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Scientific Viability of the USArray Transportable Array Network As a Real-Time Weather Monitoring Platform

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1. ABSTRACT

Earthscope's USArray Transportable Array (TA) network has proven to be highly successful at real-time monitoring of seismic events at 40 samples per second (sps). While the TA network was originally designed with seismic research interests in mind, since early 2010 the network has been retrofitted with atmospheric pressure and infrasound monitoring equipment. Most of the approximately 500 stations are now capable of recording atmospheric phenomena in real-time at 1 sps with VTI SCP1000 MEMS barometric pressure gauges. Meanwhile, over 100 of the stations also record at 40 sps with Setra 278 barometric gauges and NCPA infrasound sensors. The viability of the TA network to monitor weather with these instruments has been previously discussed, and the data presented in this paper will provide conclusive support for their observations. Analysis of gust front speeds and thunderstorm pressure couplets will help determine the severity of storm systems in real-time. Infrasound acoustic observations of thunder can potentially be used to filter noise from seismic data. Additionally, the 2011 tornado season provided a unique opportunity for real-time monitoring of tornadoes via combined seismic, surface pressure and infrasound observations. In total, the analysis of data presented in this paper will show that the USArray TA network is a powerful tool for real-time monitoring of weather phenomena.

2. INTRODUCTION

Previous research findings provided by the USArray TA network have been limited to real-time observations of severe weather (Tytell et al., 2011 and Vernon et al., 2011). This functionality has expanded in 2011, however, with the addition of the Setra 278 barometer and NCPA infrasound to each new station (as well as several existing stations). The additional data provided from these new sensors has refocused the scientific potential of the USArray platform from a meteorological perspective. Now, the TA network's utility as a large-scale imaging tool spotlights a new avenue of scientific viability. Furthermore, the new sensors within the TA footprint supplement real-time observations of localized, severe storm events with 40 sps acoustic and barometric data, adding new validity to these real-time observations. While some examples in which the TA data provide conclusive support for observational meteorology are still works-in-progress (i.e. determining real-time storm severity and thunder noise filtration), the material presented from the TA's new sensors will demonstrate the USArray's potential for providing scientific findings in unique and perhaps unexpected ways.

3. PRELUDE TO INFRASOUND – ROCKET BLASTS

The USArray TA deployment is shown in Figure 1, including decommissioned stations and the footprint at the end of January 2012. As mentioned in earlier presentations, the original designation of the USArray was to monitor seismic events and ground motion in real-time (Tytell et al., 2011 and Vernon et al., 2011). This objective received a new direction, however, after a series of infrasonic sources were detected.

Eleven rocket motor detonations occurred between May and September of 2007 from Utah's UTTR facility. Figure 2 shows Canada's IMS Infrasound Network (blue triangles) mapped concurrently with the USArray deployment footprint throughout those months (green triangles). Infrasonic signals were clearly visible at 0.8 to 3.0 Hz with the handful of IMS sites (Figure 3). But perhaps more significant was the USArray's ability to also detect this acoustic signal in the seismic data filtered at the same frequency band (Figure 4). This discovery fueled PIs at UC San Diego to acquire MRI-R^2 awards from the National Science Foundation (NSF) to supplement the USArray stations with Setra 278 barometers and NCPA infrasound sensors.

4. INCORPORATION OF SETRA AND INFRASOUND

The incorporation of the new sensors required some modification to the typical vault design of each USArray station (Figure 5). The seismometer is still located in the base of the vault, but the Vault Interface Enclosure (VIE) now incorporates the Setra 278 as well as the NCPA infrasound sensors. A hose from an external bilge port allows for the air input to these sensors. Figure 6 shows the frequency bands in which the three pressure sensors are best attuned for observation.

The stations with the new VIE enclosures began deployment in early 2011, with a rapidly increasing footprint as new stations were deployed (Figure 7).

5. VISUALIZATION TOOL

The USArray TA network is also providing scientific results through basic visualization of the real-time data.

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Researchers can display movies of surface air pressure as low-pressure ridges move across the network, highlighting significant features such as tornado reports (Figure 8). It is also possible to filter the infrasound data on a low-frequency spectrum (2-6 hour period band) and generate a visualization of infragravity waves propagating across the network (Figure 9).

A closer inspection of one infragravity wave in particular allows us to further examine the utility of the TA data in this fashion. Figure 10 shows a representation of the infragravity waves propagating outward from a source near Memphis using colors to highlight the signal on the left side of the figure. On the right side of Figure 10 is a comparison of the barometric pressure signal with the best fitting correlation with a rotated horizontal seismic signal in red (upper right panel) and with the most anti-correlated horizontal seismic signal in green (lower right panel). Figure 11 shows the same representation of the infragravity waves propagating outward from a source near Memphis as Figure 10 on the left side, but shows the waveforms of the infragravity waves as they propagate from south to north across the central US.

6. TORNADO NEAR-PASS CASE STUDIES

The tornado season in April and May of 2011 included a few events that passed very closely to some of the TA stations. Two of these near-passes in particular were stations that had been fully equipped with the new VIE package. On April 4th, 2011 an EF1 tornado ended its track ~ 2.5 km from TA station 245A southeast of Jackson, MS (Figure 12). The pressure perturbations at the surface were clearly evident during this approach (Figure 13). A closer examination of the 40 sps infrasound and seismic data reveal an interesting feature (Figure 14), namely a sharp rise in pressure of ~ 7 mb within 20 seconds, followed by a highly turbulent period with numerous pressure fluctuations. The seismic data reveals ground motion and vibration during the same time period.

The devastating Joplin, MO EF5 tornado also passed closely to one of our stations near the end of its track. Station T38A was within ~ 1.7 km of the tornado as it passed nearby (Figure 15). The raw data reveal similar features to the Jackson, MS event, though over a longer period of time (Figure 16). In this case the rise in pressure was ~ 3 mb over 2.5 minutes, followed by a highly turbulent period lasting for 6 minutes. Other tornado near-pass examples are currently under investigation for specific energy characteristics that may be common among tornadoes and detectible within the TA data.

7. DEPLOYMENT PLANS

The deployment schedule for the rest of 2012 is shown in Figure 17. As the USArray TA network continues its eastward march the westernmost stations with only seismic and MEMS sensors will be replaced with stations that include the full assortment of pressure sensors. Additionally, there will be 36 stations that will include full meteorological monitoring capabilities (wind speed, direction, temperature, etc.) to aid in additional research opportunities. Lastly, when the USArray experiment concludes its eastward journey, the plan is to continue the project with a new deployment strategy in Alaska starting in 2014 (Figure 18).

8. DISCUSSION AND CONCLUSION

Incorporation of a Setra 278 barometer and NCPA infrasound onto USArray TA stations has created additional research opportunities within surface meteorology. At the end of January 2012 there were 318 stations with the full barometric and infrasound VIE package, and this number is expected to grow as the USArray footprint continues toward the East Coast. Furthermore, 36 of these stations will be installed with a full meteorological package as described in the previous section. In the near-field of surrounding tornadoes the TA data has observed large amplitude pressure rises followed by high frequency pressure perturbations. Visualization of the full network of over 2 million km^2 has illuminated the phenomenon of travelling gravity waves in addition to standard surface pressure observations. Lastly, the USArray is expected to continue its deployment strategy in Alaska beginning in 2014.

9. ACKNOWLEDGEMENTS

The authors would once again like to thank the USArray installation teams and their continued expertise in the field as they install and decommission stations on a daily basis. Furthermore, we would also like to acknowledge the Jackson, MS and Springfield, MO NWS offices and the work they have done in cataloging and distributing data online in relation to severe weather and tornado events.

