Near Storm Environment Parameters: A Review and Recent Case Study

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Part One: Near Storm Parameters Review

I. Introduction

One of the toughest forecasting challenges for an operational meteorologist is determining the potential for an individual thunderstorm to produce a tornado. Through the years, many studies have been completed to determine significant or essential pre-existing environmental conditions that may enhance the potential for tornadic development. Several past studies have shown the importance of surface or "near surface" boundaries in the enhancement of low level helicity of the role it plays in the development of tornadoes (Markowski 1998 and Schaub 2006).

Even so, no "magic bullet" has yet been found to discriminate between atmospheric conditions that are specifically conducive to tornadogenesis. Through the years, studies have shown encouraging correlations between various thermodynamic and kinematic parameters and tornado occurrences. This particular paper will summarize some of these latest studies and provide a brief case study of tornado occurrences during the severe weather outbreak across the southeastern United States from November 15th and 16th, 2006. This study is not meant to be an inclusive summary of the tornado events of those two days, but is designed to provide a snapshot of several tornado occurrences and the near-storm environmental conditions in which they occurred.

II. Overview of parameters studied

There are a variety of parameters and derived indices that can be analyzed both from diagnostic and model fields to assess the potential for severe weather and tornadogenesis. However, the vast array of derived quantities available can often make the decision making process more confusing, complicated, and "clouded" instead of adding value for the forecaster who is ultimately tasked with making the final decisions. To help alleviate some of the uncertainty and confusion, studies have been conducted to determine correlations between specific thermodynamic and kinematic parameters and the probability of tornadogenesis. Based on these results, we will look closely at five specific parameters that have shown a strong correlation in various studies: Convective Inhibition (CIN), 0-3km Convective Available Potential Energy (often referred to as "Low Level CAPE"), 0-1km Storm Relative Helicity (SRH_{0-1}), 0-1 km Energy Helicity Index (EHI_{0-1}), and the Level of Free Convection (LFC).

III. Convective Inhibition (CIN) and the Level of Free Convection (LFC)

It is generally understood that tornadoes are less likely in environments where surface-based instability is absent and the only available CAPE is from elevated parcels originating from above the boundary layer. In these "elevated" thunderstorm cases, the boundary layer is typically too stable to support tornadogenesis, but occurrences of large hail are quite possible with strongly rotating (primarily in the mid-levels) supercells.

However, a distinction must be made between these "elevated" thunderstorms that have no surface based CAPE as defined by Colman (1990) and thunderstorm settings that consist of surface-based CAPE located above a layer of surface-based CIN with relatively high level of free convection (LFC) heights. This type of situation may be characterized by a low level thermal inversion or capping inversion that produces an area of CIN below a larger area of CAPE for surface based parcels. A recent study by Davies (2004) utilized Rapid Update Cycle (RUC) proximity soundings similar to previous works by Benjamin (2004) and Thompson (2003). The objective of the Davies study was to better describe and assess CIN and LFC environments relative to supercell tornado occurrences in a variety of estimated storm settings.

Relevance to Severe Weather Forecasting

Supercell thunderstorms can occur in environments where air parcels originating near the ground realize their instability only after forced ascent through a deep layer of negative buoyancy. These environments will typically contain sizable CIN and relatively high LFC heights. How storms develop in such large CIN environments is not completely clear though certainly a variety of forcing mechanisms can aid in parcel ascent.

Rasmussen and Blanchard (1998) found in their study database that proximity soundings associated with supercells producing significant tornadoes tended to have less CIN than soundings associated with nontornadic supercells. These findings are supported by Rotunno and Klemp (1982) who stated that updrafts in environments with CAPE located above an area of large CIN require significant vertical pressure gradient forces to lift near-surface parcels past the LFC.

Even with a sizable amount of CAPE above the near surface layer of CIN, the stretching of parcels by the updraft may be reduced or inhibited at the surface due to the negative buoyancy at low levels. Because tornadoes are understood to be a surface phenomenon (Markowski 2002), it is likely that this kind of thermodynamic setting may interfere with tornado development. The Davies (2004) study took the qualitative assessments of previous studies and attempted to provide more quantifiable thresholds for surface based CIN and LFC heights.

