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Tracking Outflows from Severe Thunderstorms Using NSF EarthScope USArray Pressure Sensors

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1. ABSTRACT

The NSF Earthscope USArray Transportable seismic network, a dense array of over 400 seismic stations deployed in a grid with 75km station spacing, provides real-time monitoring of seismicity as well as surface barometric pressure from instrumentation housed within enclosed vaults. On June 22nd 2010 several of the stations in North and South Dakota, Nebraska and Kansas observed sudden and dramatic increases in surface pressure (~2.0 to 3.5 mb in less than 5 minutes, with a gradual increase following). Doppler radar, local observations and infrared satellite images confirmed the passage of severe thunderstorms coinciding with these pressure jumps. On further investigation, it was determined that the USArray stations observing the pressure jumps were actually observing outflow gust fronts from the thunderstorms. Analysis of additional severe thunderstorms events on separate occasions also confirms the passage of thunderstorm outflows coinciding directly with pressure jumps among the various USArray stations. The data presented within this paper will reveal the temporal nature and speed of these outflows using the high-resolution continuous 1sps pressure data from several USArray stations as a backbone. Additional data will be provided from Doppler radar and satellite images as well as local observations. The overall utility and viability of the USArray pressure data will then be discussed as a supplemental aid for now-casting severe weather events.

2. INTRODUCTION

The USArray Transportable Array of seismic stations is provided via the National Science Foundation and their Earthscope program. In April 2004, the USArray experiment began as an ambitious seismic data collection platform. Stations are equipped with a common suite of instrumentation including a seismometer, dataloggers, satellite or cellular telemetry and GPS positioning equipment. Deployments adhere as closely as possible to a planned strategic grid formation with roughly 70 km spacing. The first letter of a station name designates the row, “A” being the northernmost row. The second and third numbers designate the column in the grid increasing toward the east. The nature of the network is in its designation as a transportable array (TA) – stations are removed after about two years and reinstalled further east. As a result, the TA network “rolls” across the country as the experiment progresses. Some stations have been redeployed at older locations or left behind permanently per agreements with regional seismic networks. Thus, the initial station install base of approximately 400 active stations along the west coast of the continental United States has grown to over 500 by the end of 2010. Furthermore, the TA stations record data between 1 and 40 samples per second and transmit it, in real-time, to the Array Network Facility (ANF) in San Diego and then to the IRIS Data Management Center in Washington state. This allows seismologists and researchers to analyze data in real-time to meet the demands of news agencies as well as the general public when a large earthquake event occurs.

As the TA network was being installed at approximately 100° W each station was installed with internal VTI SCP1000 MEMS barometric pressure gauges. These instruments also allow surface pressure readings to be recorded and transmitted in real-time at one sample per second. As of the end of 2010, over 300 of the 500+ stations had been deployed with MEMS gauges and were recording surface pressure in this fashion. The majority of stations were located in the Great Plains.

While the USArray network was initially designed to be a seismological research experiment, it is only with the recent implementation of the MEMS barometric pressure gauges that the network is additionally viable as a real-time surface weather-monitoring platform. Weather monitoring networks represent a vital tool for the purpose of now-casting severe weather scenarios but are often confined by regional and data access limitations. With the USArray TA network there now exists a large, real-time surface weather network with high spatial resolution, sampling precision and data that is freely available to the public.

3. OBSERVATIONS

Researchers with the analytical team of the ANF discovered evidence in both seismic and pressure data corresponding to the passage of severe thunderstorms over portions of the TA network on June 22nd 2010. These observations coincide with those of the National Oceanic and Atmospheric Administration’s (NOAA) Storm Prediction Center (SPC). The evidence in the pressure data revealed sudden increases in pressure by as many as 4 mb within 5 minutes. This was not isolated to the June 22nd case, as several dozen similar case studies would eventually be discovered within the TA pressure data throughout the summer months of 2010. This paper will focus on pressure jumps from two case studies: The initial June 22nd observation in North and South Dakota and another on August 13th and 14th in Kansas. Pressure increases ranged between 1 and 4

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mb depending on the storm system. Both case studies matched observations of severe weather reports indicated by the SPC. Further analysis revealed these pressure rises to be directly associated with gust front passage from severe thunderstorms.

But pressure observations in the TA data were not isolated to pressure jumps from gust front passage. One case study presented in this paper also reveals influences of the high-pressure regions associated with the dense, evaporatively cooled regions of thunderstorms. This observation coincided with an increase of surface pressure lasting only as long as the storm cell overlay the individual observing station.

Additionally, the recent layout of the TA network throughout south Texas allowed for the observation of tropical storm Hermine as it made landfall on September 7th 2010 and migrated northward within the state.

4. LAYOUT AND INSTALLATION

The layout of the TA network as of December 2010 is shown in Figure 1. Yellow stations indicate the stations equipped with MEMS barometric gauges that cover a large portion of the Great Plains. Each new station installed within USArray network as it continues its eastward rolling deployment is also projected to include pressure-monitoring equipment. Figure 2 depicts the typical vault configuration at each station installation. Vaults are the appropriate method for deploying seismic instrumentation, and the seismometer is indicated at the base of the ~2m vault enclosure. While power and telemetry are located outside, the enclosure for the communications equipment, computer, and MEMS barometers is located just below the top of the vault.

5. GUST FRONTS – TWO CASE STUDIES

The TA data show clear observations of the pressure changes associated with gust front passage. Two case studies are examined here from storm systems of different severity and intensity. The first is from North and South Dakota on June 22nd 2010. Figure 3 reveals the pressure jumps at several stations near Aberdeen, South Dakota. As the timescales indicate, pressure jumps occur within only a few minutes and have observed pressure increases of 3 to 4 mb. Also noticeable are smaller scale features from both gust front and thunderstorm cell structures. F29A, for example, reveals the roll within a gust front head as air gradually circulates back to the surface behind the initial pressure jump in the gust front nose. Turbulent wake regions behind the gust front head are observable in many of the stations, such as G29A and E28A. Low-angle Doppler scans from Aberdeen are shown in figure 4. These scans reveal the general positions of storm cells as well as positions of arc clouds as they develop from uplifted air above the head of the gust front. These scans are used merely to reference the positions of these storm features and not to infer thunderstorm dynamics.

