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Real-Time Observations of the May 22nd Joplin, Missouri EF5 Tornado by the USArray Transportable Array Network

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1. ABSTRACT

The EF5 tornado that devastated Joplin, Missouri on May 22nd of 2011 also passed through Earthscope's USArray Transportable Array (TA) network. Stations within the TA network are configured to observe seismic and surface pressure phenomena at 1 and 40 samples per second in real-time with a suite of instrumentation including infrasound and environmental sensors inside the vault installations. The Joplin event passed approximately 2 km south of station T38A, whose location near the town of Joplin allowed for the observation of the storm in a unique and compelling way. The data presented here will further depict the intensity of the EF5 storm. Possible implications of the TA network for aiding the determination of tornado severity and perhaps providing additional early-warning detection will be presented by comparing data of surrounding stations.

2. INTRODUCTION

The USArray TA network, the flagship project within the National Science Foundation's Earthscope Initiative, was originally designed to be a large-scale network of seismic stations capable of monitoring ground motion in real-time. Observations from the seismic instrumentation encouraged the addition of barometric pressure sensors via MRI-R^2 awards from NSF. Observations from the addition of VTI SCP1000 MEMS barometers have already proven to be quite reliable at monitoring pressure fluctuations associated with severe weather in real-time (Tytell et al., 2011 and Vernon et al., 2011).

Beginning in early 2011 two more sensors were included with the installation at each station: one Setra 278 barometer and one NCPA Infrasound per installation package. While the MEMS barometers are capable of observations at 1 sample per second (sps), the Setra and NCPA instruments are capable of 1 and 40 sps observations. The higher sampling rate of these two additional surface pressure-observing instruments provides a new method for real-time observation of surface weather phenomena.

These additional sensors were incorporated into new station installations but were also retrofitted into some previously installed stations within the TA network. One station that had received this latter upgrade was station T38A; coincidentally located ~ 16 km east of Joplin, MO. During the devastating EF5 tornado that leveled a large portion of Joplin on May 22nd, 2011 station T38A was able to observe strong fluctuations within the surface pressure field. Surrounding TA stations had not yet been upgraded to the full suite of pressure sensors.

3. TA DEPLOYMENT AND PROXIMITY TO TORNADO

USArray TA stations are installed in a 70 to 75 km grid formation across the United States. The deployment footprint on May 22nd 2011 is shown in Figure 1. The stations are managed according to a strict rolling deployment schedule where stations along the western edge of the footprint are decommissioned after ~ 2 years and the equipment is then installed as a new station along the eastern edge.

Each station installation is designed to be a vault configuration shown in Figure 2. The vault itself measures about 7 feet deep with the seismometer located at the base. Just beneath the lid of the vault is the Vault Interface Enclosure (VIE); a carefully constructed package that includes the datalogging equipment as well as the three pressure sensors (MEMS and Setra barometers and NCPA infrasound). A hose feeds into the VIE from an external bilge port that provides the air intake for pressure observations. Telemetry is located a few feet meters from the vault.

The Joplin tornado moved east/southeast of the town as it began to steadily lose strength (Figure 3). TA station T38A was situated just north (~ 1.7 km) of the tornado as it was dying away.

4. OBSERVATIONS

Based on the approximate positions of the velocity couplets from the Springfield, MO Nexrad, we were able to conclude that the tornado made its closest approach to station T38A between ~ 23:03:07 and 23:07:57 UTC on May 22nd (Figure 4). The real-time observations from T38A are shown in Figure 5, all 40 sps data, with NCPA on the top, Setra in the middle, and seismic on the bottom. The range of the Doppler before-and-after pass-by window is shown. A clear ramp-up of pressure is observable as the tornado is approaching the station, followed by sudden and persistent fluctuation of the surface pressure field during the window of the tornado pass-by.

Zooming in on the window of the tornado passage (Figure 6) reveals more clearly the extent of the pressure perturbations at T38A. Also apparent is a more dramatic spike in surface pressure just after

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23:05:00. Zooming in on this spike (Figure 7) allows us to conclude that the NCPA infrasound observes an approximate 3 mb rise and drop within 5 seconds, while the Setra barometer observes this same feature at ~ 1 mb. It is important to mention that the NCPA sensor is configured to observe higher frequency signal responses than the Setra barometer, which is more attuned to monitor the general surface pressure field. Regardless, while the real-time observation of the pressure perturbations in the detail provided is fascinating, we cannot decisively link any of the pressure spikes to the tornado itself.

5. SPECTRAL ANALYSIS

The nature and design of the USArray TA network allows for something that the meteorological community does not quite have: a tool for detecting tornadoes in real-time. In order for such a tool to work accurately we must first identify characteristic energy signatures of tornadoes and, if successful, a real-time algorithm can be developed to actively scan the TA data for tornadoes in real-time.

Spectral analysis techniques were implemented on T38A's real-time observations of the Joplin event in an effort to identify potential energy signatures of the tornado. The results of the NCPA infrasound data are shown in Figure 8. The top plot shows approximate tornado positions and EF-scale intensities for eight time periods along its track (based on the Springfield Nexrad data). The middle plot shows a logarithmic spectrogram of the infrasound data overlaid with time bars corresponding to the tornado positions and lagged by the speed of sound. The idea is to indentify acoustic energy signals propagating from the tornado. The bottom plot shows the raw data.

These plots indicate that as the tornado approached T38A from ~ 10 km away there was an observable increase of power density in the pressure field surrounding the station. Looking at the Setra 278 barometric data reveals the same features (Figure 9). This ramp-up of increased energy further stands out when you compare the NCPA and Setra 278 observations to the exact same time period but 24 hours earlier, when there was no severe weather in the region (Figures 10 and 11 respectively). Finally, it is important to note that the NCPA sensor is expected to be more sensitive to observations above 1 Hz, while the Setra 278 sensor is expected to be more sensitive to observations below 0.1 Hz. This is noticeable when analyzing a side-by-side comparison of the NCPA and Setra 278 spectrogram data from during the tornado passage (Figure 12). This difference in sensor sensitivity is the prominent reason why the TA stations were redesigned to incorporate a range of pressure monitoring equipment and not just one sensor.

While the two 40 sps pressure sensors clearly observe a high level of detail in the raw data and within spectral analysis of the same raw data, there does not appear to be a specific energy signal related to tornado passage that stands out from the Joplin example. The ramp-up of power density within the surface pressure field around T38A is expected for situations in which there is a large amount of wind turbulence. This can be ascribed to any number of severe weather scenarios, not specifically related to tornado passage.

