P2.25 THE USE OF OBJECTIVE ANALYSES IN THE NATIONAL WEATHER SERVICE'S GRAPHICAL FORECAST EDITOR TO ANTICIPATE A LOCALIZED TORNADO OUTBREAK

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1. **Introduction**

On 3 April 2012, a localized tornado outbreak occurred in and near the highly populated Dallas-Fort Worth Metropolitan area (DFW Metroplex). Beginning around 1740 UTC and only spanning six hours, 21 tornadoes occurred across north and northeast Texas, including one EF-3 tornado and three EF-2 tornadoes. These tornadoes impacted over 650 homes and resulted in an estimated $800 million in damage. 29 people were injured, of which three were classified as serious, but there were no fatalities. While tornadoes are not uncommon to this region of Texas, the location of several strong tornadoes affecting a highly populated area received local and national media attention.

Although a threat for severe weather was expected in the days and hours leading up to the event, a tornado outbreak was not anticipated. In spite of the poor forecasts, in the hours preceding the first tornado, forecasters at the Fort Worth, Texas Weather Forecast Office (WFO) were able to anticipate a tornadic event thanks in part to the hourly objective analysis of convective parameters that were locally generated utilizing the Graphical Forecast Editor (GFE) software system.

The focus of this research is to explain how the objective analysis from the GFE is generated and to document its performance and operational utility on 03 April 2012 when compared to the Rapid Update Cycle (RUC) and the objective analysis produced by the Storm Prediction Center (SPC).

2. Synoptic and Mesoscale Analysis of 3 April 2012 Tornado Outbreak

The synoptic forecast data valid for 3 April 2012 indicated an environment supportive for the development of severe convection based on an ingredient based methodology; namely, moisture, lift, instability and vertical wind shear were all present in favorable quantities to support an organized thunderstorm mode (Johns and Doswell 1992). However, several factors indicated there would be a limited tornado potential. Those factors included seemingly relatively weak low level vertical wind shear, an expectation for the early onset of thunderstorm initiation (i.e. storms developing before the peak heating hours of the day), a low ceiling of stratocumulus clouds ahead of a Pacific front, and a forecast storm mode to be predominantly linear given a weak capping inversion and strong forcing for ascent associated with the front.

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Severe convective forecasts issued by the SPC 36 hours before the tornado outbreak addressed these concerns and indicated the main severe weather threat was large hail, while the

"RELATIVELY WEAK LOW LEVEL SHEAR SUGGEST ANY TORNADO THREAT WILL BE MINIMAL."

Just 12 hours before the onset of the tornado outbreak, forecast data was suggesting some threat of tornadoes, but there was little indication that conditions would in fact become very favorable. The 0600 UTC day one convective outlook from SPC began to mention a threat of tornadoes, stating:

"DESPITE NEARLY UNIDIRECTIONAL...SLY DEEP LAYER WIND FIELDS...SOME LOW LEVEL HODOGRAPH CURVATURE SUGGESTS A TORNADO THREAT IS POSSIBLE."

Likewise, the area forecast discussion from the Fort Worth WFO issued 8 hours before the first tornado occurred also stated:

"LOW LEVEL FLOW IS NOTABLY WEAKER [TODAY]…BUT DOES CONTAIN SOME DECENT DIRECTIONAL TURNING AND THUS A LOW TORNADO THREAT CAN NOT BE DISCOUNTED."

At 1200 UTC, surface, satellite, rawinsonde, and Weather Surveillance Radar-1988 Doppler (WSR-88D) observations were not strongly supportive of tornadoes, but an investigation of the mesoscale environment revealed several factors that evolved to enhance environmental support for tornadoes through 1800 UTC.

At 1200 UTC, objective upper air analysis depicted the presence of a 558 dm, 500 hPa cut off low located over eastern New Mexico. 1200 UTC RUC analysis depicted a trough of potential temperature on the 1.5 potential vorticity unit surface, extending from the center of the cut off low, south-southwest over El Paso, TX. This potential temperature trough was co-located with a shortwave trough in the height field at the 500 hPa level and is consistent with an upper tropospheric positive (cyclonic) potential vorticity (PV) anomaly. Water vapor satellite imagery from 1200 through 1800 UTC indicated that this positive PV anomaly was moving northeast on the outer periphery of the cut-off upper low. This feature was likely spreading large scale forcing for ascent downstream over much of north and central Texas in the form of deep layer warm air advection. 1200 UTC objective upper air analyses depicted warm air advection within the 925 hPa - 700 hPa layer, in line with expectations for induced forcing for ascent associated with the shortwave trough.

The 1200 UTC KFWD rawinsonde observation (RAOB) (Fig. 1) depicted the presence of deep moisture in place around the DFW Metroplex with an observed mean mixing ratio of 13 g kg^{-1} in the surface to 800 hPa layer. The RAOB also indicated the presence of an elevated mixed layer in the middle troposphere which contributed to steep (8 °C km^{-1}) mid-tropospheric lapse rates. The elevated mixed layer also provided a modest capping inversion for surface based convection with a thermal inversion observed in the 775 to 700 hPa layer. The juxtaposition of the elevated mixed layer over deep lower tropospheric moisture led to an observed surface based convectively available potential energy (CAPE) value of around 1700 J kg^{-1}. The RAOB also observed a 0-6 km bulk shear vector of 250° at 38 kt, which is comparable to expected values for supercell thunderstorm environments. (Rasmussen and Blanchard 1998; Johns and Doswell 1992).

A 1200 UTC Barnes objective analysis of mean sea level pressure, temperature, mixing ratio and streamlines from automated surface observations (Fig. 2) indicated an elongated 1006 hPa surface low between Lubbock, TX and Childress, TX. A north-south oriented moisture discontinuity associated with a convergence of streamlines and a thermal gradient was analyzed as a Pacific cold front which became a source of strong forcing for ascent.

By 1500 UTC, a north-south quasi-linear convective system (QLCS) developed west of the DFW Metroplex along the Pacific front (Fig. 3). WSR-88D analysis indicated a few supercell thunderstorms embedded in this eastward progressing line of thunderstorms which were responsible for producing large hail from 1200 to 1500 UTC. At 1500 UTC, the convective evolution was in line with forecast expectations with primary concerns for large hail and damaging winds.

A 1500 UTC Barnes objective analysis (Fig. 4) indicated that an east-west oriented boundary had moved south from the Red River to the northern fringes of the DFW Metroplex while the Pacific front had moved east approximately 50km since 1200 UTC. This analysis also indicated that the surface low had become more consolidated while moving east and was located 150 km west of the DFW Metroplex. An investigation of the origin of the east-west boundary suggested that this boundary was likely remnant outflow from a mesoscale convective system that dissipated while moving southeast across southern and southeastern Oklahoma at 1200 UTC. The 1500 UTC objective analysis indicated that the boundary had characteristics similar to a warm front with backed easterly flow in the vicinity of the boundary and a cool, but moist, air mass in place north of the boundary. 1515 UTC visible satellite imagery resolved the boundary (Fig. 5) as a sharp edge of overcast skies moving south towards the DFW Metroplex. At 1500 UTC, WSR-88D derived winds from KFWS combined with commercial aircraft observations taking off and landing at KDFW and KDAL airports, indicated that the wind directions at most levels between the surface and 3 km had backed by 20 to 30 degrees and increased around 5 kt in magnitude since the 1200 UTC FWD RAOB. This seems to be in response to the combination of the approach of the outflow boundary from the north and the approach of the surface low from the west. This change in the low level wind fields results in a more clockwise looping 0-3 km hodograph which results in an increase of over 100 m^2s^{-2} of 0-3 km storm relative helicity (SRH) from the 1200 UTC FWD RAOB. At 1500 UTC, aircraft vertical profiles of temperature and dew-point indicated that the elevated mixed layer inversion remained in place, but the combination of some insolation and positive moisture advection resulted in very little (surface based) inhibition for air parcels to release convective instability if lifted to their level of free convection. However, WSR-88D reflectivity data indicated that the storm mode remained largely quasi-linear with a lack of discrete convection initiation ahead (east) of the pacific front.

By 1800 UTC two discrete supercells had developed south of the DFW Metroplex (Fig. 6), one of which had already produced a tornado 20 minutes earlier 30 km south of Fort Worth. Visible satellite and regional WSR-88D data combined with the earlier synoptic analysis suggested that the discrete storms initiated within the low level warm air advection regime east of the Pacific front. A subjective analysis of surface observations indicated that the east-west oriented outflow boundary had stalled and that the north-south temperature gradient along the boundary had increased due to the combined effects of frontogenetic flow and differential heating. Wind fields remain backed and easterly around the DFW Metroplex due to the persistent influence of the stalled outflow boundary and the surface low now 50 km west of Fort Worth.

Aircraft derived vertical wind profiles combined with KFWS WSR-88D VAD wind profile (VWP) at 1800 UTC indicated an increase in magnitude of the low level wind fields by as much as 15 kt in the 1-3 km layer. An upper air skew-T chart and hodograph was recreated using available radar and aircraft data and has been included as Figure 7. The recreated hodograph uses actual observed (from WSR-88D) storm motion as opposed to using the traditional approach assuming a Bunkers right-moving supercell storm motion (Bunkers et al. 2000).

The reconstructed 1800 UTC sounding and hodograph demonstrate that the mesoscale environment had evolved to become very supportive of tornadic supercells. Table 1 shows the evolution of convective parameters at 1200 UTC, 1500 UTC, and 1800 UTC. The increase in the low-level directional shear (0-3 km SRH in excess of 250 m^2s^{-2}) and instability (0-3 km CAPE values in excess of 200 J kg^{-1}) are of particular interest in this case. Mesoscale features, such as the surface low and outflow boundary, seem largely responsible for the dramatic increases in these particular fields.

3. WFO Fort Worth Situational Awareness for Tornado Warnings

At WFO Fort Worth, the situational awareness for a tornado outbreak may have suffered had it not been for objective analyses of convective parameters that were locally generated and available in real time to operational meteorologists. Through post-event interviews, the GFE objective analysis proved to be instrumental in raising the situational awareness of forecasters to anticipate the potential for a significant tornado event. Not surprisingly, the GFE convective parameters produced on 03 April 2012 were more representative than any other available short-term guidance or composite observation data source.

a) About the GFE Objective Analyses

National Weather Service meteorologists use the GFE to produce and manipulate gridded data as part of the forecast process. While the primary purpose of the GFE is to produce gridded forecasts of basic sensible weather elements (such as temperature, wind, and probability of precipitation) the GFE can be used as a forecast tool to enhance situational awareness and assist in decision making. At WFO Fort Worth, Python computer programs are used to generate a variety of convective indices that have been shown to correlate to severe weather threat (Johns and Doswell 1992). This method was developed at WFO Tulsa (McGavock et al. 2004) and has been used in operations at WFO Fort Worth for seven years. The domain is slightly larger than the WFO Fort Worth forecast area and has a horizontal grid spacing of 2.5 km.

