CASE STUDY 3: JARRELL TEXAS TORNADO OUTBREAK ON MAY 27, 1997

John Paul Argenti

Department of Atmospheric and Oceanic Science, University of Wisconsin-Madison, Madison, Wisconsin

ABSTRACT

This Case Study is focused on a supercell event that occurred over central Texas on 27 May 1997, which ultimately spawned an F5 tornado in spite of a forecast for no tornadoes on this day. Emphasis will be given to the synoptic pattern and mesocale mechanisms that contributed to the event. Model, Observational, Radar, and Satellite data primarily centered around 18Z 27 May 1997 are presented to help in this process. Surface convergence, upper level divergence, extreme CAPE values, and an MCS generated gravity wave are among the key ingredients that allowed for a deadly and unforeseen event to transpire.

INTRODUCTION

On the afternoon of 27 May 1997 an unusual supercell outbreak took place across central Texas. Unusual in that the synoptic weather pattern lacked some of the classical features associated with severe weather in the Texas region during this time of year. The event took place after a forecast for just severe thunderstorms rather than tornadoes and supercells. Extremely high CAPE and low environmental shear characterized the environment associated with the tornado outbreak. A stationary boundary that was present may have allowed for a long-lived rotating supercell to develop in the absence of the environmental shear.

Radar and Satellite imagery both show that the supercells did form along the stationary boundary associated with a weak cold front, dry line, and strong moisture convergence at the surface. A jet streak located above 300mb moved eastward and oriented itself in a position putting the right entrance region over the area affected by the supercells. This may have created some upward vertical motion and divergence aloft. Supercells typically require many favorable conditions all-occurring simultaneously in order to be produced. This paper will attempt to provide reasonable evidence and arguments as to *why the Jarrell Tornado event occurred despite what appeared to be an absence of critical features such as low-level shear and an uplift mechanism*.

There were 34 reports of severe weather including 12 for large hail and 22 for tornadoes from this event. The most violent (F5) tornado that was spawned occurred near the town of Jarrell in Williamson County TX causing 27 of 30 total fatalities during the outbreak.

Data from the storm are summarized

in section 1 and listed throughout this paper in figures where applicable. The overview of the synoptic pattern will be presented in section 2, with specific emphasis on the distributions of moisture, instability, divergence, boundaries, and large-scale wind patterns. The mesoscale convective initiation and the genesis of the Jarrell supercell are presented in section 3. Section 4 summarizes the important atmospheric factors that produced this unusual supercell event.

DATA

The data presented in this case study has been gathered from several sources. The four-panel plot of Synoptic scale weather at key atmospheric levels (300, 700, 850, 850-500 mb) represents Eta Model analysis for 12Z 27 May 1997 and was copied from the Unisys Weather Archive. The Miller Diagram was hand drawn using Upper Air Sounding Observations at levels of 300, 500, 700, and 850mb from the GARP program at 12Z 27 May 1997. The four-panel plot of the surface dryline, frontal boundary, surface low, surface observations, and gravity wave position from 16Z 27 May to 19Z 27 May 1997 was taken from a figure on a paper written by Stephen F. Corfidi, further noted in references. The two-panel plot displaying wind barbs and moisture convergence at 975mb as well as a streamline analysis at 975mb was created using the Eta model 6-hour forecast for 18Z 27 May. The 500mb streamline and temperature advection plot over Texas was created using GARP and the Meso-Eta model 6-hour forecast for 18Z 27 May 1997. The surface to upper atmosphere plot of Convective Available Potential Energy was created using the Meso-Eta model 6-hour forecast for 18Z 27 May 1997. The two-panel plot showing 250mb isotachs and wind barbs in one panel and 250mb streamlines and divergence in the other panel was created using GARP and Meso-Eta model 6-hour forecast for 18Z 27 May 1997. The four-panel plot of Upper Air soundings taken over Fort Worth, TX and Corpus Christi, TX represents data from 0Z 27 May to 0Z 28 May 1997 and was taken from the University of Wyoming sounding archive. The cross-section plot of mixing ratio values between Norman OK, Fort Worth TX, Corpus Christi TX, and Brownsville TX was created using upper air sounding text data from those cities respectively taken from the University of Wyoming sounding archive for 12Z 27 May, 1997. The four-panel plot of GOES-8 visible satellite imagery was taken from archived data via the GARP program showing data from 1615Z to 1915Z over Texas at 4km resolution. The four-panel plot of radar reflectivity images from the Nexrad site at New Braunfels, TX covering 2043Z to 2100Z was taken from a website related to the NWS covering the Jarrell Tornado and contains the time frame of the Jarrell F5 tornado touchdown at 2048Z.

SYNOPTIC OVERVIEW

On 12Z 27 May a weak upper level trough was centered over the central plains states accompanied by a jet streak oriented southwest to northeast over north Texas through Missouri. This orientation of the jet put north central Texas under the right entrance region typically known to allow for ascent at mid levels and divergence aloft, two conditions favorable for a supercell outbreak. A 12Z 27 May Eta model