10. REFERENCES

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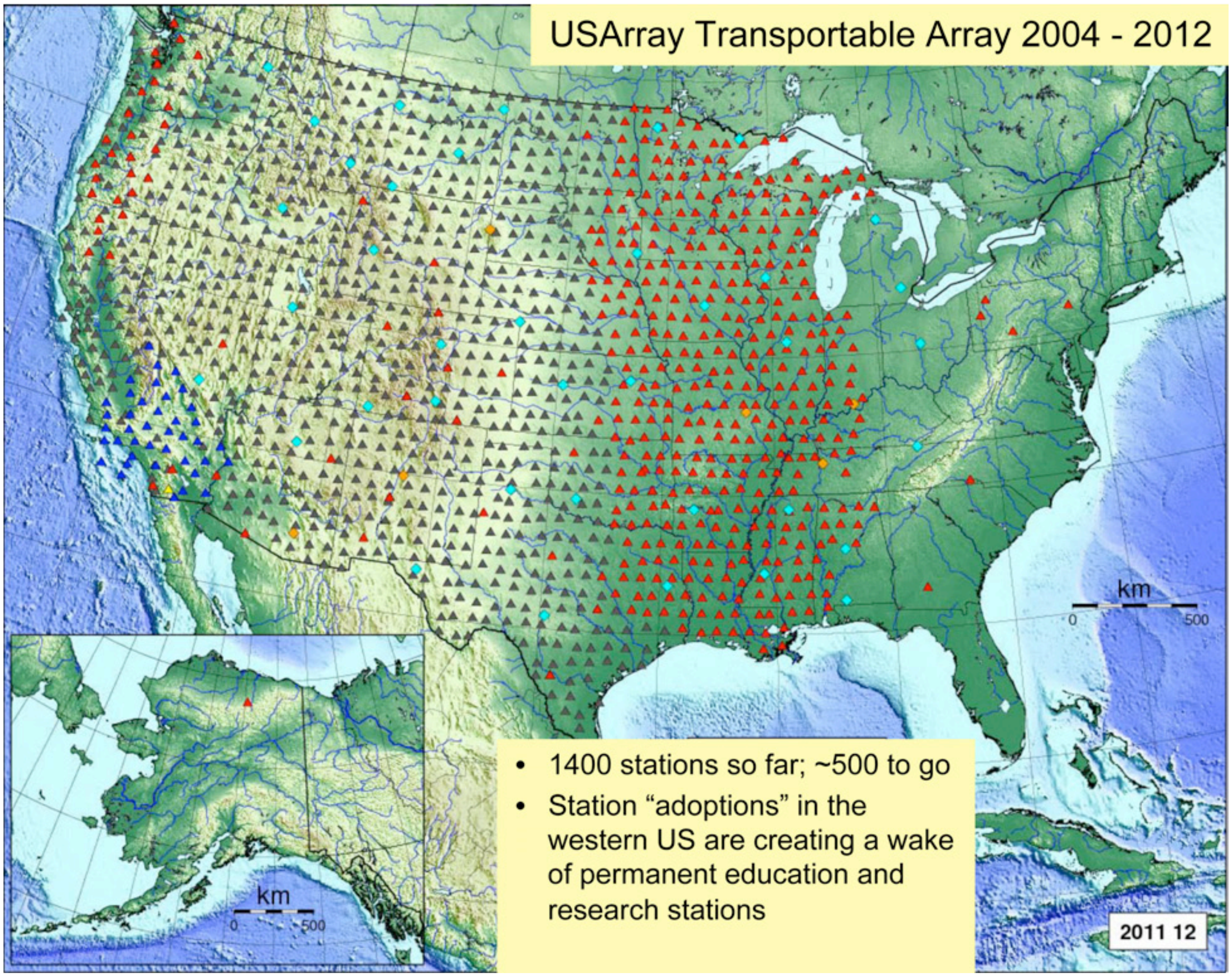


Figure 1 – Full deployment map of the USArray TA network. Grey triangles represent stations that have been decommissioned. Blue triangles and orange squares depict partnered networks. Red triangles represent the USArray footprint at the end of 2011.

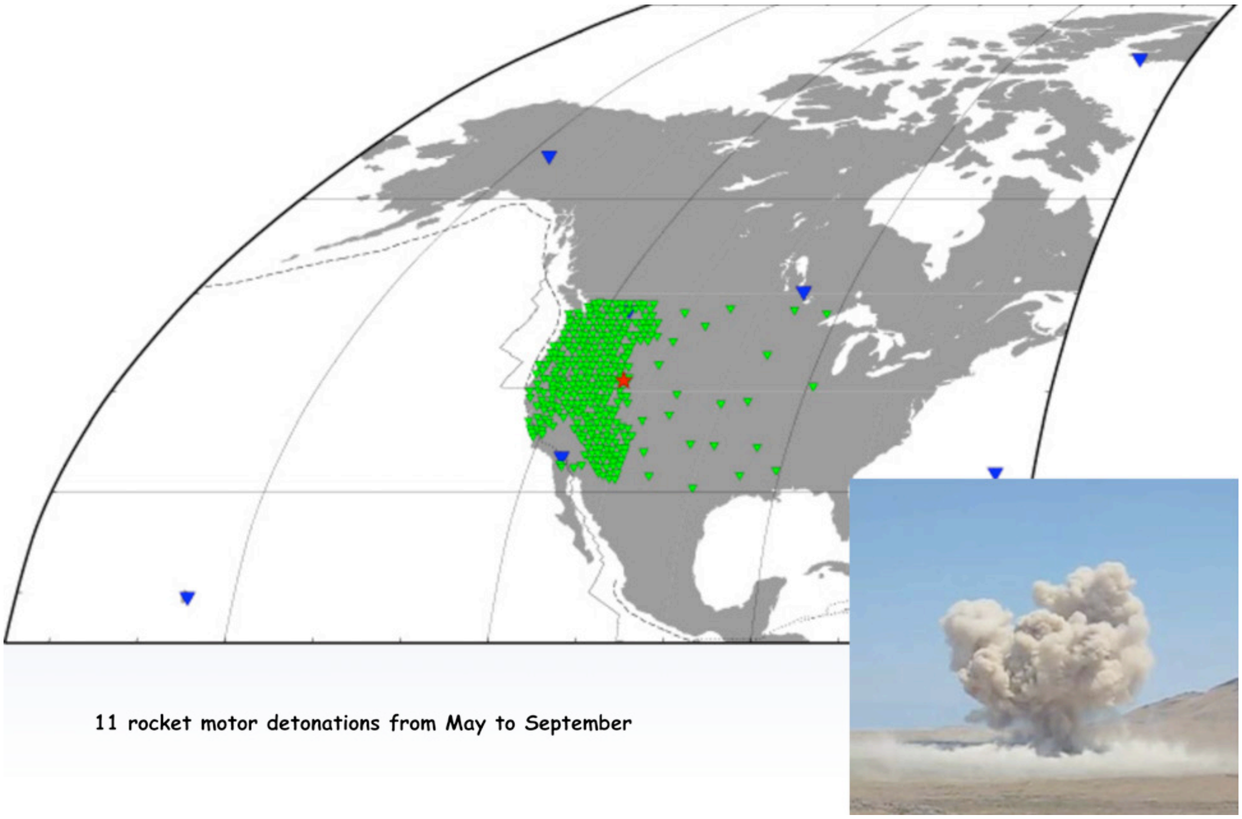
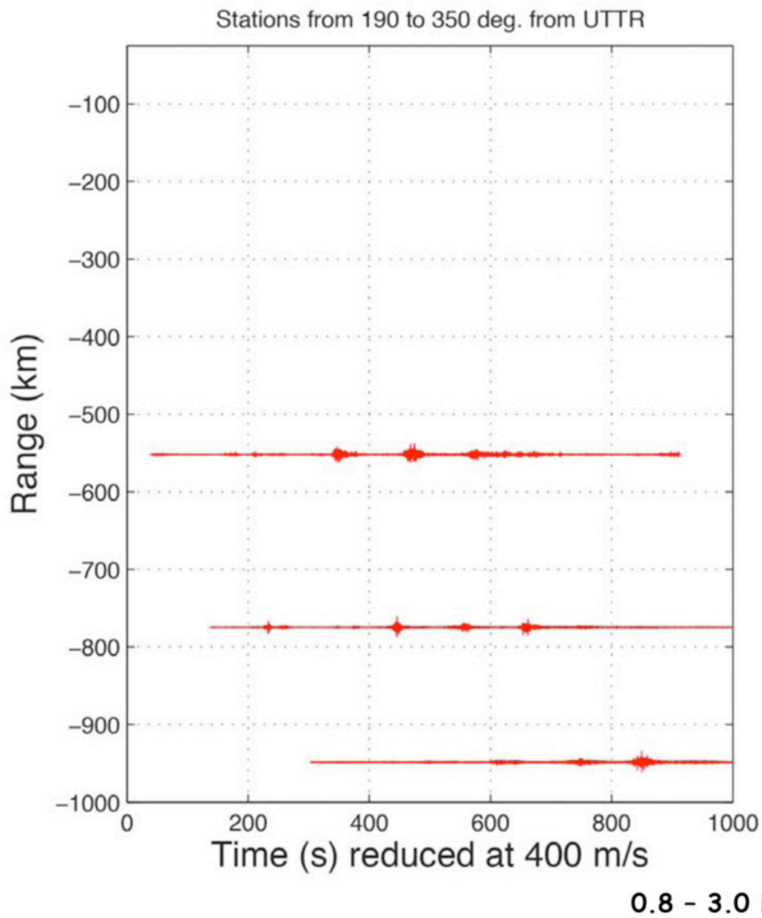


Figure 2 – Utah's UTTR facility depicted by red star. Canada's IMS Infrasound Network depicted by blue triangles. USArray TA stations are green triangles from during the period from May through September 2007. Inset image is a picture of a rocket motor detonation.



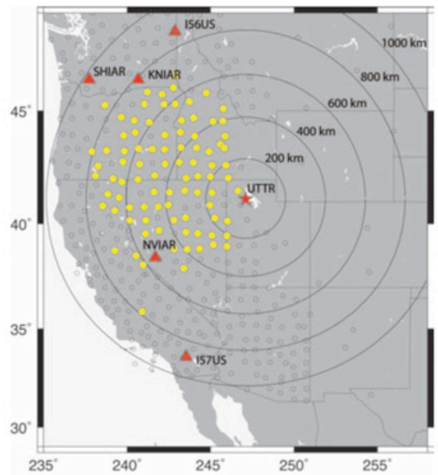


Figure 3 – Images from Hedlin et al., 2010. Left image depicts the infrasonic signal detections (red) by the IMS network for a particular blast during the May through September 2007 time span. The right image depicts a range map, with IMS stations as red triangles, USArray stations as red and grey circles, and the UTTR facility depicted as a red star. Data is filtered between 0.8 and 3.0 Hz.