It is also interesting to note that previous studies focused more on the LCL height (an estimate of cloud base) as a potential tornado discriminator as opposed to the LFC height. However, in environments where the CIN is relatively large, the LCL will be a poor diagnostic tool because it provides no information about the specific level where positive CAPE begins as parcels ascend above the cloud base.

Recent Studies and Findings

For the Davies study, RUC proximity soundings were utilized in conjunction with actual surface observations to provide the best possible estimate of near-storm environmental conditions. The database included 518 total profiles of which 275 included tornadic events. The computations utilized the mixed-layer lifted parcels (Craven 2002) which typically is a bit more realistic for operational purposes. In addition, the virtual temperature correction (Doswell and Rasmussen 1994) was also included which properly calculates density when computing CAPE and related thermodynamic parameters. It is important to note that the application of the virtual temperature correction (VTC) varies between operational software packages. Specifically, the AWIPS sounding application does not apply the VTC while the NSHARP application does. Because the VTC is density dependant, it has most of its significant impacts in the low levels of the atmosphere (adding water vapor to a parcel makes it less dense) and the correction can have significant impact upon the derived quantities. In general, the VTC correction will increase CAPE, reduce CIN, and lower LFC heights. Thus, forecasters should be aware whether their software package of choice utilizes the VTC correction.

For the study, the events were placed into three separate categories: non tornadic (243 events total), weak tornadoes (170 F0-F1 tornadoes), and significant tornadoes (105 F2-F4 tornadoes). In this particular study, there were no recorded F5 tornado events. As can be seen from Table 1, Davies found that the tornadic cases had a tendency to be associated with a smaller MLCIN (mixed layer CIN) and lower MLLFC (mixed layer LFC) with the most significant difference between the nontornadic and significant tornado cases. Specifically, the mean values for each category were as follows:

Event Type	MLCIN (J kg^{-1}) VTC Applied	MLCIN (J kg^{-1}) VTC Not Applied	MLLFC (m AGL) VTC	MLLFC (M AGL) No VTC
Non Tornado	44	72	2042	2338
F0-F1 Tor	23	38	1554	1871
F2-F4 Tor	17	31	1309	1493

Table 1. Mean values for each event category in the Davies 2004 study.

It is also interesting to note that a breakdown of tornado occurrences by MLCIN categories shows a fairly substantial dropoff with increasing values. Specifically, of the 167 tornadoes that were F1 intensity or greater in the study only 31 (18.5%) occurred when the MLCIN was greater than 50 j/kg and only 15 (or 9%) when the MLCIN exceeded 75 J/kg. Since the likelihood of tornadogenesis decreases substantially as CIN increases above 50 J/kg (based on these and other findings), one might utilize this value as an initial threshold for determining the potential for tornadic development.

A similar trend was also noted in the MLLFC distribution with decreasing potential for tornadogenesis with increasing MLLFC heights. Specifically, nearly 87% or 145 of the 167 tornado occurrences (F1 or greater) occurred with an LFC height below 2000 m AGL (6562 ft AGL). As a first guess, one could use this value as a threshold for the higher end of LFC values capable of supporting tornadoes.

From a physical standpoint, an environment with large CIN and associated high LFC heights may inhibit low-level parcel ascent and stretching near the ground, reducing the likelihood of tornadoes. Davies also theorized that it is also possible that tornadogenesis may, in part, be related to rapid upward acceleration and stretching within the layer containing largest helicity. If CAPE is not positive and large within the same layer where Storm Relative Helicity (SRH) is large (in other words, the CAPE is located above and vertically "disconnected" from the layer of large SRH) then tornado development becomes less likely.

This suggests a direct physical connection between low-level CAPE (associated with smaller CIN and lower LFC heights) and low-level SRH regarding tornado formation. Taking this information into account may aid in reducing tornado warning false alarms in some situations when CIN or LFC values are not conducive to tornadogenesis.