The second gust front case study is from a string of severe thunderstorm cells that passed through eastern Kansas on August 13th 2010. As with the previous cases study, Figure 5 reveals a timeline of pressure observations from the TA stations near Topeka, Kansas. The magnitudes of these pressure jumps are smaller, averaging between 1 and 2 mb. This example reveals more of the observed small-scale features from overriding thunderstorm cells. A Doppler analysis for this example is shown in Figure 6, where an elliptical shaped gust front boundary is shown to develop. A downburst from an additional cell along the northeast of the squall line is seen to cross station P36A. Arc clouds appear to lag behind the initial pressure jumps as expected, and by several minutes depending on the distance from the initial downburst. Station R36A reveals a pressure jump of ~2 mb, indicating that the initial gust front was travelling for over 3 hours and almost 200 km from its initiating downburst.

6. THUNDERSTORM HIGH

Dense pockets of evaporatively-cooled air within low-level regions of thunderstorms can be monitored via surface pressure observations. These are revealed as localized high-pressure anomalies. Caskey et al. (1963) refers to this phenomenon as the “Thunderstorm High.” There is usually a pressure couplet observed in this scenario, where a low-pressure center follows immediately after the high pressure within the thunderstorm cell. A case study near Bismarck, North Dakota on August 13th 2010 shows this phenomenon well. As is revealed in these scans, an increase in surface pressure coincides directly with the times in which most of the storm system was overlying station E28A (Figure 7). As the storm system moves beyond E28A the ~4 mb increase in pressure is followed immediately by a rebound drop in pressure of ~6 mb within 20 minutes. The lower pressure indicates the possible proximity of the lower pressure center from this particular pressure couplet. Doppler scans from Bismarck reveal the general storm cell position during its passage over E28A.

7. TROPICAL STORM HERMINE

On September 7th 2010 Tropical Storm Hermine made landfall in south Texas and tracked northward, passing over San Antonio as it weakened. The TA stations located within Texas at the time had been positioned perfectly to monitor the storm track in real-time as the low-pressure center moved through (Figure 8). The low-pressure center passes very close to stations 035A and 734A during its move to the north. The TA observations indicate a drop in pressure between 6 and 8 mb associated with Hermine’s central pressure. Additionally, a contour plots from direct 1-second samples reveal the location at 1800 UTC (Figure 9).

8. DATA SAMPLING COMPARISON

Another way to highlight the viability of the TA pressure data is to compare it to data from the Automated Surface Observing System (ASOS). The information provided from ASOS stations is extremely valuable for conducting research projects with surface weather data in mind. There are, however, a few key limitations to this data. 1) Data is recorded usually only once per hour with the exception of severe weather events when it is common to have a few more observations per hour. A select number of stations record data once every five minutes. 2) Data requires paid subscription access or access through a research institution. Both limitations effectively kill the viability of ASOS data for now-casting purposes. In contrast, the USArray TA network provides free, real-time surface pressure observations.

There does exist a precedent in which one of the ASOS stations (KEMP) and one of the TA stations (R35A) lay within close proximity; ~1.5 km. They are also at roughly the same elevation of 367 m. This region south of Emporia, Kansas experienced a pressure jump from the same gust front outflow discussed earlier (Figures 5, 6e). Twenty-four hours of data for both stations are shown in Figure 10. Clearly there is a difference in resolution between data recorded at one sample per hour versus data logged in real-time at one sample per second. Station KEMP also experiences additional observations during the passage of the storm system on August 14th, but even that does not allow for the gust front to be captured in any reasonable detail.

Also of note is the difference in observed pressure between the two data sources. Specifically ASOS station KEMP measures ~ 1 mb higher than R35A. This is most likely due to differences in the instrumentation positions, where ASOS monitoring instrumentation is usually located ~ 2 m above the surface while pressure sampling in a TA station occurs within a vault buried just below the surface.

9. DISCUSSION AND CONCLUSION

Despite the unique configuration of the MEMS barometric gauges within vault enclosures, the USArray TA pressure observations have proven to be highly reliable and accurate for the purpose of identifying pressure changes associated with severe thunderstorm passage. The pressure data therefore expands on the success of the USArray network as new research avenues are explored. In the interest of now-casting severe weather phenomenon, having access to the TA pressure data in real-time can prove to be extremely useful as a supplemental tool in helping to make determinations on the severity of storm systems. This is of particular importance in the more rural regions of the country where observations are currently limited.

As for the future of the USArray network, plans are to include infrasound equipment at each station deployment in addition to the onboard pressure gauges. As the TA stations reach the end of their deployments in the east coast of the United States they will be deployed throughout Alaska within about a 75 km grid formation. With the ample amount of data being collected the USArray network will continue to provide research opportunities for years to come.

10. ACKNOWLEDGEMENTS

The authors would like to thank the efforts of the IRIS Data Management Center for their hard work at managing the copious amounts of real-time data coming in from the USArray network. Furthermore, we would like to thank the USArray installation teams and their continued expertise in the field as they install and decommission stations on a daily basis.

11. REFERENCES

Caskey, J. E. et al., 1963: Environmental and thunderstorm structures as shown by National Severe Storms Project observations in spring 1960 and 1961. *Mon. Wea. Rev.*, **91,** 271-292.