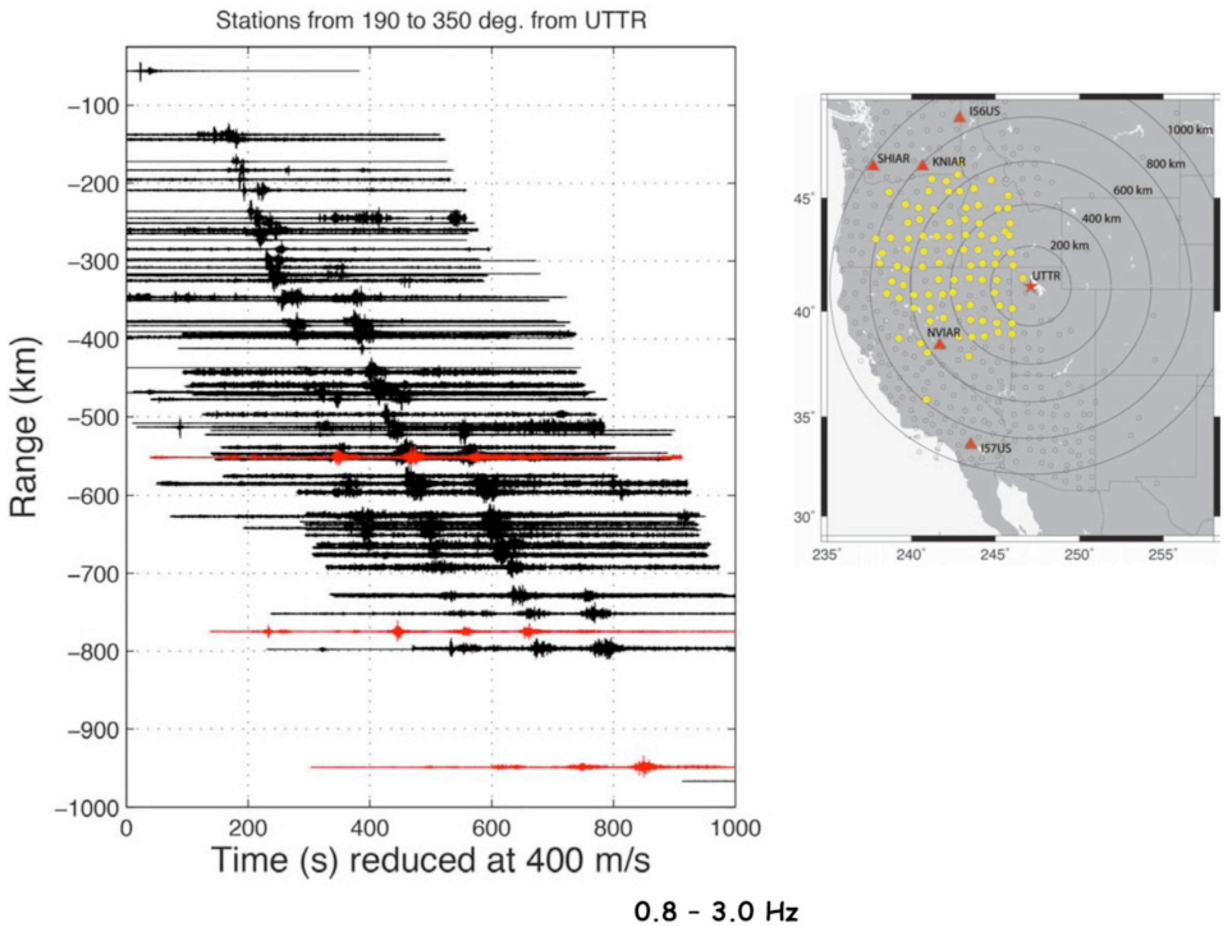


Figure 4 – As in Figure 3. Left image is seismic data (black waveforms) from select USArray TA stations (yellow circles from right image) overlaid with the infrasonic signals (red) detected by the IMS network for the same blast. The signals represented within the left image appear to correlate well. Data is filtered between 0.8 and 3.0 Hz.

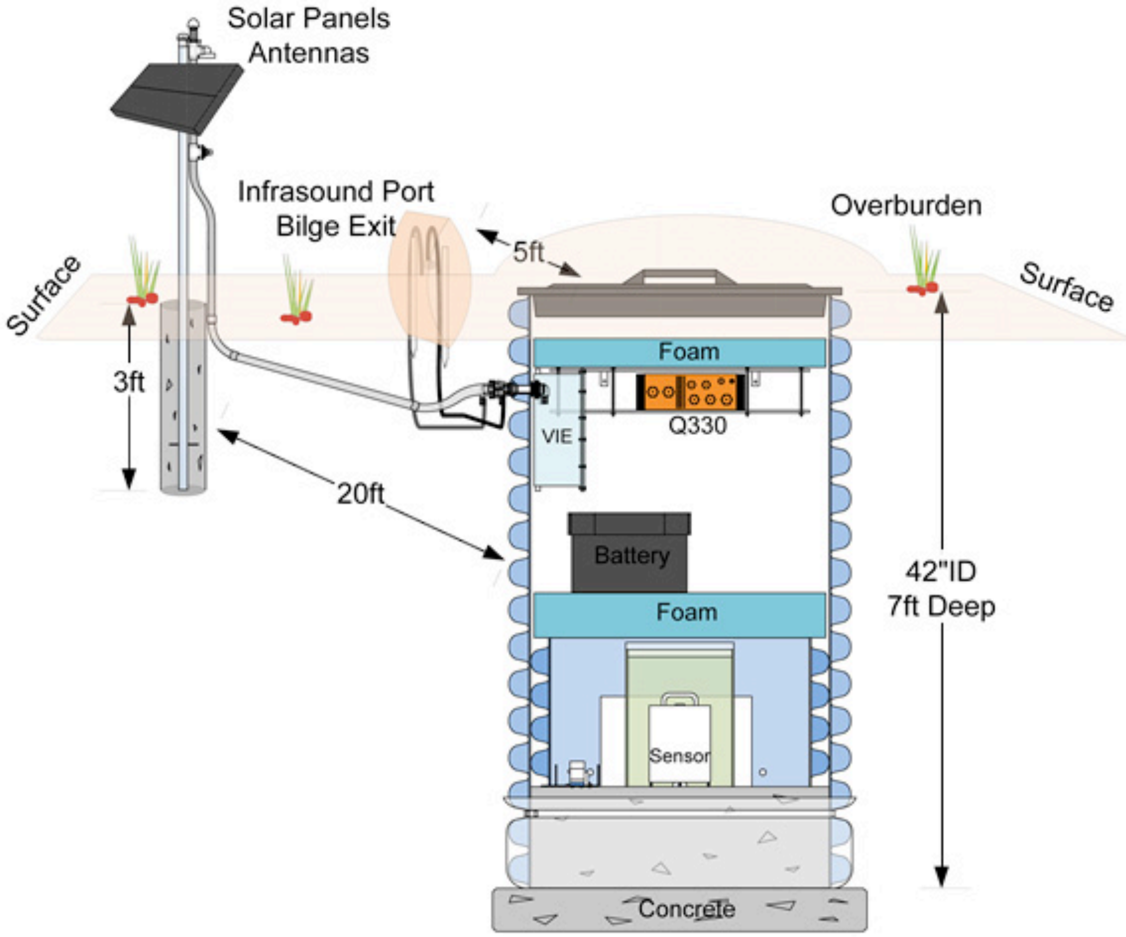


Figure 5 – Standard vault design and configuration for all TA stations. Seismometer is located in the base on a bed of concrete. The VIE is located just under the lid and contains the data-logging and pressure sensing equipment. A bilge port external to the station provides the air intake for the pressure monitoring equipment in the VIE. A GPS sensor for timing and telemetry are located a few meters away from the vault.

