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Observations of Weather Phenomena by NSF EarthScope USArray Seismic and Pressure Sensors

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1. ABSTRACT

On June 22nd, 2010 two severe weather systems were tracked across portions of the Great Plains by the NSF Earthscope USArray Transportable seismic network; a dense array of over 400 seismic stations with a 75 km station spacing located in grid formation across the continental United States. While the seismic stations are equipped with a standard package of seismic instrumentation, many are also equipped with internal VTI SCP1000 MEMS barometric pressure gauges. Data from these sensors show clear correlation in time with thunderstorm cell passage and pressure changes and low-frequency seismic noise at the target USArray stations. The unique nature about all instrumentation onboard the USArray stations is that data is recorded continuously at 1 sps and transmitted in real- time. With the high quality of atmospheric pressure data return and a spatial distribution that is denser than the NEXRAD Doppler array, the USArray network provides a unique perspective on surface weather research and potential tool for now-casting severe weather events. This paper will present the observations from June 22nd 2010 and other storms to introduce potential research areas based on the various data acquired.

2. INSTRUMENTATION AND DEPLOYMENT

Equipment at each USArray Transportable Array (TA) station is housed within an enclosed vault (Figure 1). While the seismometer is housed in a separate enclosure at the base of the ~2m vault, the computer and communications equipment is housed near the top of the vault. GPS, satellite telemetry, and a solar panel are located outside of the vault. Part of the computer and communications enclosure includes the MEMS barometric gauges. These sensors were installed as the TA network rolled into the Great Plains. As of December 2010 approximately 300 of the nearly 500 stations included MEMS barometers (Figure 2). While MEMS barometers were initially the sensors of choice for monitoring surface pressure, newer stations will incorporate Setra Systems model 278 barometers.

But the MEMS barometers have so far proven to be useful and highly reliable. Figure 3 shows the instrumentation, features and channel naming convention, while Figure 4 compares the pressure spectral density of several instruments, including the MEMS and impending Setra 278 sensors.

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As shown in Figure 3 there are three data channels in any stations' datalogger devoted to data recorded via either barometer. The most significant of the three channels is the vault's internal absolute pressure (EP-LDM). These data are transmitted in real-time to the IRIS Data Management Center in Washington State.

3. SIGNAL TYPES

Each data channel within a TA station's datalogger is configured to monitor specific signals of data. For seismological analysis it is important to understand that seismic energy propagates in two directions: P-waves follow the vertical (Z) plane of motion while slower S-waves follow horizontal (X and Y) planes of motion. Data channels associated with seismometers are therefore configured to display ground motion in specific directions of an X-Y-Z plane.

A typical signature from a large earthquake detected across the USArray network can be seen in Figure 5a. In this figure only the vertical (Z) energy propagation is displayed. In contrast to this example, a case study from June 22nd 2010 reveals a different pattern in the vertical motion earthquake channels (Figure 5b). What is normally a situation where the pulse of energy associated with a P-wave arrival spans the course of several minutes across the entire USArray network has changed. Now this pulse of energy appears spread-out over several hours over isolated sections of the network. A closer examination of even more stations from this case study is shown in Figure 6.

Pressure data from several of the TA stations are what ultimately help to explain this scenario (Figure 7). The seismic signals being observed were not associated with earthquakes at all, but rather passage of severe weather. The Storm Prediction Center and data from Doppler images confirm the passage of gust fronts from severe weather over these TA stations coinciding with time of signal pulses within the seismic and pressure observations (See submitted abstract 2A.3).

4. DATA VIABILITY

A closer examination of three stations (F28A, F29A and F30A) on June 22nd 2010 reveals the similarities in signal acquisition for one of gust front case studies (Figure 8). The initial unfiltered seismic data in Figure 8a shows rough similarity with the pressure increases. Applying a low-frequency filter to the seismic data, however, reveals remarkable similarities between surface pressure fluctuation and crustal response

(Figure 8b). This suggests energy dispersion from the gust front passage into the crust.

An even closer examination at TA station F28A reveals how the crust responds to gust front passage at any station (Figure 9). Integration of the filtered seismic data within the time frame of the storm's passage reveals the total displacement of the crust in response to the gust front (Figure 9c). Additionally, the derivation of observed surface pressure reveals the change in surface pressure over time (Figure 9f).

Crustal response observations are not isolated to severe thunderstorm passage. Infrasound studies of atmospheric acoustics are also possible by analyzing the seismic data. A case study involving a large blast at Utah's UTTR facility on June 11th 2007 is shown in Figures 10 and 11. Figure 10 shows the vertical seismic data from several of the TA stations at the time of the blast. Different acoustic propagation sources (i.e. direct or ducted signals from the stratosphere or thermosphere) are shown. Figure 11 represents the map of the study area with TA stations used in the analysis highlighted in yellow.

The detailed, analytical possibilities of TA data are only possible due to the one sample-per-second data acquisition rate. Another method of highlighting the viability of the data provided through USArray is to compare it with data sampling from the ASOS network. TA station R35A and ASOS station KEMP lay within ~ 1.5 km of each other and also at roughly the same altitude of 367 m. As is expected, the sampling resolution of a data source that records at roughly once per hour does not compare with data recorded at one sample-per-second (Figure 12). ASOS stations cannot capture smaller time-scale events such as the gust front shown in Figure 10, even when they record multiple samples per hour during severe weather events.

5. PLANNED DEPLOYMENT AND RESEARCH

In addition to improved pressure sensors (Setra 278), newly installed TA stations will include infrasound equipment (Figure 13). The applications of these sensors will only bolster analysis of case studies such as the UTTR blast described in the previous section. Additional instrumentation options are currently being investigated. The USArray network will continue to roll eastward over the next few years as stations are gradually removed from the western flank and reinstalled at the eastern flank. When its deployment schedule along the East Coast of the United States is completed, an additional planned deployment will commence for Alaska.

In the meantime the copious data coming in from the TA stations proves to be a continuous source for new research opportunities. Real-time observations of severe weather can potentially help now-casts, while the energy distributed into the crust through storm passage is an entirely unique avenue of seismology. Furthermore, the addition of infrasound equipment will help provide a new avenue of atmospheric acoustic analysis as data is received over the USArray network in real-time.

6. ACKNOWLEDGEMENTS

We would like to thank the data management team at the IRIS DMC as well as USArray installation teams from Earthscope for all of their continued hard work in maintaining the USArray network.

7. REFERENCES

Hedlin, M. A. H., D. Drob, K. Walker and C. de Groot-Hedlin, 2010. A study of acoustic propogation from a large bolide in the atmosphere with a dense seismic network. J. Geophys. Res., 115, 1–17.