The GFE objective analysis begins with a routine that calculates a surface grid of temperature, dewpoint temperature, and wind speed/direction based on all automated weather observations received from a variety of sources. An analysis routine that employs "serpentine curves" combines an initial model source such as RUC, with observation data to create a surface grid that is valid for each observation site (Colin and Barker 2003). This routine produces a surface grid that maintains the exact reported value at each observation site's grid point while maintaining small-scale detail or gradients that exist in the initial model source. The primary disadvantage to this technique is that there is no automated quality control, and thus the observations are assumed to be accurate at all times. Any incorrect observations must be removed by a forecaster through the use of another computer program to ensure a viable surface grid.

The GFE interpolates selected model data from its native resolution to a 2.5 km grid, using a downscale algorithm called "smartinits" (Hansen et al. 2000). The model data containing information on the atmospheric parameters of several layers above the surface is combined with the previously analyzed surface data to create a complete vertical profile. This allows the GFE to create fields from thousands of synthesized vertical profiles at 2.5 km resolution. This is then used to calculate a variety of convective indices. Technically any model can be used for the non-surface fields, but the 1 hour forecast of 13 km RUC model is used exclusively at WFO Fort Worth because it provides the highest resolution and continuous hourly updates.

The GFE convective parameter objective analysis method is very similar to the technique used by the SPC viewed at http://www.spc.noaa.gov/exper/mesoanalysis/ in real time (Bothwell et al. 2002). Both methods combine surface observation data with non-surface RUC model data to generate a vertical profile of the atmosphere. The SPC analysis routine runs hourly, using the latest 40 km RUC forecast as a starting point. It utilizes a comprehensive surface objective analysis scheme called SFCOA. The SFCOA program uses a 2-pass Barnes analysis technique that attempts to fit surface data to the 1 hour RUC forecast surface grid which is used as a "first guess".

However, there are some important differences between the GFE method and SPC method. The first main difference is that the GFE method has a much higher resolution (2.5 km) that can help the meteorologist better identify and define mesoscale features. This is especially true when there is a high spatial density of surface observations available to calculate the surface observation analysis grid. The lower resolution (40 km) of the SPC objective analysis may smooth over or eliminate important mesoscale features. The second main difference is that the SPC SFCOA package may assign a lower weight to or perhaps disregard values of good observations to better fit "first guess" grid from the RUC. While the SPC analysis method will effectively and automatically quality control bad observations, it has the undesirable effect of producing a less precise and possibly less accurate analysis. SPC surface analysis quality may suffer when observations are changing rapidly and/or the surface fields are not well forecast by the 1-hour RUC. Lastly, the GFE convective parameters are not computationally intensive and are available 10 to 15 minutes before the SPC analysis parameters are posted online. After seven years of operational use at WFO Fort Worth, most forecasters feel the GFE method provides a more timely and accurate objective analysis. As a result, it has become an integral part of WFO Fort Worth severe weather operations.

b) RUC, SPC mesoanalysis, and SPC guidance on 3 April 2012

Section 2 showed that the atmosphere had evolved to become increasingly favorable for tornadoes across the DFW Metroplex between 1200 and 1800 UTC. This atmospheric change was not well forecast by any of the available short-term model guidance. Several model runs of the RUC before 1800 UTC consistently indicated an atmospheric profile considered to be less favorable for tornadoes than what actually occurred. The 2-hour forecast from the 13 km RUC initialized at 1600 UTC (Fig. 8) is an example. Comparing this forecast sounding to the reconstructed sounding (Fig. 7) at the same location and valid time shows notable differences in the low level wind profile as well as differences in temperature and dewpoint values. Forecast surface dewpoint temperature by the RUC was 65ºF, while the actual observed value was 70ºF.

The authors believe the poor performance of the RUC forecasts negatively impacted the quality of the hourly objective analysis from SPC. Surface data from the 1800 UTC SPC mesoanalysis (Fig. 9) compared to Figure 6 show both surface temperatures and dewpoint temperatures were 3 degrees too cool over DFW Metroplex. The analysis of 0-3 km CAPE from SPC (Fig. 10) depicted values of slightly less than 50 J kg^{-1} over the DFW Metroplex, which was approximately 170 J kg^{-1} less than values obtained from the reconstructed sounding (Fig. 7). In addition, calculating 0-3 km storm relative helicity from commercial aircraft weather reporting and VWP data as well as adjusting storm motion to a more accurate value, resulted in 0-3 km SRH values of over 100 m^2 s^{-2} higher than the SPC mesoanalysis product (Fig. 11).

After 1600 UTC, subjective analysis began to reveal the location of the outflow boundary and the possibility it would become a critical player in the expected severe weather threat. SPC issued the 1630 UTC Day One convective outlook and recognized the enhanced threat of tornadoes stating:

“A FEW TORNADOES ARE ALSO POSSIBLE /ESPECIALLY ACROSS PARTS OF N-CNTRL AND NERN TX/ GIVEN MODESTLY STRONG LOW-LEVEL FLOW AND PRE-EXISTING OUTFLOW BOUNDARIES WHICH WILL LOCALLY ENHANCE LOW-LEVEL SHEAR.”

A Mesoscale Convective Discussion (MCD) issued at 1647 UTC mentioned the possibility of upgrading a previously issued severe thunderstorm watch to a tornado watch citing:

“ISOLATED TORNADOES SHOULD INCREASE -- AS SURFACE-BASED SUPERCELL POTENTIAL FURTHER INCREASES IN THE FAVORABLY SHEARED/DESTABILIZING ENVIRONMENT.”

At 1710 UTC the severe thunderstorm watch was upgraded to a tornado watch. The first tornado occurred 25 minutes later in Johnson County, just to the south of Fort Worth in Tarrant County. The probabilities for tornadoes within the watch was categorized as moderate and cited a 40% chance of 2 or more tornadoes, but just a 20% chance of one or more EF2 tornadoes. The tornado event was underway when a second MCD was issued at 1815 UTC:

SMALL SUPERCELL STORMS MOVING TOWARD -- AND DEVELOPING NEAR -- THE METROPLEX HAVE PRODUCED A FEW TORNADOES IN THE PAST HALF HOUR TO HOUR -- LIKELY AS THEY CROSS/INTERACT WITH THE MORE FAVORABLE VORTICITY/LOW-LEVEL SHEAR ASSOCIATED WITH THE BOUNDARY. THOUGH IN GENERAL EXPECT ANY SINGLE TORNADO TO BE RELATIVELY BRIEF AS STORMS MOVE QUICKLY NEWD ACROSS THE BOUNDARY

By this time the third tornado (11 km long track; EF-2) had touched down and a “tornado emergency” would be issued for both Dallas and Tarrant Counties by 1825 UTC. The event would continue to unfold during the next five hours and produce an additional 18 tornadoes in the WFO Fort Worth and WFO Shreveport county warning areas, including two more long-track EF-2 tornadoes and one EF-3 tornado.

c) GFE objective analysis on 3 April 2012 and its impacts on situational awareness

While the magnitude of the tornadic event was underestimated in official forecasts, the GFE objective analysis provided the warning operations meteorologists at WFO Fort Worth critical information that the tornado threat was increasing by 1500 UTC. Although indications were appearing in subjective analysis after 1600 UTC, software limitations make it difficult and time intensive to calculate and quantify shear profile changes in real-time. Commercial aircraft data was not viewed in real-time and was only assessed after the event. The stronger and more easterly low level winds on VAD wind profiles from WSR-88D and terminal Doppler radars were noted by forecasters around 1700 UTC. In addition, for reasons not investigated here, supercell motion of the tornadic cells deviated from the predicted motion put forth by the Bunkers technique. Actual motion of the tornadic supercells was approximately 210º at 20 kt versus the predicted value of approximately 240º at 35 kt. The difference in forecast versus observed storm motion served to increase the calculated values of 0-1 km and 0-3 km SRH. While the indications were that wind shear was stronger than forecast, the GFE analysis helped to quantify the increase in SRH caused by using true surface wind and storm motion data. WFO Fort Worth forecasters were also unaware that the RUC surface temperature and dewpoint temperature forecasts were too low until viewing much higher instability values calculated by the GFE objective analysis using surface temperature and dewpoint temperature observations.

At 1500 UTC 0-3 km CAPE calculations from the GFE showed values of 50-150 J kg^{-1} (Fig. 12) in an area where the SPC objective analysis method indicated less than 50 J kg^{-1} (Fig. 13). These unusually high values of low level instability (Hampshire et al. 2012) were one of the key pieces of information that were instrumental in raising situational awareness for tornadoes (Cavanaugh 2012; Dunn 2012). Based on the 1500 UTC GFE objective analysis, two messages were sent via NWSchat to highlight an increasing tornado threat.

15:34 NWS chat message: “Locally calculated parameters indicate this is a good source of low level wind shear and could quickly enhance low level organization of the storm.”

16:02 NWS chat message: “Closely watching Erath, Palo Pinto, Hood county storm for tornado potential. Environmental *conditions are actually becoming more favorable for a tornado threat headed into this afternoon."*

The GFE objective analysis continued to show a trend of increasing values of low level instability and low level wind shear developing to the south of the outflow boundary and to the east of the Pacific front and QLCS through 1700 UTC. At 1700 UTC a large area of 0-3 km CAPE with values exceeding 250 J kg^{-1} was present over greater Fort Worth and locations to the south (Fig. 14). The values on the 0-3 km CAPE analysis were some of the highest that the warning forecasters had ever seen on the GFE analysis (Cavanaugh 2012; Dunn 2012) and matched the values put forth by the reconstructed sounding. At 1800 UTC the GFE (which uses a more accurate storm motion that is partly weighted toward observed values based on WSR-88D algorithm data) showed 0-3 km SRH exceeding 300 m^2s^{-2} over the DFW Metroplex (Fig. 15). This was approximately 150 m^2s^{-2} higher than the SPC mesoanalysis (Fig. 11) and 50 m^2s^{-2} higher than the corresponding value from the reconstructed wind data indicated in Section 2.

d) An experimental convective index: Low Level EHI

One of the advantages of the open software architecture of the GFE is the ability to create new experimental convective parameters that may show promise in forecasting severe convective threats. One such index developed at WFO Fort Worth is a low level Energy Helicity Index (EHI). Low level instability has been shown to play an important role in tornadogenesis. (Davies 2001; Davies 2006). By combining low level instability fields with a low level SRH calculation, the GFE can develop a graphical image that depicts the locations where the best combination of instability and shear are present simultaneously. The typical EHI calculation (Hart and Korotky 1991) is given by:

$$\text{EHI} = \frac{\text{0-3 km SRH} * \text{total CAPE}}{160{,}000}$$

The experimental low level EHI calculation uses only 0-3 km surface based CAPE for the energy part of the calculation. Since subjectively high values of 0-3 km surface based CAPE is roughly an order of magnitude lower than subjectively high values of total CAPE, the low level EHI equation is given by:

$$\text{Low Level EHI} = \frac{\text{0-3 km SRH} * \text{0-3km CAPE}}{16{,}000}$$

Before further discussion, the authors caution that no official or formal verification has been performed on the utility of this experimental parameter. However, its use during other severe weather events when multiple tornadoes occurred subjectively indicates some skill in highlighting favored regions for tornadogenesis. The low level EHI performance in these cases was shown as part of intraoffice training in 2011. Because non-zero values of 0-3 km CAPE are fairly uncommon, this index is often zero. A positive low level EHI value does quickly highlight the regions where positive 0-3 km SRH coincide with positive 0-3 km CAPE. However, because tornadoes can often occur in the absence of 0-3 km CAPE values, the low level EHI index appears to have a lower than ideal probability of detection rate.