Specifically, a degree of restraint in issuing tornado warnings for supercells occurring in environments where MLCIN is larger than 150-200 J/kg or MLLFC is higher than 3000 m may result in some amount of reduction regarding tornado warning false alarms. Unless low level shear values are very large (see EHI_{0-1} section), severe thunderstorm warnings may be more appropriate in such situations.

IV. The LCL versus the LFC

Several studies including the Craven 2002 study have shown low LCL heights to be associated with tornadic storms. However, it is important to reiterate that LCL height and LFC height are very different thermodynamic variables. Specifically, a low LFC implies a low LCL, but the reverse is not necessarily true. In other words, the LCL is not always the LFC and the LCL heights can remain relatively low as LFC heights become increasingly high and CIN larger. This shows that LFC values alone provide little direct information about whether instability in a particular environment is located above a CIN layer.

V. Storm Relative Helicity (0-1 km Layer)

The traditional method of calculating storm relative helicity has been to integrate through the 0-3 km above-ground level (AGL) layer. Recent findings on the importance of boundaries (Markowski 1998) and the character of the near-ground shear in simulation storms (Weisman 1998) suggests that perhaps the shallower near-ground layers are of most importance in affecting the development of supercells and tornadoes. The results of an updated climatology study by Rasmussen (2003) substantiate these findings: they indicate that the 0-1 km AGL SRH (SRH_{0-1}) is a better forecast parameter for distinguishing among the tornado and supercell classes than the commonly used 0-3 km AGL SRH. The box and whiskers diagram for SRH_{0-1} is shown in Fig. 1. It should also be noted that Edwards and Thompson (2000) have found a similar signal with RUC-2 derived SRH_{0-1} in their analysis of a set of radar-identified supercells.

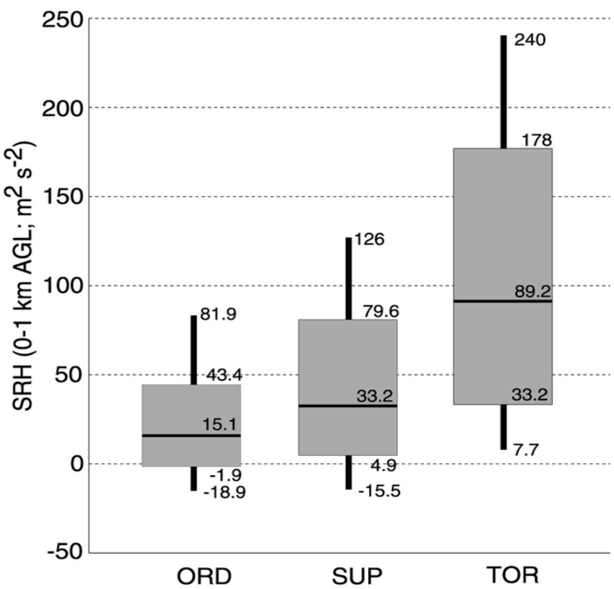

Fig. 1. Box-and-whisker graph (from Rasmussen 2003) of 0-1km AGL SRH for soundings associated with significant tornadoes (TOR; right), sounding with hail > 5.1 cm in diameter but without significant tornadoes (SUP; middle), and nonsevere thunderstorms (ORD; left). Gray boxes denote 25^{th}-75^{th} percentiles, with heavy horizontal bar at the median value. Vertical lines (whiskers) extend to the 10^{th} and 90^{th} percentiles.

VI. Energy Helicity Index

As mentioned earlier, large CIN values (>50 J/kg) act as a layer of stability to parcels attempting to ascend from below. This situation typically inhibits or reduces parcel ascent and stretching near the ground, and likely limits tornado frequency with supercells developing in this environment. However, we must be careful to dismiss environments with large low level CIN or high LFC heights as completely non-conducive to tornadogenesis. In cases with strong vertical shear interacting with an updraft, the resulting shear-induced vertical pressure gradient could induce significant upward accelerations to help overcome this.

