments: "One display will not fit all." For example, there are different perspectives (e.g. warning forecaster versus warning coordinator). "Display needs a lot of work."

Recommendations:

- Pass on display concepts directly to Ann Keane and Dave Welsh and work interactively to optimize displays and create new options.
- Some specific recommendations concerning displays were:
  - Add correlation coefficient color scale
  - Provide a storm centric display option with correlation time series values shown for three stations for limited azimuth sectors including the storm
  - Provide a post processed product with this capability
  - Provide the option to toggle between radar and ISNet images
  - Provide a zoom feature option
  - Provide a radar mosaic option
  - Provide the option to carry rays out to longer ranges. Make the ray sectors transparent so that their relationships to cells remains clear and their intersection regions are emphasized
  - Investigate bringing infrasound data into AWIPS

Other uses for ISNet data

Recommendations:
Focus on tornado detection for now. Save all data, but do not use energy and resources in other directions.

How long to keep ISNet archive accessibility?

Recommendations:
Move the data to a DVD archive. All three offices would like DVD copies as a resource.

Numerical model applications

Comments: "There is a need to understand the physics of what is going on and not get caught up in pattern recognition." This work is not currently funded. A proposal to NSF has been submitted to continue the numerical work.

Based upon preliminary simulations to date, the creation of a strength index and a frequency index was suggested. These would be used with guidance from numerical simulations to identify different situations (e.g. a convective cell producing weak sound and higher frequencies may be associated with a landspout).

Recommendations:
Apply numerical models to explore questions concerning potential warning time, touchdown detection, and landspout detection.

Where are we now?

Comments: "I see things that are tantalizing…", "encouraging, but need harder evidence…", "more well-documented cases...", "we are at the start of the yellow brick road – what path to take?" We are performing a prototype assessment.

ISNet: where to go next?

- Not operate network – but focus on data analysis

  Recommendations: "Need to continue data taking.", "this is not an option.", "get better data next severe storm season."

- Operate as is – maintain system, but do not make changes

- Operate, making upgrades:
  - Fix problem with data acquisition / archiving computer
  - Upgrade hardware to increase time between data archiving
  - Improve timeliness for BAO data at Denver / Boulder WFO
  - Provide additional algorithm and display options responding to suggestions of WFO's

    Recommendations:
    It was the unanimous recommendation of the group that this is the path that should be followed.

- Operate making upgrades and adding one or two additional network sites.

  Recommendations:
  Additional sites should not be added at this point to make sure existing resources are not strained.

Other

- In presenting data, use calendar day instead of Julian day to permit easier comparisons between ISNet and Storm Data
  - Develop some distance scale on plots (e.g. 250 km) to identify network signals
  - Case study analyses: how to proceed? Cases are being identified for which more detailed ISNet data will be provided
  - Need to develop criteria for defining a "hit", a "miss", and a "false alarm"

- A review of a draft of a proposed set of papers at the Severe Local Storms Conference resulted in changes.