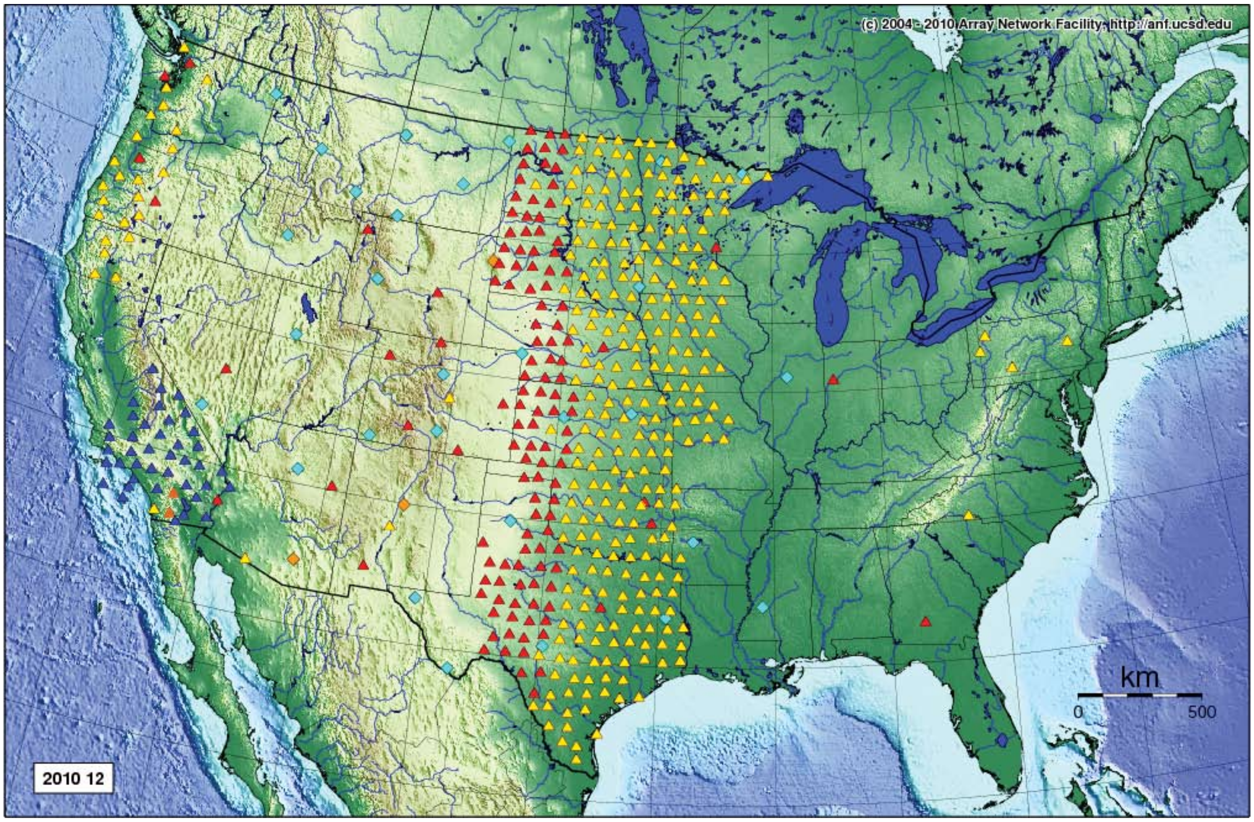

Figure 1. Layout of the USArray Transportable Array (TA) network as of December, 2010. Yellow triangles indicate stations that have been installed with MEMS barometric gauges and record pressure data in real-time at one sample per second.

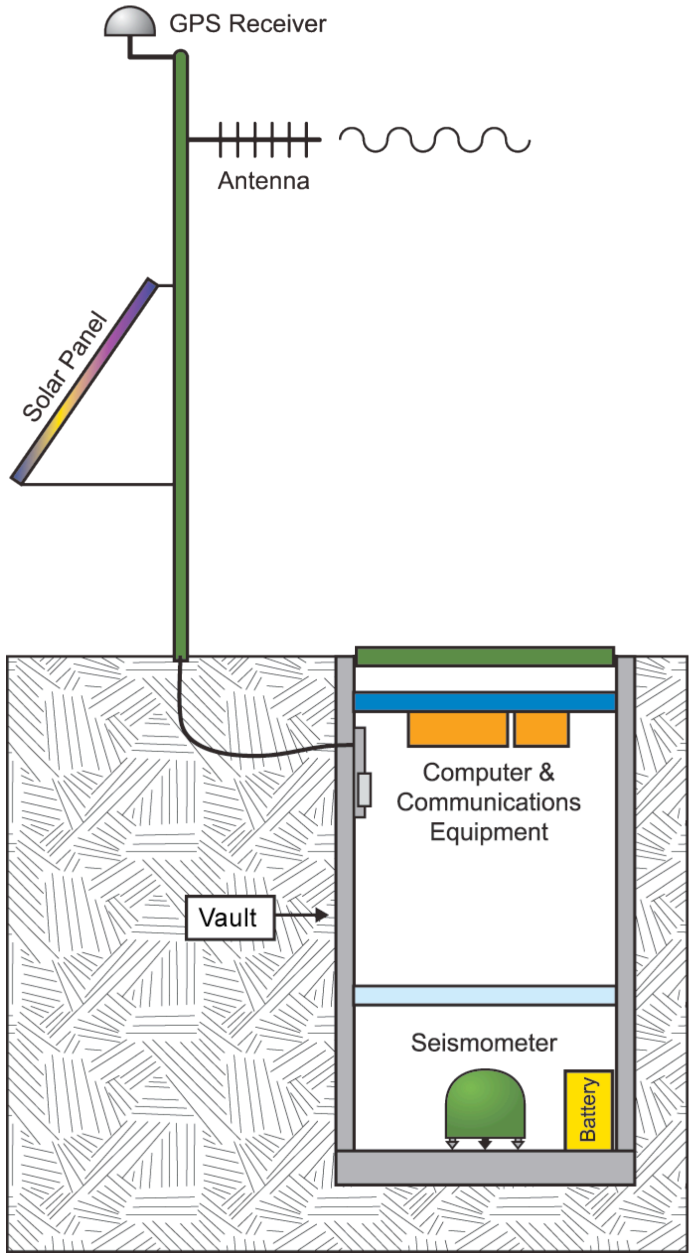

Figure 2. Typical vault installation at each USArray station location. The seismometer is protected in a separate enclosure at the base of the 2m vault while the computer and communications equipment is housed near the top of the vault, but just below the surface. The MEMS barometric gauges are installed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