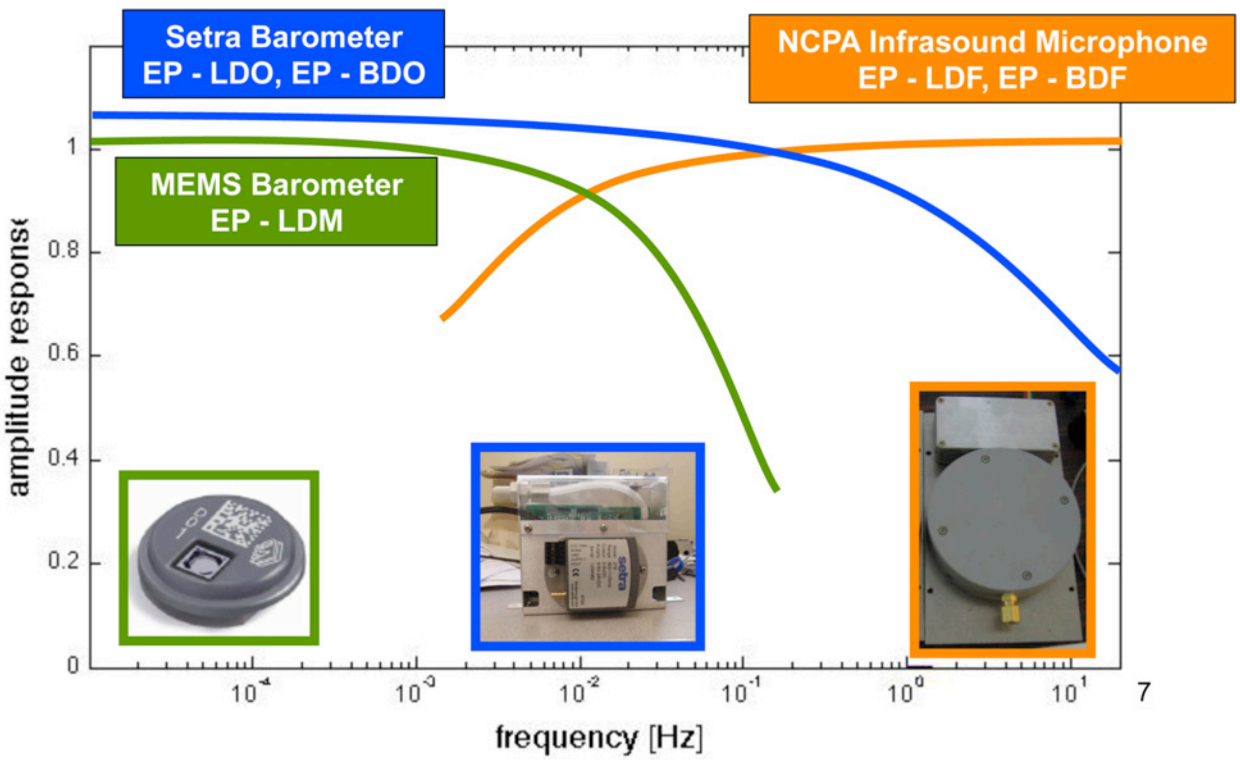


Figure 6 – Overlapping pass-bands provide continuous coverage from DC to 20 Hz. The MEMS barometer is more attuned to low-frequency data, while the Setra 278 barometer performs well from DC up to 0.1 Hz. The NCPA infrasound covers much higher frequency data and performs best above 1 Hz.

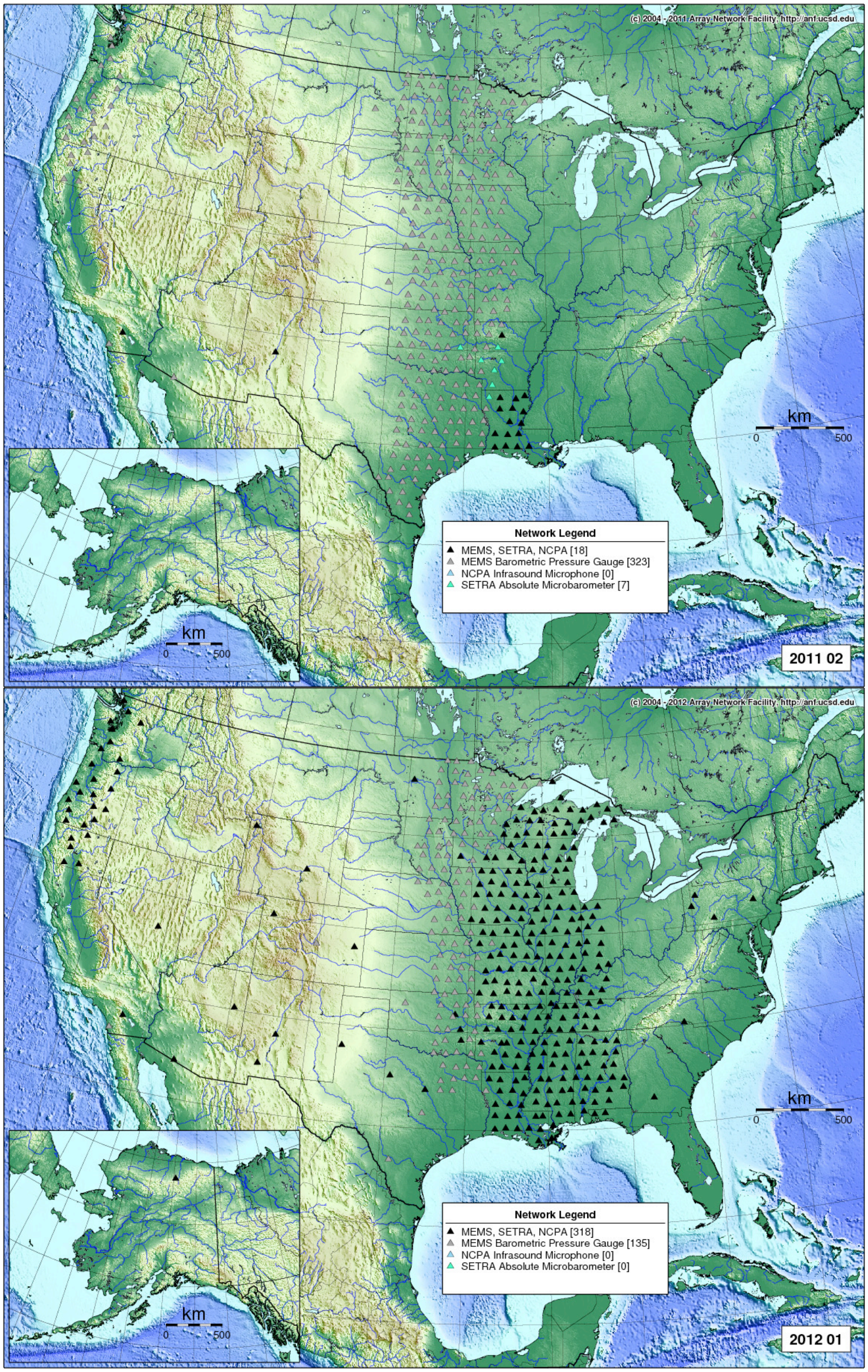


Figure 7 – USArray deployment footprints at the end of February 2011 (top) and January 2012 (bottom). All stations contain seismic monitoring capabilities. Grey triangles depict stations with seismometers and MEMS barometers, black triangles are stations that contain seismometers, MEMS and Setra 278 barometers and the NCPA Infrasound sensors. The number of stations with infrasound capabilities is expected to grow until all stations are equipped with the NCPA sensor.