On 3 April 2012, the warning forecasters cited the unusually high values of the low level EHI between 1600 UTC and 1800 UTC as an important piece of information that quickly alerted them to an increasing threat of tornadoes (Cavanaugh 2012; Dunn 2012). Figure 16a shows that the 1700 UTC low level EHI highlighted the DFW Metroplex and locations to the south, as a region where high 0-3km CAPE and 0-3 km SRH were juxtaposed. The black markings in Fig. 16a give the locations of the six tornadoes from 2 separate supercells which occurred between 1700 UTC and 1900 UTC. The 1800 UTC low level EHI graphic (Fig. 16b) continued to highlight the DFW Metroplex with some of the highest values this index has ever shown in north Texas over the last three years of testing. Up until 1800 UTC only one tornado had occurred, but between 1800 and 2000 UTC eight tornadoes occurred, including two long-track EF-2 tornadoes, spawned from three separate supercell thunderstorms. By 1900 UTC the low level EHI values decreased as 0-3 km CAPE diminished from convective overturning (Fig. 16c). Between 1900 and 2100 UTC, ten tornadoes, including an EF-2 and an EF-3, from six separate supercell storms occurred. It is interesting to note that the 1900 UTC low level EHI showed a very sharp gradient across the northern DFW Metroplex where the outflow boundary was positioned. The lack of instability to the north of boundary allowed warning forecasters to anticipate supercell thunderstorms would have a diminishing tornado threat as they moved across the outflow boundary into the cooler air mass.

4. Conclusions

The 3 April 2012 tornado outbreak across north and northeast Texas was not well forecast in advance. Synoptic forecast data had indicated a low tornado potential due to limited low level wind shear. An outflow boundary from earlier convection in Oklahoma was likely responsible for rapidly enhancing the low level wind shear and instability values that favored tornadogenesis. A sounding was reconstructed from several data sources for comparison with the available guidance for accuracy.

Short-term RUC guidance did a poor job analyzing the state of the low level atmosphere in the hours before the tornado event. The erroneous RUC analysis likely caused the SPC convective mesoanalysis to also underestimate the actual values of low level wind shear and instability.

Because the GFE objective analysis routine uses true (unfiltered) surface observations for its calculations and has a very high resolution to resolve fine mesoscale details, it produced a far more representative analysis than any other guidance. The objective analyses produced locally by the GFE alerted forecasters at WFO Fort Worth to the increasingly favorable environment for tornadoes. Integration of the GFE objective analyses into warning operations at WFO Fort Worth likely enhanced the situational awareness of forecasters for the potential threat of a significant tornado event hours before it occurred.

Acknowledgements:

The authors wish to thank Greg Patrick, Science and Operations Officer at WFO Fort Worth, for technical assistance.

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Table 1. A table of calculated convective kinematic and thermodynamic parameters at 1200, 1500, 1800 UTC on 3 April 2012 over the DFW Metroplex. The 1200 UTC data were calculated directly from the FWD RAOB. The 1500 and 1800 UTC calculations were based on reconstructed profiles of temperature, dewpoint temperature, and wind observations (see text for explanation).

Parameter	1200 UTC	1500 UTC	1800 UTC
SBCAPE (J kg^{-1})	1738	2036	3312
MLCAPE (J kg^{-1})	1696	1626	2280
0-3 km CAPE (J kg^{-1})	40	55	217
0-6 km shear (m s^{-1})	20	28	33
0-1 km shear (m s^{-1})	10	5	10
0-3 km helicity (m^2 s^{-2})	95	151	277
0-1 km helicity (m^2 s^{-2})	100	41	116

Figures:

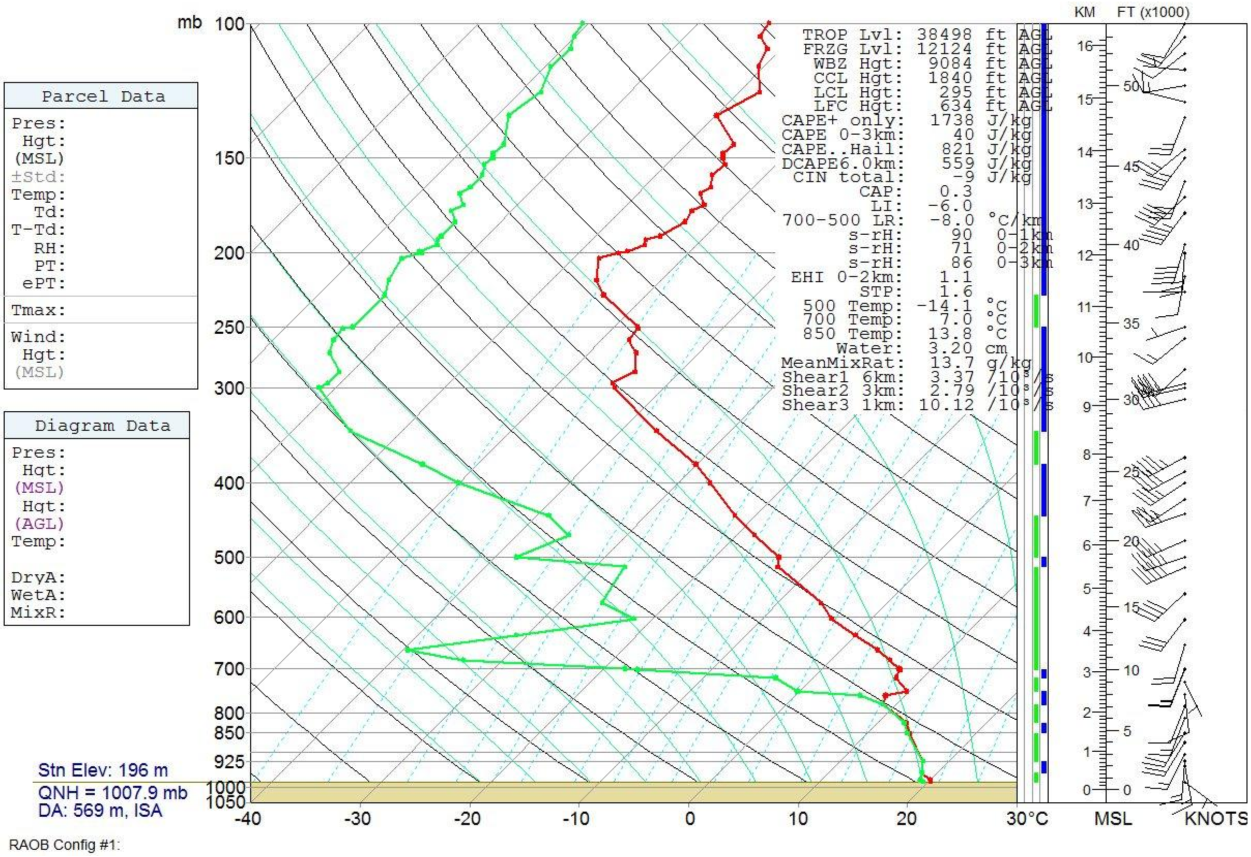

Fig. 1. 1200 UTC 3 April 2012 rawinsonde observation (RAOB) from the Fort Worth, TX National Weather Service Forecast Office (KFWD).

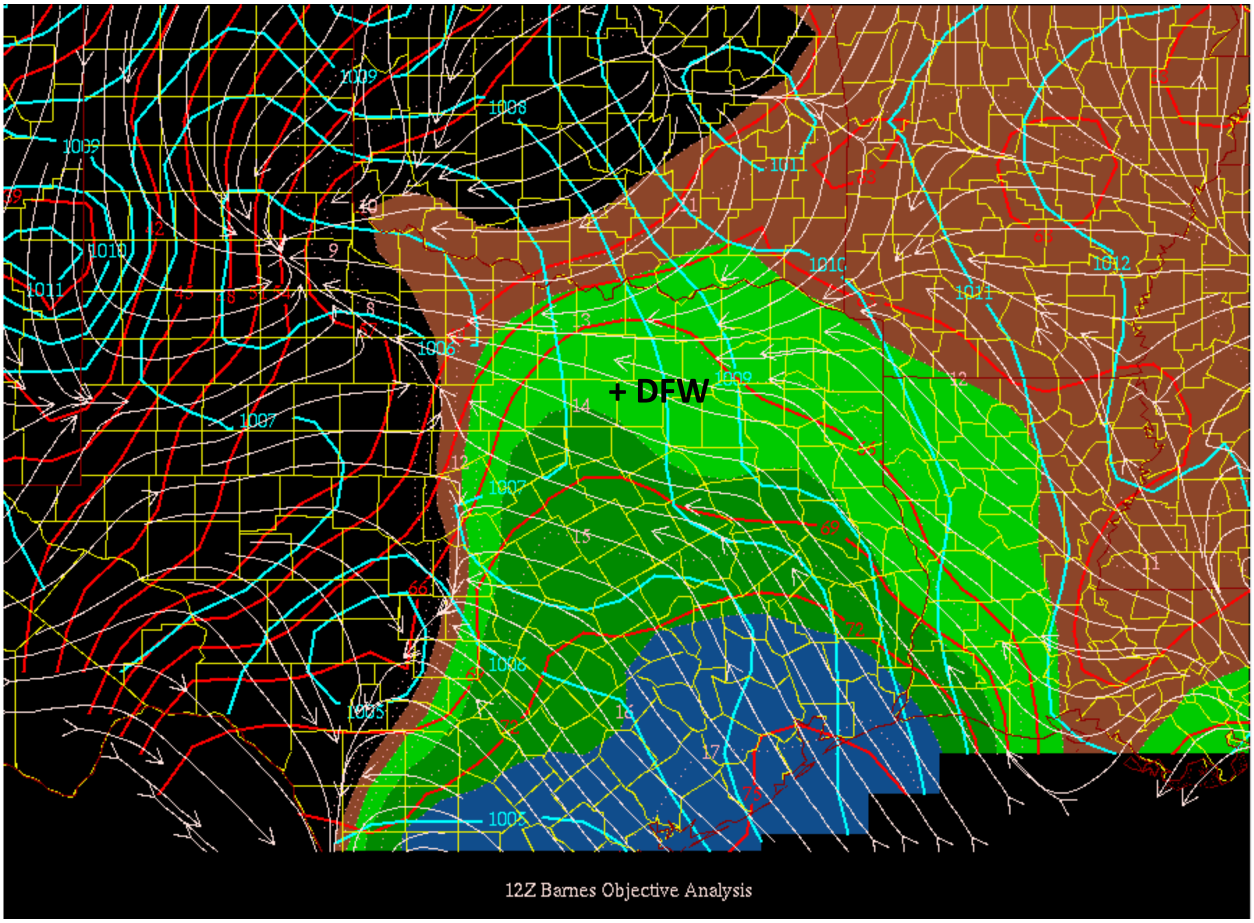

Fig. 2. 1200 UTC 3 April 2012 Barnes objective surface analysis. Mean sea-level pressure are cyan contours, with a contour interval of 1 mb. Surface temperature in °F are the red contours, with a contour interval of every 3 °F. Streamlines are the white contours with arrows pointing in the direction of the surface wind flow. The background image is mixing ratio, with values of 12 g kg^{-1} or greater shaded in green to blue, and values less than 12 g kg^{-1} shaded in brown to black. Mixing ratio is contoured on the image as a light pink dotted line, with a contour interval of 1 g kg^{-1} for mixing ratio values between 8 and 18 g kg^{-1}. The location of Dallas Fort-Worth International Airport is plotted with the cross (+) in the image.