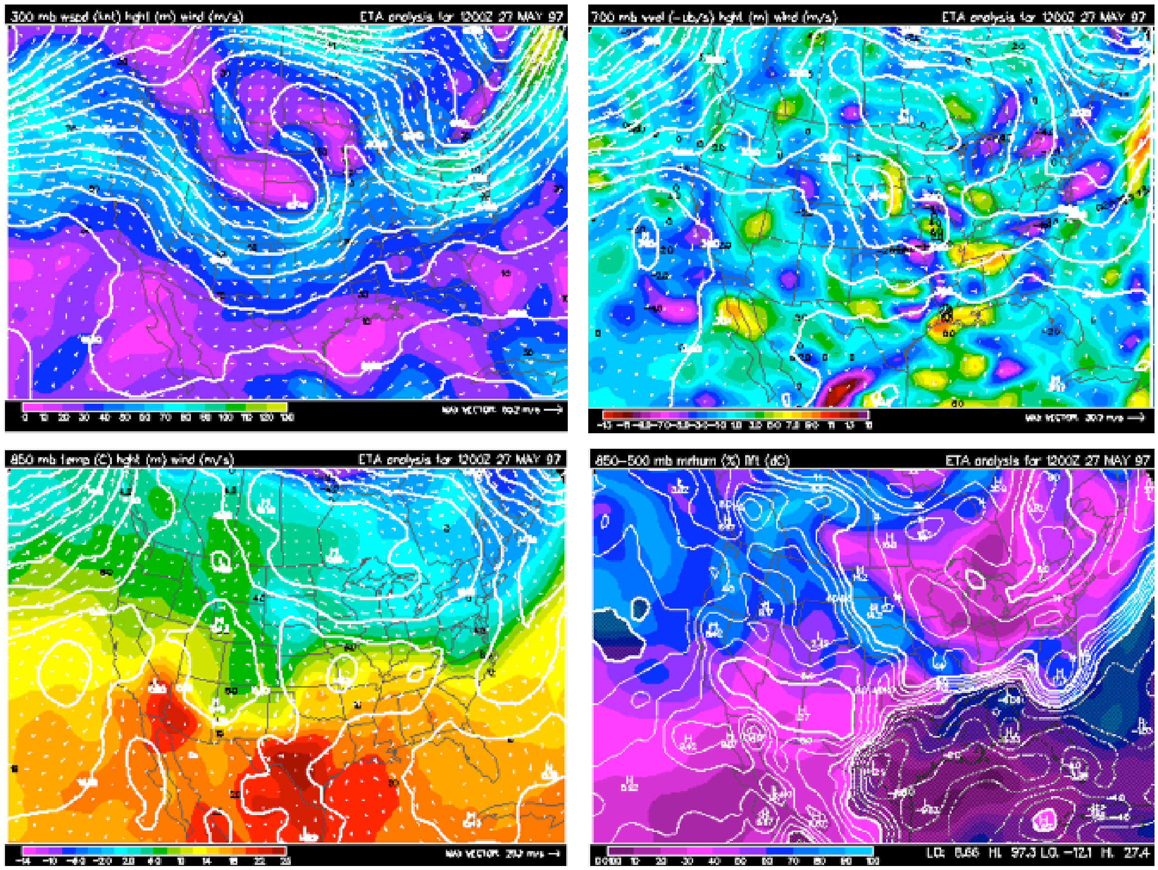

Figure 1) Four-panel plot from the 12Z 27 May 1997 Eta Model analysis of a) 850 mb Temperature (C), Geopotential Heights (m), wind velocity (arrow), b) 300 mb wind speed (knot), Geopotential Height (m), wind velocity (arrow), c) Surface pressure (mb), 1000-500mb thickness (m), and d) Lifted Index.

analysis of several synoptic scale features is shown in **Fig 1** to highlight the favorable conditions for supercells mentioned. In the first panel of Fig 1 (top left) we can see the jet streak north of Texas, and on the southeast side of a trough at 300mb. The wind vectors at this level indicate there is divergence south of the right entrance region. The second panel of Fig 1 (top right) showing 700mb vertical velocity confirms that upward vertical motion is occurring over central Texas underneath the area of divergence. These features are very important considering Texas had an onshore flow pumping moisture and high temperatures across the surface beneath an elevated mix layer (EML) cap (Corfidi 1998). The cap was probably strong enough to suppress convection for a few days and produce a loaded gun sounding of warm moist air beneath an EML that only needed a trigger (vertical motion) to produce convection.

The third panel of Fig 1 (bottom left) shows a forecast of very warm temperatures from Del Rio up toward Dallas Texas that relates to the cap inversion mentioned earlier having suppressed convection for a few days. The fourth panel of Fig 1 (bottom right) displays the lifted index (LI), which is a useful indicator of the potential for severe weather. Values below -6 are usually taken to represent a significant risk of severe weather and/or supercells. Values over central Texas at 12Z range from -6 to -12 in the Eta model and this analysis was done for 7am before

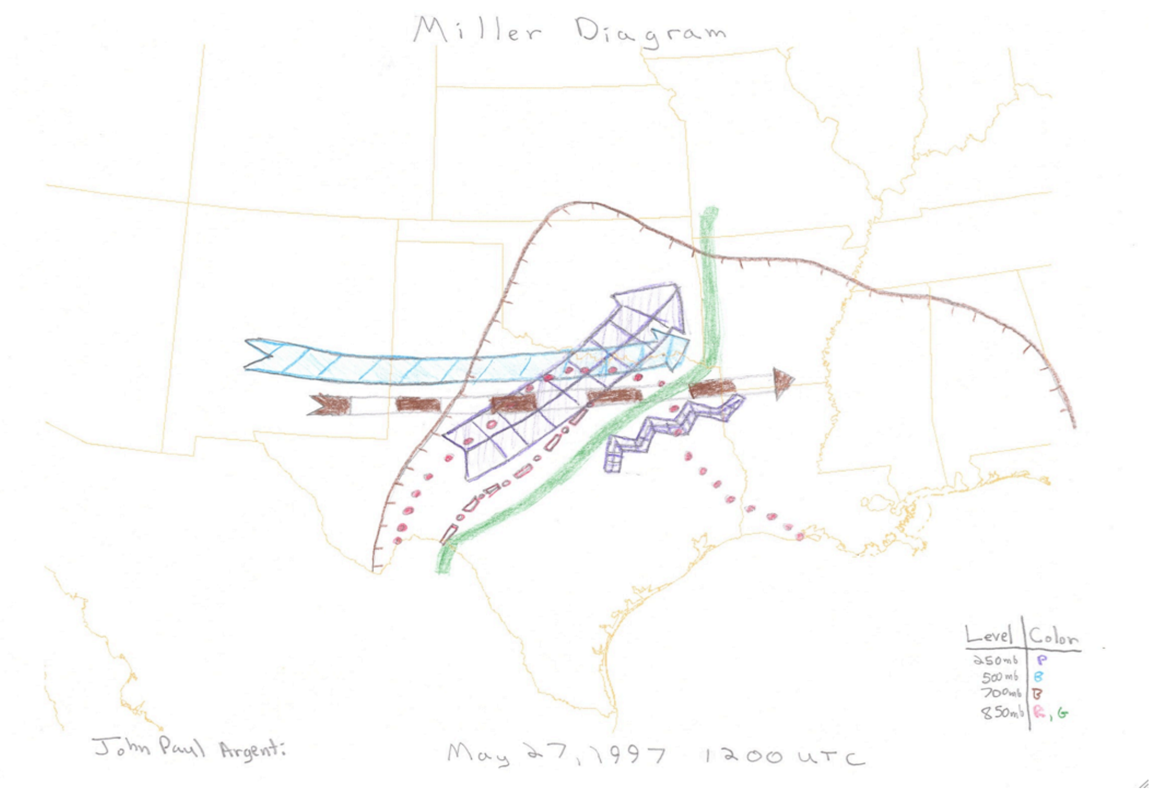

Figure 2) Miller Diagram for 12Z 27 May 1997. Purple color is 250mb, Blue color is 500mb, Brown color is 700mb, and Red/Green colors are 850mb. Used as a 3-D aide for thinking about the environmental set up for a severe weather event.

daytime heating has a chance to decrease these values. The same panel shows a layer of air between 850 and 500mb with low relative humidity covering Texas indicative of an EML and remaining presence of the cap inversion that can produce severe weather.