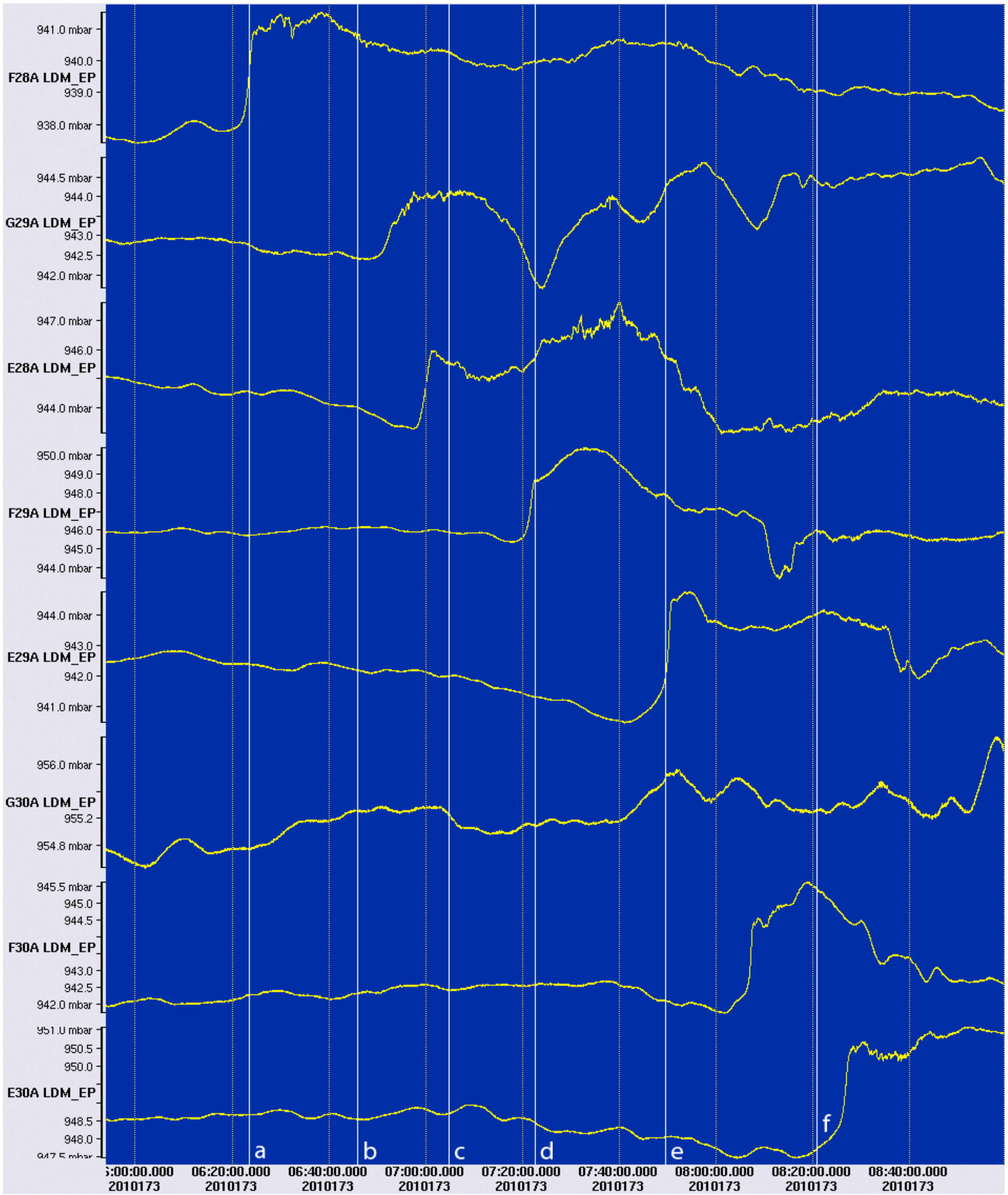

Figure 3. Gust front passage near Aberdeen, South Dakota on June 22nd 2010. As presented, 20 minutes lay between each dashed time tick mark. Total time for the passage of this particular gust front is ~ 2 hours for the stations presented. Solid white time marks correspond with Figure 4. Pressure jumps at each station are ~3 mb but range upwards of 4 mb after the initial jumps.

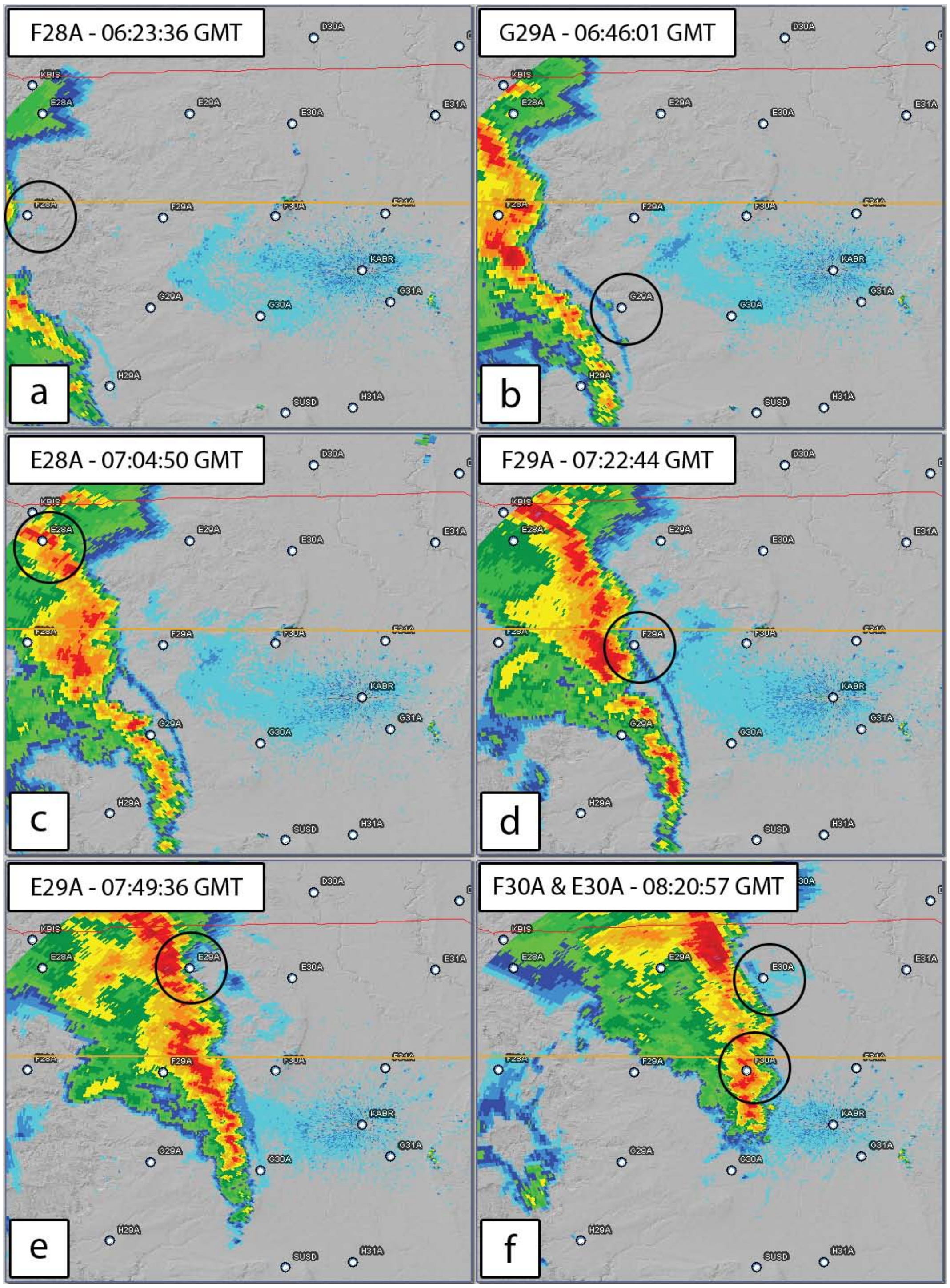

Figure 4. Doppler analysis from Aberdeen, South Dakota on June 22nd 2010. The letter at each image section corresponds with their respective solid-line time marks in Figure 3. Stations are circled as the gust front passes them. These Doppler images are generated from NOAA's Weather and Climate Toolkit and use 0.5 degree angle scans of base reflectivity. The gust front is obscured by an overlying anvil in panels (e) and (f).

