The Jarrell Tornado of May 27, 1997

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ABSTRACT

A tornado outbreak occurred over Central Texas on May 27, 1997. This outbreak included a devastating F5 tornado that hit the town of Jarrell, caused millions of dollars in damage, and killed 27 people. The tornado outbreak on this day was caused by a southward moving cold front in northern Texas, a warm and moist low-level jet flowing into Central Texas, extremely unstable air in the region, and multiple upward vertical motion forcings. High convective inhibition and a strong inversion at the PBL prevented convection from occurring early on, but daytime heating helped to break the cap and allow convection to ultimately occur. An analysis of model data, soundings, surface observations, radar and satellite data, and storm reports help piece together the cause of this deadly convective outbreak.

1. Introduction

Jarrell is located in the heartland of Texas. It is about 40 miles north of Austin and in 1997 boasted a population of roughly 1,300. On May 27, 1997 an outbreak of 20 tornadoes swept through Central Texas. The most powerful of these tornadoes, an F5 on the Fujita scale, ripped through Jarrell. This tornado had 260 mph winds, measured ¾ of a mile wide, and tracked across the ground for 7.6 miles. After the tornado had dissipated 27 lives had been lost and an estimated $120 million in damage had been done. This would rank as the fourth deadliest tornado of the 1990’s.

A tornado with this strength and magnitude does not come along very often. The conditions must be just right for a super cell to spawn such a massive tornado. An analysis of the atmospheric conditions over Central Texas on May 27, 1997 indeed shows that the necessary conditions were there. A southward moving cold front was intersected by a southwest moving outflow boundary and by a warm and moist low-level jet from the Gulf of Mexico. The atmosphere was also highly unstable with soundings showing CAPE values over 6,000 and a lifted index near -13. The Jarrell tornado can also be tracked with radar. The National Weather Service was able to give a 15-minute warning about the tornado by looking at severe weather radar signatures. The severity of this tornado, however, proved to be to great even with this warning to limit the loss of life.

2. Data

The data used to analyze this case study came largely from the ETA model from May 26-28, 1997. GARP and gempak were used to analyze the ETA model’s information and create maps and study different atmospheric variables. The ETA model proved to be pretty accurate in comparison with actual observations from the storm.

The radar information and images came from a NEXRAD national composite at the time of the event, from May 27. The satellite information and images came from the GOES-8 satellite at the time of the event. Visible images with 1 km resolution were used along with infrared and water vapor images. Atmospheric soundings were taken in Fort Worth, TX, Midland, TX, Corpus

Christi, TX, and Del Rio, TX throughout the duration of the event. These soundings helped to show the areas of instability and they were used to analyze actual atmospheric conditions throughout the event. Additionally, data archived from the SPC and NWS was also used to help derive, analyze, and explain the existence of these storms.

3. Synoptic Overview

The main synoptic feature over Central Texas on May 27, 1997 was a cold front. Figures 1a-d show 850 mb frontogenesis and temperatures at 6Z on the 27th and 12Z on the 27th. These figures show the location of the cold front over Central Texas and its southward movement. A gradient of 15° C from the panhandle to Central Texas define this cold front at 12Z. The figures show frontogenesis is occurring at this time. This front is not that strong, but it does provide enough forcing to help the convection occur in the highly unstable atmosphere over Central Texas. The upper level jet streak associated with this front is not particularly strong. Model analysis shows about 50 to 60 knot easterly winds blowing over the region. Frontogenesis creates vertical motions. Martin (2006) explains that horizontal advection increases the magnitude of the temperature gradient, which subsequently causes an increase in wind shear and the jet core wind speed. The more intense jet results in an increase in vorticity. This increased vorticity suggests that there is divergence in the area, which implies there is also upward vertical motions.