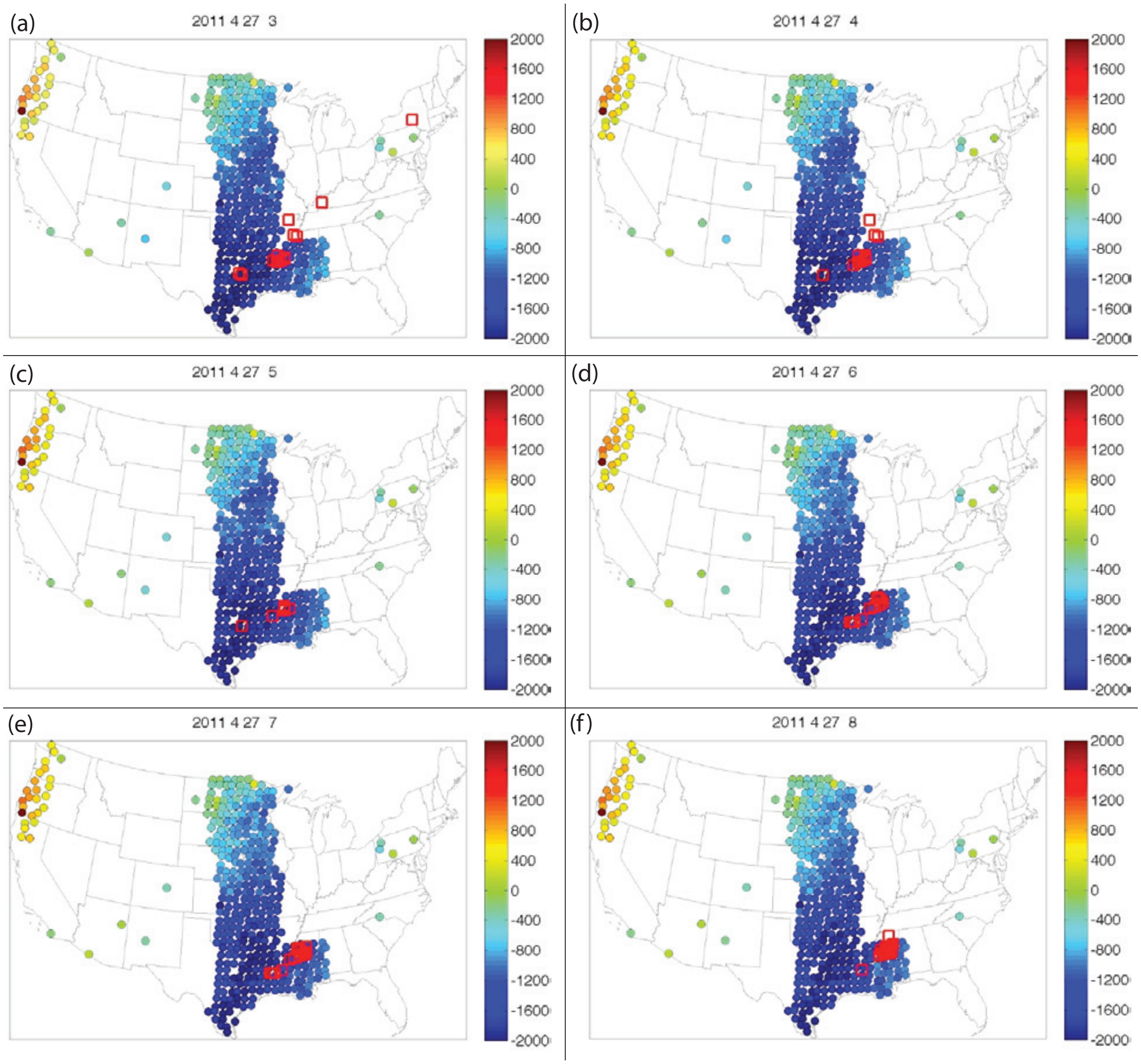


Figure 8 – Unfiltered surface barometric pressures (Pa) calculated as a difference from the stations' standard pressures at their respective altitudes. Images are hourly, covering 0300 to 0800 UTC on April 27th, 2011. Red squares are tornado reports from the NOAA Storm Prediction Center (SPC).

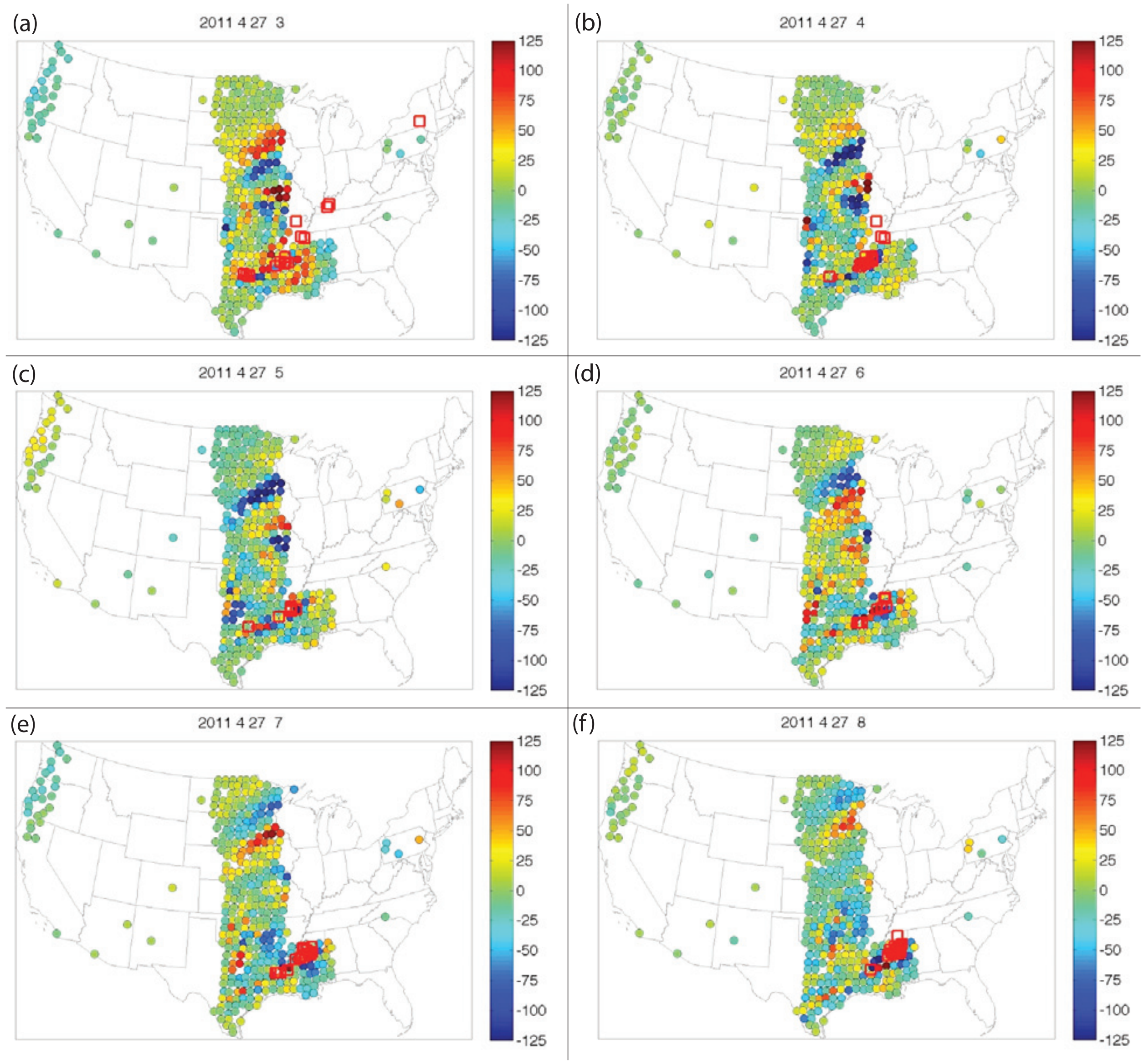


Figure 9 – As in Figure 8 and for the same time period and frames, but the data is from the NCPA infrasound and filtered on a 2 to 6 hour period band. Gravity waves can be seen propagating northward from near Memphis, Tennessee.

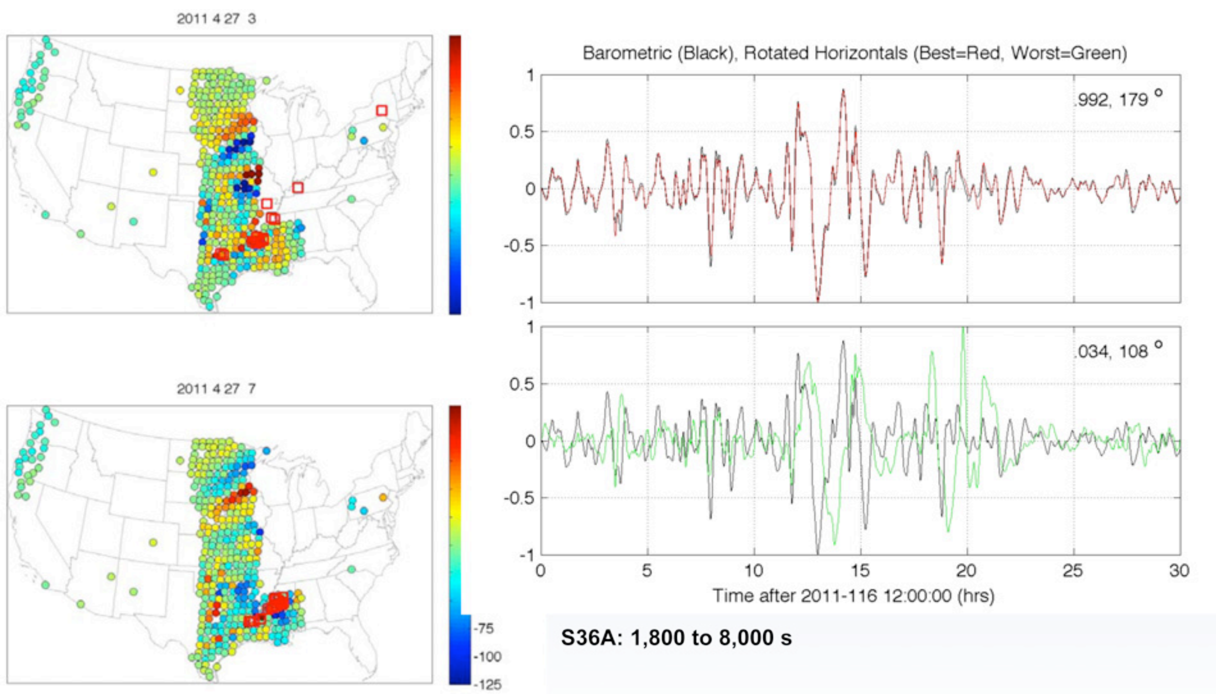


Figure 10 – Same case study as in Figures 8 and 9. Upper-right panel shows a comparison of the barometric pressure signal with the best fitting correlation with a rotated horizontal seismic signal in red, and with the most anti-correlated horizontal seismic signal in green (lower-right panel).