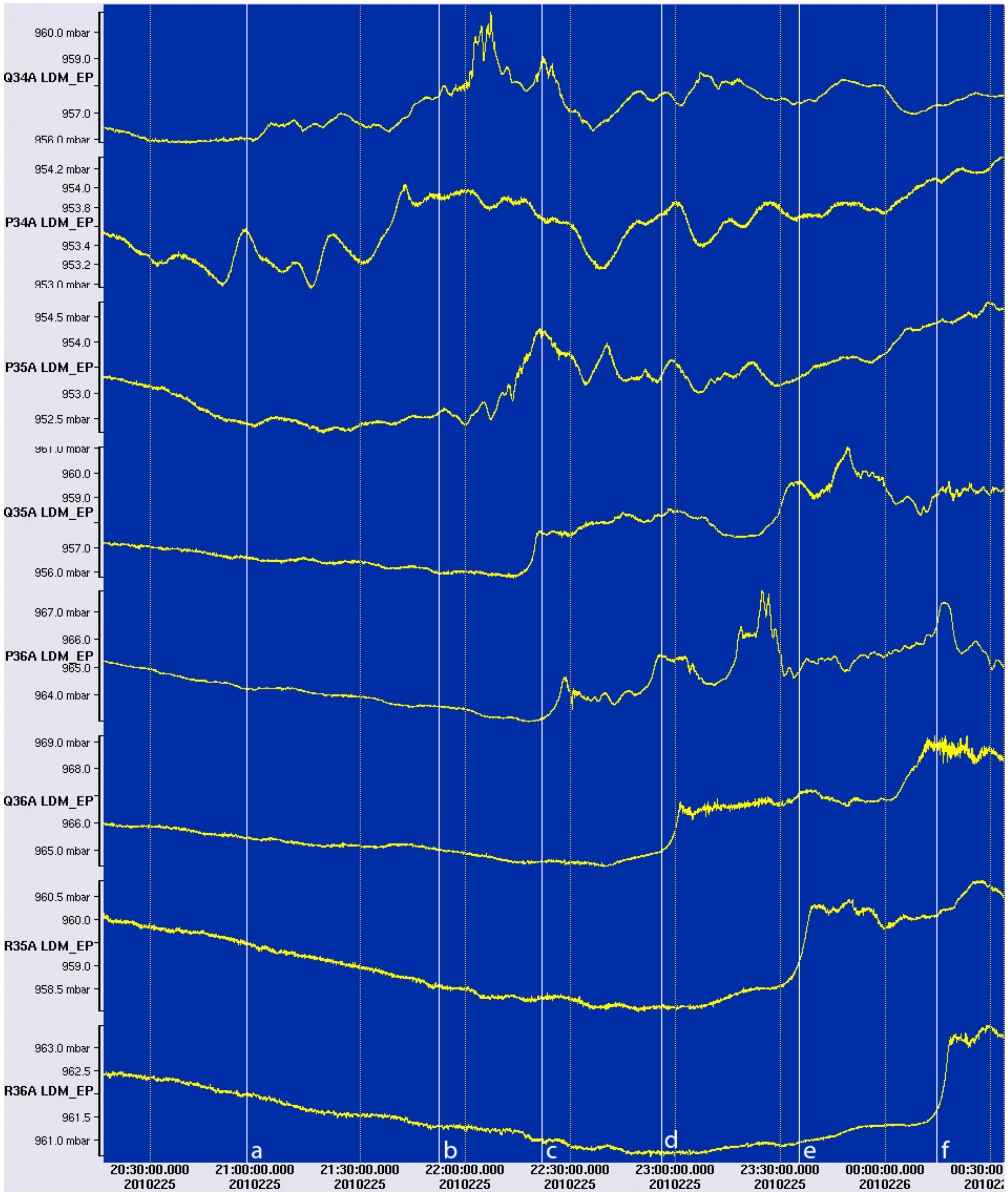

Figure 5. As in Figure 3 but for a case study near Topeka, Kansas on August 13th 2010. 30 minutes are represented between dashed time mark ticks. Solid white marks correspond with Figure 6. The gust front stabilizes ~ 1 hour after the initial downburst and spreads far from the origin. The stations presented here reveal a time-span of ~ 3.5 hours for this particular gust front, with pressure jumps between ~ 1 to 2 mb.