To examine the cumulative potential of low level shear and buoyancy, the energy helicity index was developed by Hart and Korotky (1991). More recently, Rasmussen (2003) revised the EHI formulation to focus on SRH in the lowest 1 km in conjunction with the mixed-layer CAPE (MLCAPE) defined as:

$EHI_{0-1} = (MLCAPE \times SRH_{0-1})/160{,}000$

This modified version is identical to the traditional form except for the substitution of the SRH_{0-1}. The scatter diagram of this parameter space is given in Fig. 2, and the box and whiskers diagram is shown in Fig. 3. Recent studies by Rasmussen (2003) indicate that this formulation of EHI_{0-1} is substantially better at distinguishing between TOR and SUP classes than any parameter utilized in their 1998 study (Rasmussen and Blanchard 1998). In fact, nearly 2/3 of the tornado soundings in the study had EHI_{0-1} values over 0.5.

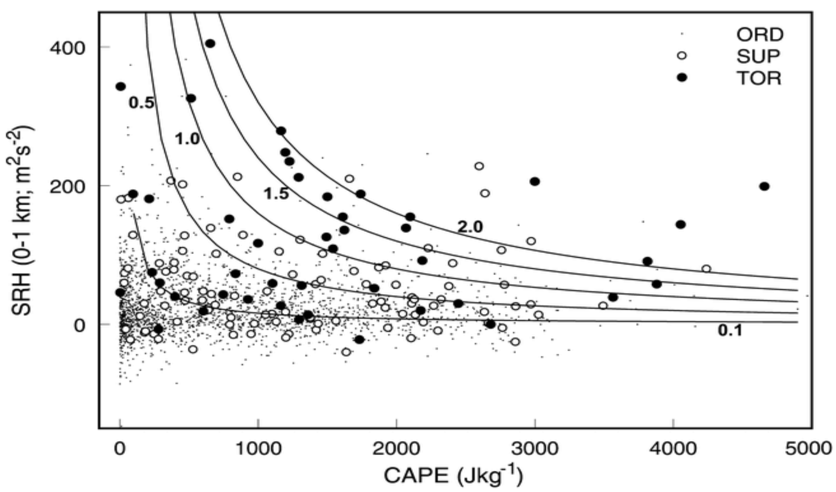

Fig. 2. Mixed Layer CAPE versus 0-1 km AGL SRH parameter space diagram from Rasmussen 2003 study. Labeled curves are lines of constant EHI_{0-1}.

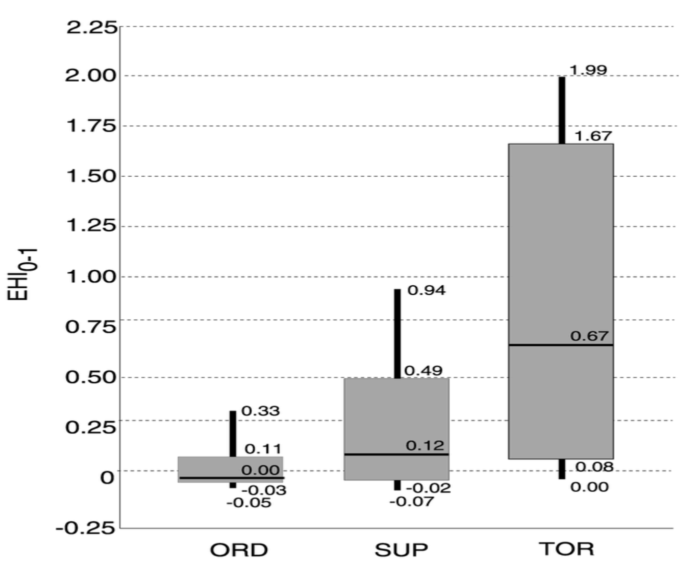

Fig. 3. As in Fig. 1, but for EHI_{0-1}.