The wind patterns at all levels of the atmosphere at 12Z 27 May were somewhat atypical for a tornadic supercell event, except at jet-stream level. There was not a well-defined low-level jet the day of the outbreak, rare considering the spawning of a F5 tornado. Winds on the surface were generally onshore, while at 850 they were disorganized and weak. At 700 and 500mb winds were out of the west across Texas and rather weak. In fact one of the unique aspects of this case study was the lack of any strong shear in the lower atmosphere whatsoever. Shear is widely considered a necessary ingredient for supercell development, making the formation of supercells on 27 May an eye-opener in many respects.

A good way of piecing together how a severe weather event occurred is to combine features throughout the atmosphere into one visual aide. **Fig 2** is a hand drawn Miller Diagram that gives a 3 dimensional picture of the atmosphere above north central Texas at 12Z 27 May, five hours before the first thunderstorm kicked off. This Miller Diagram contains features from 250, 500, 700, and 850mb that are color coded in the figure. At upper levels the flow is southwesterly with divergence immediately to its south and east over north Texas. At 500mb and 700mb there is straight-line westerly flow along with

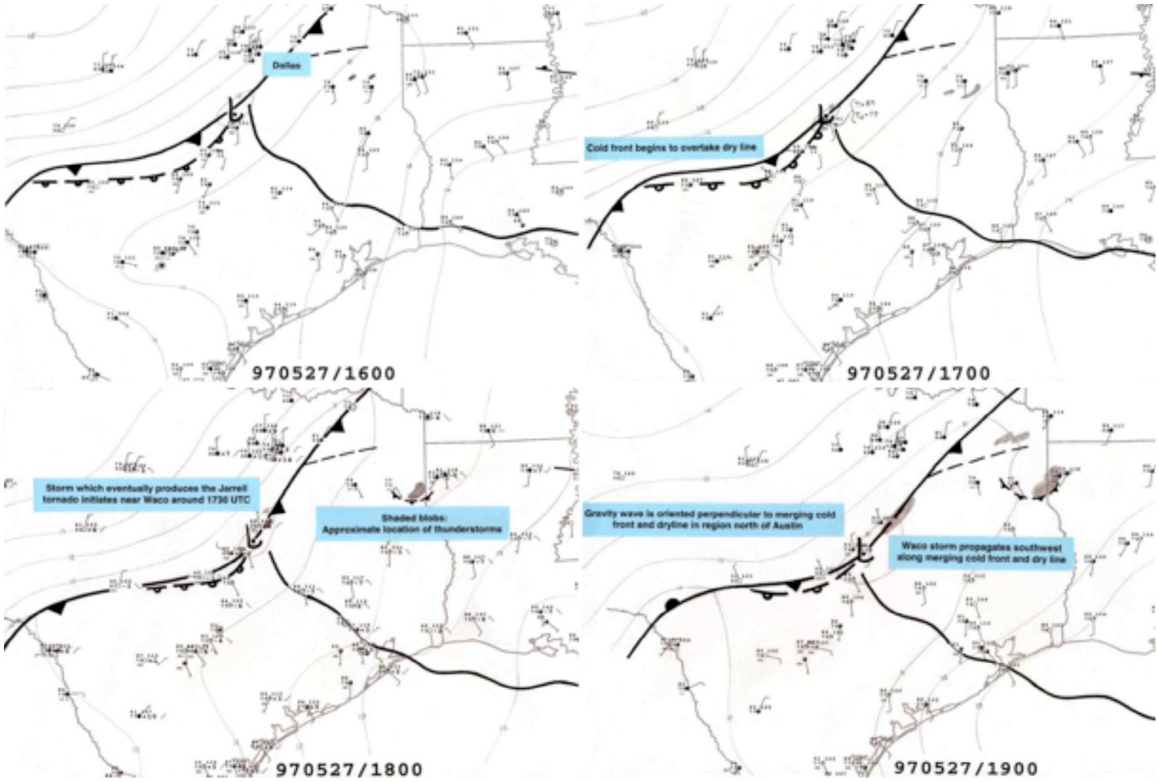

Figure 3) Four-panel plot covering 16-19Z respectively 27 May 1997 showing the evolution of a frontal boundary, dry line, gravity wave, and surface low in conjunction with surface observations.

relatively moist air over the southern states at 700mb. At 850mb a thermal ridge noses toward through central Texas covering most of the state. In addition there's a dry line stretching from Del Rio to Fort Worth just behind an axis of moisture. Together these features show some favorable conditions for severe weather such as the upper level divergence, moisture out ahead of a dry line at low levels, and a thermal ridge at low levels. What might appear to be missing is any obvious shear or dry tongue at mid levels. The dry line also has little movement accompanied with it at 850mb, as the wind pattern at this level is weak and disorganized. Sources for lifting motion aside from the jet streak must be located along the surface and/or are undetectable in data observations.

With no major upper level systems over Texas the day of the Jarrell Tornado Outbreak, there must have been some important surface features that may have aided toward the outburst of convection through the EML. **Fig 3** consists of a four-panel plot of hourly surface observations between 16 and 19Z 27 May that helps to diagnose the position of a dry line, a weak cold front, wind patterns, and a southward propagating gravity wave that were all in place as the Jarrell supercell developed. On the surface there was a weak cold front associated with the upper level disturbance way to the north over Nebraska and Missouri. Just out ahead of the cold front was a dry line that dragged down from a small low-pressure center southeast of Dallas (Fig 3a). This dry line separated extremely moist

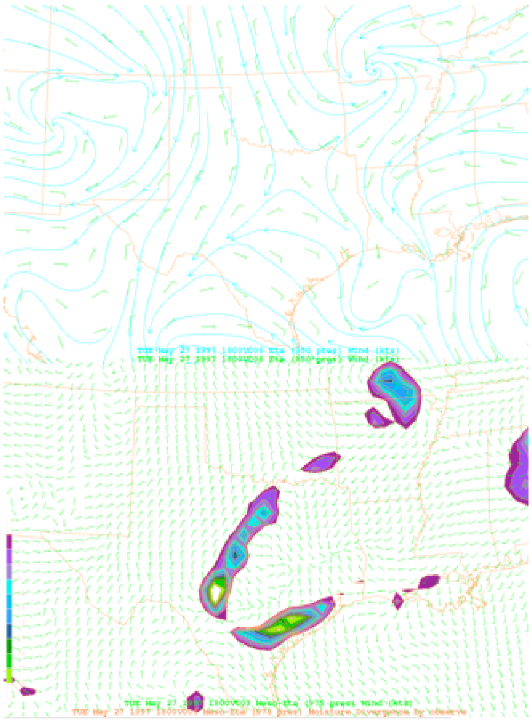

Figure 4) a) 975mb wind barbs and streamlines and b) 975mb wind barbs and moisture convergence (g/kg) for the 6-hour Meso-Eta model forecast 18Z 27 May 1997.

boundary layer air from drier continental air from the west. Throughout the supercell outbreak the front and dry line were quasi stationary making the front more of a wind-shift boundary.