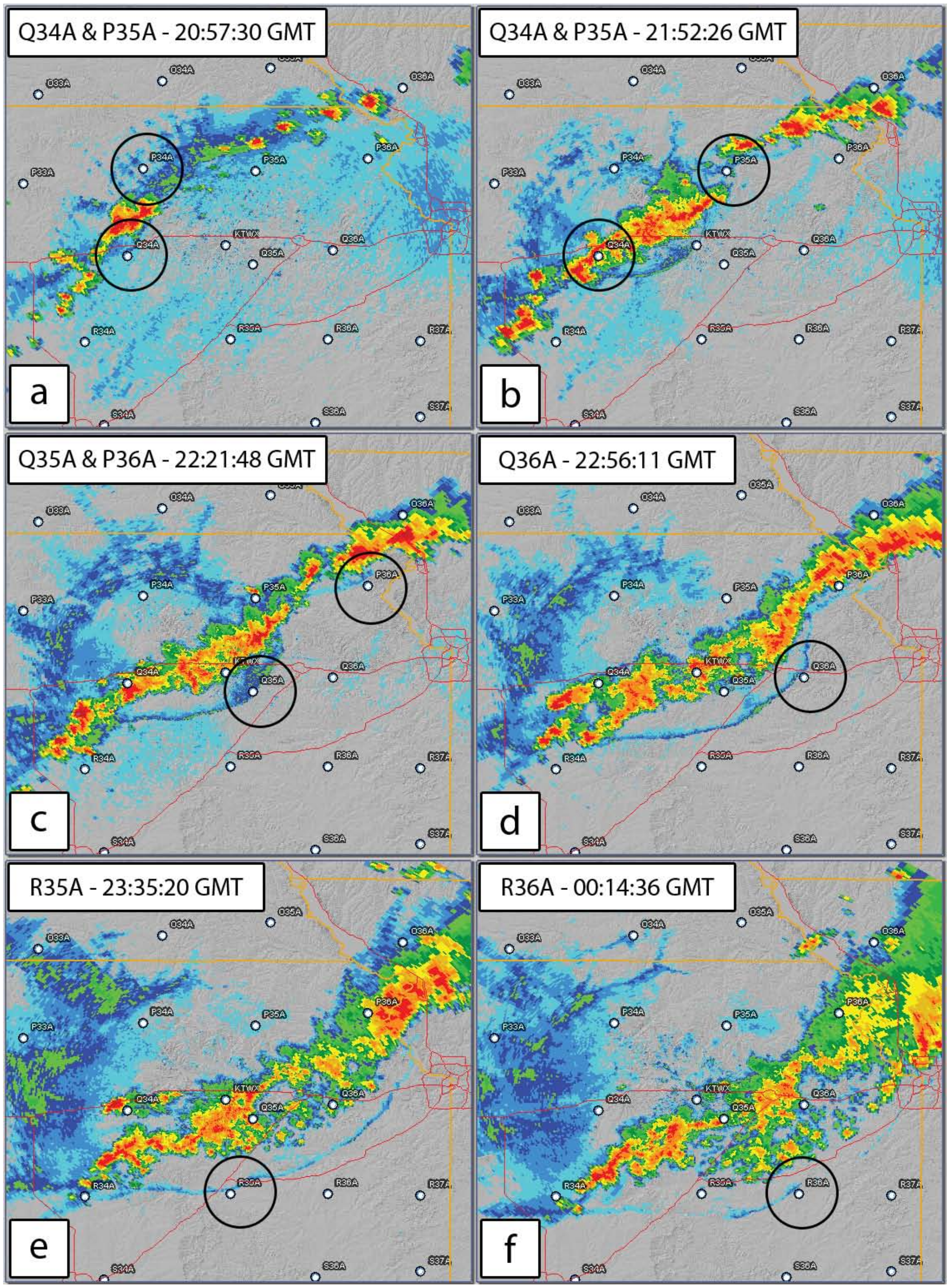

Figure 6. As if Figure 4 but for the case study near Topeka, Kansas on August 13th 2010. Panel letters correspond with solid-line time marks in Figure 5.

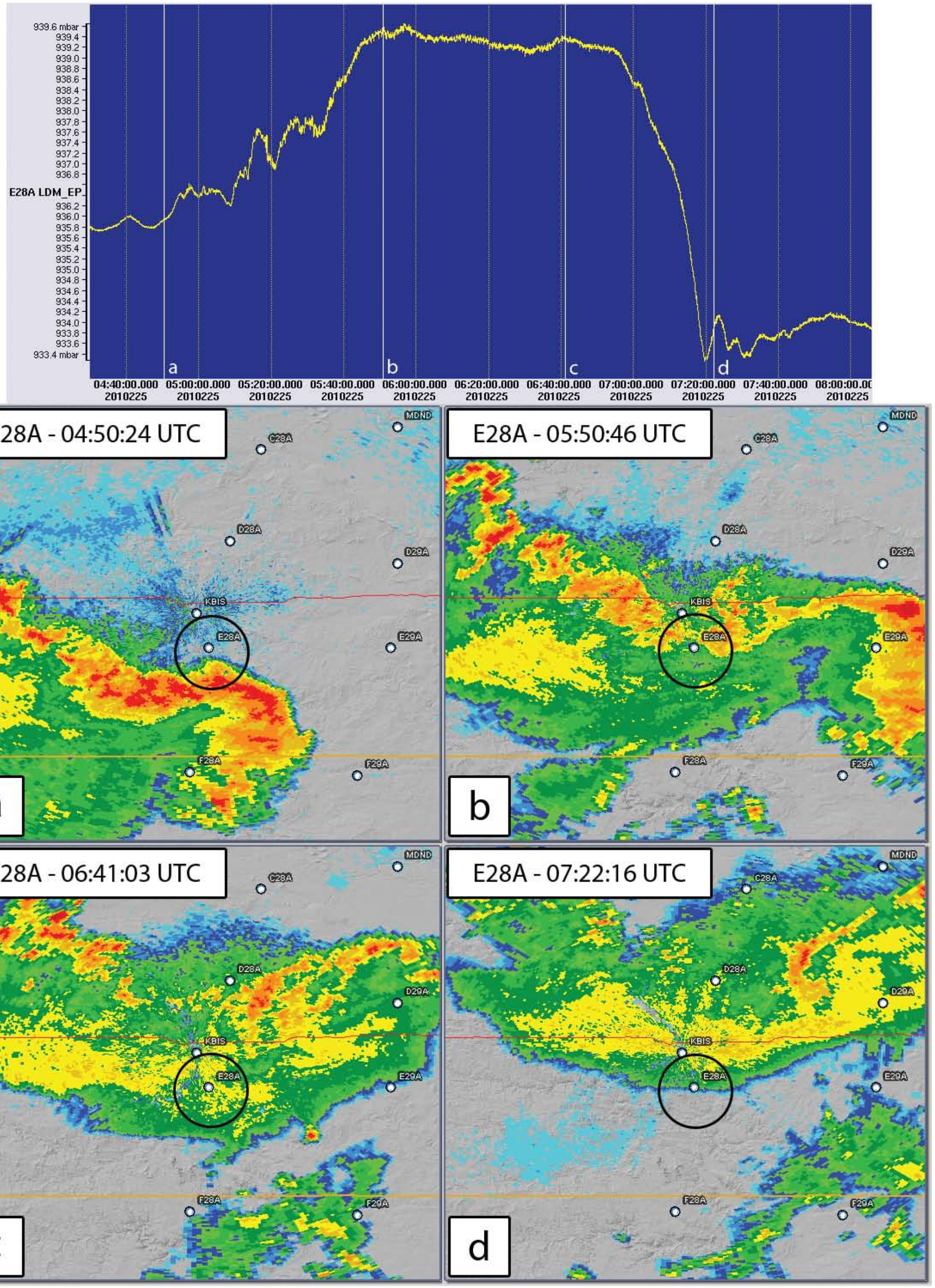

Figure 7. Analysis of case study near Bismarck, North Dakota on August 13th 2010. This figure demonstrates the significance of a “thunderstorm high,” where the dense pocket of evaporatively cooled air within a thunderstorm cell produces and observable high-pressure at the surface. Station E28A (above) is circled in each of the four panels below. 20 minutes lay between each dashed time mark within the station time series. As this storm system passes over E28A an increased pressure of ~ 4 mb is observed. This rebounds downward by ~6 mb within 20 minutes as the edge of the storm system approaches. This denotes the possible proximity of the low pressure region of the couplet observed here.