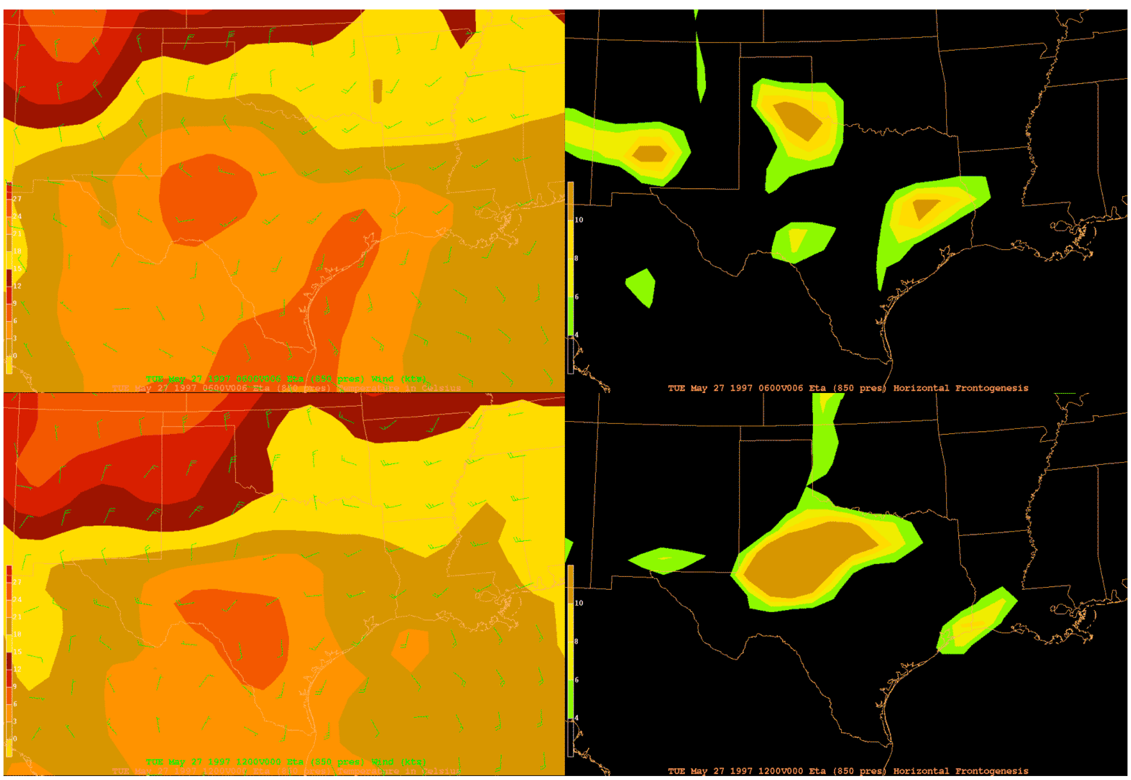


Figure 1: (**a**) May 27 6Z temperatures and wind (upper left). (**b**) May 27 6Z frontogenesis (upper right). (**c**) May 27 12Z temperatures and wind (lower left). (**d**) May 27 12Z frontogenesis (lower right).

So Martin is saying that an increase in the magnitude of the temperature gradient requires the production of a vertical circulation in the atmosphere.

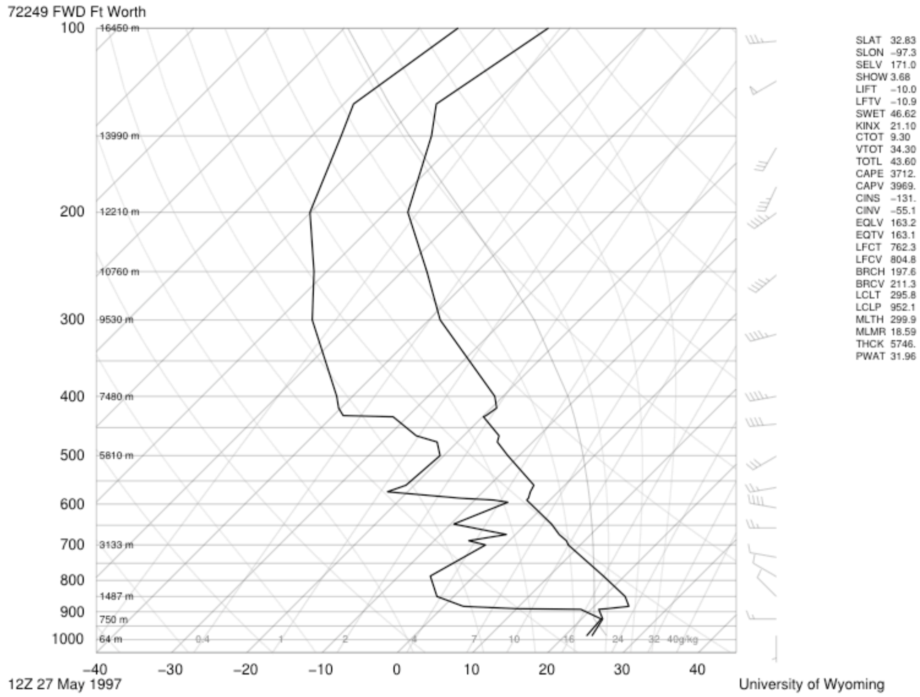
This frontal feature is the main synoptic feature effecting Central Texas during the Jarrell tornado. Another synoptic feature was the existence of a weak long wave and trough over Texas. The trough is not an overwhelmingly dominant feature, but it does play a minor role in the synoptic forcings over Texas. The trough has only a slight curvature associated with it. Its location over Central Texas helps aid in additional upward vertical motions downstream of its axis. Ageostrophic wind divergence associated with the curvature of the long wave causes upward vertical motions. Though the curvature is not that strong, this feature is worth mentioning because it does provide another synoptic forcing in the region. It is a minor yet relevant feature in the synoptic overview.

4. Mesoscale Analysis

There are multiple mesoscale features that play a significant role in the tornado outbreaks, particularly the Jarrell tornado. This presence of a low-level jet bringing warm moist air from the Gulf of Mexico into Central Texas is a very important feature. The presence of an outflow boundary and its interaction with the cold front was an important mesoscale feature with significant implications. Additionally the extremely unstable air in the atmosphere, which allowed this event to be as intense as it was, is an essential feature. It is this unstable air that will first be discussed.

To aid in this discussion of atmospheric instability soundings from the day of the event will be analyzed. Unfortunately the closest soundings available on the day of the event were located a couple hundred miles away from Jarrell. These areas were Fort Worth, TX, Midland, TX, Corpus Christi, TX, and Del Rio, TX. The most relevant soundings were taken from Fort Worth, TX and Del Rio, TX.

Figure 2a shows the Fort Worth sounding taken on May 27th at 12Z. This is a good example of a "loaded gun" sounding. It has a low moist level, an inversion capping the planetary boundary layer (PBL), and an elevated mixed layer above this inversion. Now this is not a perfect sounding for severe weather, but there are definitely some strong indications that severe weather is possible. This sounding gives a convective available potential energy (CAPE) value of 3712 J/kg, a very strong value. However, it also has a convective inhibition (CIN) value of -131 J/kg, which is a pretty high value. This means that it will be difficult to break through this level of stable air. Because CIN hinders the production of updrafts necessary to create super cells and thunderstorms this sounding indicates that severe weather will only occur if this high level of CIN can be overcome. Since this sounding was taken at 12Z, or 6AM local time, it is important to note that daytime heating could very well help break the cap on the PBL and intense convection may occur. When large amounts of CIN are reduced due to heating and moistening convective storms are a lot more severe than in cases when no CIN is present. This may play a role in explaining why the Jarrell tornado was so severe. It is interesting to note that the listed indices for this particular sounding do not seem to show any definite signs of severe weather. The SWEAT index is only