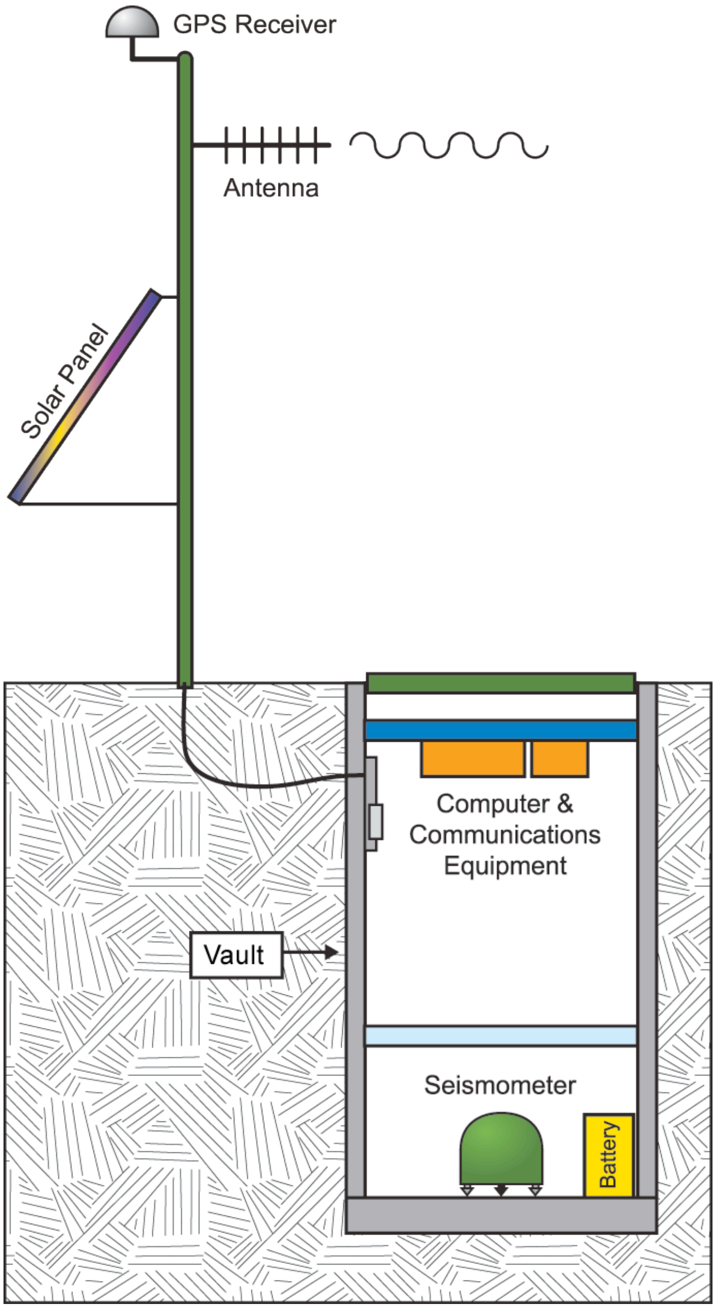


Figure 1. Typical vault installation at each USArray station location. The seismometer is protected in a separate enclosure at the base of the 2m vault while the computer and communications equipment is housed near the top of the vault, but just below the surface. The MEMS barometric gauges are installed within that instrumentation enclosure. Telemetry is located outside of the vault, including satellite and GPS communications and a solar panel for power.

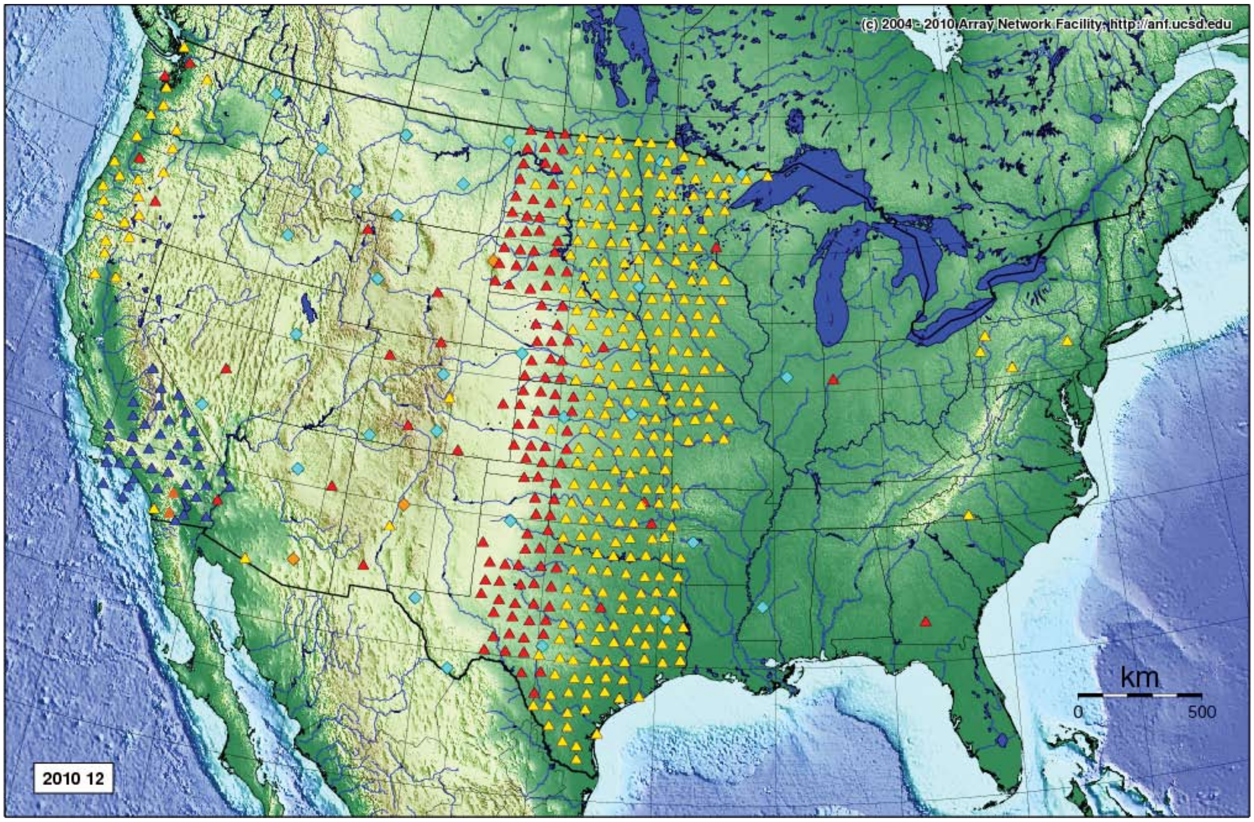


Figure 2. Layout of the USArray Transportable Array (TA) network as of December, 2010. Yellow triangles indicate stations that have been installed with MEMS barometric gauges and record pressure data in real-time at one sample per second.

SEED Channels available from the DMC:

- EP-LDM 1sps absolute pressure in vault
- EP-LIM 1sps relative humidity in enclosure
- EP-LKM 1sps temperature in enclosure

Features:

- DSP-enhanced MEMS barometer
- 0.1 Degree Temperature
- Internal Humidity
- Optional 3-channel 24-bit “expander”--up to 40sps
- Interface to SDI-12 meteorological devices
- Precision Phase-Locked Time base
- Serial Interface to Q330

Figure 3. Pictures of the Setra 278 barometric sensor attached to some instrumentation (upper-left) and picture of the MEMS barometric sensor (upper-right). Also some descriptive information related to the features of the MEMS barometer and channels available via IRIS DMC.