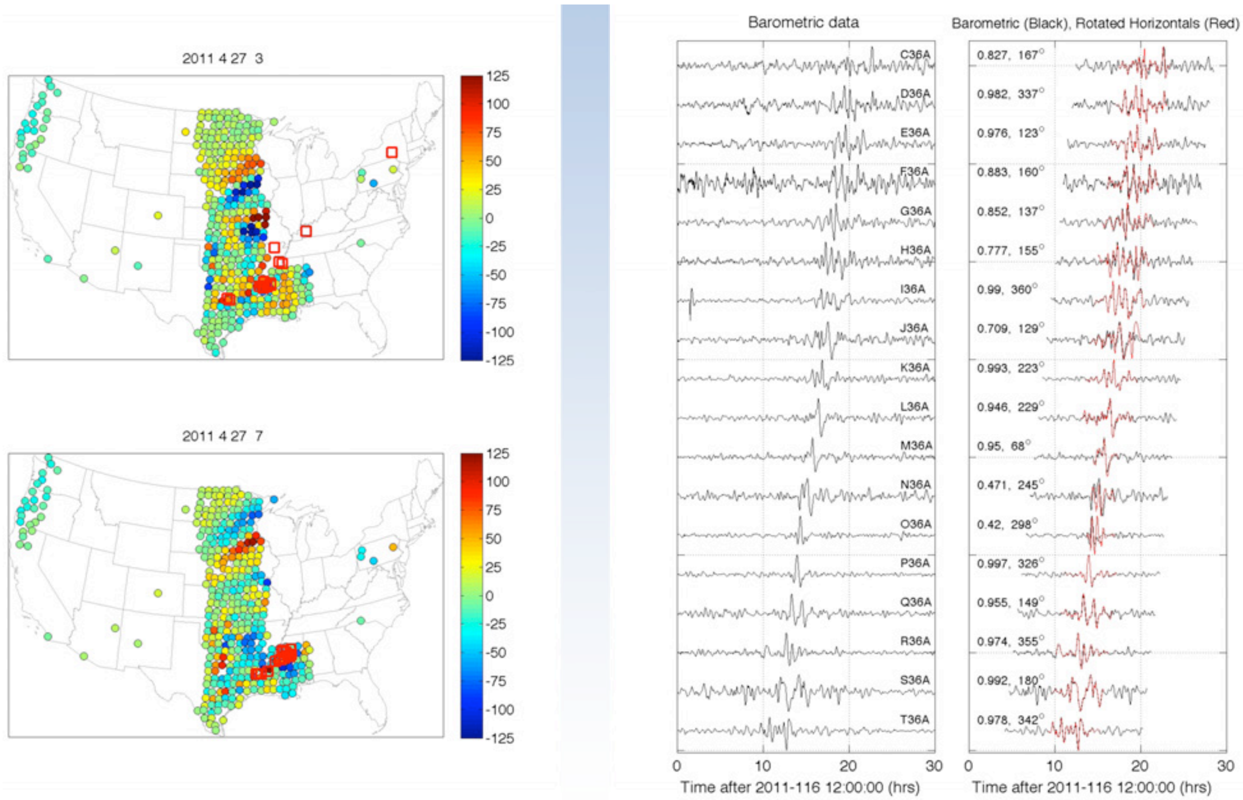


Figure 11 – As in Figure 10. Right two panels depict the waveforms of the infragravity waves as they propagate from south to north across the central US

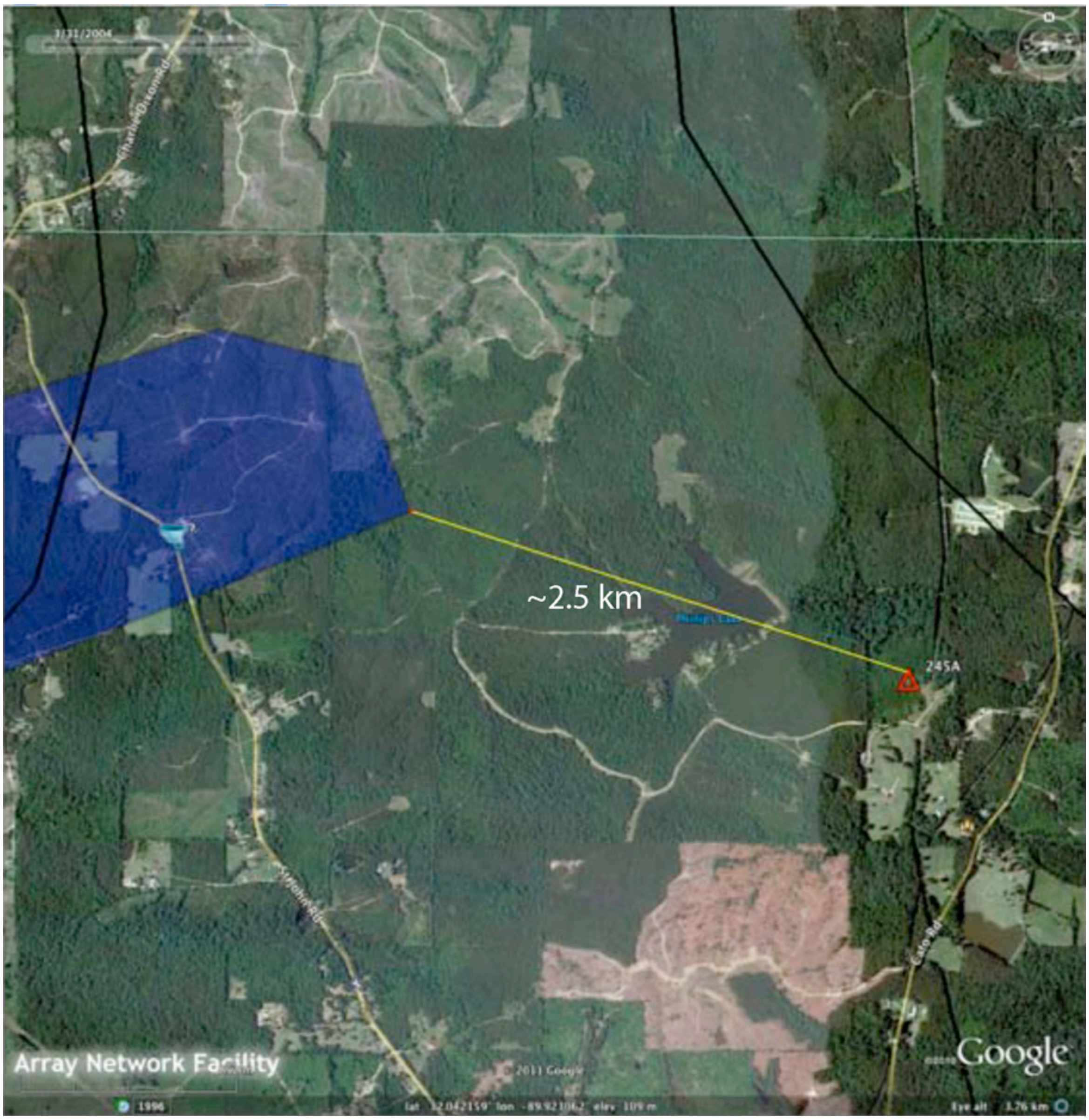


Figure 12 – TA station 245A, located southeast of Jackson, MS, located approximately 2.5 km from the general region of a tornado's dissipation (blue region) on April 4th, 2011.