The wind-shift boundary and dry line had extremely strong moisture convergence associated with them as seen in **Fig 4**. The first plot in Fig 4 shows 975mb wind barbs and streamlines from the 6 hour Eta Model Forecast of 18Z 27 May. Although not exactly correspondent to the actual surface wind convergent zone, this plot clearly shows a striking convergence axis over central Texas bringing flow from contrasting moist and dry air masses. More evident in the second plot of Fig 4 is a very significant axis of moisture convergence with values in excess of 15 g/kg carried by the surface winds toward the frontal boundaries. This moisture axis near the surface also underlies the one shown at 850mb in the Miller Diagram (Fig2). Dew points rose to the mid and upper 70s just east of the dry line carrying mixing rations of 15g/kg or more thanks to the stationary boundaries and days of onshore flow without convection.

Surface moisture convergence combined with hot temperatures, as seen in the third panel of Fig 1 and in observations (Fig 3), typically produce conditionally unstable conditions. One additional ingredient for an unstable atmosphere and a more negative LI is cold mid-level temperatures. **Fig 5** shows a plot of 500mb cold-air temperature advection (CAA) and streamlines from the 6 hour Eta model forecast of 18Z 27 May. In this figure it is evident that at mid levels cold air is being advected right over the Jarrell Texas area, moisture convergence zone, and warm surface temperatures. This is a powerful thermodynamic environment for supercell development. Nothing is more telling of this fact than the Convective Available Potential Energy (CAPE) values produced by all the thermodynamic features mentioned. Plotted in **Fig 6** are the CAPE values from the 6-hour Eta model forecast of 18Z 27 May over Texas. Nosing northward along near the location of the

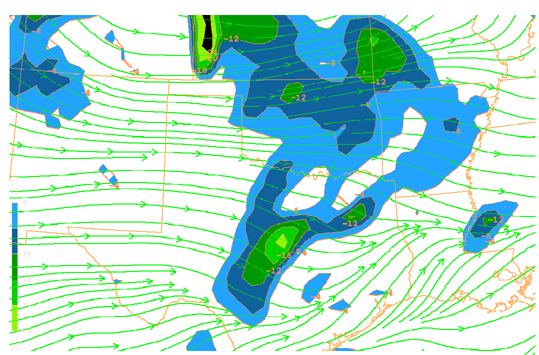

Figure 5) 500mb streamlines and Cold air advection for 18Z 27 May 1997 Meso-Eta 6–hour forecast.

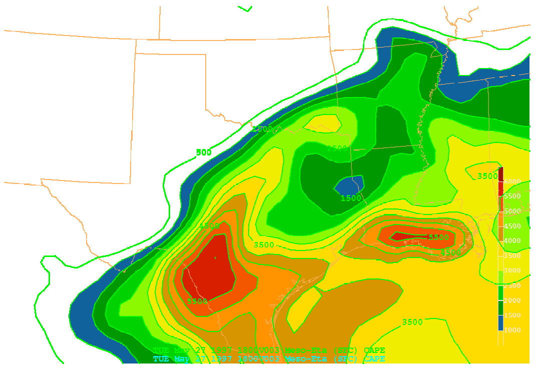

Figure 6) Surface to Atmosphere CAPE in J/kg for 18Z 27 May 1997 Meso-Eta 6-hour forecast.

dry line, frontal boundary, and moisture convergence axis are values in excess of 5000 J/kg. In actual observations, CAPE values rose to near 6000 J/kg +. All that is needed to produce and sustain a supercell in this environment is a lifting mechanism to break any existing cap inversion and some source of vorticity.

The night of the 26th, thunderstorms had developed along a dryline in Oklahoma and evolved into a large Mesoscale Convective System (MCS) that weakened and collapsed by the morning of the 27th. An outflow boundary created by the MCS moved across southern Arkansas by the afternoon along with a well-defined gravity wave plotted in Fig 3. The gravity wave, dry line, and stationary front would become the key mechanism for firing the loaded thermodynamic gun to be discussed further in the next section. Following the timeline in Fig 3, at 18Z the gravity wave is seen to pass by the intersection of the dryline and cold front while moving southwestward. The dryline barely moves, likewise for the wind-shift boundary (cold front) during this time period. In fact the dryline appears to merge with the frontal boundary by 19Z in Fig 3. It is during these hours, particularly at 18Z, that convection is fired off near Jarrell Texas in association with the passing of the gravity wave along the dryline and frontal boundary. Other convective cells continued to fire off along the stationary frontal boundary with passage of the gravity wave (not shown here). It will be the next step to examine more closely the mesoscale features and processes that led to supercell development along the wind-shift boundary.

MESOSCALE ANALYSIS

By around 18Z 27 May the jet streak shown earlier in Fig 1 (panel 1) had oriented its right entrance region even closer to North Texas. The flow pattern into the rear of the jet streak was splitting from a northwesterly flow over southeast Texas to produce a strong area of divergence in the vicinity of the Jarrell supercell (**Fig 7**). It is likely that this area of divergence provided good

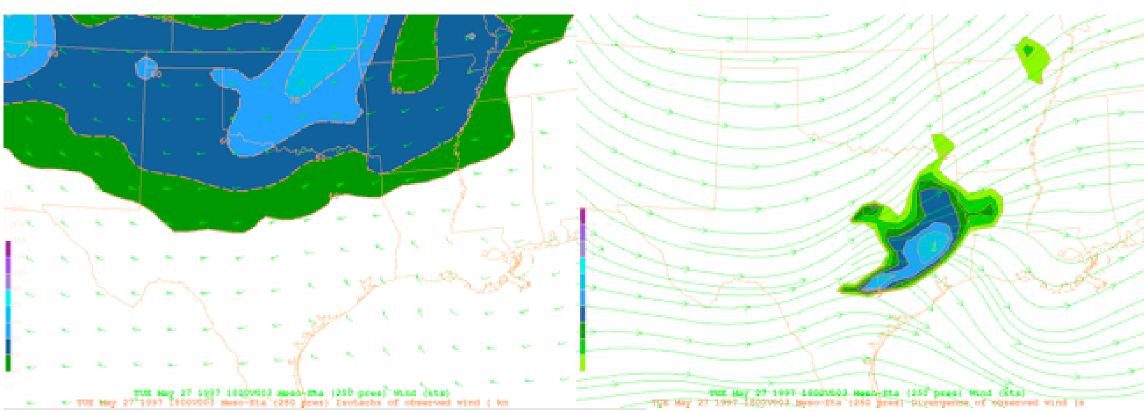

Figure 7) a) Meso-Eta model analysis of 250mb isotachs and wind barbs at 18Z 27 May 1997. Wind speed is contoured every 10 knots between 40 and 80 knot. b) Meso-Eta Model analysis of 250mb streamlines and divergence at 18Z 27 May 1997.

outflow to the supercells that developed along the frontal boundary and convergence zone at the surface. It may also have played a role in helping to break the cap inversion that had prevented convection the previous two days. However, it is unlikely the jet streak is the direct or even a close indirect reason for the development of deep convection during the Jarrell event. The UVM forced by this jet does not appear intense enough to have reached low levels of the atmosphere and force convection with significant help.