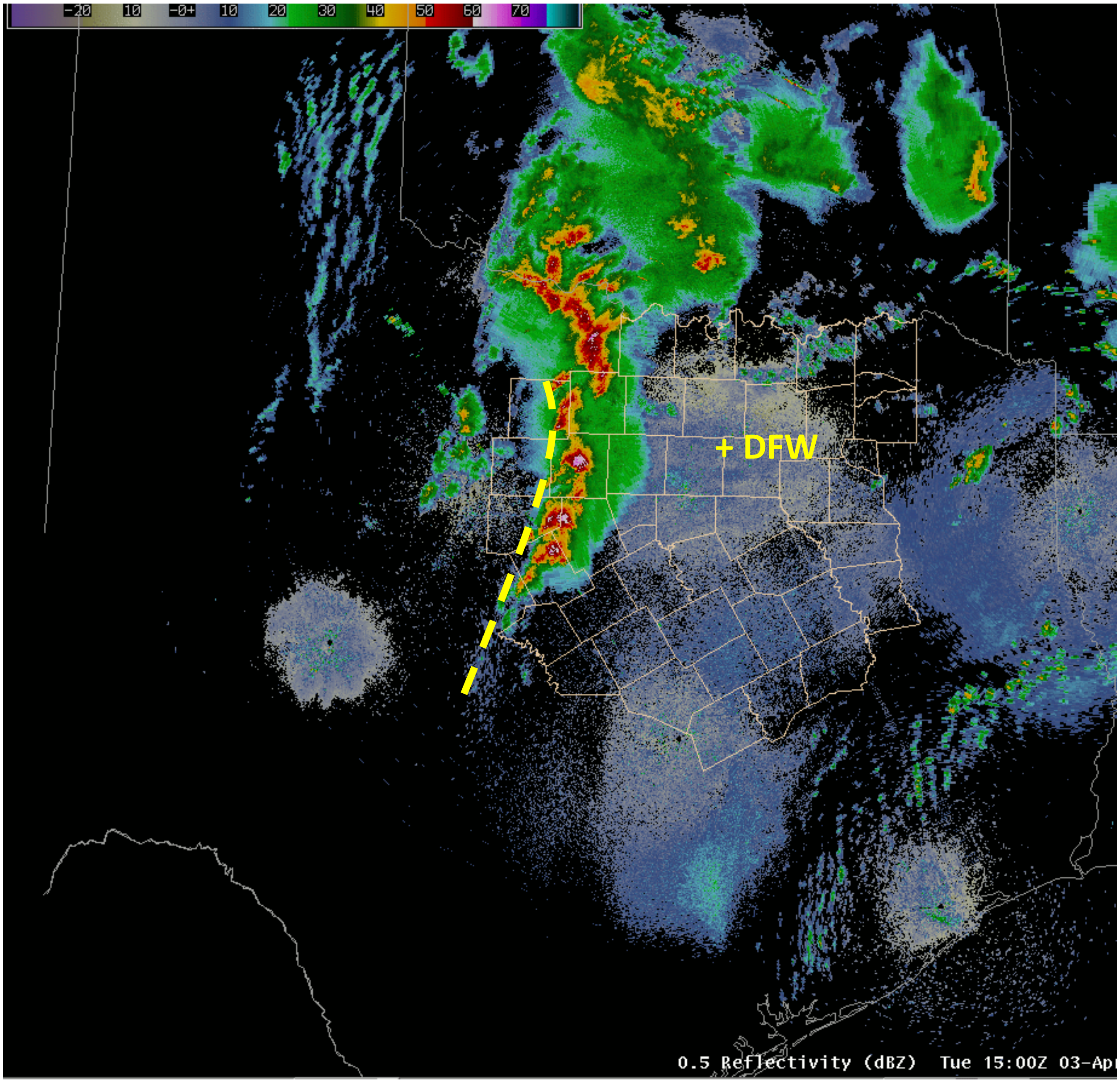

Fig. 3. 1500 UTC 3 April 2012 composite radar image of reflectivity from the 0.5° elevation created from a regional mosaic of nearby WSR-88D sites across TX, OK, and LA. Counties in the WFO Fort Worth warning area are outlined in beige, and the location of Dallas Fort-Worth International Airport is depicted as a cross (+). The line of convection is oriented along or just east of the Pacific cold front, whose position is approximated by the yellow dashed line. Although storms are organized in a linear fashion, discrete elements are evident in the reflectivity field (as gaps of lower values of reflectivity in between higher reflectivity cores).

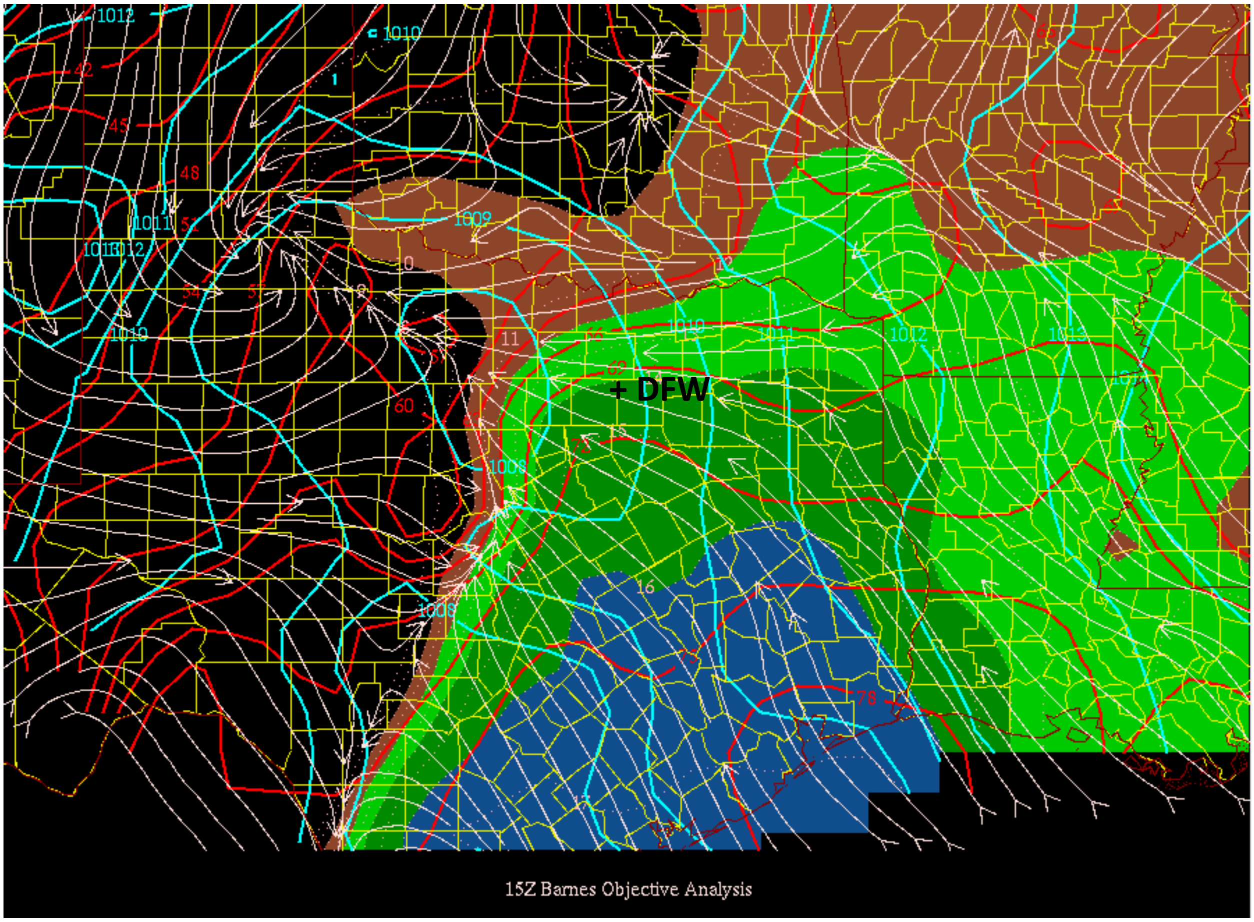

Fig. 4. The 1500 UTC 03 April 2012 Barnes objective surface analysis of surface temperature (°F), mean sea-level pressure (mb), mixing ratio (g kg^{-1}), and streamlines of the surface wind. All contouring and shading conventions are the same as in Fig. 2. The location of Dallas Fort-Worth International Airport is plotted with the cross (+) in the image.