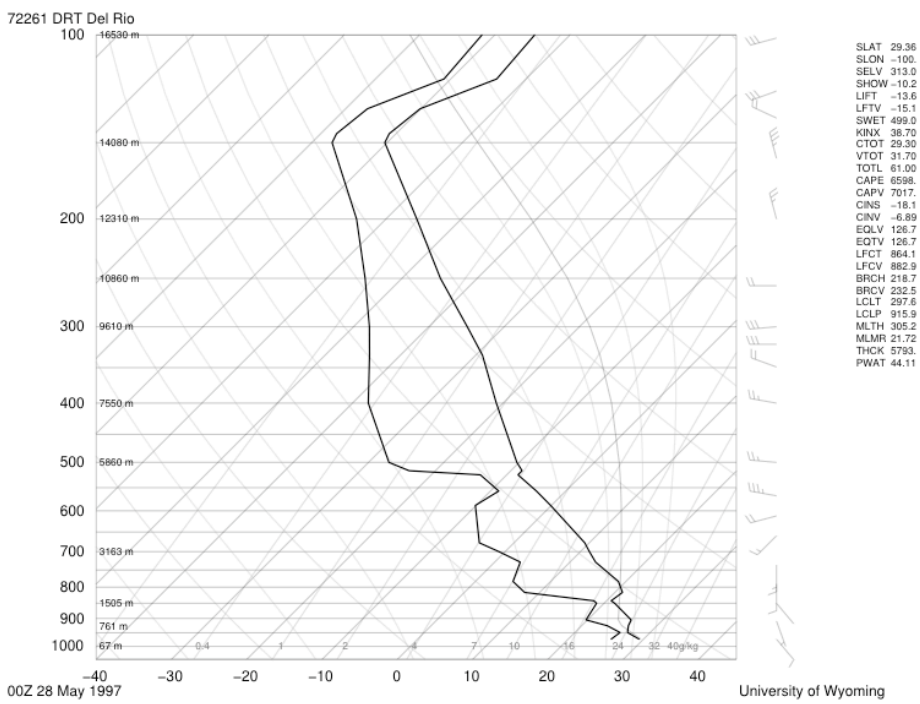


Figure 2: (**a**) Sounding from Fort Worth, TX 12Z May 27 1997 (top). (**b**) Sounding from Del Rio TX 00Z May 28 1997 (bottom).

46.62. It has a total totals index of 43.6, a Showalter index of 3.68, and a K index of 21.10. These are all very low values for severe weather outbreaks. The high CAPE value though shows that the atmosphere does have some potential to produce some significant severe weather if the cap can be broken.

Figure 2b shows another sounding. This sounding was taken at Del Rio, TX at 00Z on May 28th. In contrast with the Forth Worth sounding taken twelve hours earlier this sounding shows an imminent severe weather outbreak. Daytime heating has brought the surface temperatures up about 7° C. This heating has lowered the CIN significantly. Twelve hours earlier the CIN in Del Rio was -194 J/kg. Now it is only -18.1 J/kg. CAPE has also increased to an incredible 6,598 J/kg up from an impressive 5,520 J/kg twelve hours earlier. The atmosphere is extremely unstable at this time. The indices over Del Rio at this time all indicate severe weather. The SWEAT index is 499, the total totals index is 61, the K index is 38.7, and the Showalter index is -10.2. These are all extremely high values indicating strong severe weather. Central Texas has seen many super cells and tornadoes by the time this sounding was taken. The Jarrell tornado occurred between 20Z and 21Z on the 27th, a few hours before this sounding was taken.

It is important to note that both the Fort Worth sounding and the Del Rio sounding were chosen because of their locations to Jarrell and Central Texas. The atmosphere over Jarrell was not exactly like that over Fort Worth or Del Rio at their respective times, but it had to have been relatively similar. There was no doubt high instability and readily available moisture present in the air over Jarrell during the F5 tornado outbreak.

Figure 3 shows the lifted index values over Texas at 18Z on the 27th. This again verifies the presence of the highly unstable air. The most unstable areas are in Southwest and Central Texas. The reason that Central Texas got hit harder with severe weather was because of two key mesoscale features, the low-level jet and the outflow boundary.

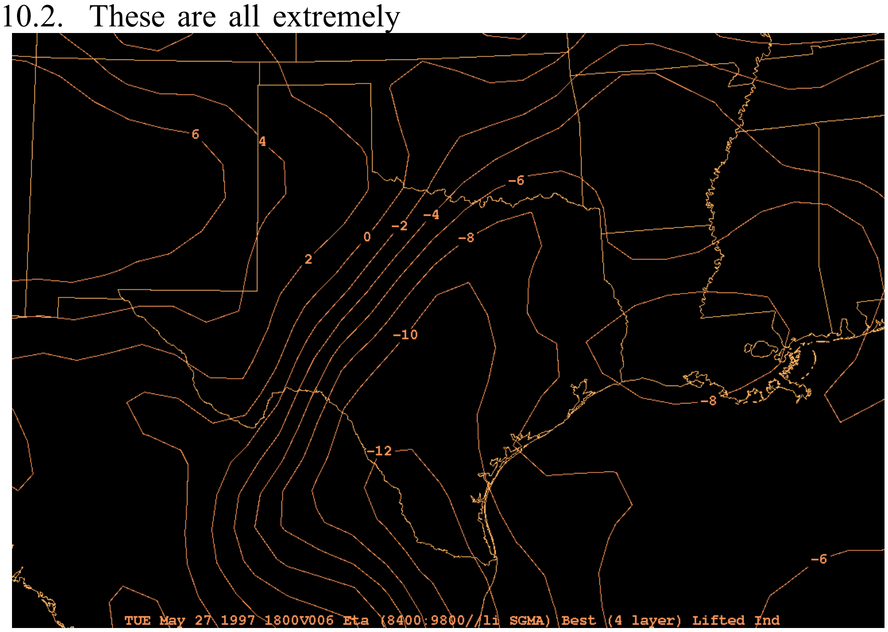


Figure 3: Lifted Index values over Texas at 18Z May 27, 1997.