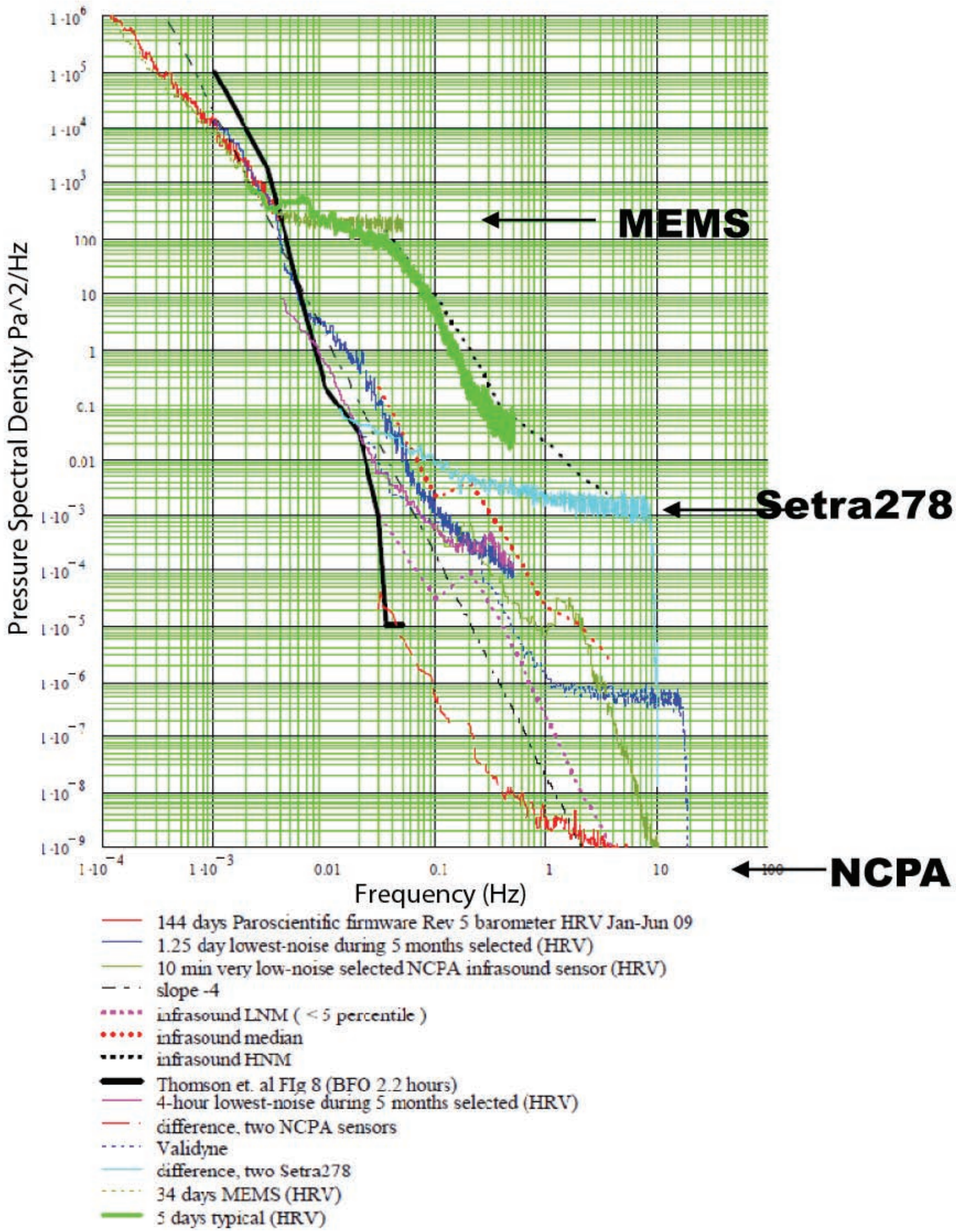
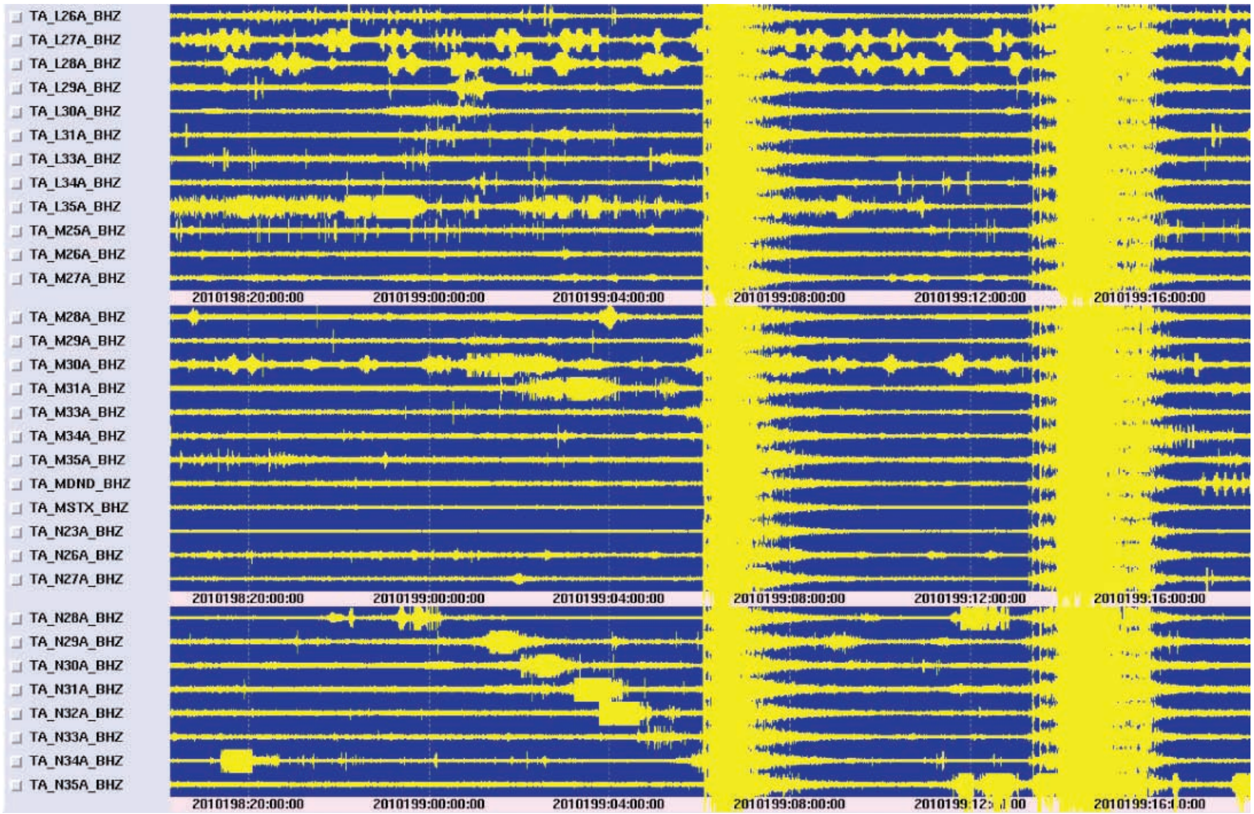


Figure 4. Detailed chart depicting the viability of each pressure sensor. The original pressure sensor configuration at each TA station included MEMS barometers (dashed green line), which are shown to perform less efficiently than other options. The Setra 278 barometer (light blue line) shows to provide better coverage of pressure in terms of spectral density. Finally, the NCPA infrasound (solid green line) is shown to provide the best pressure coverage.