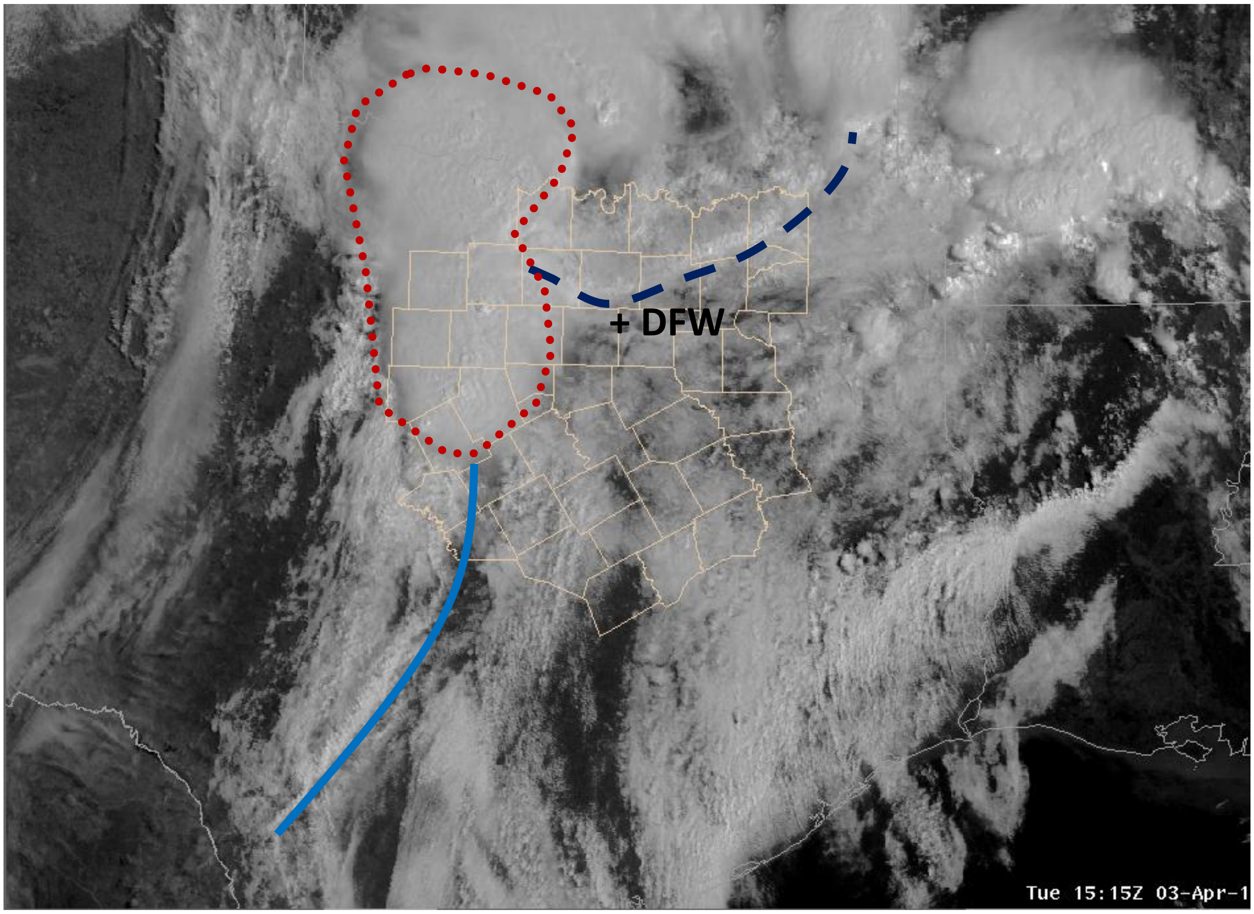

Fig. 5. 1515 UTC 3 April 2012 GOES visible satellite image. Counties in the WFO Fort Worth warning area are outlined in beige and the location of Dallas Fort-Worth International Airport depicted as a cross (+). The location of an outflow boundary moving south from Oklahoma is depicted as the dark blue dashed line. The location of a Pacific cold front is depicted as a solid blue line. The Pacific front and the outflow boundary continue north and west of their depiction in the image, however they are masked from detection by satellite due to upper level convective clouds associated with thunderstorms moving east towards the DFW area. These convective clouds are located within the red dotted loop.

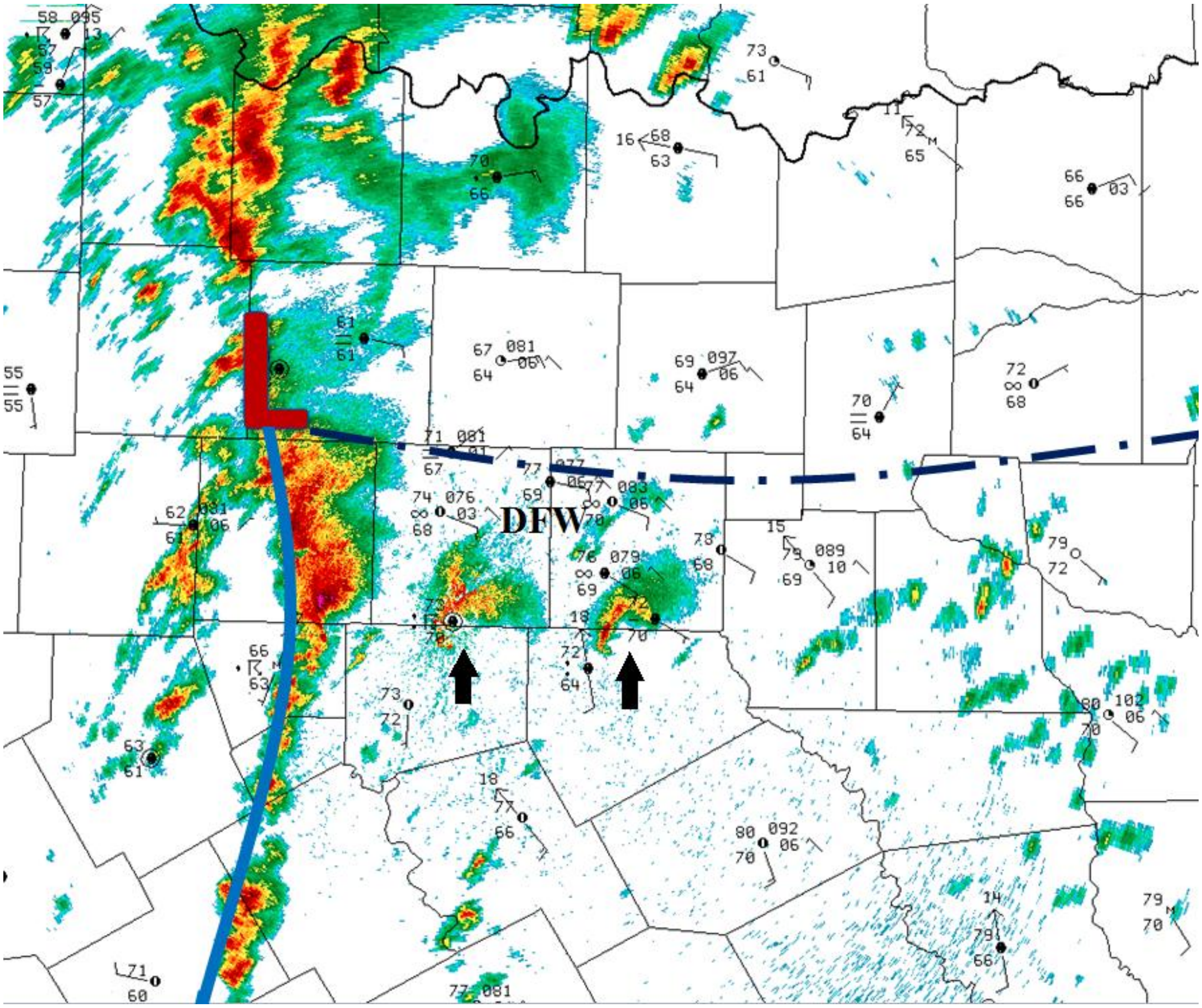

Fig. 6. 1800 UTC 3 April 2012 reflectivity radar image from the 0.5° elevation from KFWS. A station plot of automated surface observations also at 1800 UTC is shown in black. The outflow boundary that had become stationary across the northern DFW Metroplex is shown by the dot-dash dark blue line. A line of convection remains oriented along or just east of the Pacific cold front, whose position is approximated by the solid blue line. The surface low was subjectively analyzed at the region marked by the red L. Two supercells that developed to the south of the DFW Metroplex and east of the front are shown by the black arrows. These supercells produced EF-2 tornadoes near Arlington and Lancaster within 30 minutes of this image.

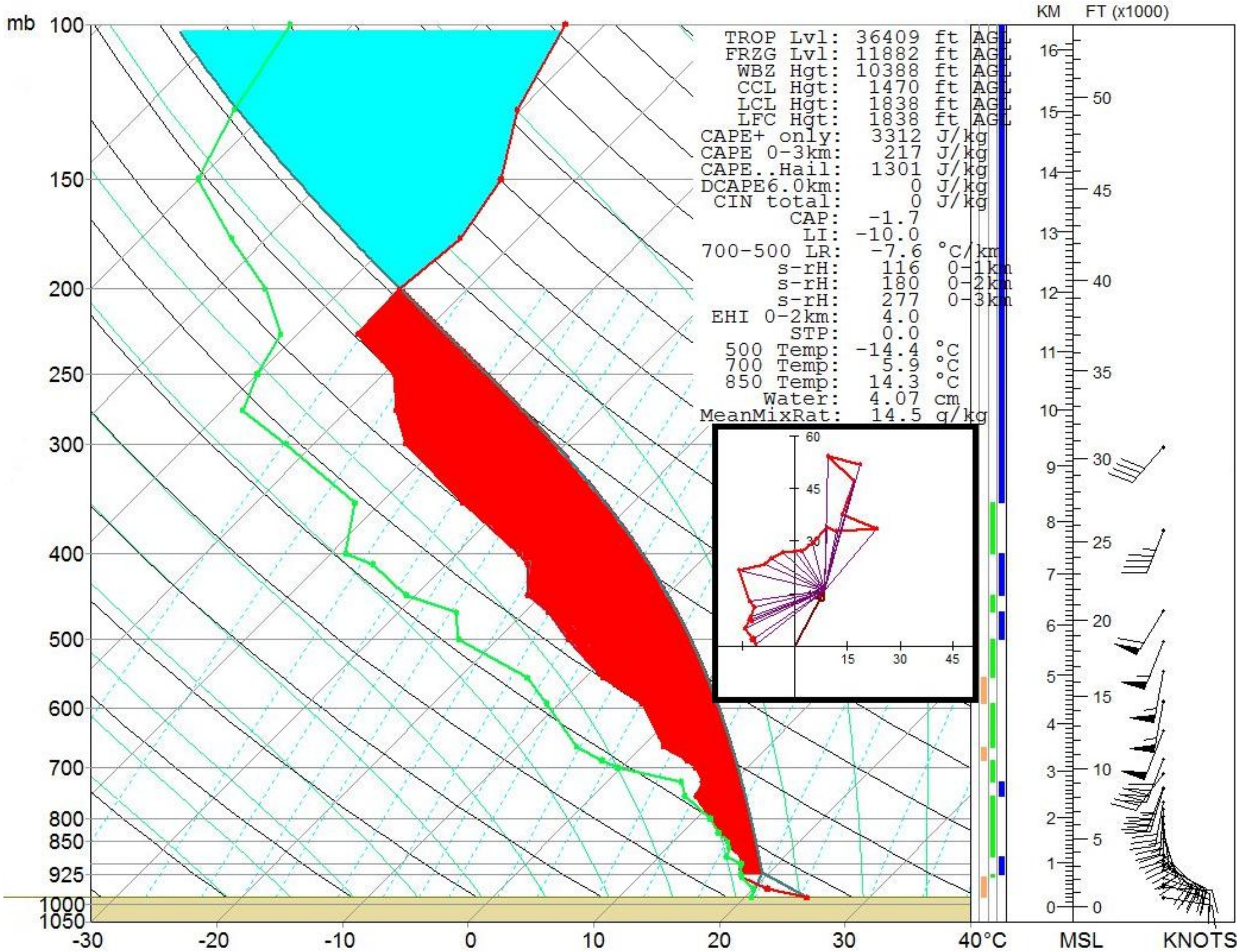

Fig. 7. Reconstructed skew T log P chart and hodograph for the DFW Metroplex at 1800 UTC 3 April 2012 based on composite observations of temperature, moisture, and wind (see text for explanation). The shaded red region is the area of available potential energy for a convective parcel lifted from the surface. The shaded blue area represents convective stability above the equilibrium level.