The low-level jet is what brought warm moist air into Central Texas from the Gulf of Mexico. Figure 4 shows this low-level jet. Figure 4a shows the 850 mb jet at 6Z on the 27th, while figure 4b shows the jet at 18Z on the 27th. The jet continues to push its way further into Central Texas as the day goes on. Southerly winds with speeds up to 30 knots cover the southeast side of Texas throughout the day. This low-level jet is a common feature over the Central United States. The low-level jet is a thermal slope flow phenomena that can be explained by a couple arguments. There is a cooling of higher elevated air in the west relative to the same geopotential height in the east because of its higher elevation in the mountains. This causes a pressure gradient of warm east air flowing to colder west air. This case also includes the cold front moving in from the northwest of Texas. This flow helps aid in the frontogenesis occurring over Central Texas at this time bringing a southerly flow into the northerly flow. As discussed in the synoptic overview section this also aids in upward vertical motions over Central Texas. When daytime heating warms up the surface these upward vertical motions are able to break through the PBL and reach the unstable air and level of free convection.

This air being pumped in by the low-level jet is very warm and moist. Figure 5 verifies this with the surface observations over Texas at 18Z. Temperatures are in the 80's (°F) and low 90's (°F), while dew point temperatures hover in the upper 70's (°F). This low-level jet is providing the necessary moisture and energy for the severe thunderstorms and super cells that form.

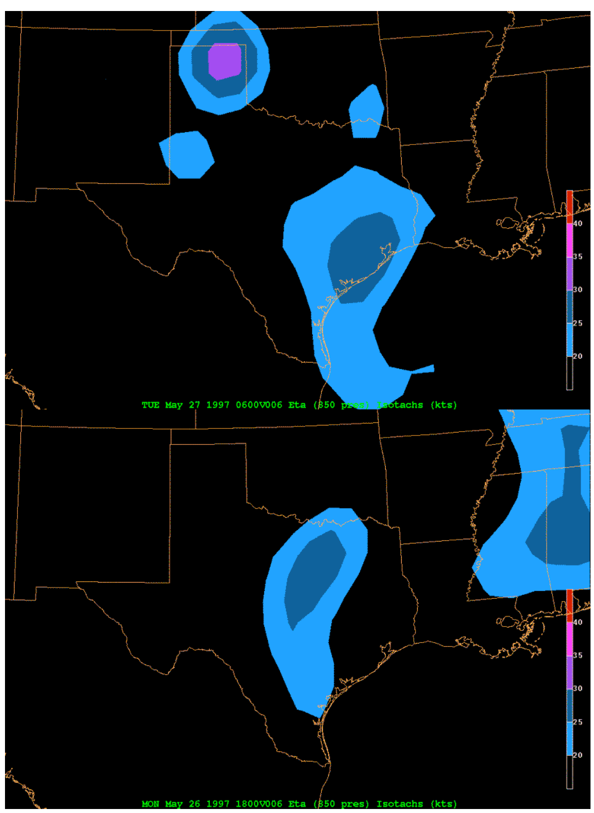


Figure 4: (**a**) 850mb LLJ 6Z May 27 (top). (**b**) 850mb LLJ 18Z May 27 (bottom).

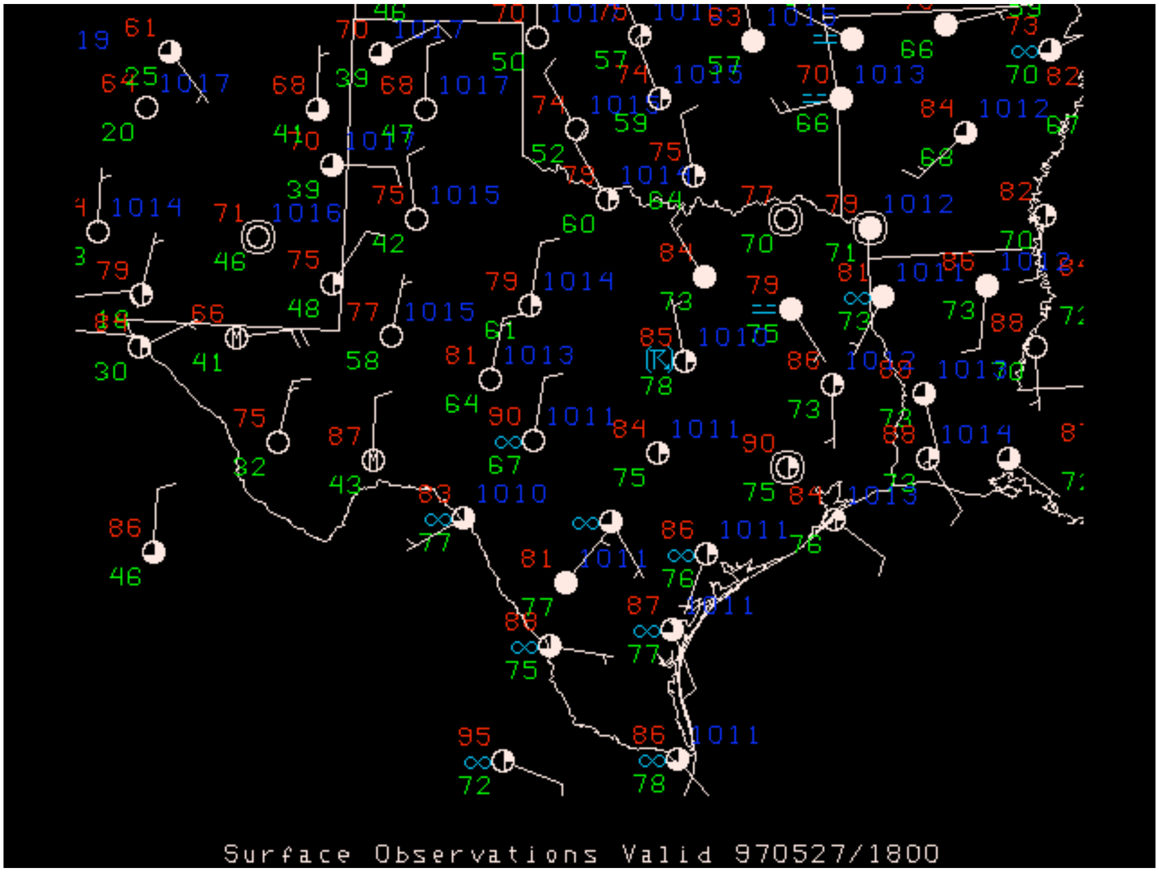


Figure 5: Surface observations from 18Z May 27, 1997.