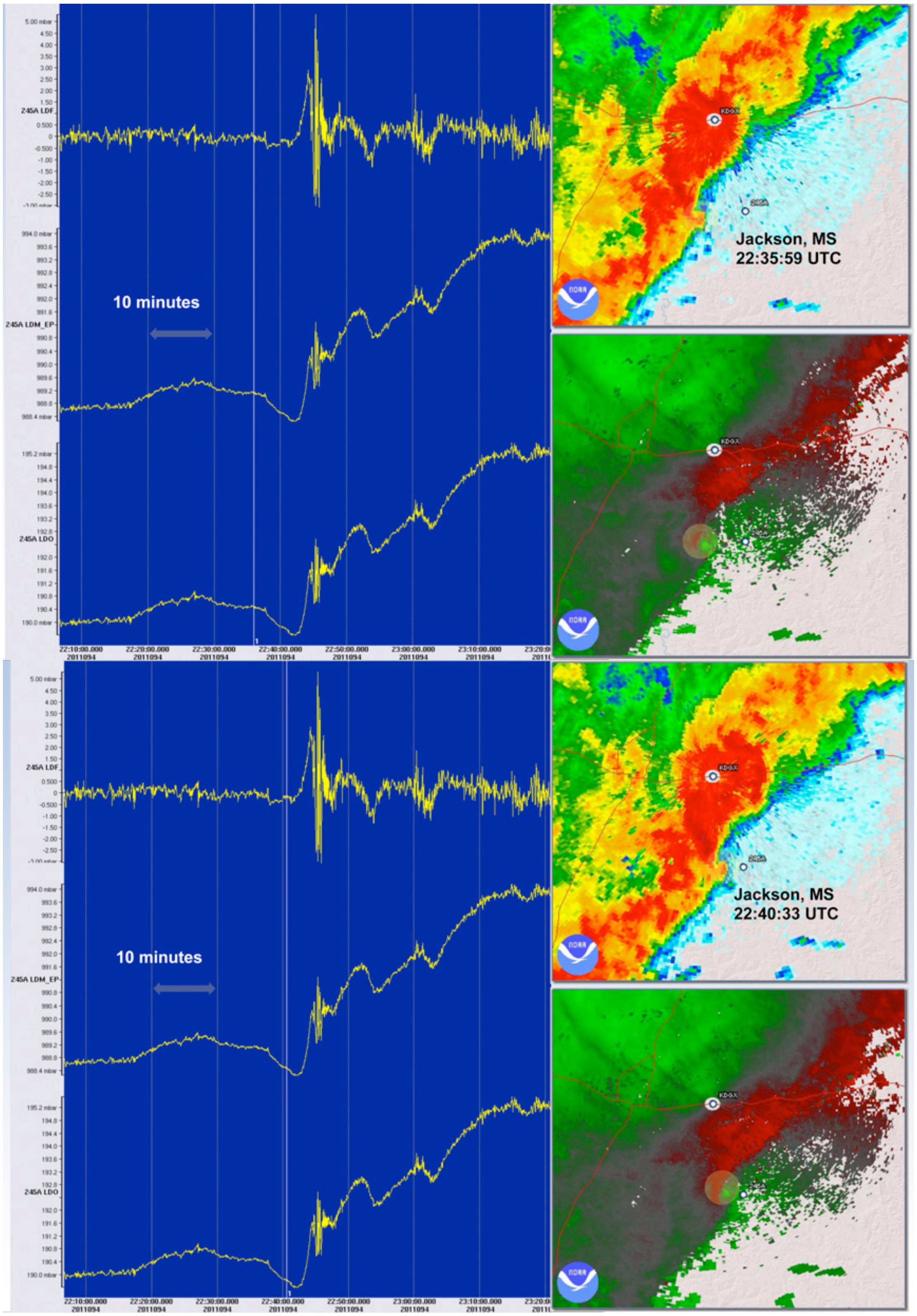


Figure 13 a and b, description below

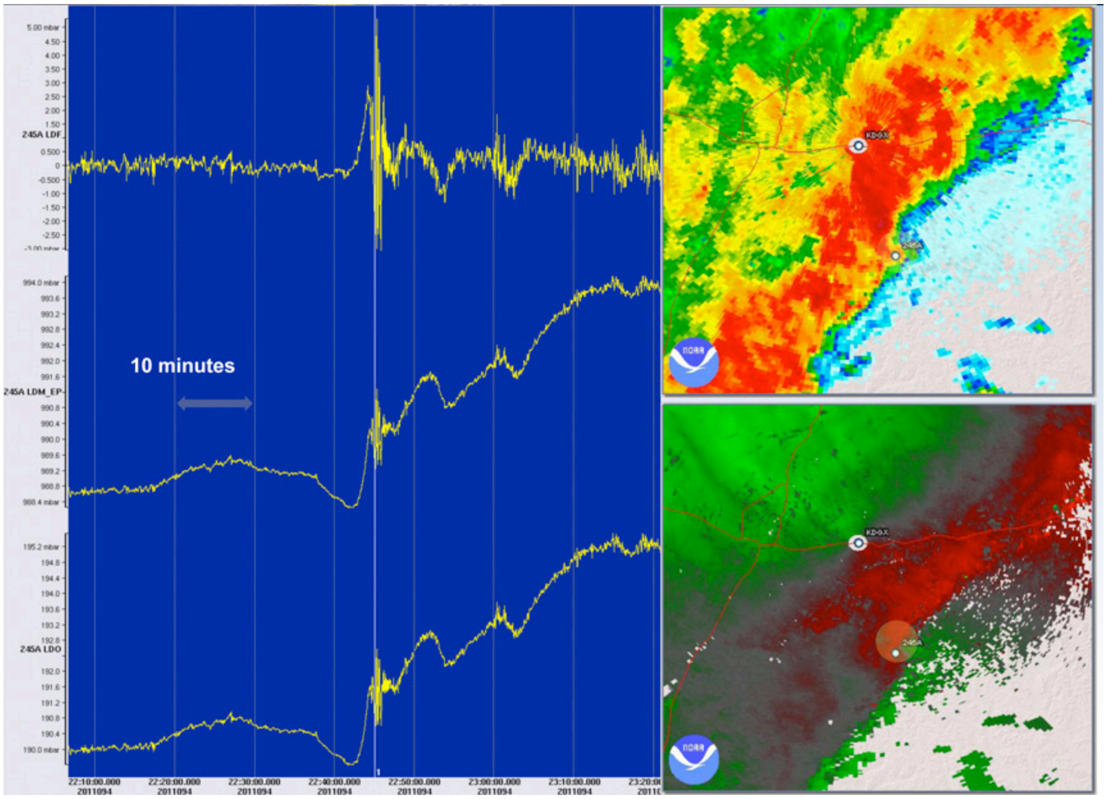


Figure 13 c – These three panels depict the raw data from station 245A (left). The left panels show 1 sps infrasound (top, in mb), 1 sps MEMS barometric data (middle, in mb) and 1 sps Setra barometric data (bottom, in mb – 800). Right images show Doppler radar data from the Jackson, MS Nexrad. For the right images the top panel is the reflectivity and the bottom panel is the velocity with the velocity couplet highlighted in each frame. White, vertical time bars on the left images correspond with the timestamps of the Doppler images to the right.

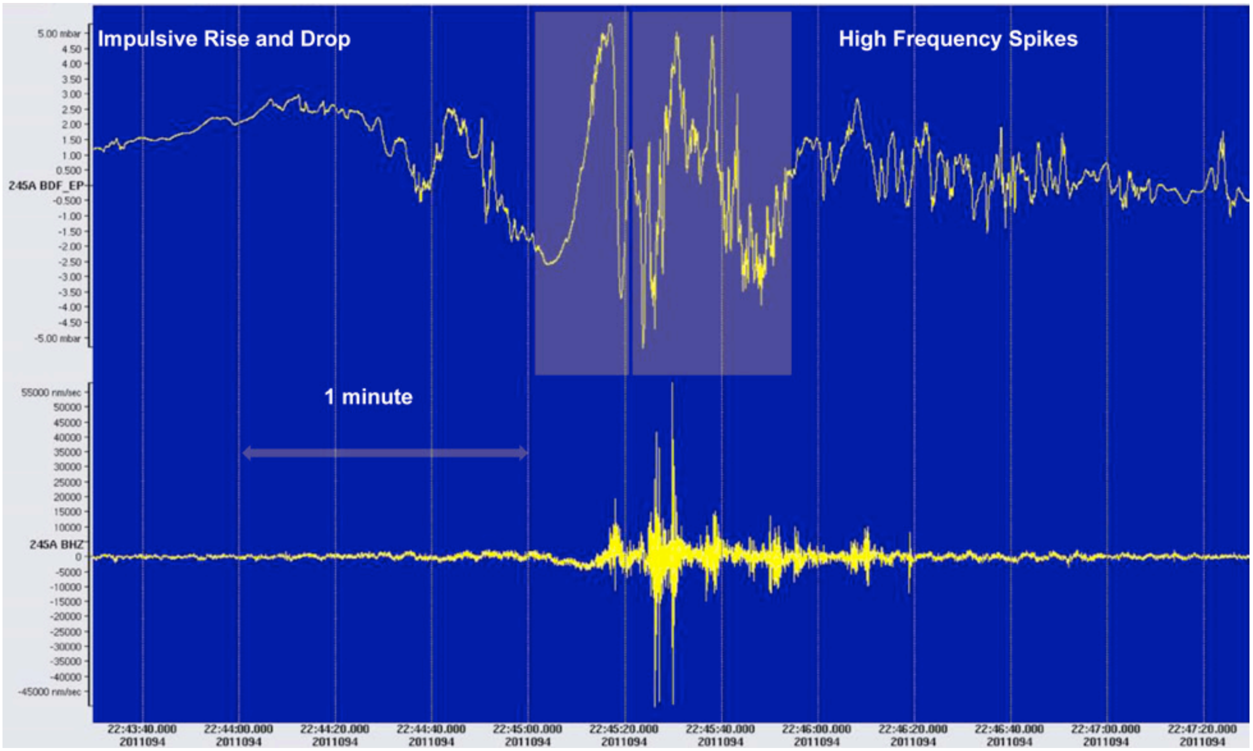


Figure 14 – Raw data from station 245A during the tornado approach. Top is the 40 sps infrasound, bottom is 40 sps seismic. Infrasound data reveals an impulsive rise and drop in the surface pressure of ~ 7 mb within 15 seconds as the tornado approaches. This is followed by a 35 second period of high frequency spikes and perturbations within the surface pressure field. The seismic data reveals clear ground motion as the tornado event approached.

Figure 15 – Station T38A located east of Joplin, MO as the devastating tornado passed by on May 22nd, 2011. Overlay of tornado track and estimated EF intensities provided by the Springfield, MO National Weather Service Office. Image shows that T38A was within ~ 1.7 km of the tornado as it passed nearby.