To get an idea of the extremely moist boundary layer in place over much of Texas and the atmospheric profile beneath the divergence zone just mentioned, balloon soundings for 0Z, 12Z 27 May and 0Z 28 May above Fort Worth Texas (FWD) and for 12Z above Corpus Christi Texas (CRP) are plotted in **Fig 8**. The FWD and CRP soundings at 12Z are plotted on the top and bottom right respectively of Fig 8 for comparison. Atmospheric conditions over FWD consisted of an EML and a warm moist boundary layer between 0Z and 24Z 27 May (Fig 8abc). Of particular interest are the 12Z soundings for FWD and CRP, just hours before the first supercell developed. Comparing both 12Z soundings shows that a low level boundary layer with mixing ratios

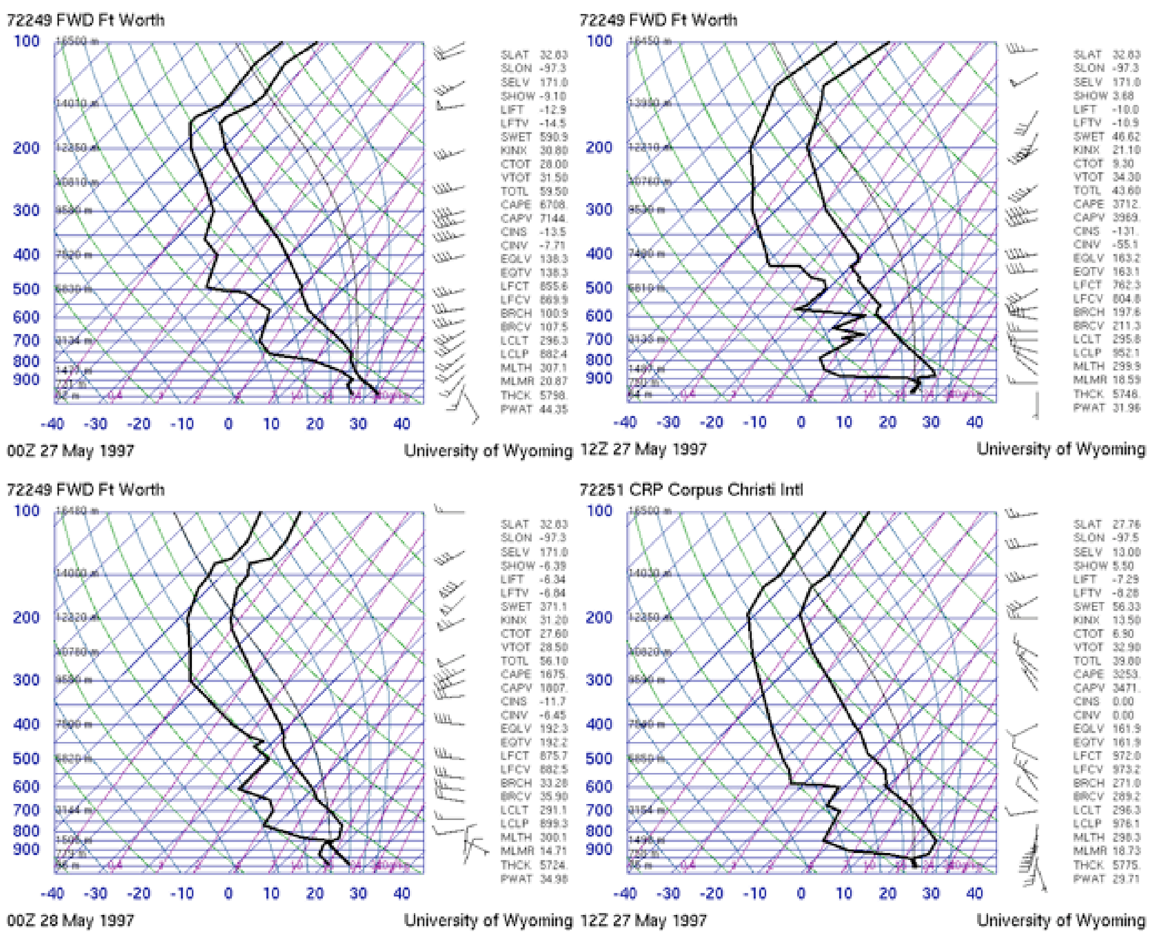

Figure 8) Four panel plot of Upper Air skew-T soundings taken over FWD at a) 0Z 27 May, b) 12Z 27 May, c) 0Z 28 May, and over CRP at d) 12Z 27 May. The 12Z soundings over FWD and CRP show a well-defined EML and shallow saturated boundary layer.

close to 20 g/kg and temperatures in the upper 70s spanned from the Gulf Coast up to FWD in the early morning hours. There is also a well-defined EML that reaches down to 850mb in CRP and 900mb over FWD. The cap inversion is fairly strong over CRP and FWD, however the LI at FWD is -10 even at 7am local time. Temperatures at 500mb are moderately cold, owing to the CAA shown in Fig 5. This has produced a CAPE value of 3700 J/kg without daytime heating. The shear profile at FWD is very weak at all time steps showing no signs of organized flow below 700mb that could normally produce such shear. Passage of the wind-shift boundary through FWD may have occurred between 12Z and 0Z 28 May judging by Fig 8b and 8c, as well as Fig 3. The presence of this wind-shift boundary near FWD, Jarrell, and other locations in Central Texas helped to force vertical motion from the ground level by creating the convergence zone discussed earlier (Fig 4) that concentrated moisture and high values of CAPE along a single line beneath the EML. **Fig 9** is a hand drawn cross section from Oklahoma City to Brownsville Texas showing a maximum value of mixing ratio south of the dryline near FWD at 12Z. The boundary is sharp separating values of 12 g/kg and 20 g/kg in the horizontal.