Figure 6 is a hand drawn cross-section from Fort Worth, TX (DFW) to Del Rio, TX (DRT). This cross section is valid for 00Z May 28, 1997. The variables drawn on this cross-section are Theta E (K) and the Mixing Ratio (g/kg). This cross section shows the high amounts of low-level moisture over Central Texas. Areas north of DRT have a mixing ratio around 23.0 g/kg while areas around DFW have mixing ratios near 14 g/kg at the surface. Theta E shows the instability of the air over Central Texas. Very high Theta e values, around 372 K, exist around the DRT area. A region with a relatively high Theta E is often the region with the most instability. Warmer low-level temperatures and higher low-level dew points increase instability, which as Figure 5 has already shown is the case. The low-level jet continues to bring in these low Theta E values. The Theta E lines also show that there is convection occurring in between DFW and DRT, which through surface observations and reports again can be verified.

Figure 7 is a hand drawn diagram depicting the surface streamlines over the United States at 20Z on May 27, 1997. The most important feature to note in this diagram is the convergence over Central Texas. These converging air masses are causing upward vertical motions. These motions along with daytime heating and additional upward vertical motion forcings are helping to break the inversion cap that is creating the convection over this region.

Figure 6: Cross-section from DFW to DRT, valid 00Z May 28, 1997, variables depicted are Theta E (K) and the Mixing Ratio (g/kg).

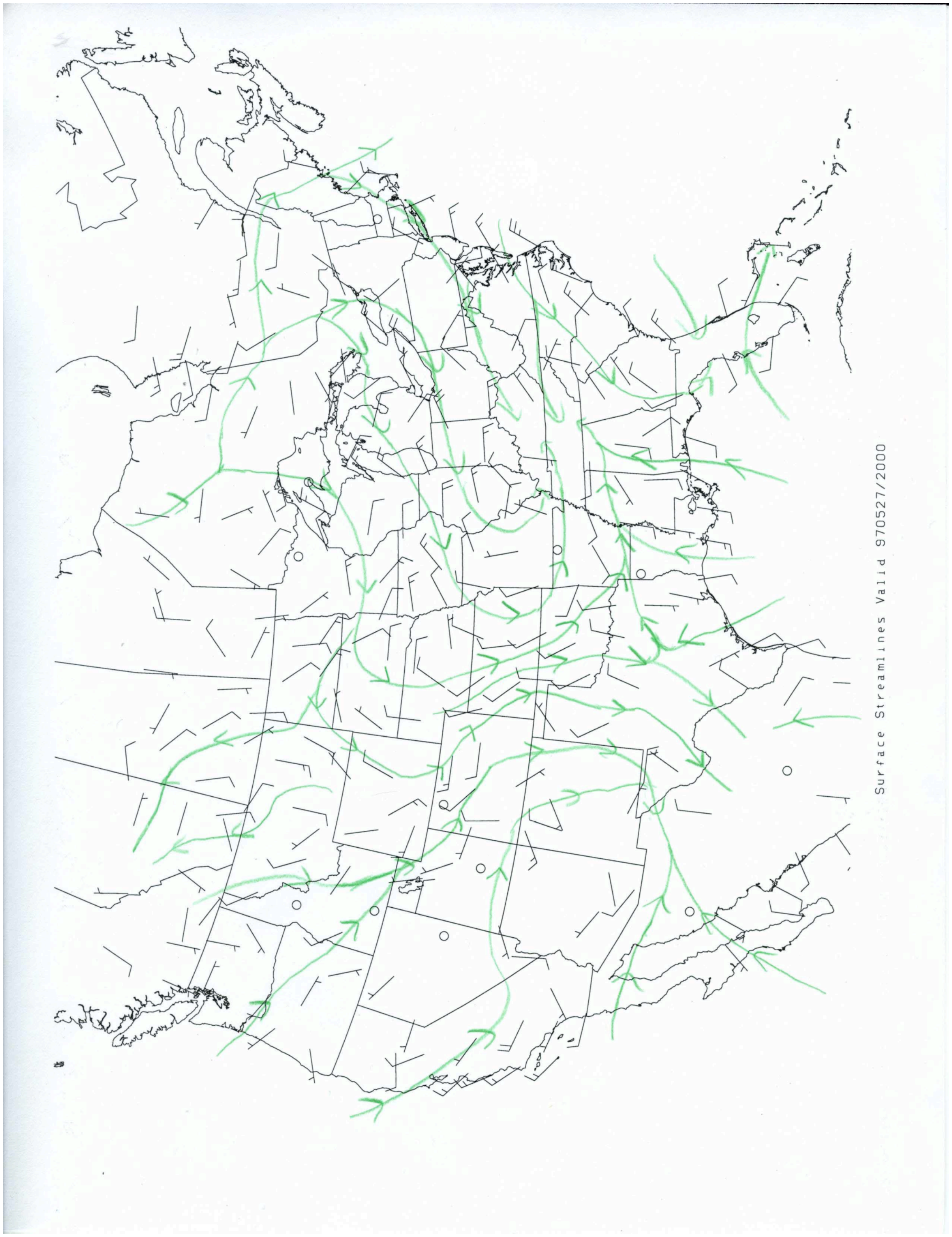


Figure 7: Surface streamline analysis valid 20Z May 27, 1997.