On the other hand, both sensors do reveal a vague high-frequency energy signal at ~ 15 Hz that is not observable on the previous day. It is uncertain if this is related to the tornado passage but it warrants further investigation with other near-pass tornado examples within the USArray footprint.

6. A NOTE ABOUT SURROUNDING STATIONS

The same spectral analysis routine was performed on over one dozen stations surrounding T38A in order to identify a low-frequency energy signature emanating from the Joplin tornado event. Each of these stations was ruled inconclusive in that we could not identify any energy signatures that stood out prominently or otherwise. Furthermore, T38A is one of the only stations in the nearest proximity to the Joplin event that contains an NCPA infrasound sensor. On stations where we did spot a curious energy signature during the Joplin event we were able to identify the exact same energy signature at earlier times when there were no reported tornadoes.

7. DISCUSSION AND CONCLUSION

Station T38A within the USArray TA network observed a variety of surface pressure perturbations during the Joplin tornado passage on May 22nd, 2011. These observations were recorded in real-time at 40 sps and coincided with an observed increase in power density via spectral analysis. While the data recorded is consistent with observations of a highly turbulent wind field, a specific pressure or energy signature related to the tornado passage was not identified. Spectral analysis of surrounding TA stations could not confirm an energy signature related to tornado passage either. One feature identified within the power density spectrum at T38A (at ~ 15 Hz) will be compared with other near-pass tornado examples in order to determine if such an energy signature is a conclusive link to tornadoes.

8. ACKNOWLEDGEMENTS

The authors would once more like to express their gratitude to the USArray installation teams and their continued expertise in the field as they install and decommission stations on a daily basis. We would also like to acknowledge the Springfield, MO NWS office and the work they have done in cataloging and distributing data online in relation to the Joplin event.

9. REFERENCES

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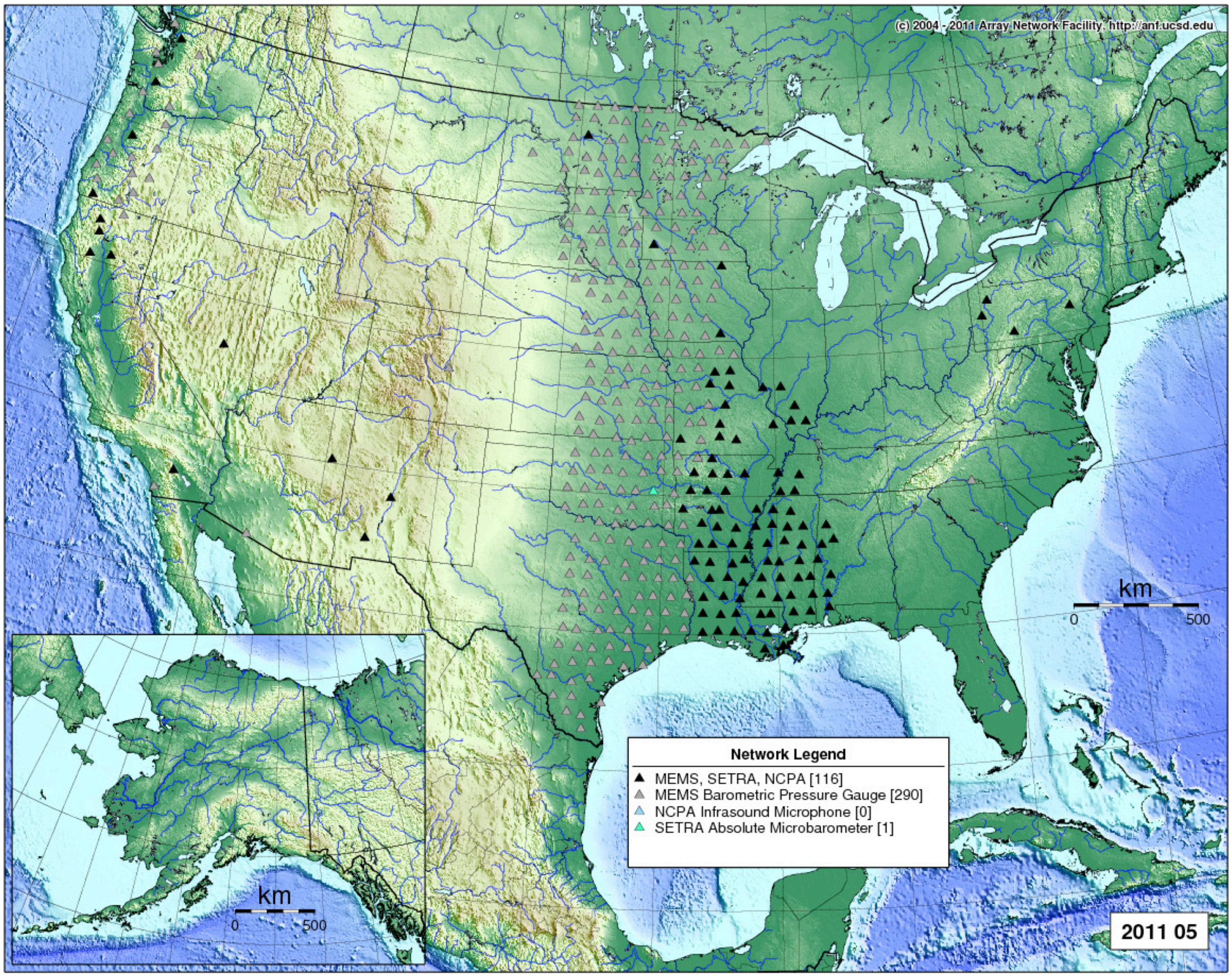

Figure 1 – Distribution of USArray footprint on 5/22/2011. All stations contain seismic monitoring capabilities. Grey triangles depict stations with seismometers and MEMS barometers, black triangles are stations that contain seismometers, MEMS and Setra 278 barometers and the NCPA Infrasound sensors.