With some ascent created by the jet streak at upper levels, and a strong moist convergent zone at the surface beneath the EML, all that is needed to produce convection is a perturbation upwards through the cap inversion. The frontal boundary and dryline were stationary and helped produce the convergence zone, rather than any strong upward

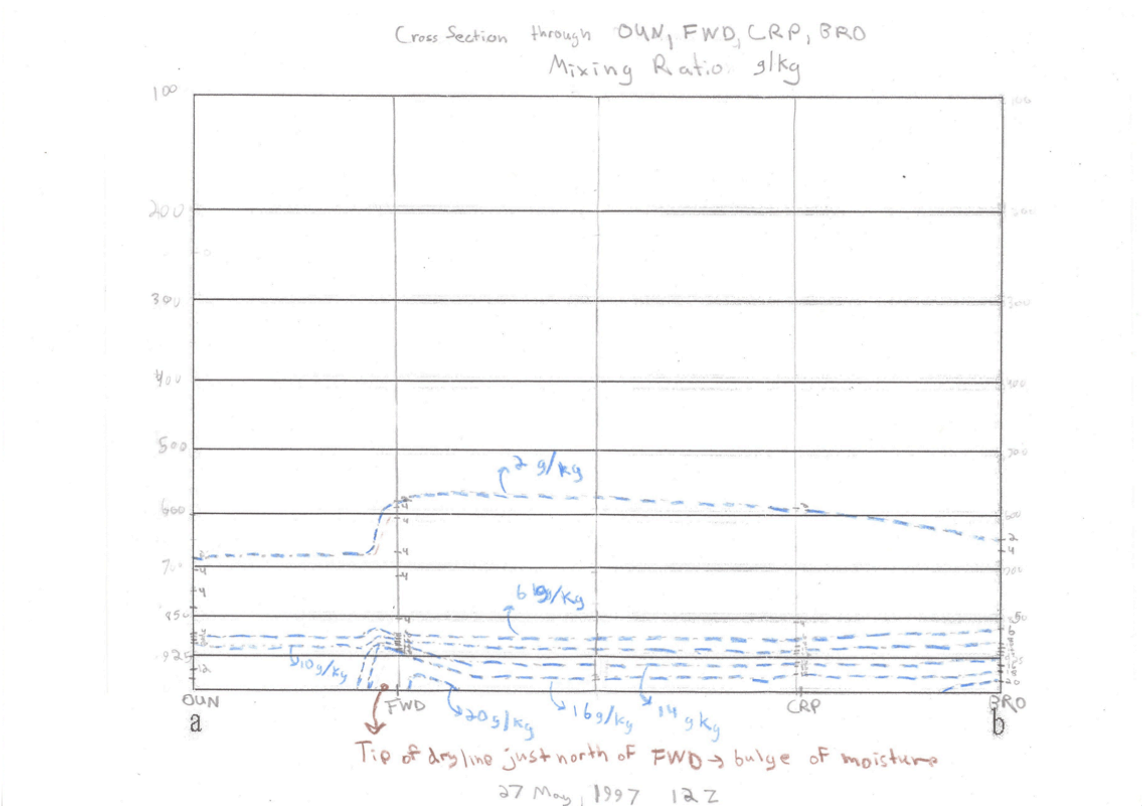

Figure 9) Cross section from Oklahoma City through Fort Worth, Corpus Christi, and Brownsville showing mixing ratio values (g/kg) at 12Z 27 May 1997.

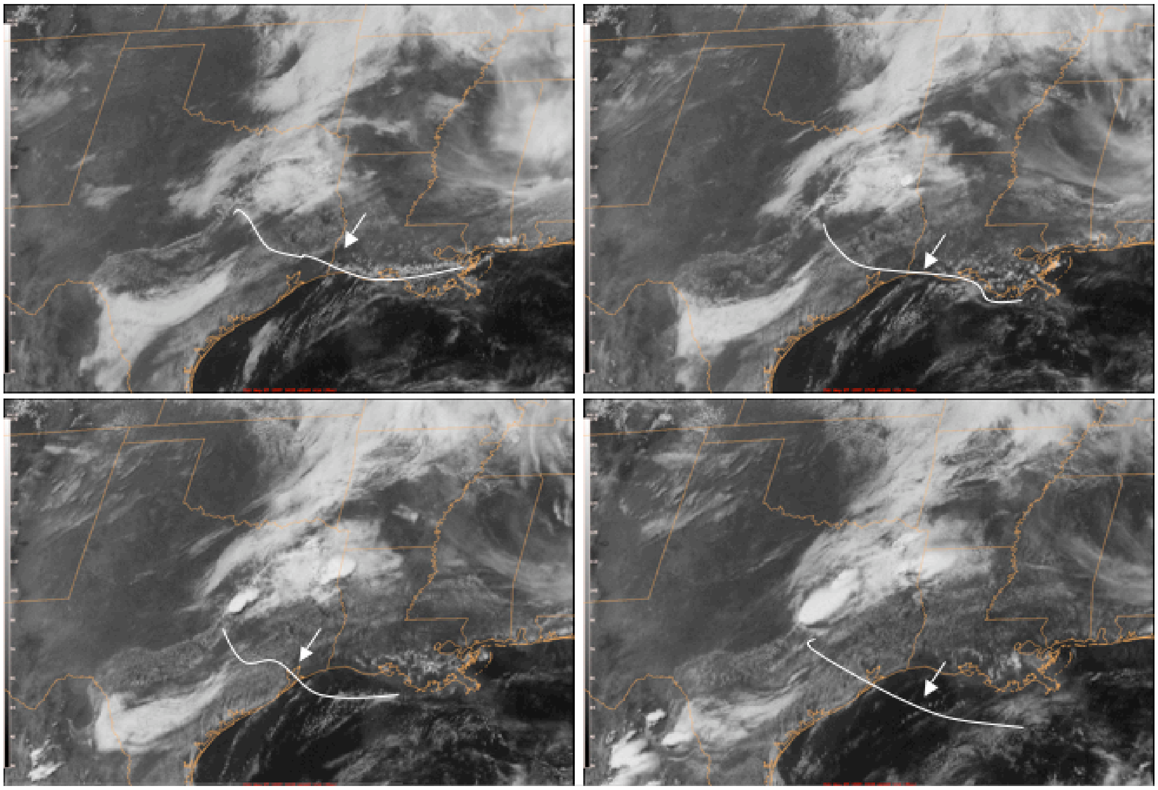

Figure 10) Goes-8 Visible Imagery at 16, 17, 18, and 19Z respectively on 27 May 1997. Gray scale is for cloud cover. Shows genesis of main supercell along frontal boundary and dryline. White line shows migration of gravity wave from north to south perpendicular to frontal boundary.

vertical motion. It is likely the passage of a gravity wave, drawn in Fig 3 between 16Z and 19Z, which somehow brought about a break in the cap inversion. A look at the GOES-8 Visible Imagery Satellite view over Texas shows the moisture convergence zone and wind shift boundary as a thin line flanked by clear dry air over central Texas (**Fig 10**). From left to right the images are taken between 1615Z and 1915Z 27 May as the main tornado-producing supercell develops explosively above Jarrell Texas. The convection occurs directly along the wind-shift boundary and moves south southwestward during later hours along the same boundary throughout. This is one piece of evidence that the gravity wave and not the stationary boundary helped provide the needed uplift by showing the supercell moving parallel to the boundary and gravity wave simultaneously. Although subtle, the gravity wave is visible in Fig 10 for at least the first three time steps (see white line Fig 10).