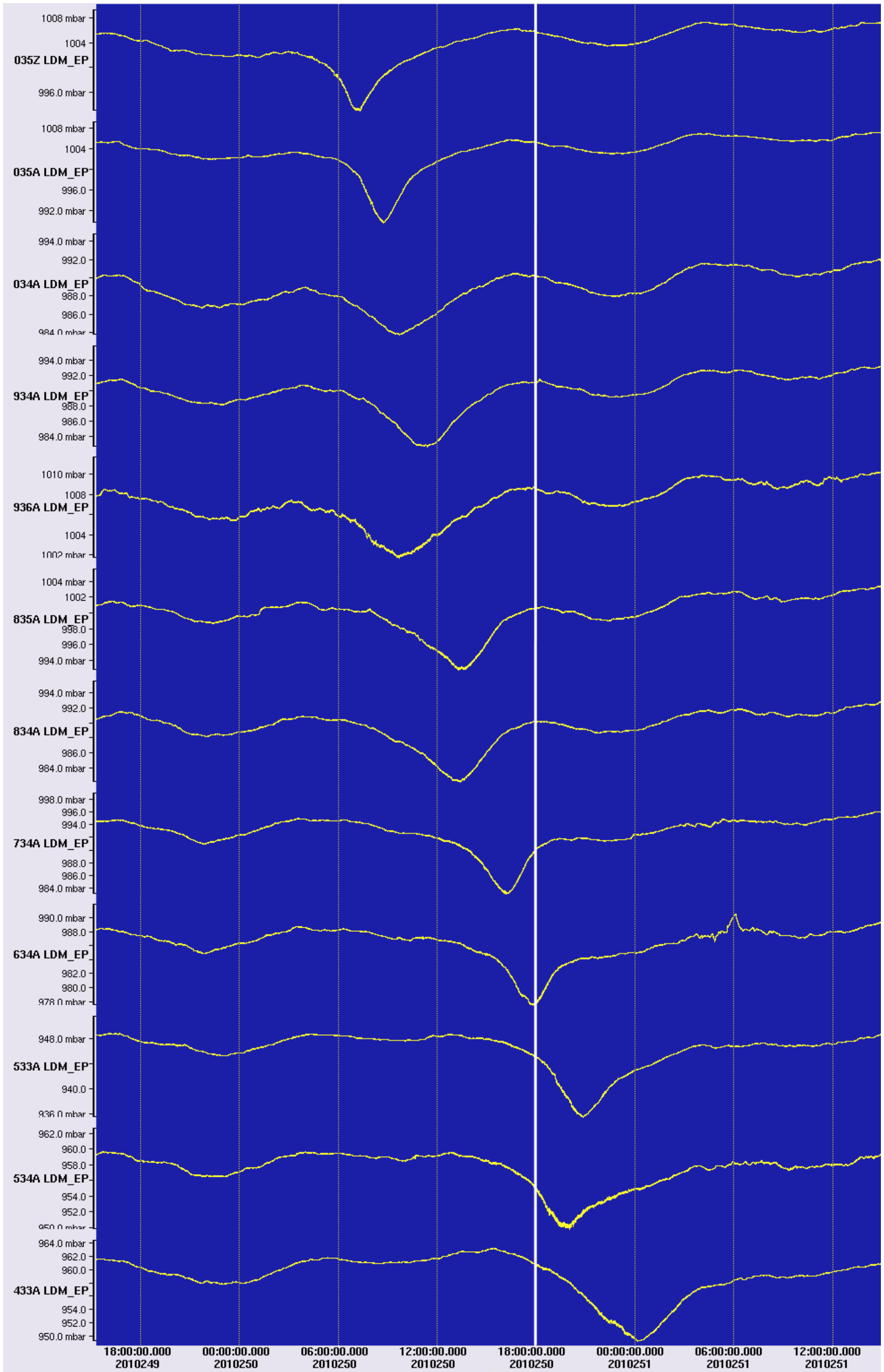

Figure 8. Time series of stations along the storm track of Tropical Storm Hermine as it made landfall in South Texas on September 7th 2010. 6 hours lay between dashed time markers. Pressure decreases of ~ 6 to 8 mb are consistently observed as the low pressure center of TS Hermine moves northward. The solid white line at 1800 UTC corresponds with Figure 9.