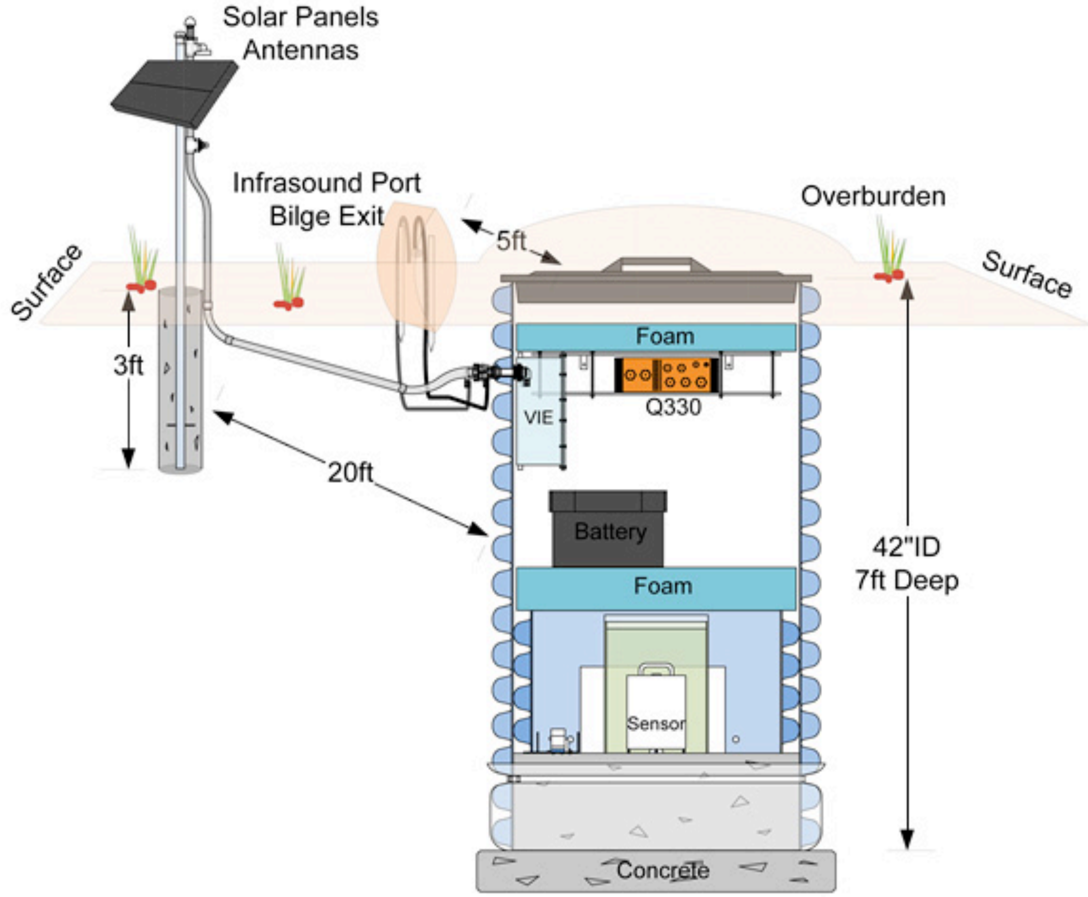

Figure 2 – Standard vault design and configuration for all TA stations. Seismometer is located in the base on a bed of concrete. The VIE is located just under the lid and contains the data-logging and pressure sensing equipment. A bilge port external to the station provides the air intake for the pressure monitoring equipment in the VIE. A GPS sensor for timing and telemetry are located a few meters away from the vault.

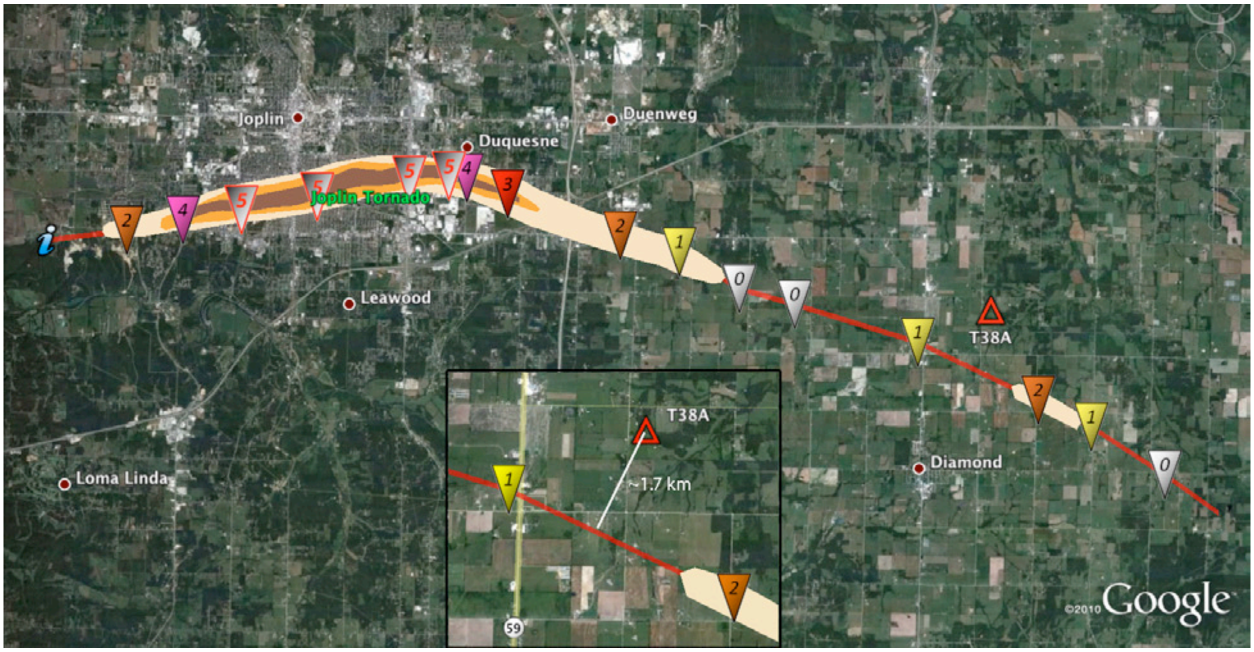

Figure 3 – Overlay data with path and estimated EF scale intensities provided from the National Weather Service office in Springfield, MO. Track reveals proximity to TA station T38A. Inset image shows the approximate closest distance as ~ 1.7 km.