The gravity wave moved rapidly southward along the frontal boundary in north central Texas around noon (Fig 10ab). As the gravity wave crossed by Jarrell, light convection that had just begun to develop with daytime heating along the wind-shift boundary, strengthened very rapidly and cells forming along the boundary began to merge together with the south-southwest migration of the main supercell (Fig 10cd). The gravity wave seemingly led a supercell along the convergence zone by initiating convection as it moved southward. Alternatively, the small

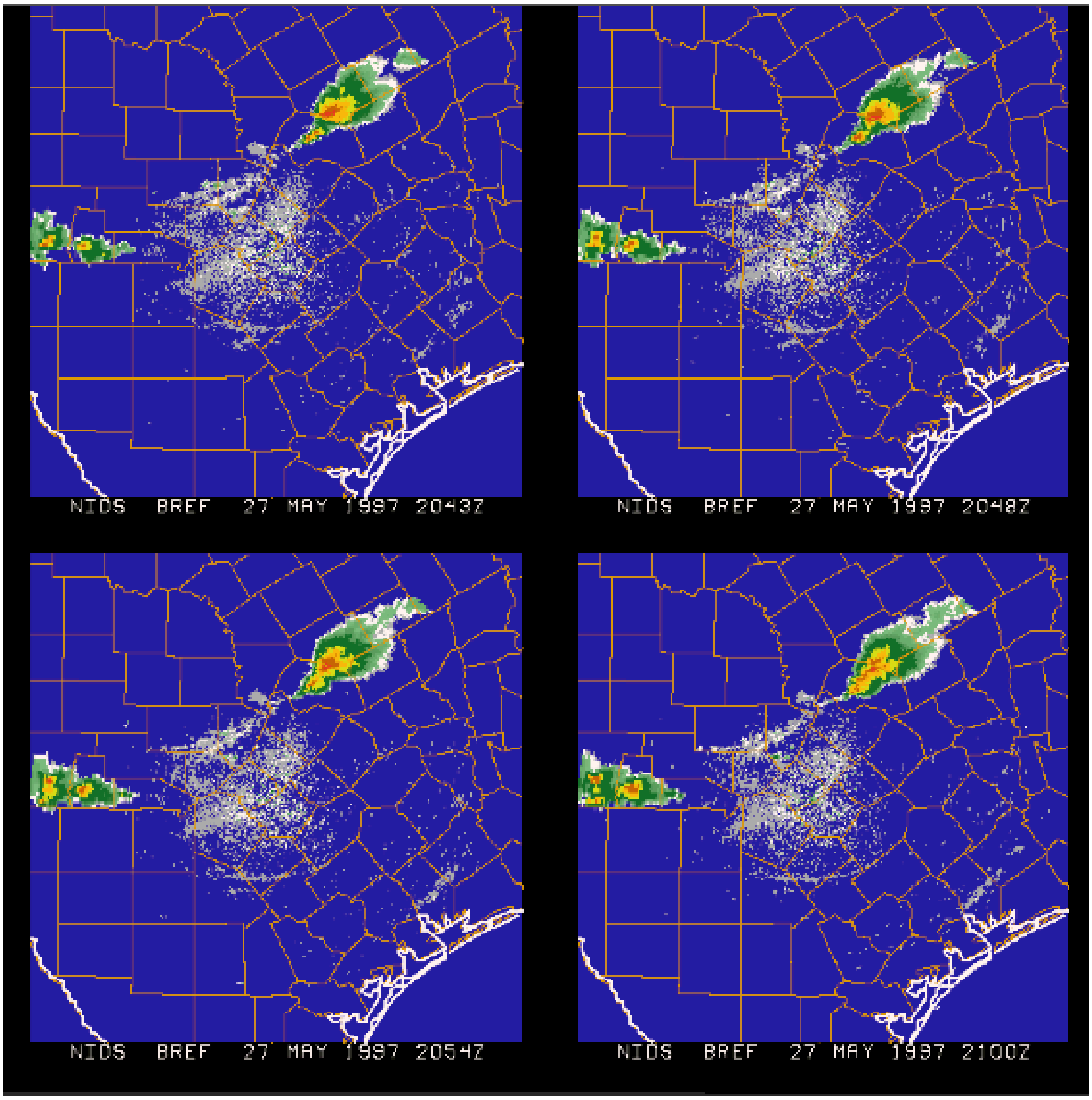

Figure 11) Radar reflectivity images from Nexrad site at New Braunfels, TX Radar for 2043Z, 2048Z, 2054Z, and 2100Z 27 May 1997 showing the merger of a small convective cell with the main supercell as it propagates southwestward.

surface low shown in Fig 3 may have provided enhancement of surface moisture convergence and initiated the first updraft only to then follow the gravity wave's propagation. In either case the gravity wave plays a crucial role in allowing the initial convection to become supercellular.

The supercell migration along the convergence zone is even clearer in radar reflectivity images from the Nexrad site at New Braunfels, TX shown in **Fig 11**. This is a four panel plot covering 2043Z to 2100Z 27 May, a span of just 17 minutes. Whether insects or birds, the wind-shift boundary is visible as a ragged line stretching southwest to northeast through a supercell in each panel. From the first to last panel, a small cell can be seen developing along the boundary southwest of the main cell. Eventually it merges with the main cell as the entire convective system moves southwestward. It was during this time span that the Jarrell F5 tornado touched down and wreaked devastating destruction.

The last piece of the puzzle in understanding how a mesocyclone and tornado could have developed under the conditions laid out in this case study is figuring out the apparent absence of 0-6km vertical shear so often looked for when forecasting or analyzing a supercell event. From the vertical soundings, Miller Diagram, and model analysis it is clear that no synoptic or mesocale wind patterns existed prior to supercell initiation that could have produced the helicity needed for MCS and tornado-genesis. One possibility is that the updraft, initiated by the gravity wave or surface low, was overlaying extremely large values of CAPE that created an area of strong positive buoyancy (Morgan et al. 1998). This would accelerate air parcels through the updraft creating a storm inflow proportionally strong. The strong winds produced by the inflow combined with storm relative winds above the inflow layer may have produced adequate shear to develop a mesocyclone and tornado. A program used to make a hodograph representative of the storm-relative wind field during a supercell produced a value of 243 m2/s2 for storm relative helicity (Morgan et al. 1998). It seems likely based on this line of argument that the supercell intensity and movement created its own favorable wind field dwarfing the environmental wind pattern.