Similar findings were noted in another study utilizing RUC proximity soundings by Thompson (2003). It is also notable that in the Davies study that the EHI_{0-1} calculation were consistently large (approaching 2.0 in many instances) for the “tornadic” cases as compared to the non-tornadic cases. The variation was primarily a function of an increase in the low-level wind shear (0-1 km shear magnitude) with the tornadic cases.

Anomalous Cases with High Low Level CIN

In the Davies 2004 study, he recognized some anomalous cases where tornadoes did occur even in the presence of relatively high boundary layer CIN (in excess of 75 J/kg). Although the statistical sample which included high CIN in conjunction with tornado occurrences was statistically small, the findings would at least suggest that some supercells are able to generate tornadoes in larger CIN/higher LFC environments when supported by large EHI_{0-1}, compensated primarily by large amounts of low level SRH. The corresponding cases in this study suggested that these supercells tend to have larger amounts of SRH_{0-1} (on the order of 200-300 m^2s^2 or more) resulting in large EHI_{0-1} values. Although not covered in this paper, it should also be noted that deep layer shear also tended to be larger in those cases as well.

VII. A Note about CAPE Calculations

In convective forecasting, one of the main problems a meteorologist faces is determining a representative value of potential instability. Deciding which parcel or layer to lift in the computation of CAPE is crucial in this process. Meteorologists have access to many different models and sounding analysis algorithms that generate forecasts of CAPE. Because many of these are labeled simply as CAPE, with no reference to which parcel is used in the calculation, the usefulness of such information is questionable. For forecasters to utilize this information in an effective manner, it is important that the techniques used in the calculations, including details such as a definition of the lifted parcel and use of the virtual temperature correction is well documented and understood by the forecasters.

Studies by Craven and Jewell (2002) generally support the computation of thermodynamic parameters using a mean-layer parcel approach in lieu of the standard surface based parcel. In a mean layer “framework”, calculations are created using the mean temperature and dewpoint in the lowest 100 millibars of the atmosphere which is approximately 1 km in depth. This technique has been utilized by the SPC, and previously the National Severe Storms Forecast Center, for roughly 50 years.

Craven and Jewell (CJ) compiled a database of approximately 400 observations and calculated convective cloud base heights utilizing both surface based techniques and mixed layer techniques. In their study, they found that both techniques underestimated the cloud bases but the mixed layer technique was a much better fit using linear regression. Because the mean-layer parcel more accurately estimates the height of the convective cloud base, it is reasonable to assume that the mixed-layer calculation of

CAPE (MLCAPE) should be more representative of the potential buoyancy than the surface based CAPE (SBCAPE). From their study, CJ concluded that the SBCAPE had larger values in nearly all the cases. In fact, the median values of SBCAPE (1492 J/kg) was more than 2 times the median value of MLCAPE (685 J/kg). This highlights the unrepresentative nature of a skin layer of relatively high surface dewpoints, which would have obvious implications in thunderstorm forecasts. Similarly the CAPE calculations using the mixed layer parcels (MLCAPE) would also be a closer fit to observed soundings.

Low Level CAPE (0-3 km)

Consistent with the idea that large low-level stretching is required for level-level mesocylone intensification and perhaps tornadogenesis, several researchers have explored the idea that the distribution of CAPE with height is important and large low-level accelerations are favorable for tornadic supercells (McCaul 1991). Fig. 4 from Rasmussen (1998) depicts the distribution of CAPE in the lowest 3 km above the LFC. It appears that the ordinary thunderstorm category (ORD) has somewhat less CAPE in the lowest 3 km than the supercell (SUP) or tornadic supercell (TOR) categories, consistent with previous findings.

However, very little difference can be seen between the TOR and SUP categories contradicting the idea that increased low-level stretching is directly correlated with the magnitude of the low-level CAPE. Instead, the required stretching probably can be attributed to dynamic pressure effects from the interaction of low-level shear and the updraft.