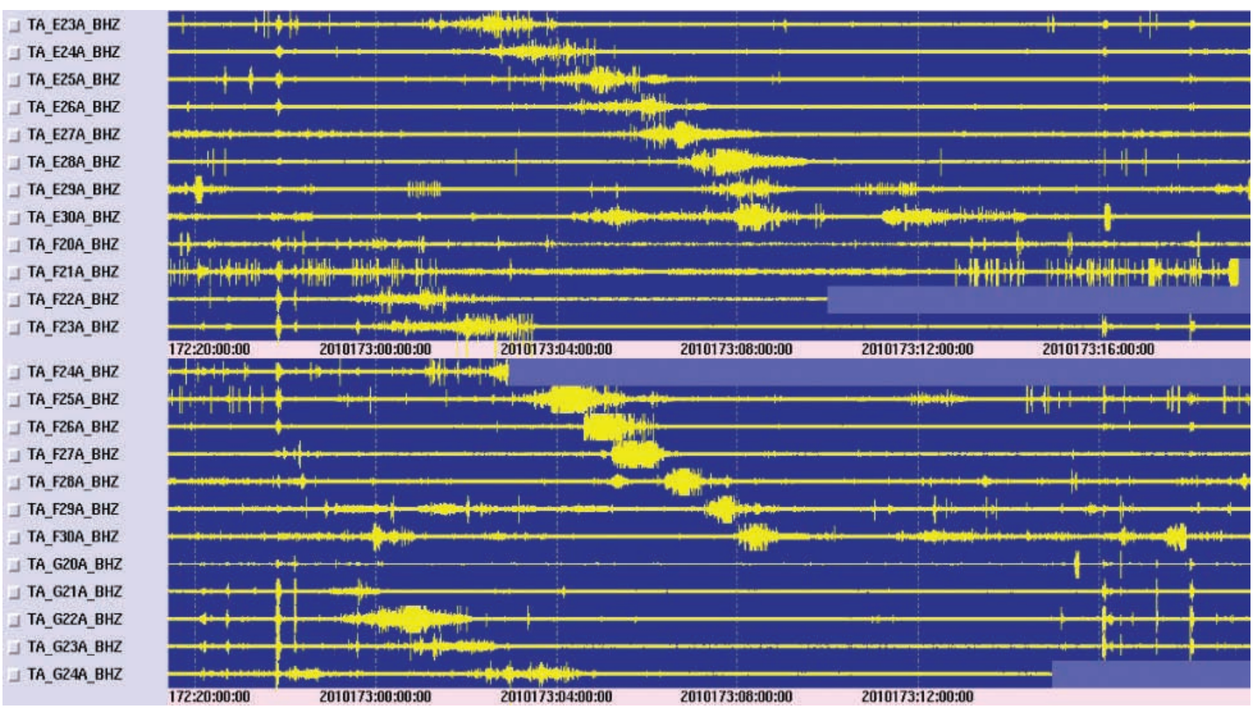


Figure 5a (top) and Figure 5b (bottom). Both are vertical seismic energy waveforms. Figure 4 shows a typical earthquake signal signature for a large teleseismic (long distance) event. This example focuses on only a portion of the entire USArray network available, but shows clearly the time span of seismic energy as it propagates along the crust. Figure 5 is a contrast case study from June 22nd 2010, where the usual time span appears “spread out_ over ~ 6 hours.

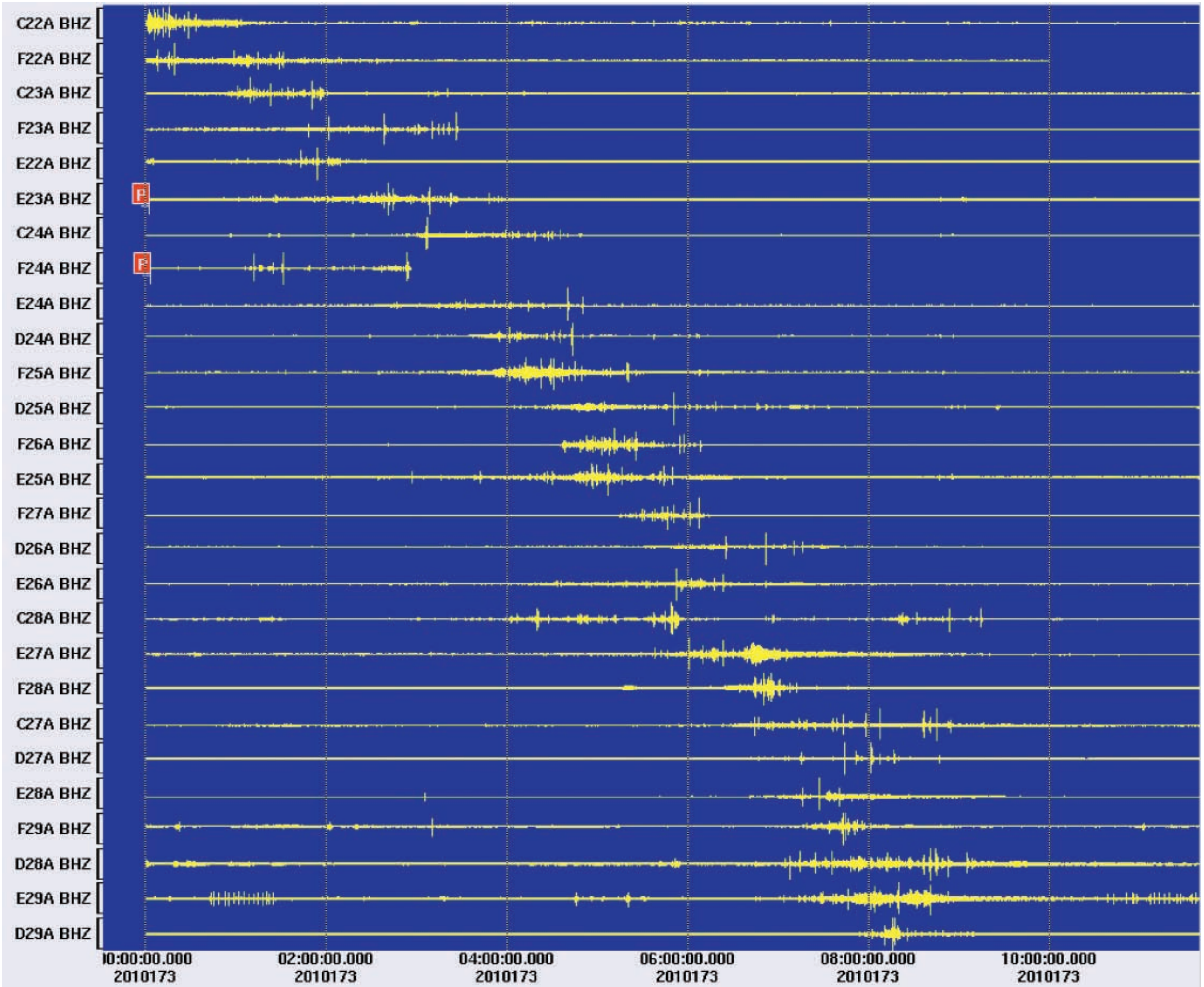


Figure 6. More in-depth examination of the vertical seismic energy from the June 22nd 2010 case study. The energy covers a large portion of the northern section of TA stations throughout North and South Dakota.