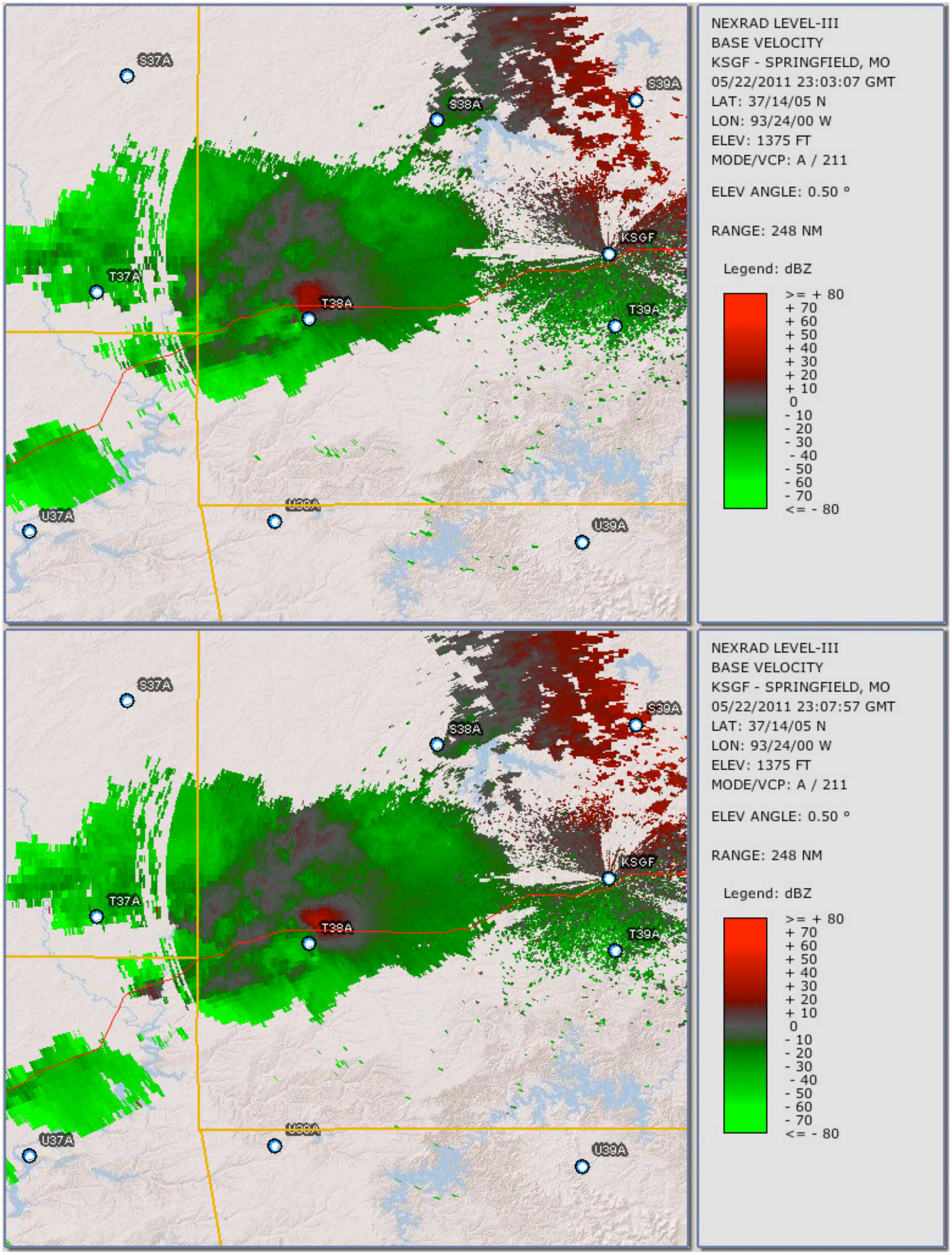

Figure 4 – Velocity Doppler images provided by the Springfield, MO Nexrad and visualized via the NOAA Weather and Climate Toolkit. Images show the tornado just before and after passing near TA station T38A.

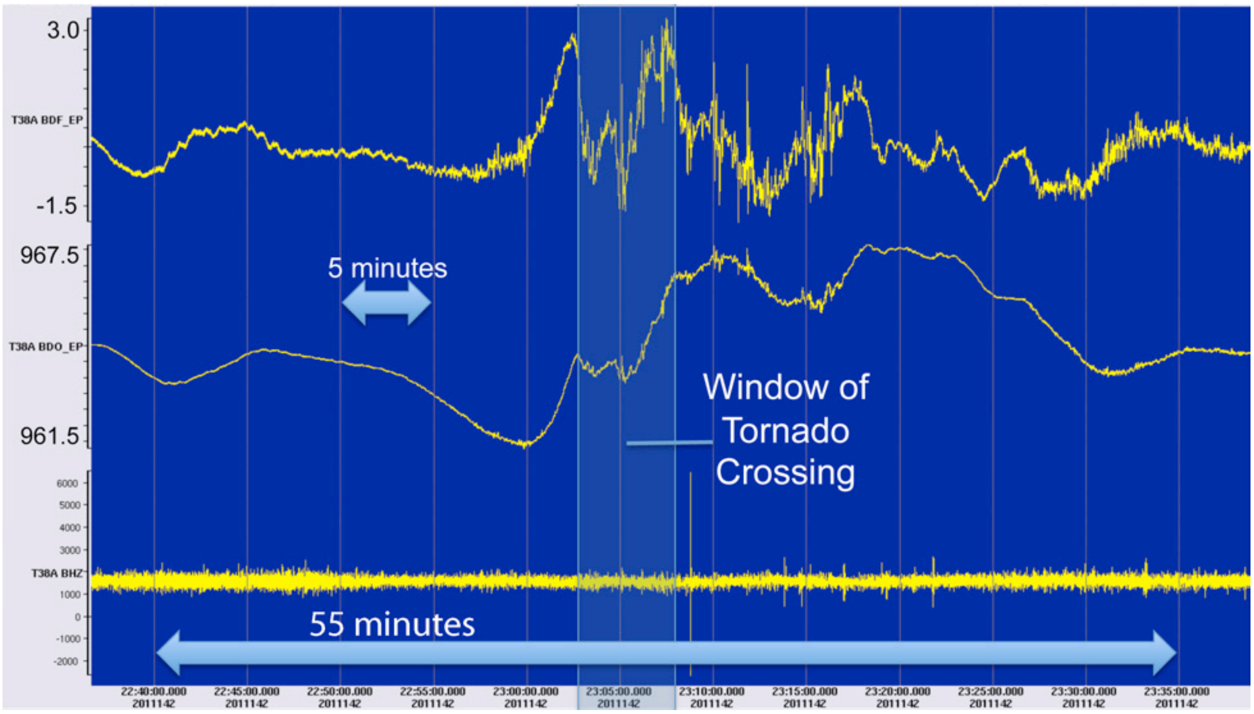

Figure 5 – Unfiltered data from TA station T38A. Top is 40 sps infrasound measured in units of mb. Middle is 40 sps Setra 278 barometric data measured in mb. Bottom is 40 sps seismic measured in nm/sec. Window of tornado's crossing of T38A based on the two Nexrad images in Figure 4 is displayed (between 23:03:07 and 23:07:57 GMT).