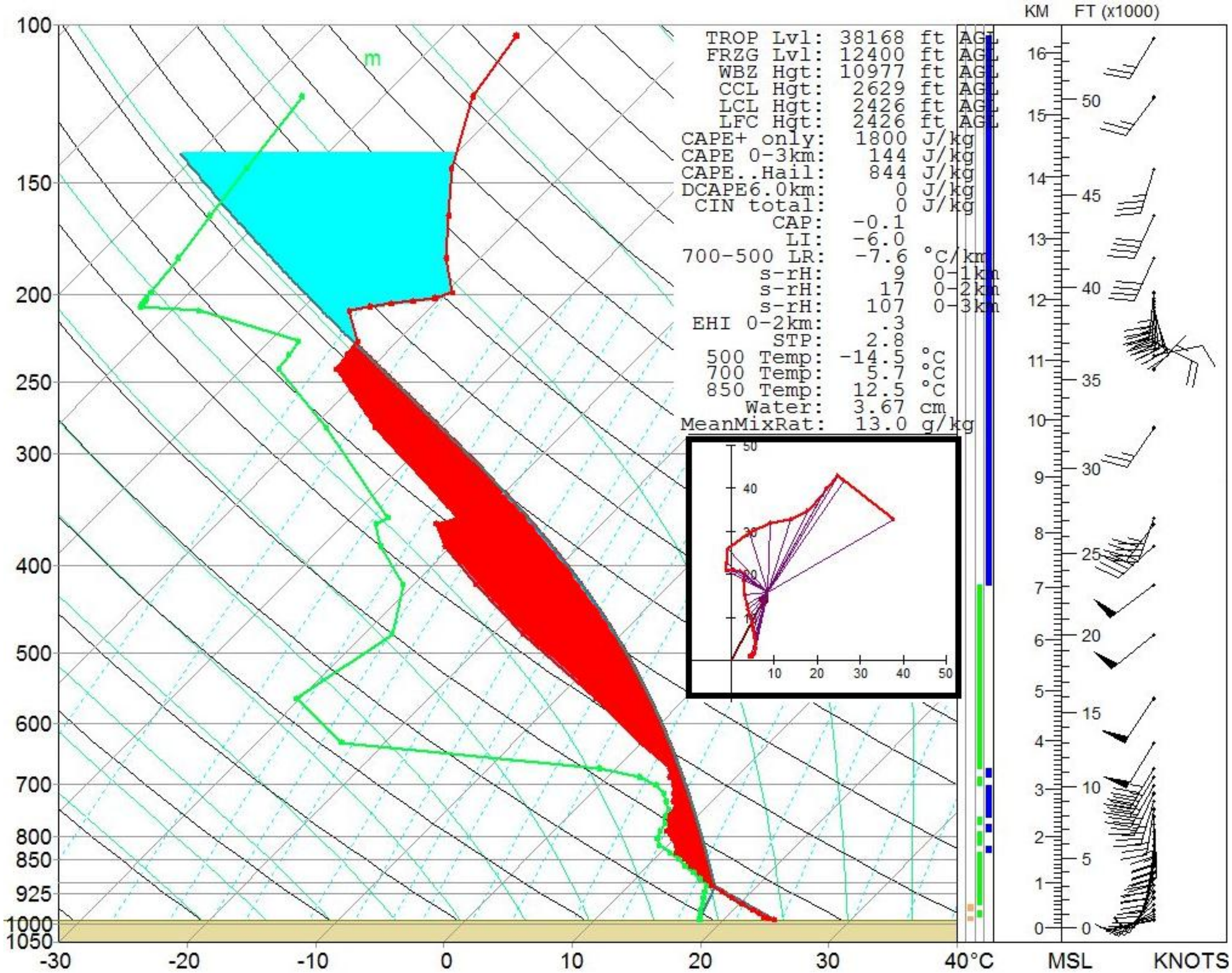

Fig. 8. 1600 UTC 3 April 2012 13km RUC 2-hr forecast sounding and hodograph valid at 1800 UTC for the DFW Metroplex. The shaded red region is the area of available potential energy for a convective parcel lifted from the surface. The shaded blue area represents convective stability above the equilibrium level.

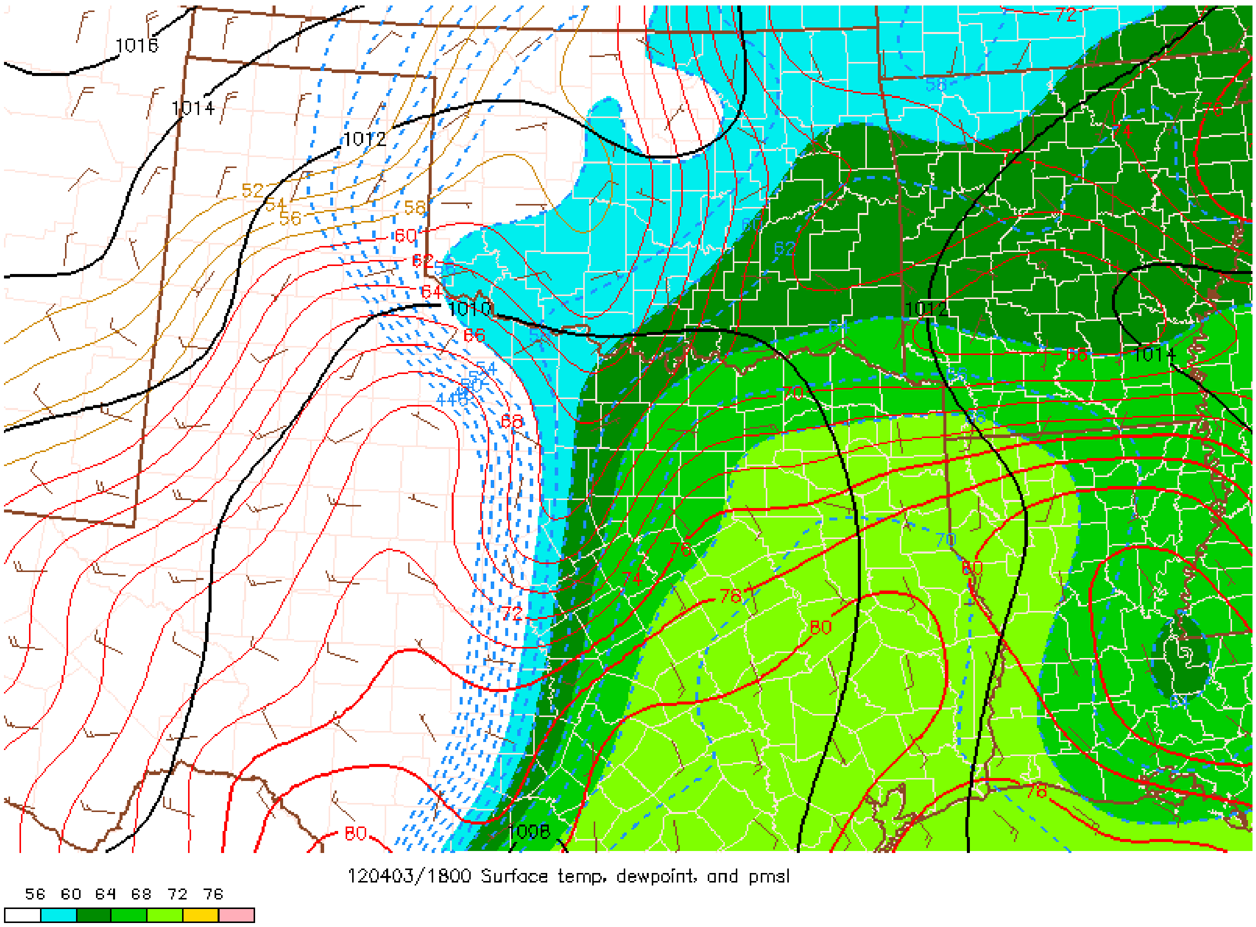

Fig. 9. 1800 UTC 3 April 2012 Storm Prediction Center (SPC) surface objective analysis. Red contours are temperature (ºF), black contours are mean sea level pressure (hPa). Dashed blue contours and shading are dewpoint temperatures (ºF). Barbs depict wind speed (kt) and direction.

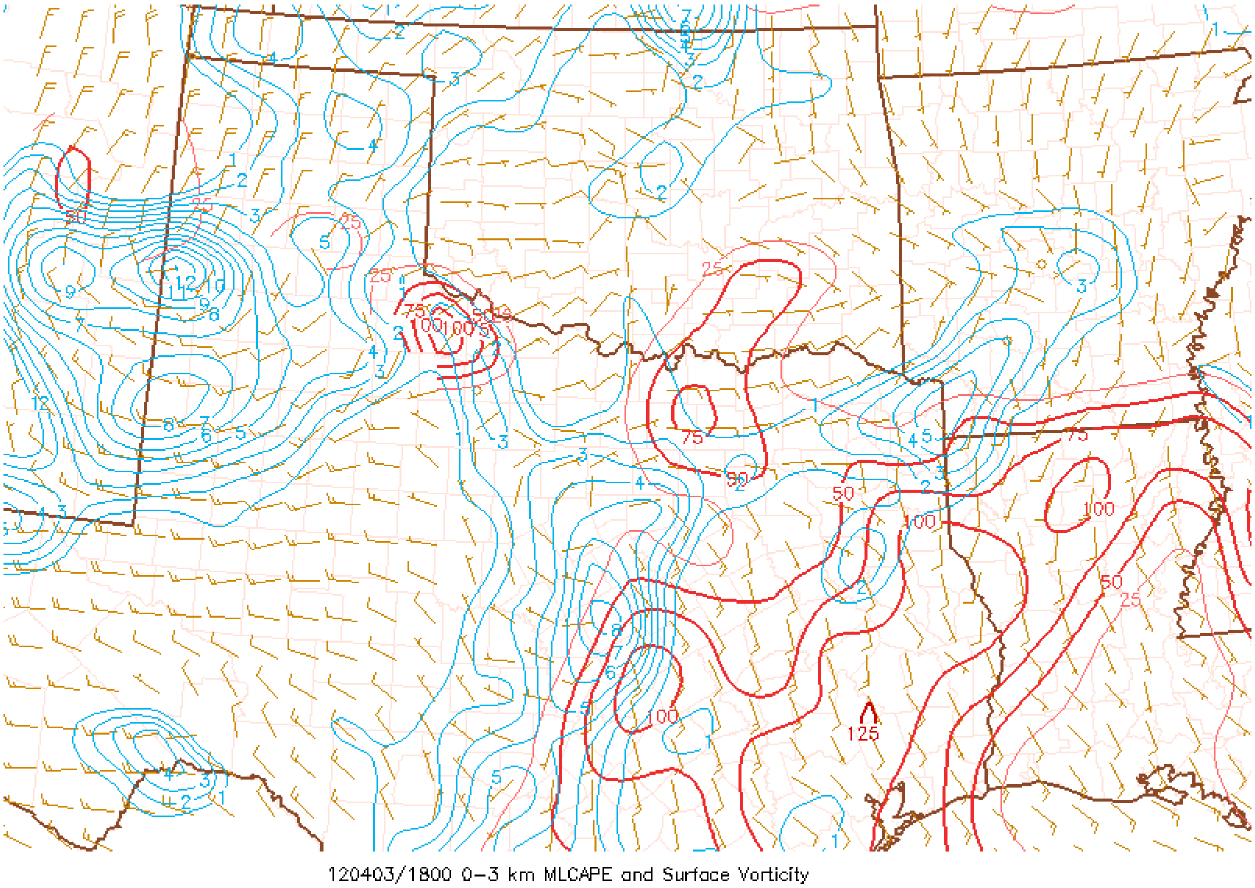

Fig. 10. 1800 UTC 3 April 2012 objective analyses from SPC. Solid red contours are 0-3km MLCAPE (J kg^{-1}). Solid blue contours are surface vorticity ($10^5 s^{-1}$). Barbs depict surface wind speed (kt) and direction.