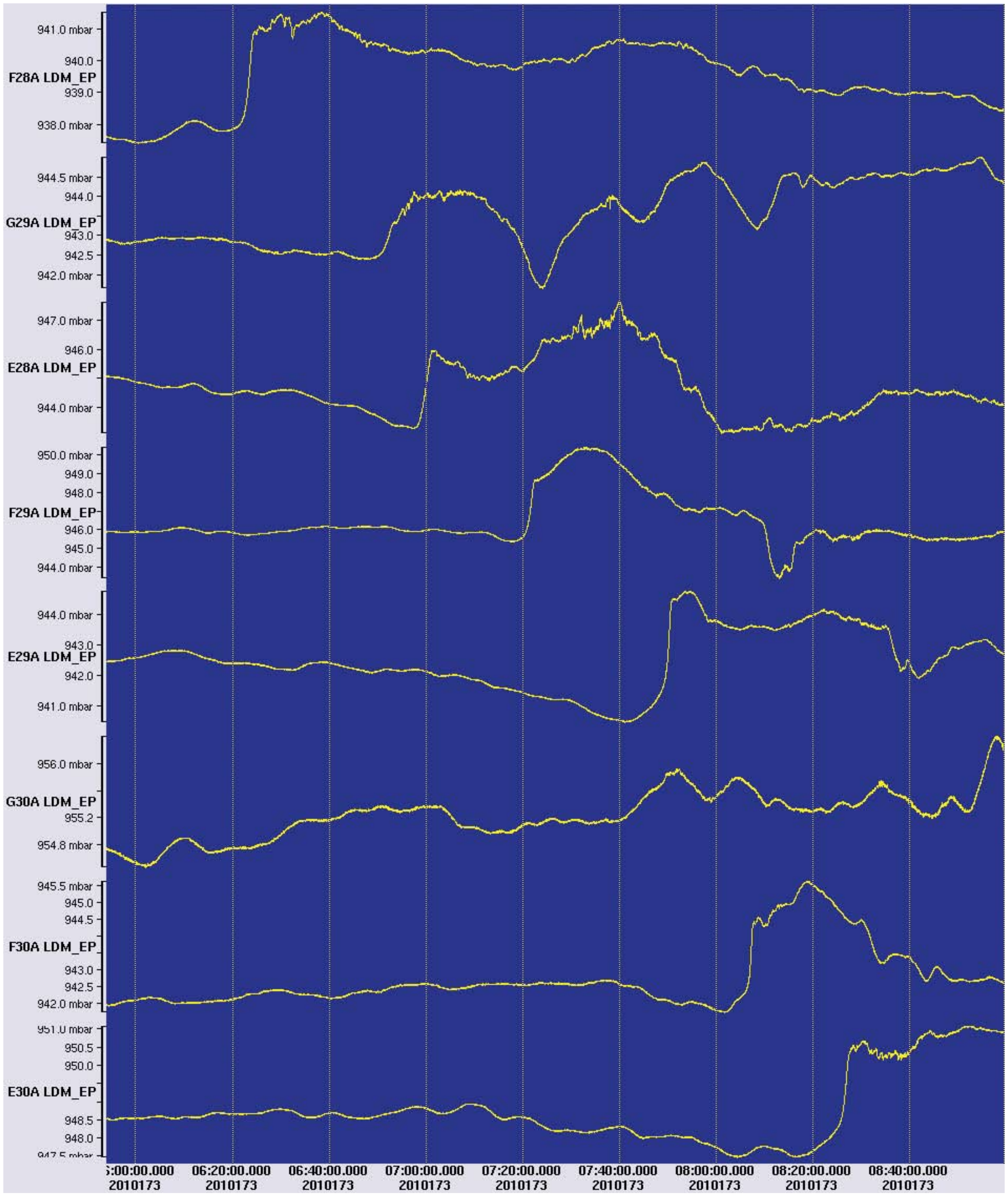
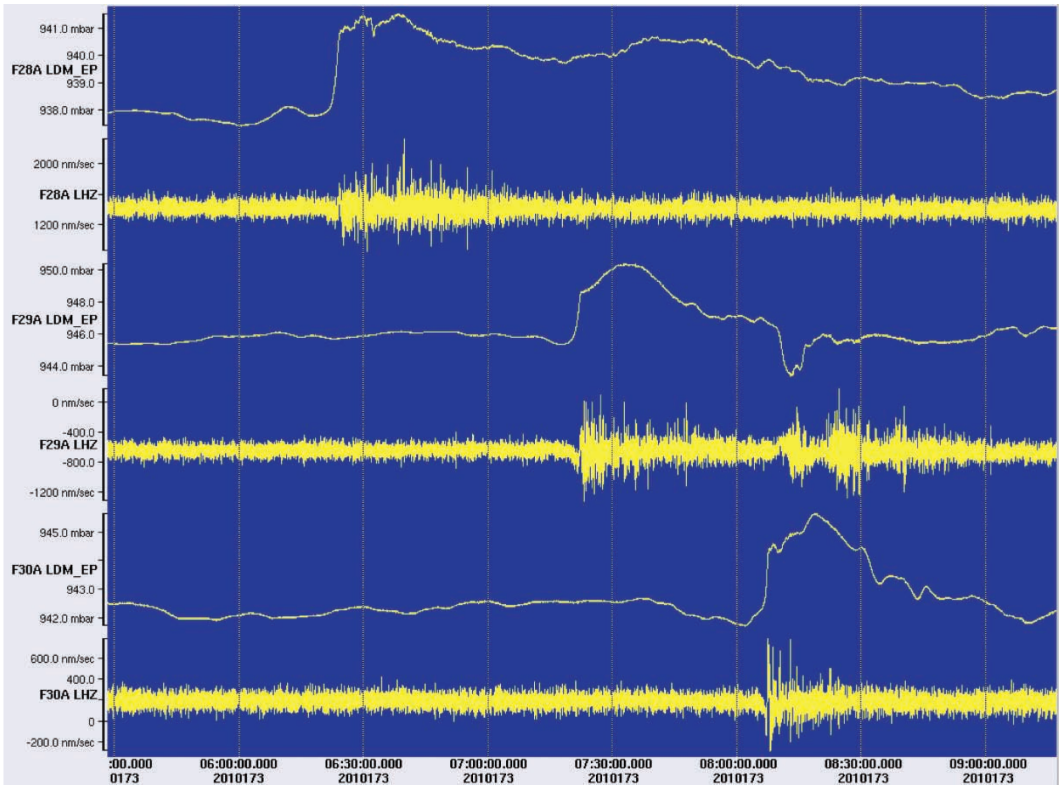


Figure 7. Examination of the pressure data during the June 22nd 2010 case study reveals sharp pressure changes coinciding with seismic noise. Additional analysis (not provided in this paper) confirms the passage of severe thunderstorms and a large gust front.