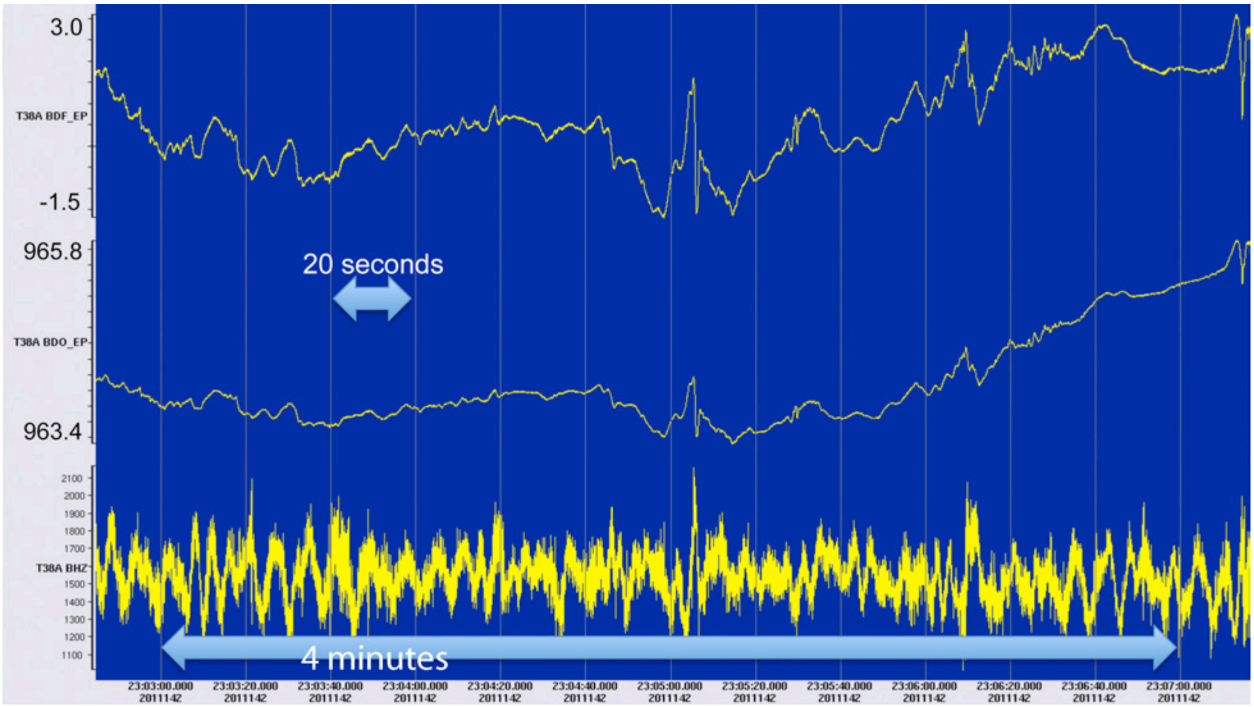

Figure 6 – Unfiltered data. A zoom-in of the window mentioned in Figure 5. Note the spike in pressure observed at ~ 23:05:00

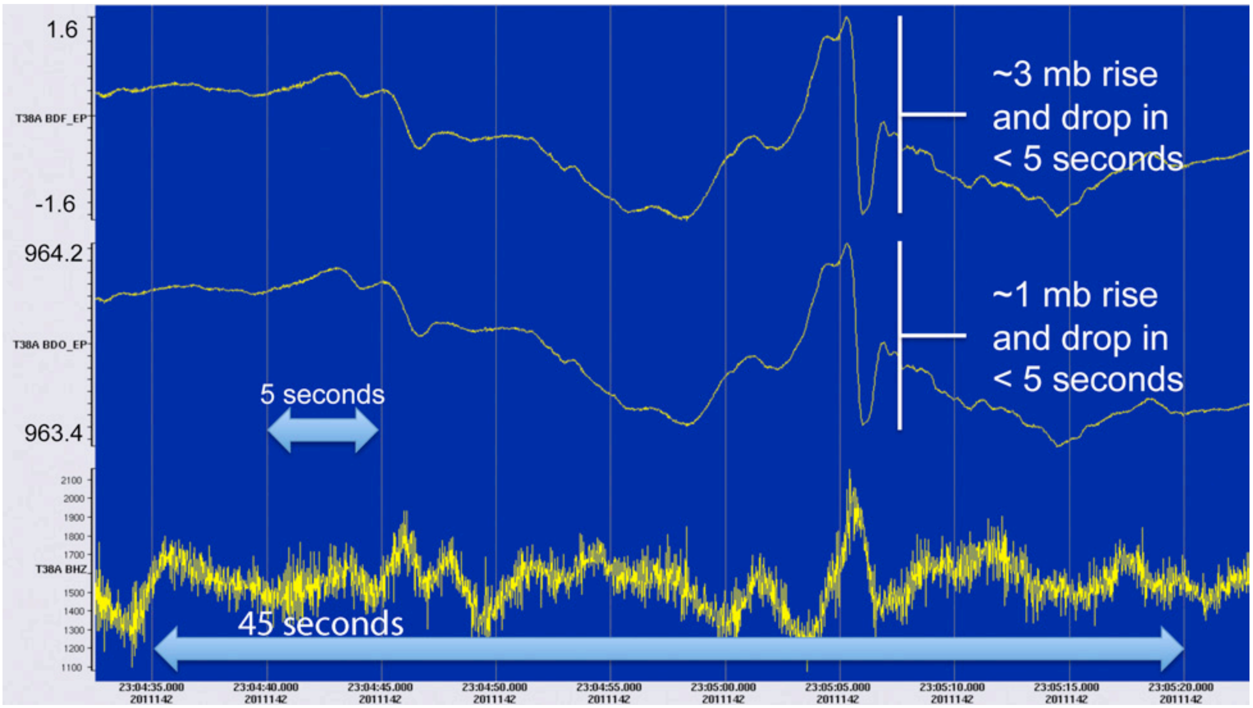

Figure 7 – Unfiltered data. Zooming in on the spike mentioned in Figure 6, the NCPA and Setra 278 offer different observations for the magnitude of the pressure change within the spike. This is largely due to the NCPA's higher response to higher frequency signals vs. the Setra 278, which is more responsive to lower frequency signals, and is more representative of the general pressure field.