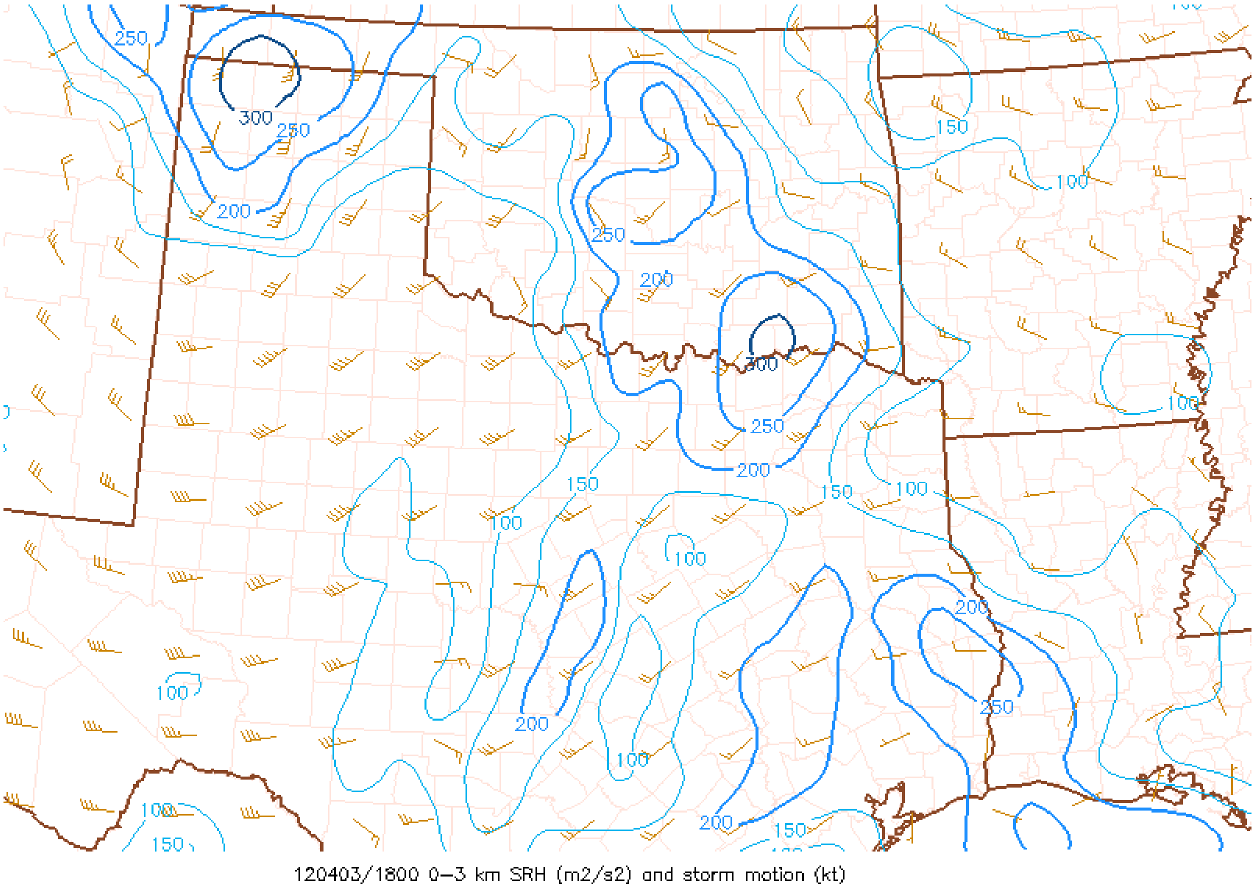

Fig. 11. 1800 UTC 3 April 2012 objective analysis from SPC. Solid blue contours are 0-3 km storm relative helicity ($m^2\ s^{-2}$). Barbs are expected storm motion (kt) using Bunkers technique (Bunkers et al. 2000).

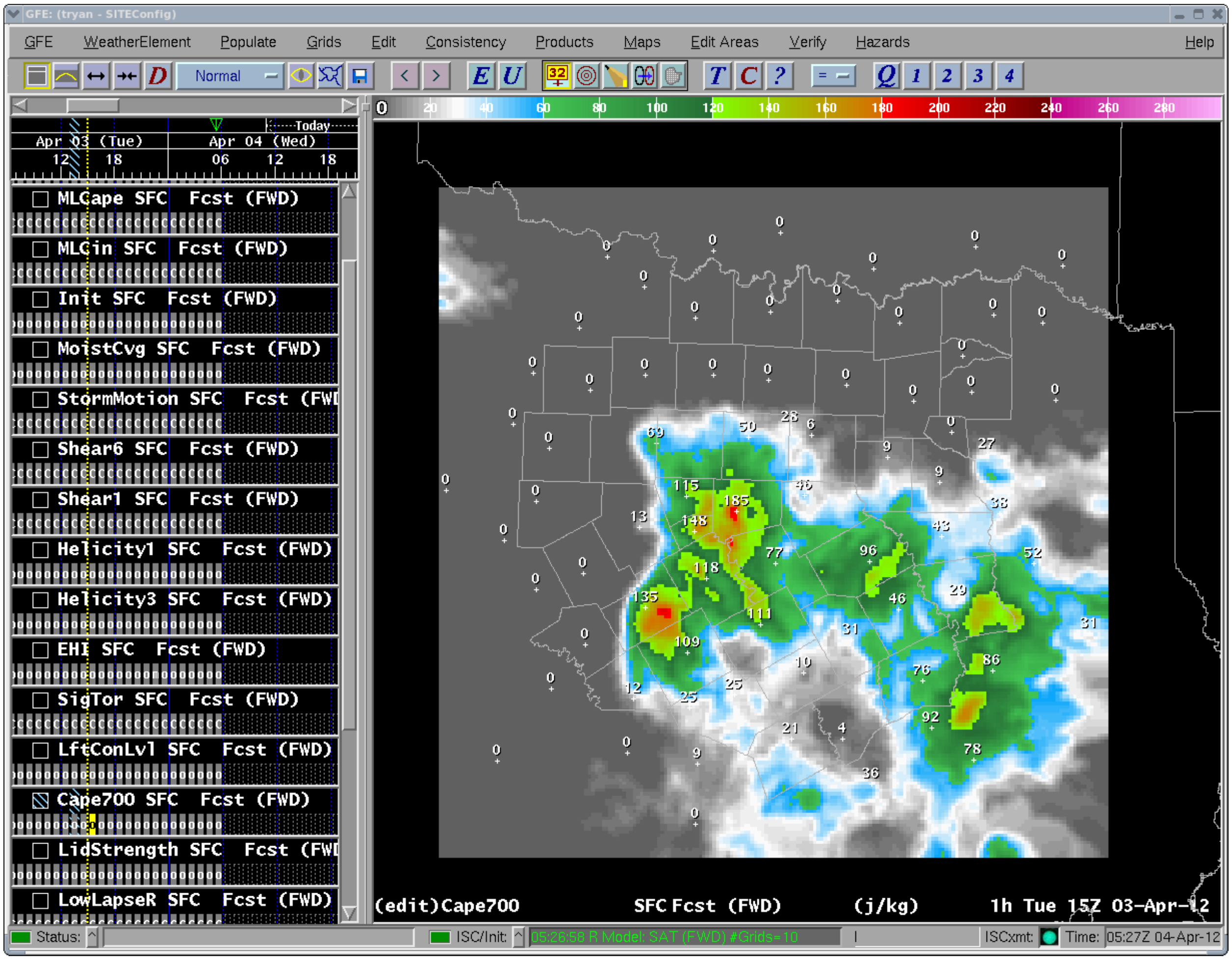

Fig.12. 1500 UTC 3 April 2012 0-3 km CAPE objective analysis from the GFE.

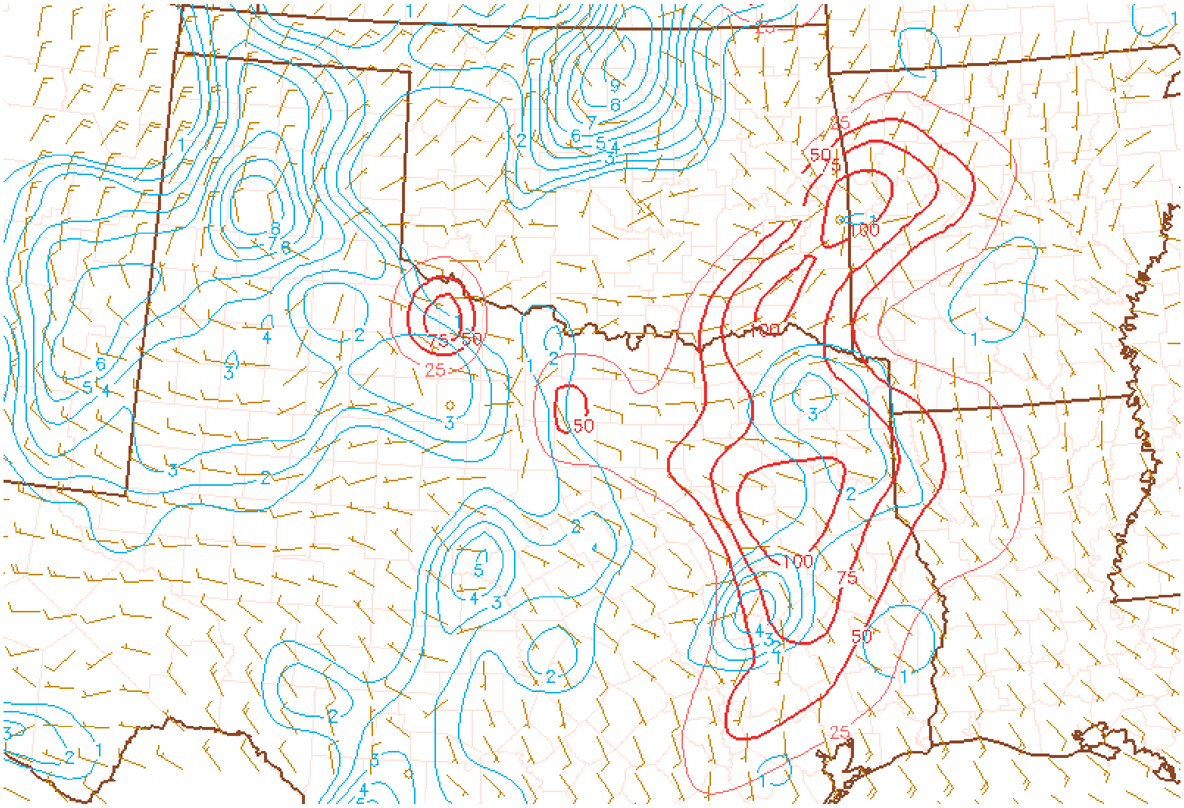

Fig. 13. 1500 UTC 3 April 2012 objective analyses from SPC. Solid red contours are 0-3km MLCAPE (J kg^{-1}). Solid blue contours are surface vorticity ($10^5 s^{-1}$). Barbs depict surface wind speed (kt) and direction.