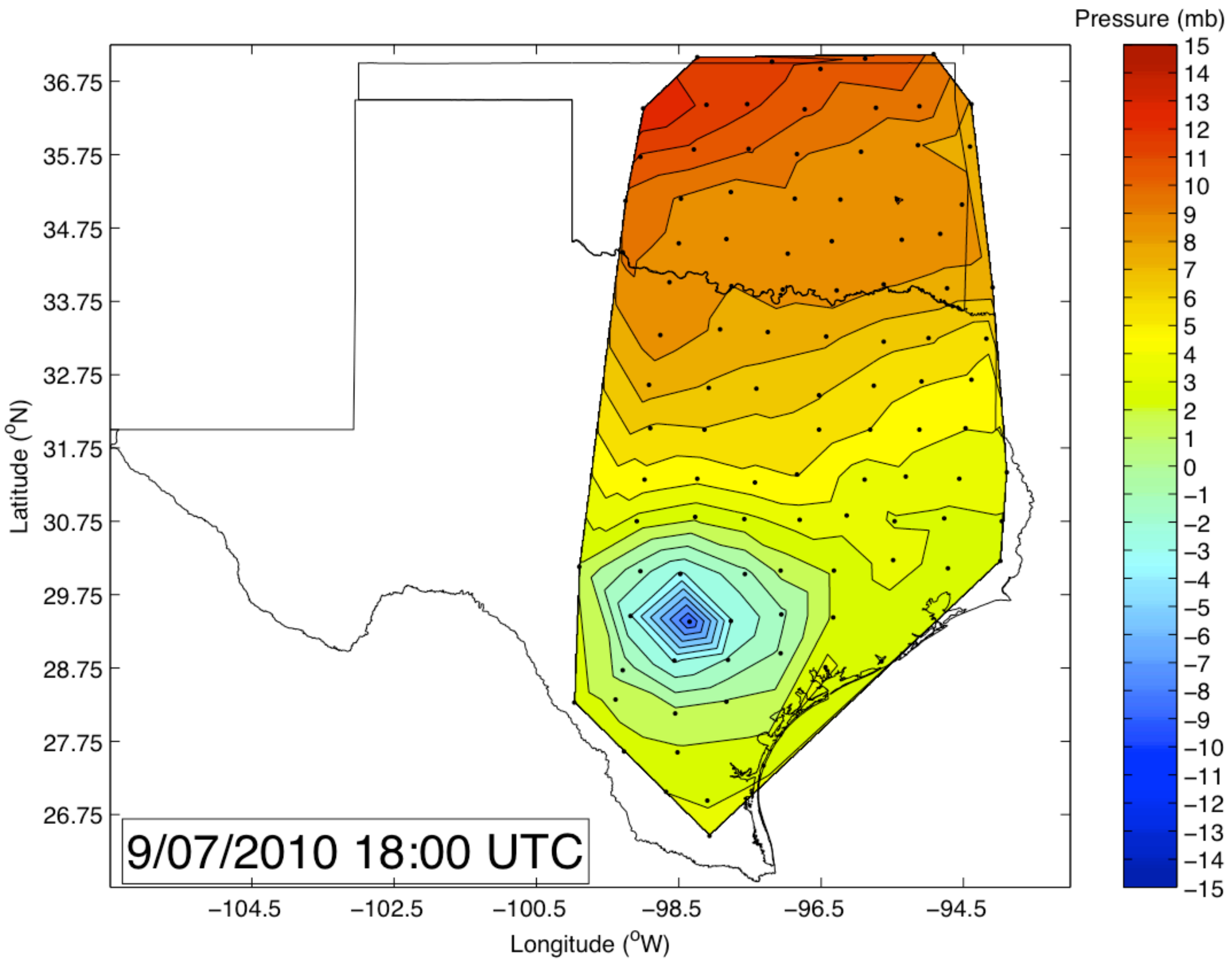

Figure 9. Contour plot of 1-second samples at 1800 UTC on September 7th 2010 from all pressure-monitoring TA stations in Texas and Oklahoma. This map represents the deviation in pressure from the initial pressure field at 0000 UTC of the same day. The low pressure center of TS Hermine is clearly visible.

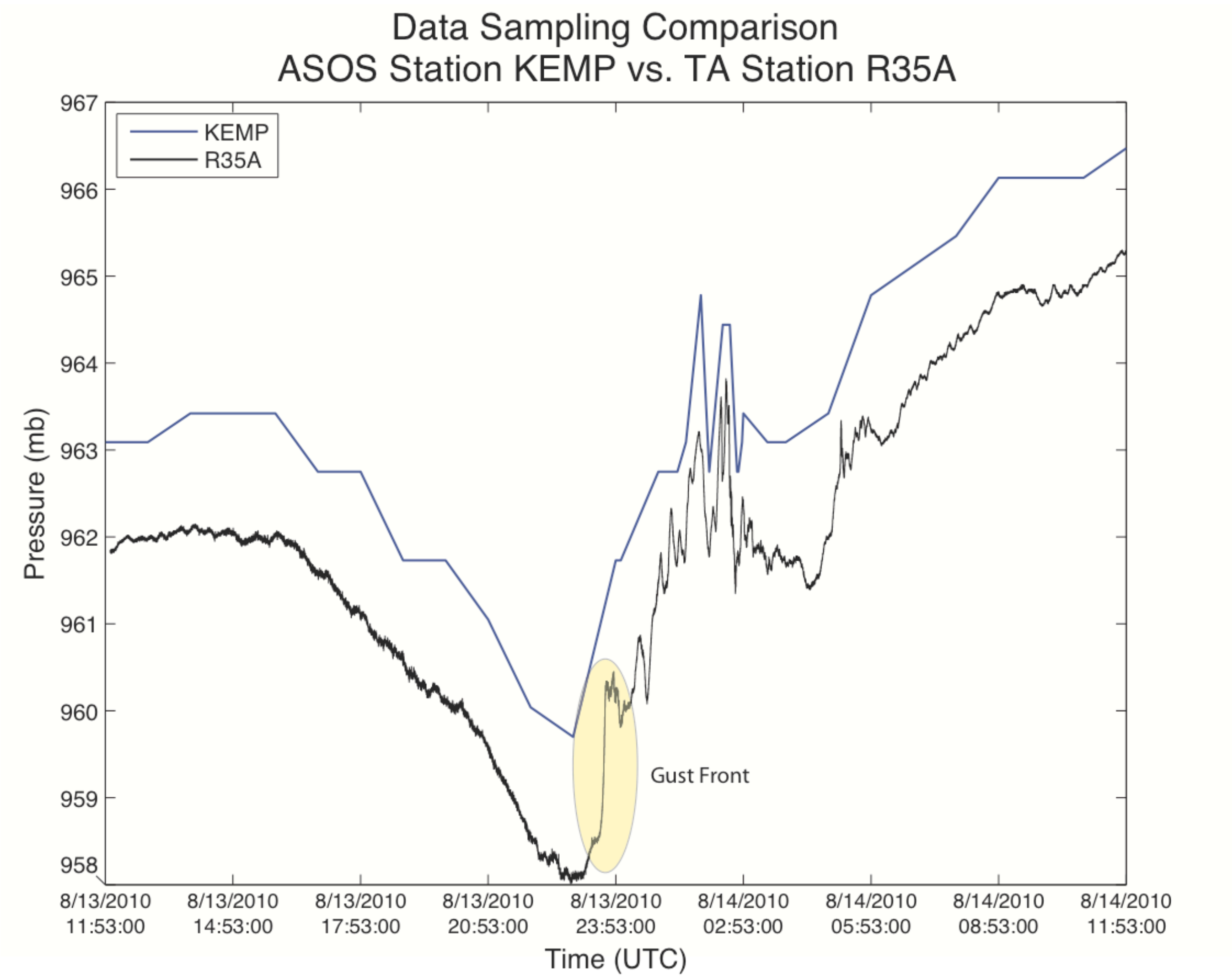

Figure 10. One sample per second (R35A) vs one sample per hour (KEMP) compared over a 24-hour period of time. The gust front shown actually corresponds to the same one in Figures 5 and 6e from August 13th 2010. During the early UTC hours of August 14th it can be seen that station KEMP records with a 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.