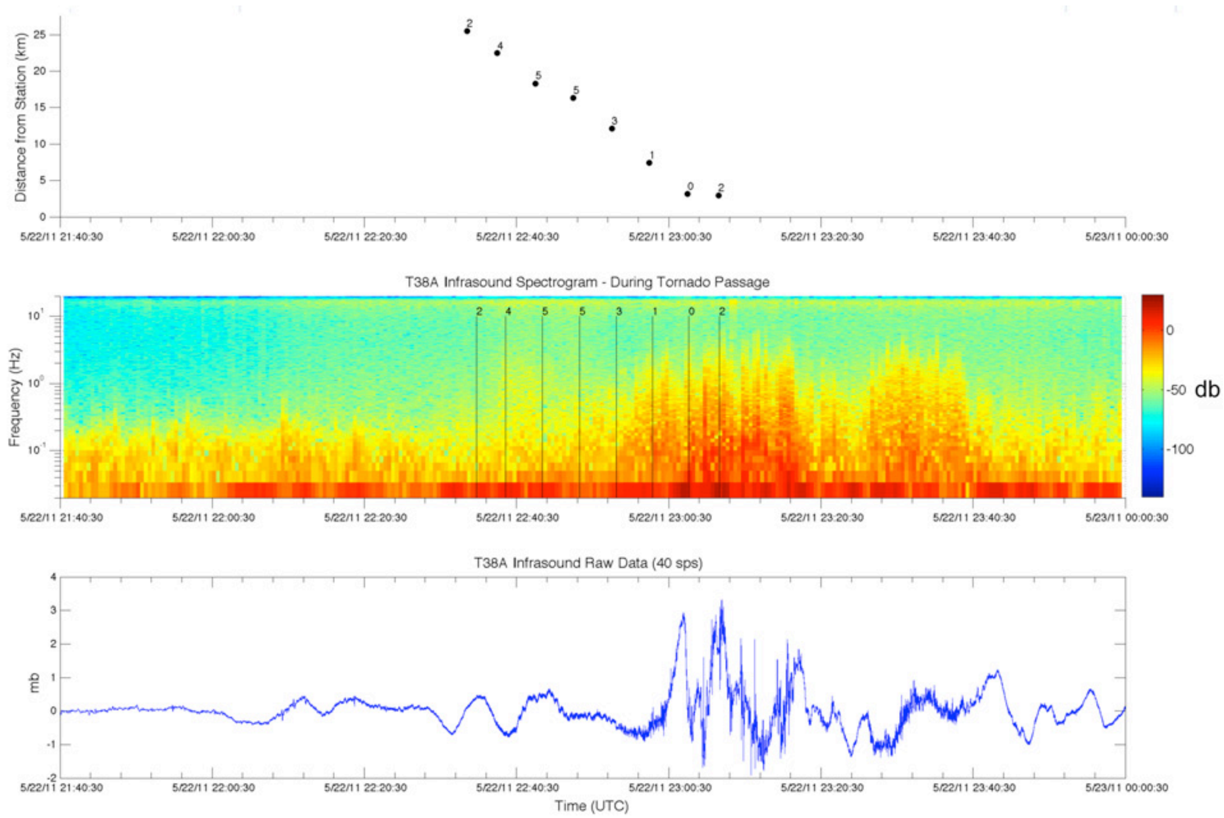

Figure 8 – Spectrogram of the NCPA infrasound data from TA station T38A for the 140 minute window before, during and after the Joplin tornado's lifespan on May 22nd, 2011. Top plot shows estimated positions and EF intensities of the Joplin tornado based on approximate locations of the velocity couplets and hook-echos within 8 Nexrad frames that span the life of the event. Middle plot is the spectrogram, with acoustic-lagged time bars corresponding to the 8 positions in the top plot. Bottom plot is the raw infrasound data. Middle plot reveals a ramp-up of power density starting when the tornado is ~ 10 km away. Also a faint line of higher power density at ~ 15 Hz during the span of the system.