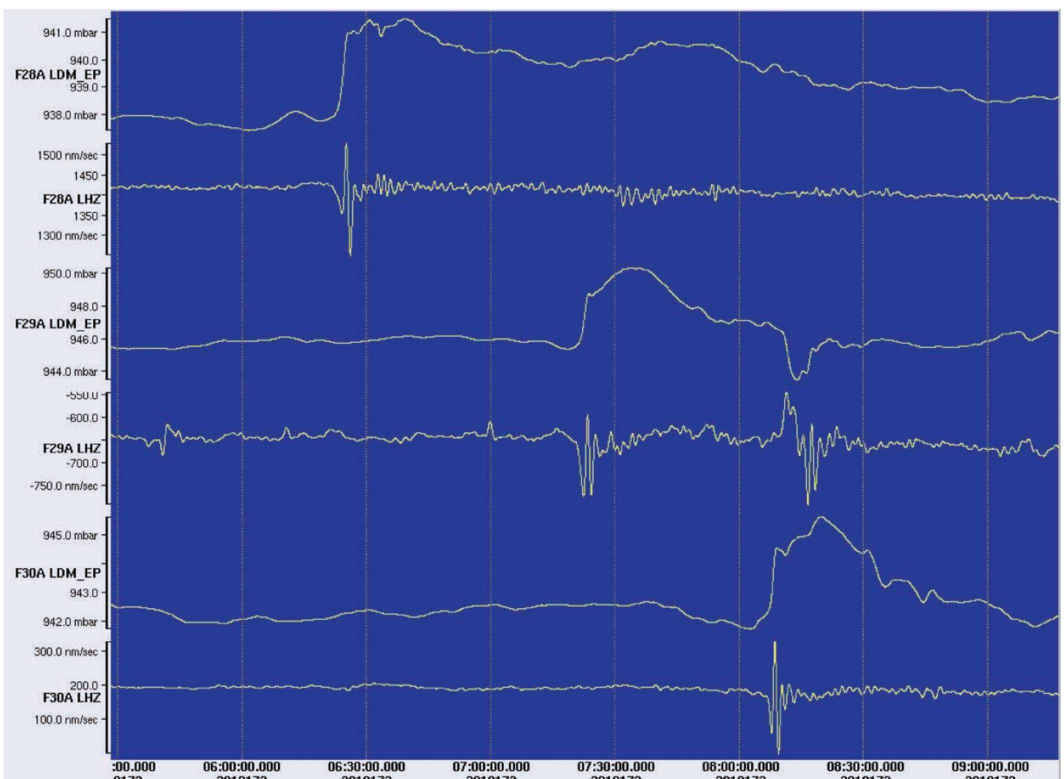


Figure 8a (top) and 8b (bottom). Figure 8a compares the pressure and unfiltered seismic data at three stations: F28A, F29A, and F30A. The initial major pulse of pressure increase coincides with an increase of seismic noise. Figure 8b shows much more dramatic correlation between the pressure and seismic attenuation with a low frequency filter (0.01 Hz) applied to the seismic data.

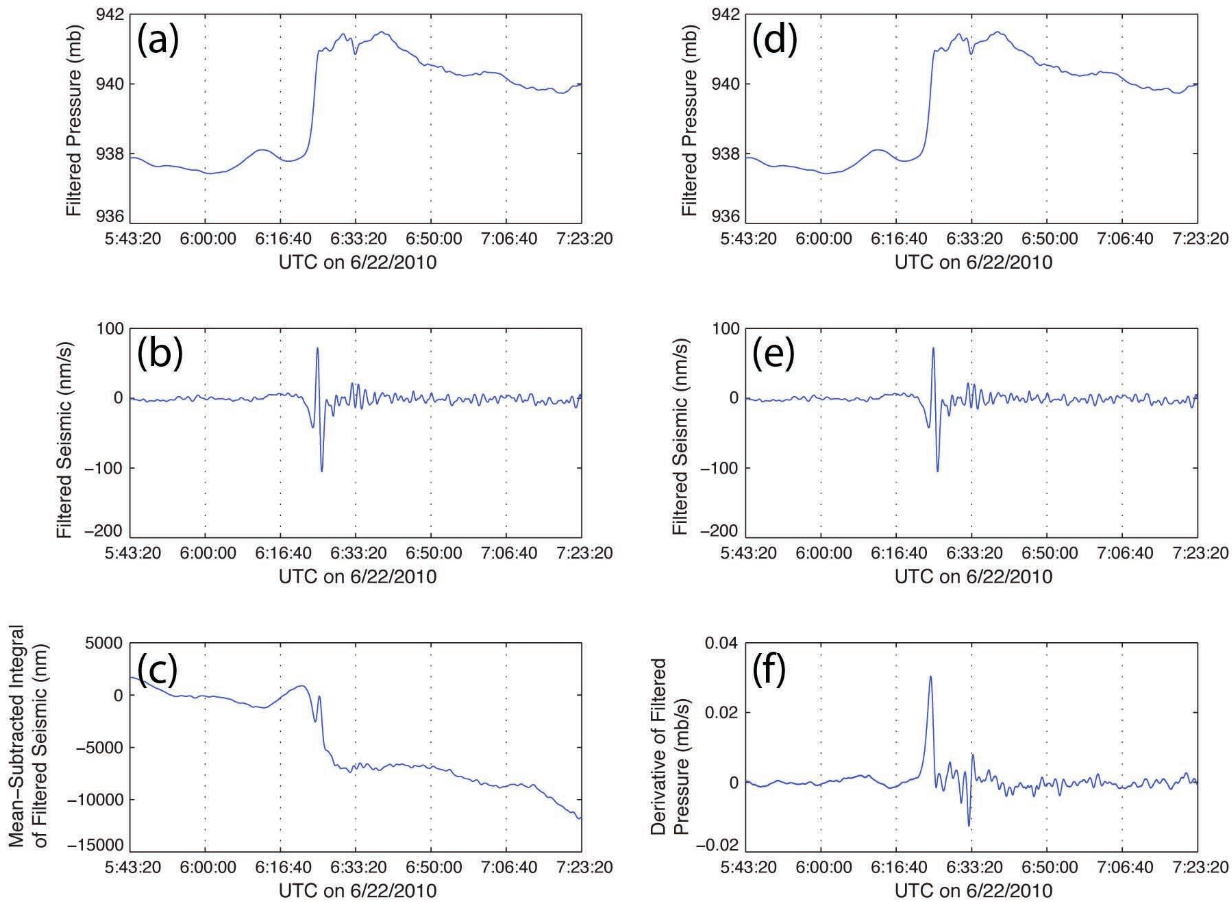


Figure 9. Panels (a), (b), and (c) reveal the crustal response to pressure jumps associated with gust front passage. Panels (a) and (d) show the pressure at F28A with a low frequency filter (0.01 Hz) applied. Panels (b) and (e) show the filtered seismic data (also 0.01 Hz) centered around zero nm/s. Panel (c) reveals the integration of the filtered seismic data, ultimately describing the total displacement of the crust in response to the gust front passage (specifically during the time window shown). Panel (f) is the derivative of the filtered pressure data, which therefore depicts the change in pressure over time.