Another important mesoscale feature that was part of these convective storms was the outflow boundary. An outflow boundary is essentially a mesoscale cold front. An outflow boundary usually originates from a thunderstorm when the colder mid-level air is brought down to the surface by a downdraft. Once a few thunderstorms were able to form this outflow boundary provided an additional mechanism to help the warm moist air rise. When this air came into contact with the colder and denser outflow boundary it was forced upward. This was an important mechanism in helping to increase the duration of the convection and severity of the storms.

Next an analysis of satellite and radar data will be made to help create a better understanding of what occurred over Jarrell during its F5 tornado. Figure 8 depicts the GOES-8 satellite 4km resolution IR imagery at 2015Z and 2215Z on May 27th. Convection over Central Texas is clear from these images. The two-hour difference in time shows a significant increase in the IR cloud tops. There are five apparent super cells that are associated with these main IR cloud features over Central Texas by 2215Z. Their anvils stretch a few hundred kilometers each. The biggest anvil at 22:15Z is associated with the super cell that spawned the F5 tornado that flattened Jarrell. This anvil is the second most easterly one in Texas.

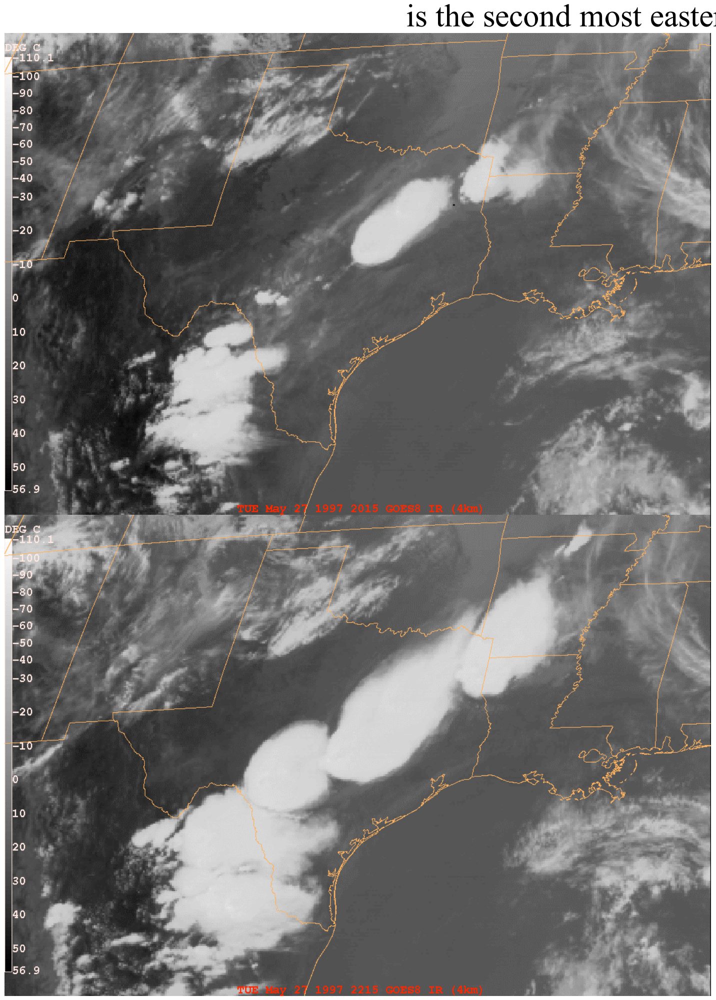


Figure 8: IR satellite images, (**a**) 2015Z May 27 (top), (**b**) 22:15Z May 27 (bottom)