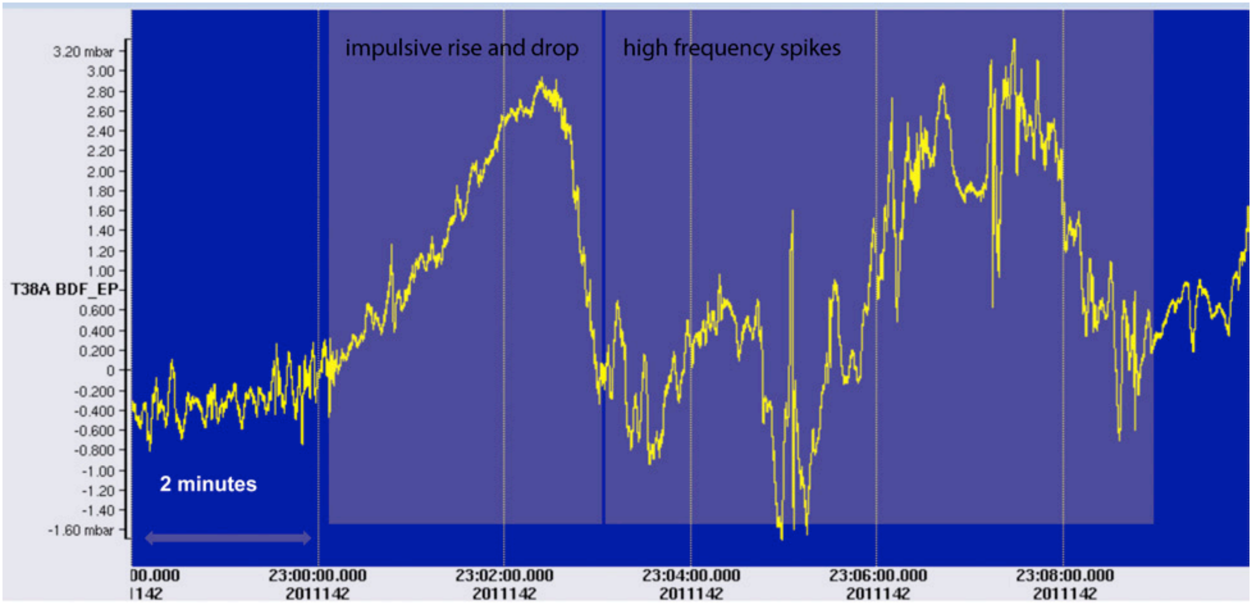


Figure 16 – As in Figure 14 but only for the 40 sps infrasound data and for station T38A as the Joplin tornado event approached on May 22nd, 2011. Like the Jackson, MS case on April 4th, 2011, there is a period of an impulsive rise and drop. In this case it is longer, ~ 3 mb over 2.5 minutes, followed by a period of high frequency pressure perturbations lasting for ~ 6 minutes.

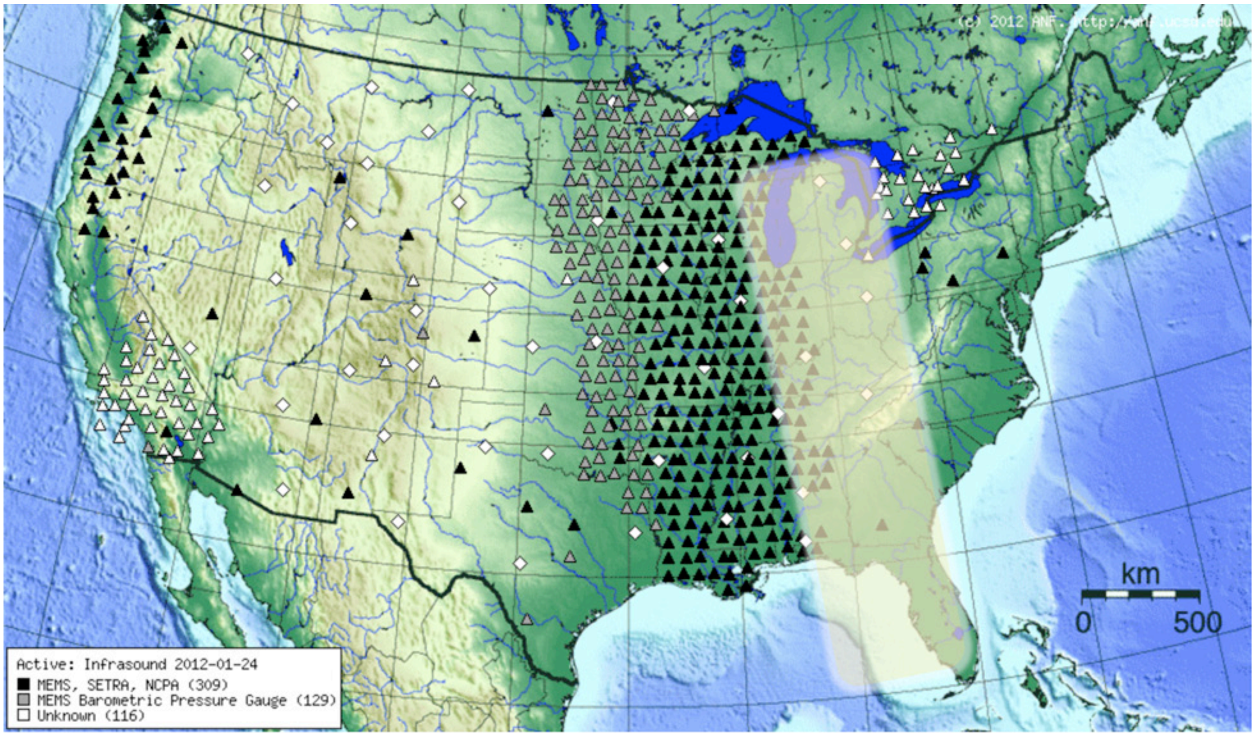


Figure 17 – As in Figure 7 but the highlighted region is the planned TA deployment throughout 2012.

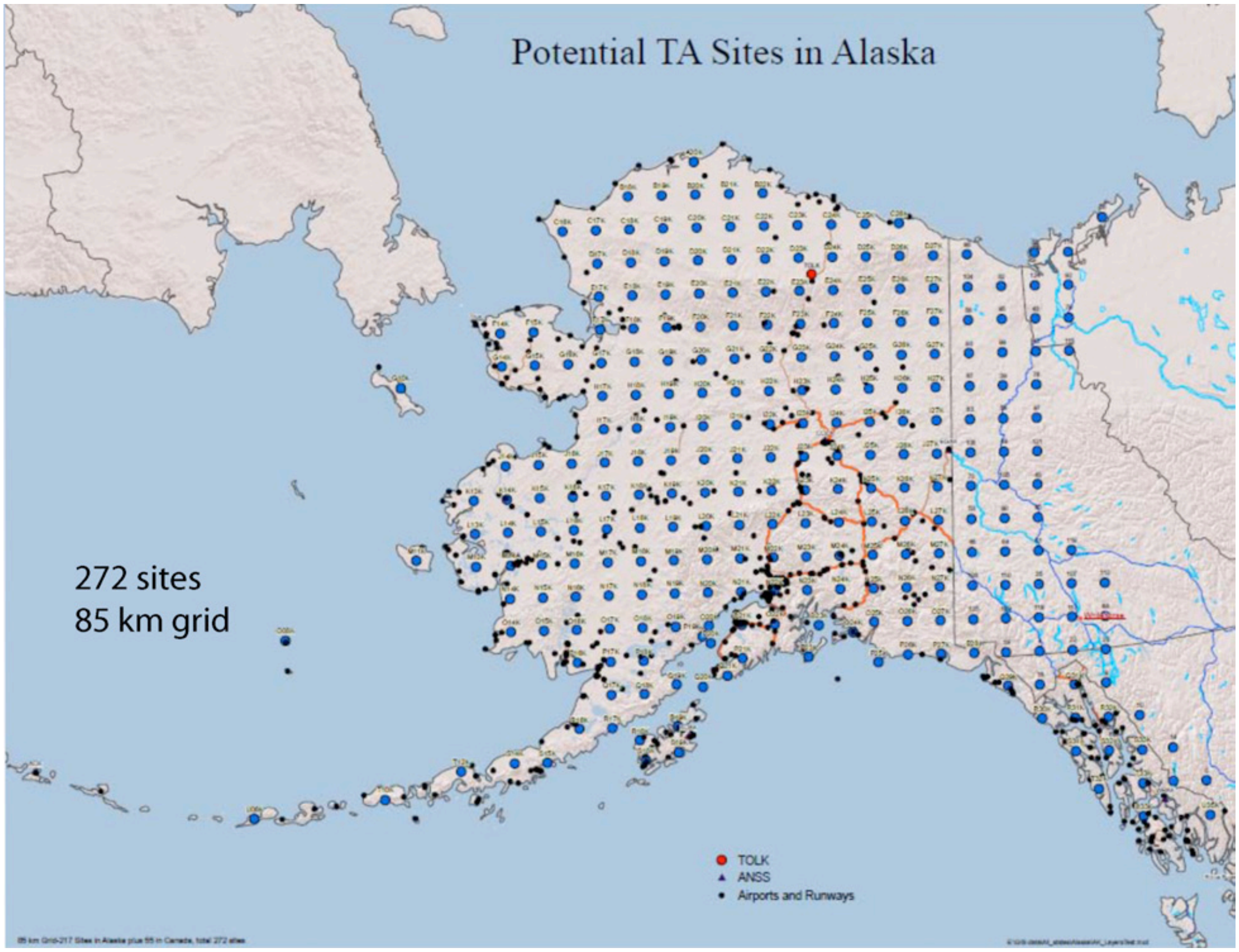


Figure 18 – Potential deployment footprint of the USArray TA network in Alaska starting in 2014. 272 potential sites with ~ 85 km grid formation.