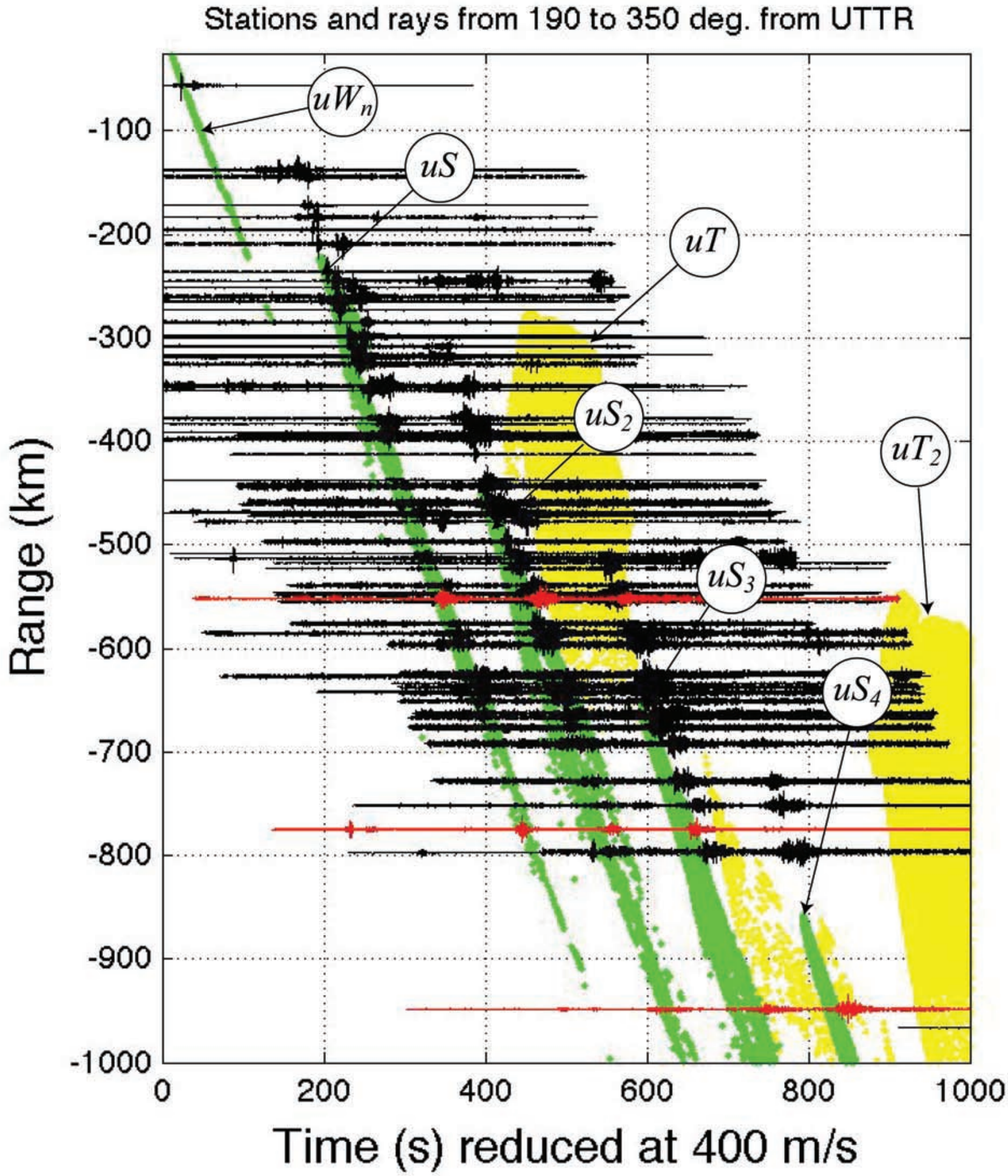


Figure 10. Vertical component seismic recordings of the UTTR blast that occurred on day 162 (June 11) are plotted in black plotted with array recordings shown in red. All stations were located between azimuths of 190° and 350° from UTTR (and are highlighted in the map above). All traces have been bandpass filtered from 0.8 to 3.0 Hz. Four branches of infrasound signals are clearly evident in this figure. The traces shown in this plot are replotted and shown with rays ducted in the thermosphere (shown in yellow) and below the thermosphere (green). The signal observed close to the source likely propagated in a low-level tropospheric duct. All branches have been identified using the nomenclature of Hedlin et al. (2010). The sub-thermospheric rays predict the onset times of the branches very well however do not predict signals observed close to the source.

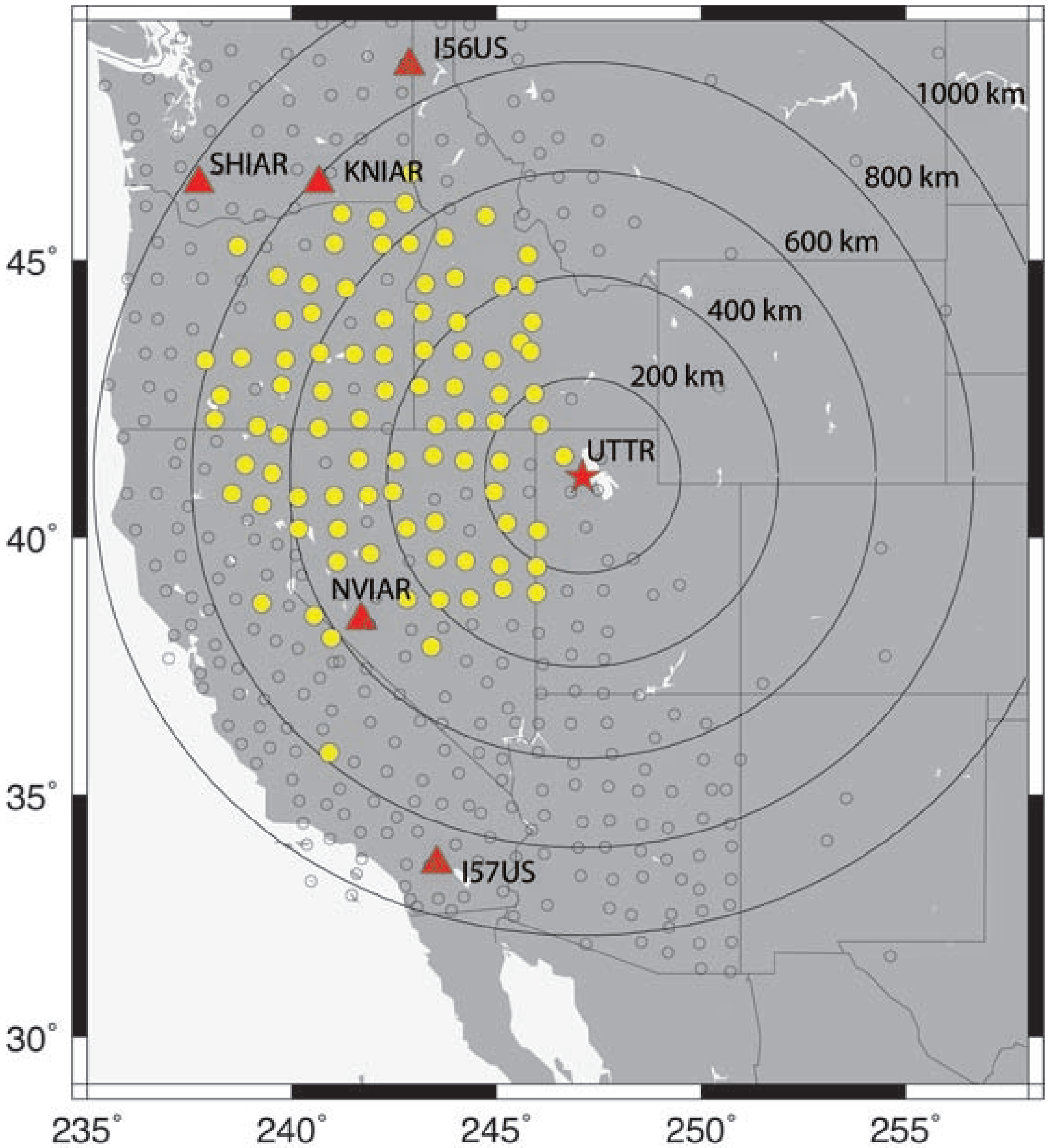


Figure 11. Map of the study area showing the configuration of USArray TA stations on June 11th 2007. At this time there were ~ 375 broadband seismic stations in the TA within 1000 km of UTTR. The subset of TA stations used in the plot to the left is highlighted in yellow.