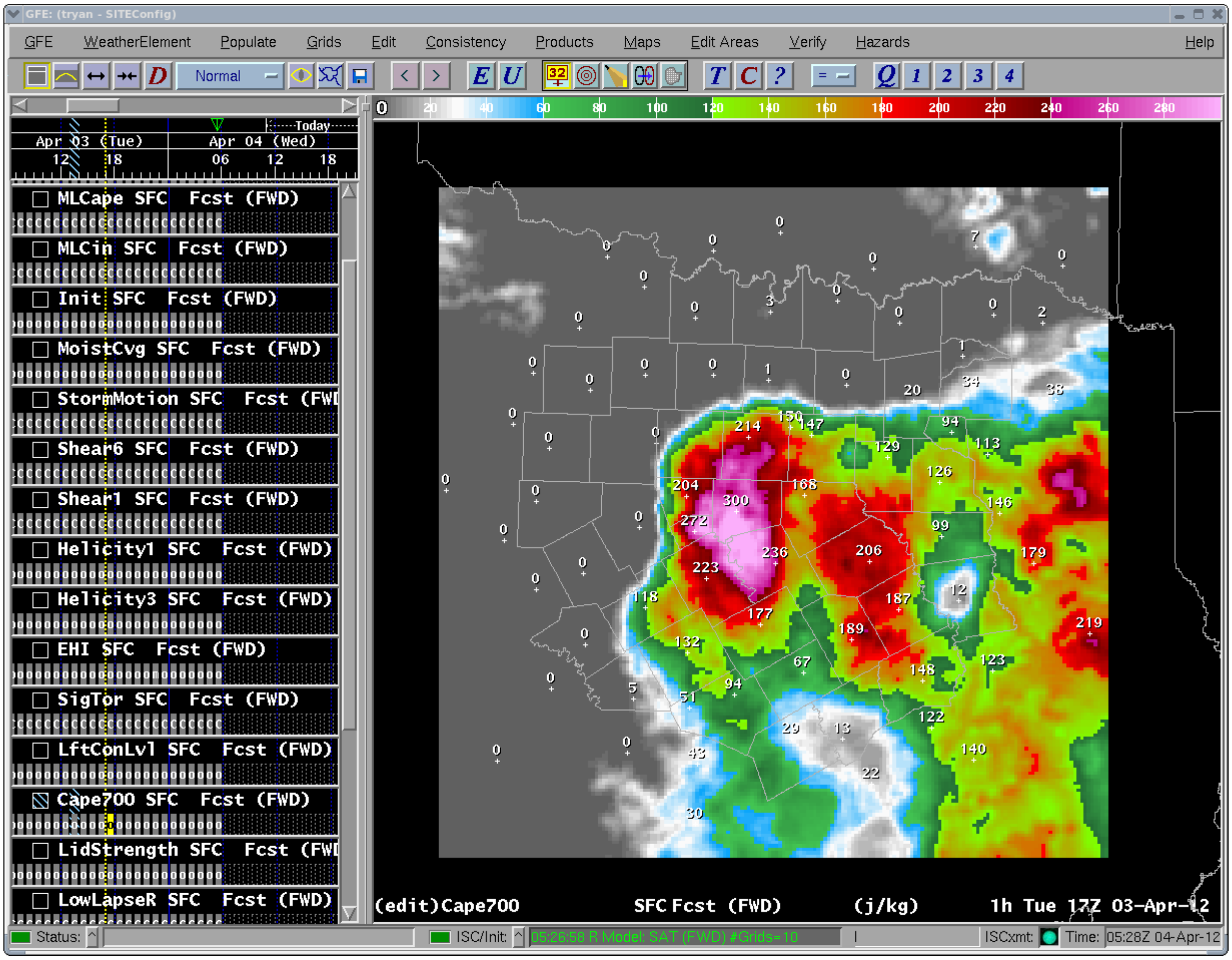

Fig. 14. 1700 UTC 3 April 2012 0-3 km CAPE objective analysis from the GFE.

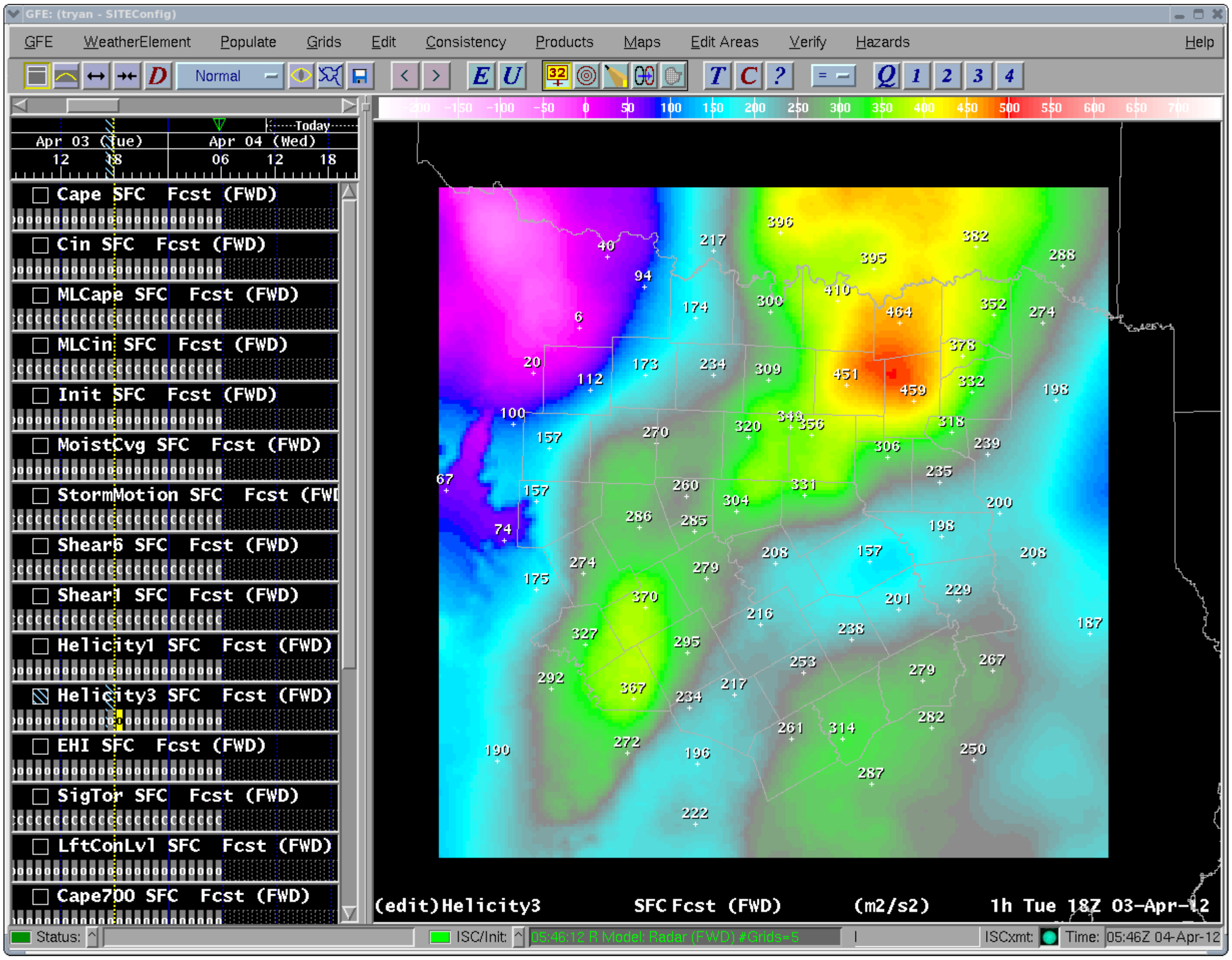

Fig. 15. 1800 UTC 3 April 2012 0-3 km SRH objective analysis from the GFE.

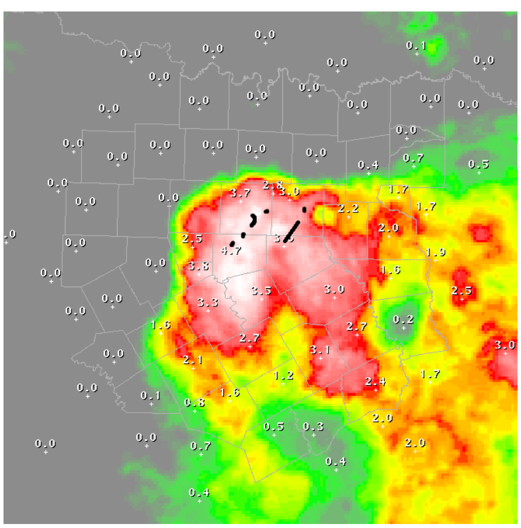

Fig. 16a. Experimental low level EHI objective analysis for 3 April 2012 from the GFE. Low level EHI is shaded at 1700 UTC; gray indicates values of 0, and yellow, orange, and white shading indicates increasingly high values of the index respectively. Black marks are tornado tracks from 1700 UTC through 1900 UTC.

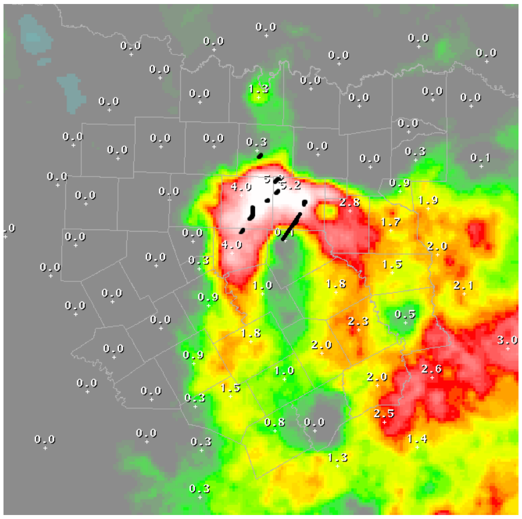

Fig. 16b. Experimental low level EHI objective analysis for 03 April 2012 from the GFE. Low level EHI is shaded at 1800 UTC; gray indicates values of 0, and yellow, orange, and white shading indicates increasingly high values of the index respectively. Black marks are tornado tracks from 1800 UTC through 2000 UTC.

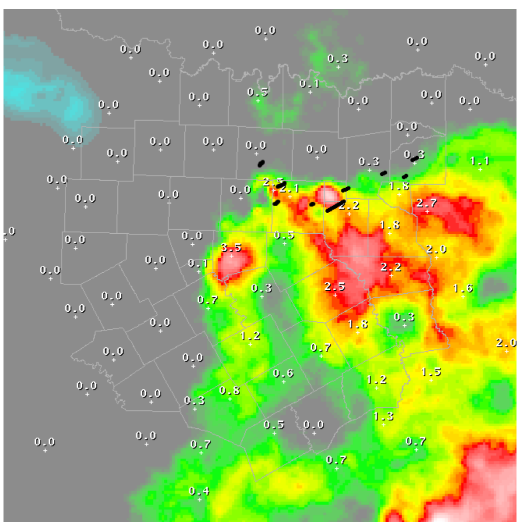

Fig. 16c. Experimental low level EHI objective analysis for 03 April 2012 from the GFE. Low level EHI is shaded at 1900 UTC; gray indicates values of 0, and yellow, orange, and white shading indicates increasingly high values of the index respectively. Black marks are tornado tracks from 1900 UTC through 2100 UTC.