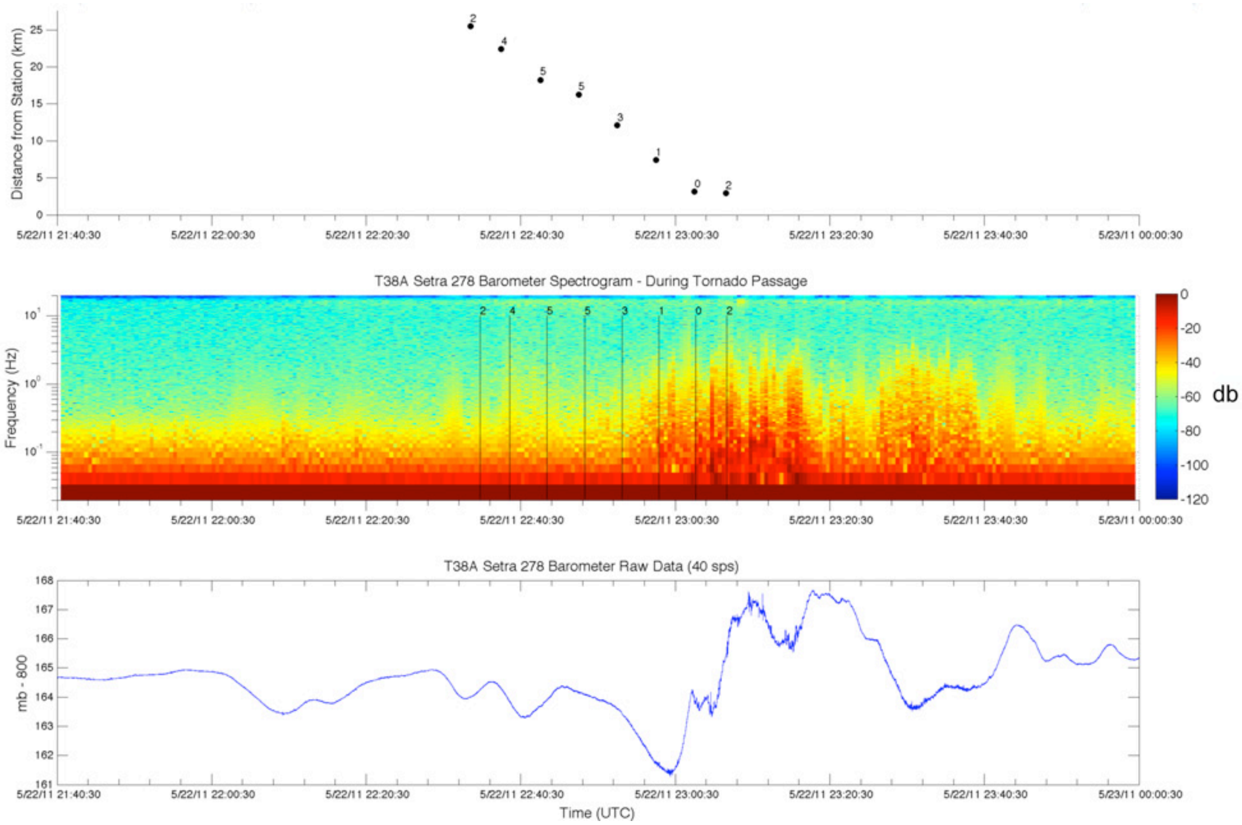

Figure 9 – As in Figure 8 but for the Setra 278 barometer. Same power density signatures can be found here as in Figure 8.

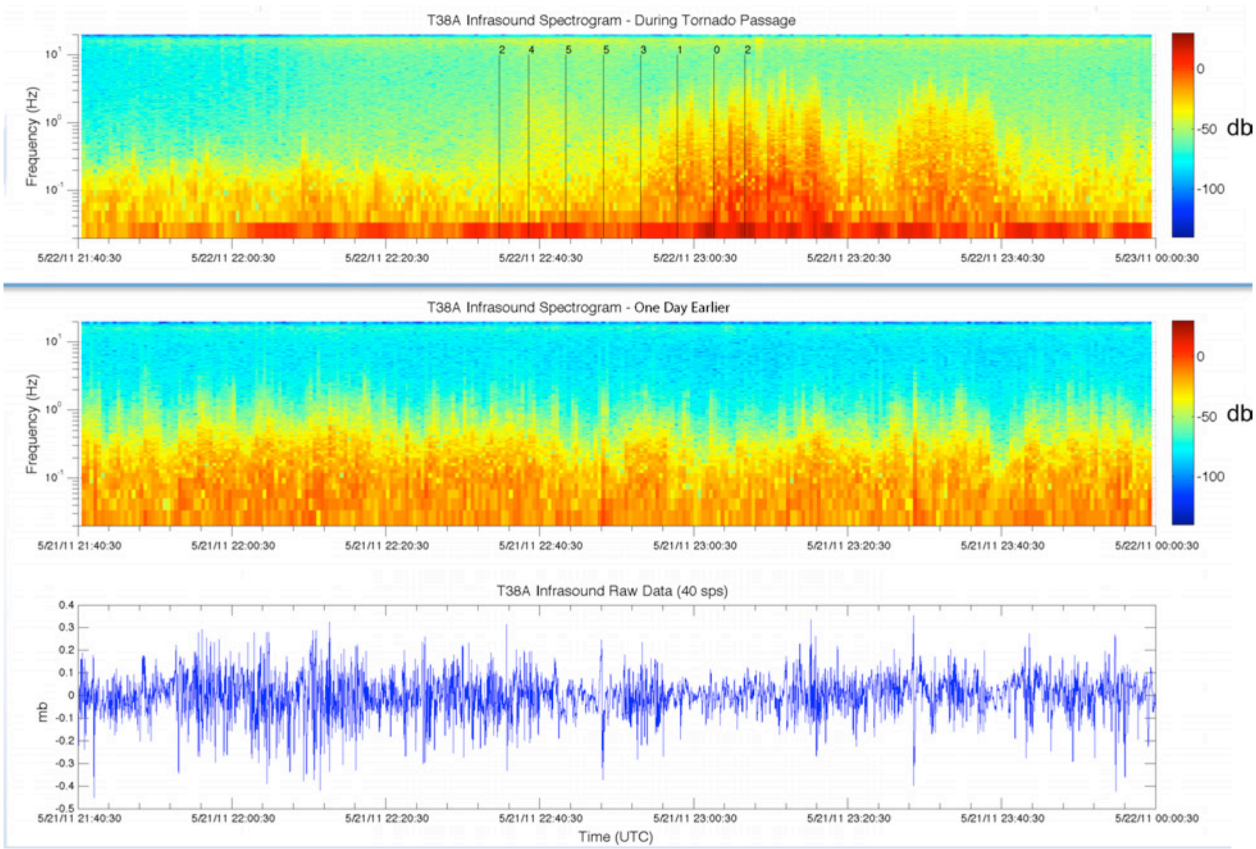

Figure 10 – Comparison of the NCPA infrasound data during the Joplin tornado event to the same time window 24 hours earlier. The idea is to show the difference in background energy between the two days. It is clear there is more background energy propagating through the air during the tornado event.