A conceptual model of this process is shown in Fig 12 to illustrate what may

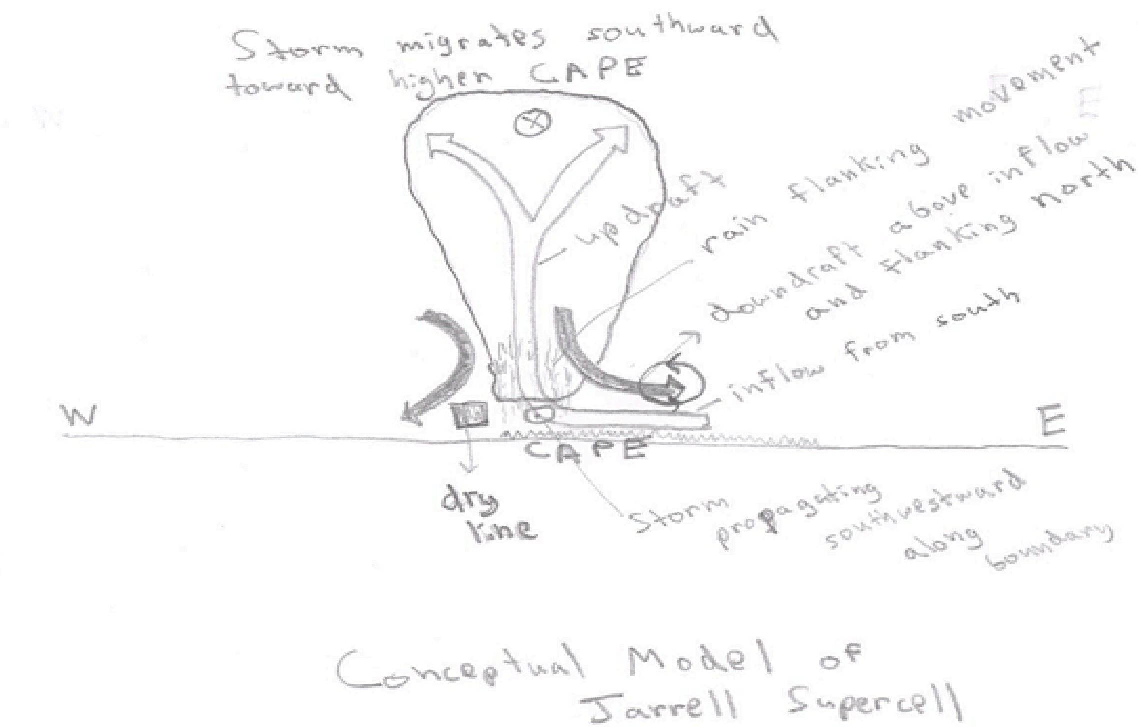

Figure 12) A conceptual model of the Jarrell Texas Supercell that produced an F5 tornado. South direction is out of the page and North into the page. The storm cell shown moves southward feeding it's updraft with high values of CAPE and uplift provided by downstream cell development.

have occurred during the Jarrell Tornado. In this figure is an X-Z north looking view of the storm cell moving southward (out of the page). To its west is the dry line separating large dew points and moisture convergence from dry air at the surface. The storm cell in the figure receives inflow from a south or southeasterly direction feeding the updraft and intensifying the system. The downdrafts fall to the sides and rear of the migrating cell while interacting with the inflow to produce storm created helicity that the storm then feeds off of to become a mesocyclone. As new cells develop downstream of the system their updrafts merge with the main cell and/or their gusts fronts enhance convection within the flanking updraft creating a stronger supercell. The southwesterly propagation of these storms allows them to move toward higher CAPE values thus maintaining a strong updraft and increasing the potential for storm induced helicity and rotation. It is likely that the Jarrell supercell developed because of a cell merger and/or a gust front enhancement of a storm cell. Ground reports indicated that the Tornado was not near a shear line when it touched down and strengthened to F5 status.

CONCLUSIONS

The Jarrell Tornado Event on 27 May 1997 displayed a mix of both favorable and neutral synoptic and mesoscale conditions for supercell development with the exception of vertical wind shear. On the Synoptic scale an upper and mid level trough moved eastward over Nebraska and Oklahoma bringing with it a pocket of cold air at 500mb and a moderately strong Jet streak at 250mb. The cold air at mid levels enhanced the temperature contrast with the surface while the jet streak aided in creating an area of divergence and UVM above the Jarrell Texas area. A surface low, frontal boundary, and dry line were draped across central Texas helping to create a strong zone of moisture convergence and large values of CAPE. Mixing ratios reached 20g/kg and temperature reached the mid 80's ahead of the front. The dryline and frontal boundary were quasi stationary but did separate air masses in addition to wind flow directions at the surface. An EML covered Texas for several days prior to 27 May causing the increase in moisture at the surface and warm temperatures. A thermal ridge covered the region at lower levels in part due to the EML and the absence of any strong wind. The EML and low-level moist boundary layer combined to create a thermodynamically favorable environment for supercell development.

The LI over central Texas the morning of the 27th was already near -10 because of the strong temperature contrast between the surface and 500mb. Daytime heating and the surface convergence most likely produced even more negative values indicative of a strong potential for deep convection. By afternoon the right entrance region of the jet streak and the convergence zone at the surface were nearly superimposed over each other. Obvious features that were lacking for supercell development on a broad scale included a strong lifting mechanism at low levels and deep vertical wind shear. The lifting mechanism that sparked an initial updraft at 17Z may have come from either an MCS generated gravity wave or a weak surface low associated with the frontal boundary. Both of these features were in the vicinity of the initial updraft.

It's more likely that the gravity wave played a direct role in storm initiation due to its motion relative to storm development and the frontal boundary. The vertical wind shear at low and mid levels that is needed for mesocyclone and tornadic development was likely created by the storm itself. Extremely high values of CAPE near the surface provided for strong positive buoyancy once the cap inversion was broken. This then triggered strong inflow that combined with storm relative winds above the inflow boundary to produce significant storm relative helicity. The unusual propagation of the storm cells south-southwest along the stationary frontal boundary combined with the creation of storm relative helicity helped create tornadic thunderstorms in this somewhat unusual severe weather event. Without a detailed and thorough study of the data and imagery available, determining the cause of this deadly and damaging tornado event would have proven illusive.

ACKNOWLEDGEMENTS & REFERENCES

Greg Tripoli

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Pete Pokrandt

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