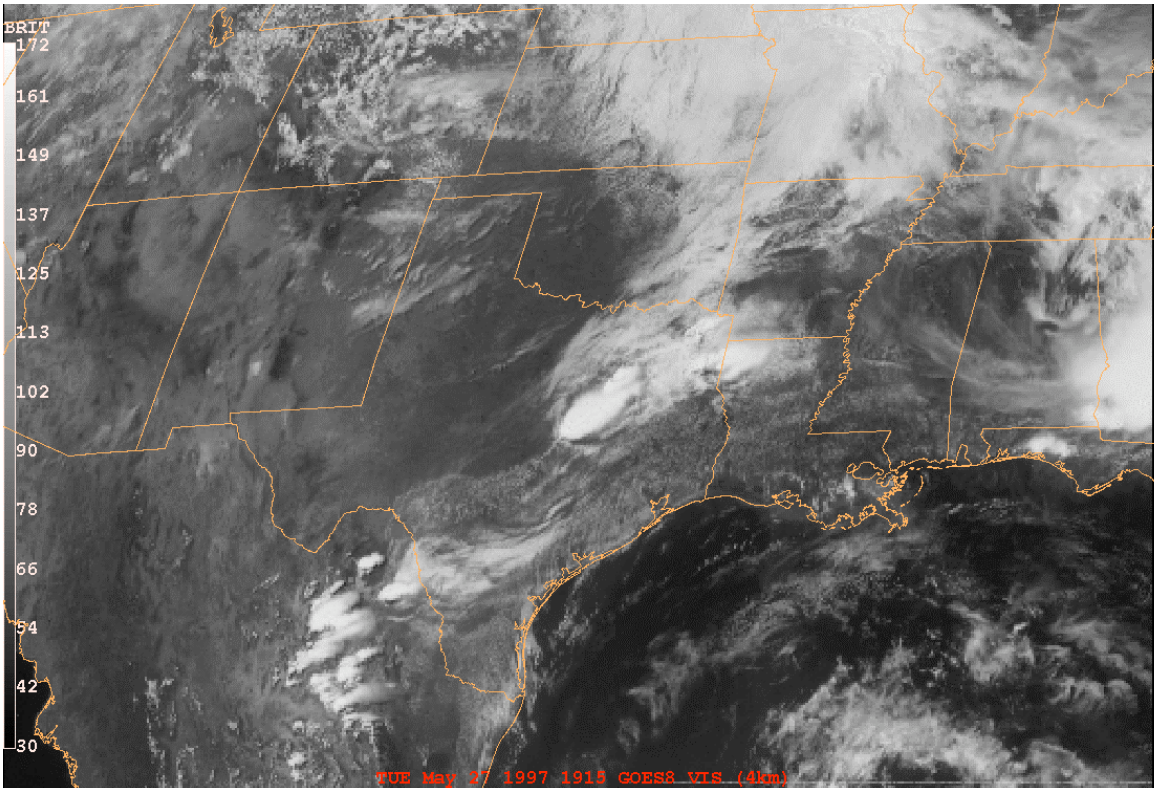


Figure 9: GOES-8 satellite visible image, valid at 1915Z May 27, 4km resolution

Figure 9 depicts a GOES-8 visible satellite image at 1915Z May 27th. Visible is the super cell that produces the Jarrell tornado. This super cell is the most pronounced cloud feature over Central Texas. The Jarrell tornado touches down about an hour plus from this time, so this super cell is still in its initial stages. Once the inversion cap was broken convection occurred rapidly because of the highly unstable air.

Figure 10 shows the Jarrell tornado on the radar. Figure 10a shows a zoomed out radar depiction over Texas at 2035Z with two kilometer resolution. The largest and most intense reflectivity in the center of Texas is the Jarrell tornado. Figure 10b zooms in on this super cell to analyze some of its features. This figure is valid at 2048Z. An obvious hook echo is visible near the southwest flank of the super cell. This is where the F5 Jarrell tornado is located at this time. This is a great example of a hook echo and a tornadic signature. A V-notch is also visible on this super cell's radar image. A V-notch is another excellent way to verify the presence of a severe thunderstorm super cell. Figure 10c shows the radial velocity at 2025Z. A radial velocity couplet of contrasting velocities is visible near Jarrell at this time. This is an excellent tornadic vortex signature (TVS). This TVS shows the presence of the Jarrell tornado from yet another perspective. Radar and satellite images can be very helpful in detecting severe weather. Using radar the NWS was able to give a 15-minute warning about this tornado. Unfortunately its intensity was still too much for many people to avoid. Its destruction was devastating to this small Texas town and nothing could prepare these people for the 260 mph winds of this monstrous F5 tornado.

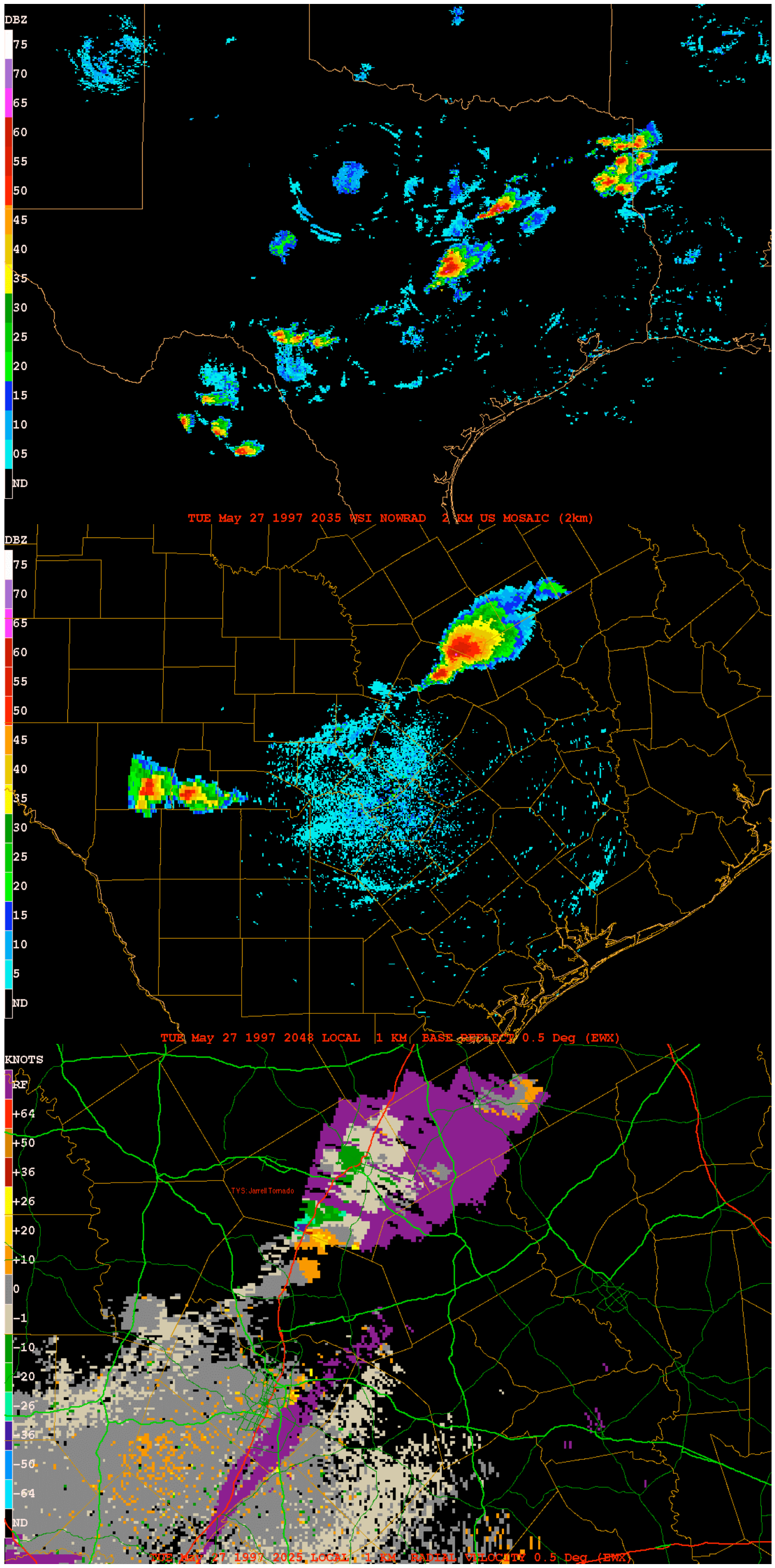


Figure 10: (**a**) radar base II level reflectivity valid 2035Z May 27 (top)
(**b**) radar base II level reflectivity valid 2048Z May 27 (middle)
(**c**) radar radial velocity valid 2025Z May 27 (bottom)