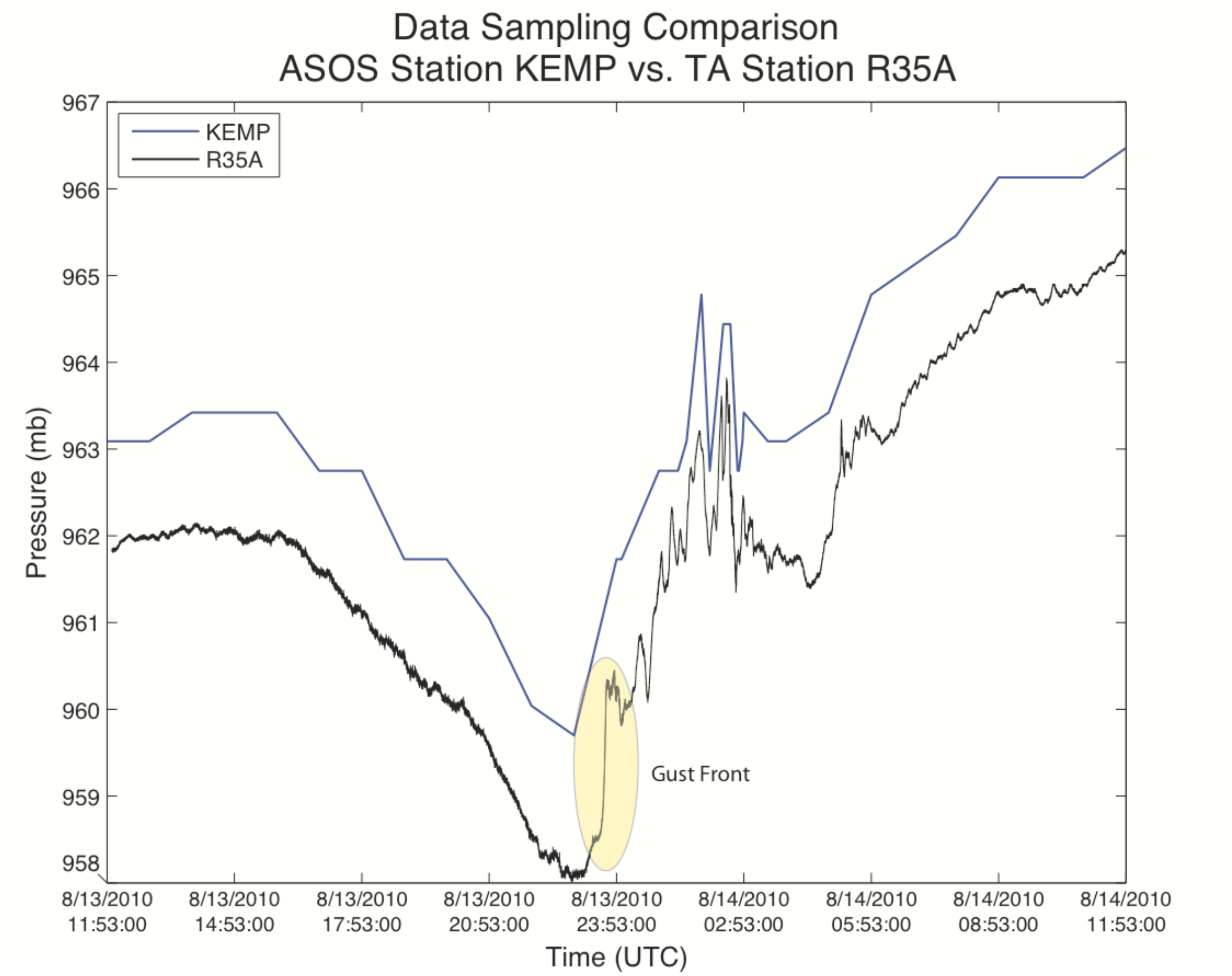


Figure 12. One sample per second (R35A) vs one sample per hour (KEMP) compared over a 24-hour period of time. The gust front shown corresponds to a case study from August 13th 2010. During the early UTC hours of August 14th it can be seen that station KEMP records with a higher sampling rate than once per hour. This is typical with ASOS stations during severe weather events, but this never matches the sampling frequency needed to capture a gust front.

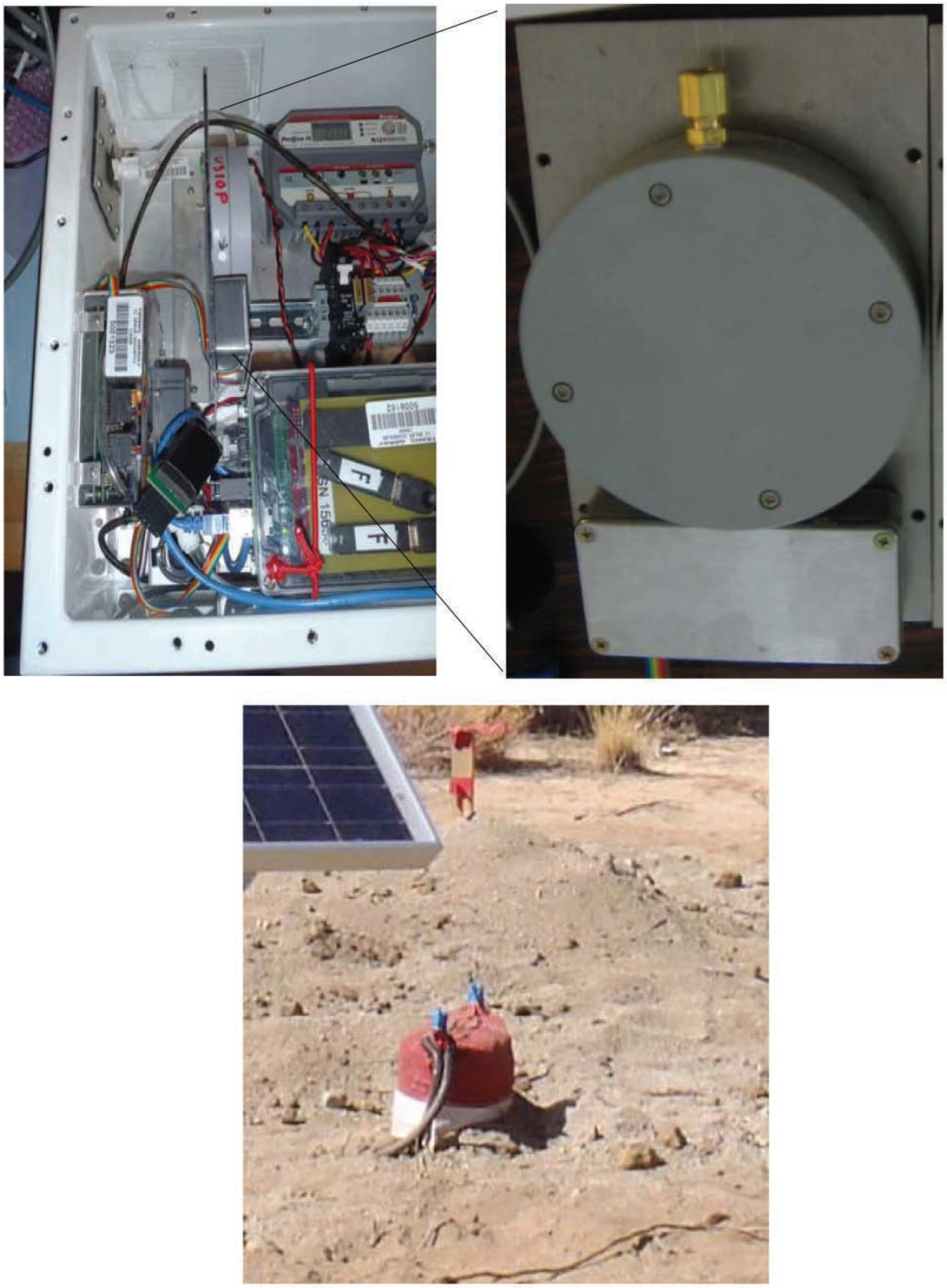


Figure 13. Photo in upper-left depicts a section of the vault interface enclosure, part of the computer and communications section at each vault. Two black lines indicate the location of the infrasound sensor (upper-right picture) to be deployed at each future station. The bottom picture reveals the installation configuration for the intake hose connected with the infrasound sensor. Essentially it is an overturned bucket filled with gravel and loose stones. The intake hose is bent into an upside down “U” formation to prevent water from seeping into the instrumentation.