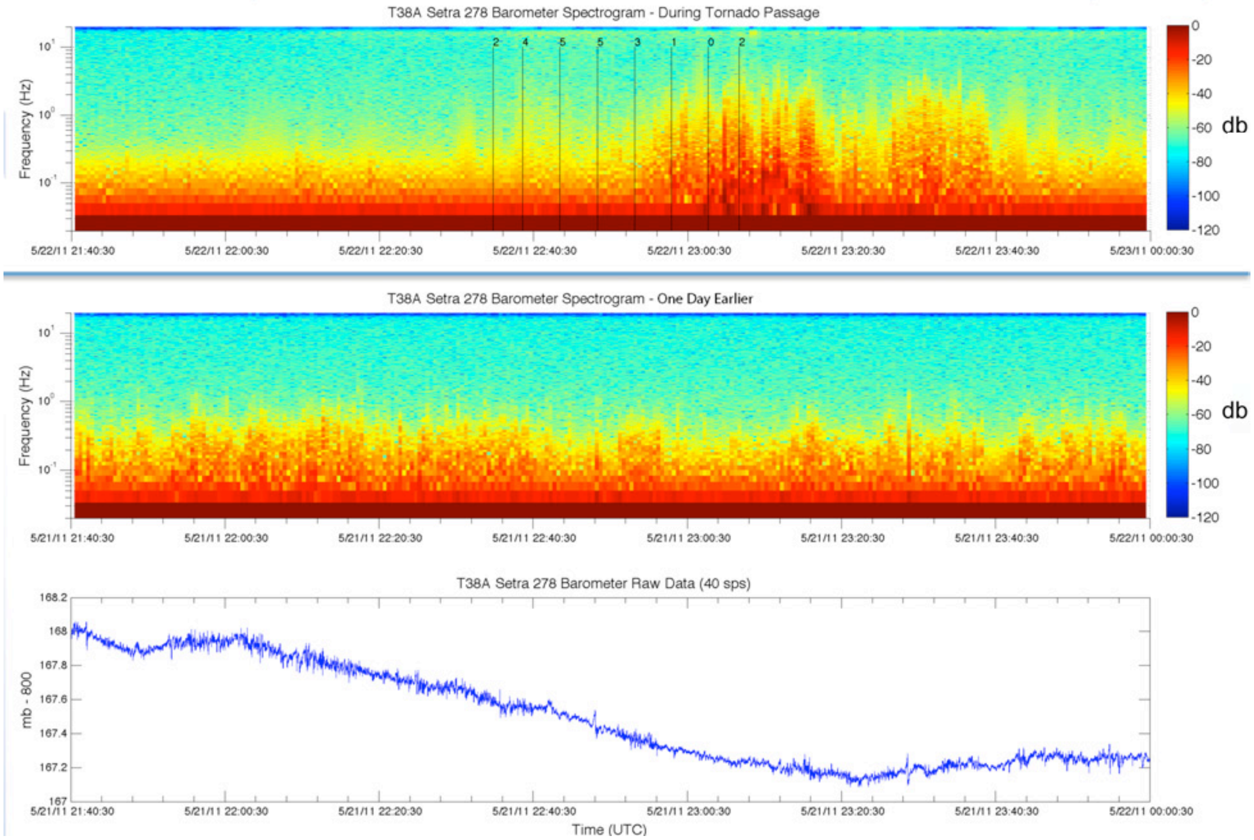

Figure 11 – As in Figure 10 but for the Setra 278 barometer.

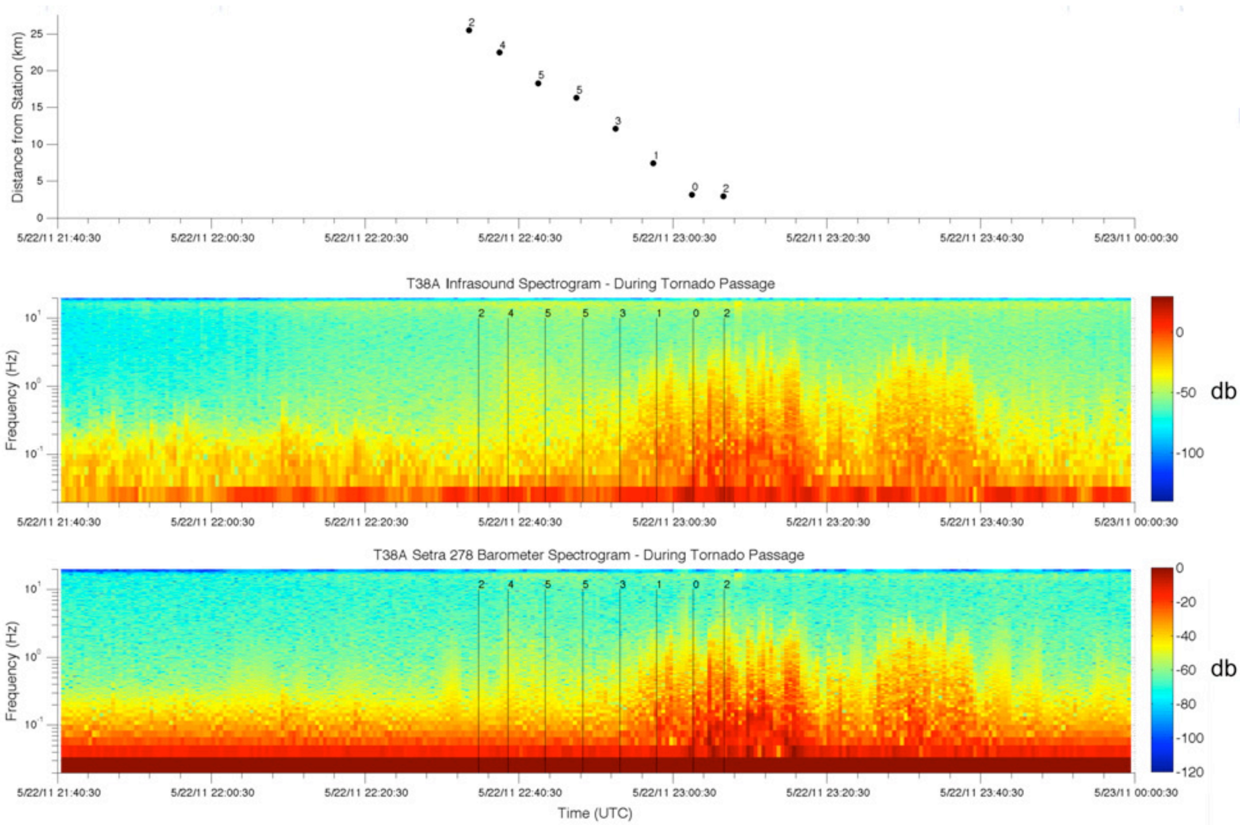

Figure 12 – Comparison of the NCPA infrasound to the Setra 278 barometric data during the window of the tornado event. Features are very similar for the two as described via Figures 8 and 9. The NCPA is more sensitive to signals greater than 1 Hz, while the Setra 278 barometer is more sensitive to signals less than 0.1 Hz, and the difference in these two sensors is evident as one looks upon the data.