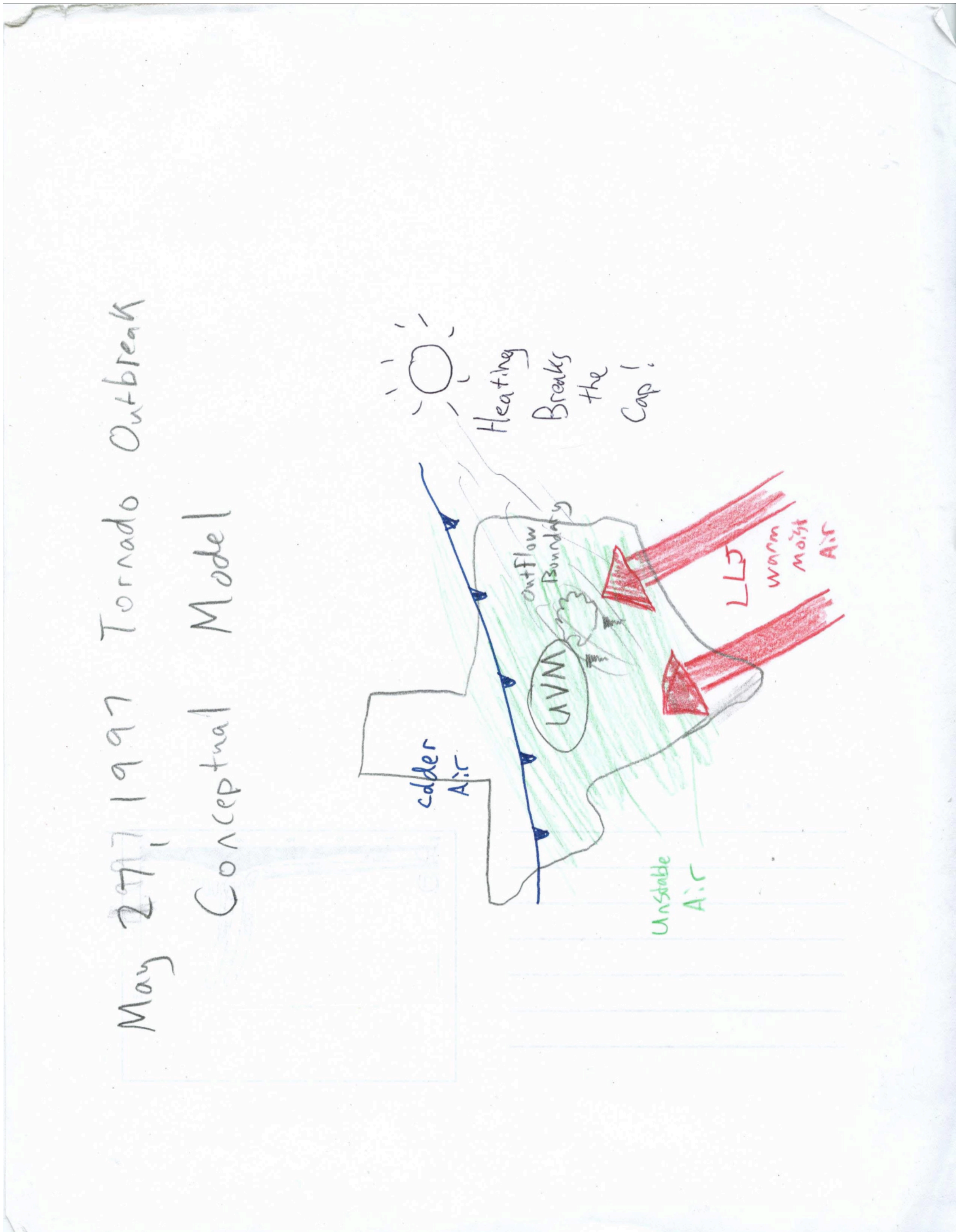


Figure 11: Hand drawn conceptual model of the tornado outbreak in Central Texas on May 27, 1997.

5. Conclusion

In conclusion, the Jarrell tornado was one of the most deadly and destructive tornadoes in US history. Figure 11 gives a hand drawn conceptual model that summarizes the main factors involved in the tornado outbreak over Texas on May 27, 1997. From a synoptic view the main feature was a cold front pushing its way south into Texas. Frontogenesis helped aid in forcing some of the upward vertical motions. From the Gulf of Mexico came a southerly low-level jet bringing warm moist air. This warm moist air from the LLJ helped destabilize the air. The air was already highly unstable with CAPE values reaching 6,000 J/kg. A strong inversion and high CIN values over the area helped prevent convection from occurring early on. Once daytime heating started to heat the surface the cap was able to break and convection occurred. A strong outflow boundary over Central Texas created from these thunderstorms' cold downdrafts helped promote additional upward vertical motions, which increased these thunderstorm intensities. The most intense super cell was the one that spawned the Jarrell F5 tornado. This tornado killed 27 people and caused over $120 million in damage with its winds exceeding 260 mph. The satellite and radar data verified this super cell's presence and intensity. Using radar data severe weather signatures can be seen. These signatures helped the NWS give a warning out to the people in Central Texas. The magnitude of the F5 tornado in Jarrell in particular made the warning ineffective in the end. This case study was an excellent example of the destructive force of a super cell when many essential atmospheric conditions are met.

6. References and Acknowledgements

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