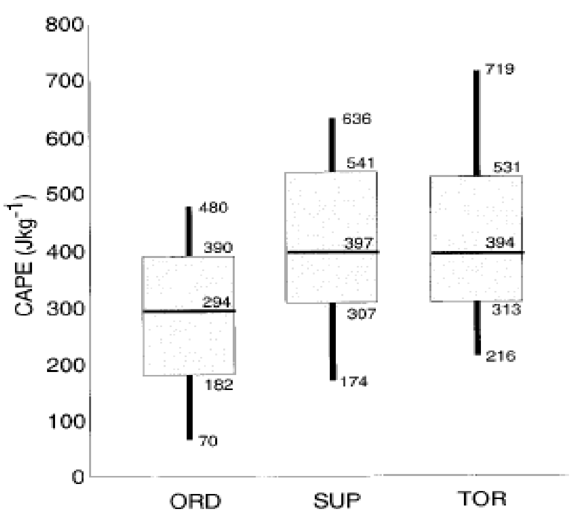

Fig. 4. Box-and-whisker diagram similar to Fig. 1 except for CAPE in the first 3 km above the LFC. (courtesy of Rasmussen and Blanchard 1998)

Evolution of Events

It is important to remember that specific values of CIN, EHI, or LFC should not be taken as a "black box" based on diagnostic or proximity soundings. In fact, the importance of monitoring the evolution of surface and upper level features along with trends in model-derived fields cannot be understated. For example, even though a cool stable boundary layer environment in a particular location may appear to have large CIN and high LFC characteristics, the near proximity of a frontal region with notably smaller CIN and lower LFC heights may be important information.

The propagation of the frontal boundary may critically impact the buoyancy characteristics of the low-levels of the atmosphere and result in an increased threat for tornadogenesis. These types of critical, albeit subtle, mesoscale changes are often not well reflected in model-derived profiles. As such, model derived profiles should not be relied on alone to diagnose relevant mesoscale and storm scale changes.

Part Two: November 2006 CASE Study

I. Event Overview

In mid-November 2006, several potent storm systems spawned tornadoes from the Gulf Coast States to the Southeast Coast. Specifically, we'll look at a few tornadic cases that occurred from November 15th through November 16th. All damage reports are courtesy of Local Storm Reports (LSRs), Public Information Statements (PNSs), and storm report summaries courtesy of the Storm Prediction Center (SPC).

During this two day period, over 200 reports of severe weather were received at the SPC including nearly 20 tornado reports (exact number still unofficial). The majority of the tornado occurrences, along with the "high end" damaging wind events, occurred along and south of the Interstate 20 corridor from Mississippi to Georgia. In addition, tornadoes also occurred in South Carolina and eastern North Carolina. The North Carolina tornado would turn out to be the deadliest tornado of the event causing 8 fatalities and a large number of injuries.

We will look at several of these events in detail, and specifically discuss the pre-storm and near-storm environmental characteristics that may have made conditions favorable for tornadic development in those specific areas. As we have already mentioned, there were numerous other severe thunderstorms on those three days. Many of those were rotating supercells that prompted tornado warnings, but for one reason or another, did not produce a tornado. Discussion of each and every storm is beyond the scope of this study, but we can only assume that special boundary layer conditions were in place that led to the tornadogenesis in the cases we will review.

II. Diagnostics and Analyses

For a review of the specific tornadic events from November 2006, we will utilize a combination of data from the Rapid Update Cycle (RUC), North American Mesoscale (NAM) model, and surface analyses and radiosonde data. Numerical and point calculations from the AWIPS "Sounding Toolkit" application will also be utilized when the necessary point data is available.

III. Mississippi Tornadoes

During the early morning hours on November 15th, 4 tornadoes tracked across portions of southeastern Mississippi. Of the four tornadoes, two had a maximum intensity of F3 producing 8 injuries and a large amount of damage to residential and commercial structures. The initial tornado touchdown occurred near Sumrall, MS at approximately 0830Z (F3 intensity) with additional tornadoes near Sandy Hook, MS (F1) at 0918Z, Laurel (F3) at 0931Z, and Sand Hill (F1) at 1057Z.

Due to the elevated risk of severe weather across the region, WFO Jackson MS launched special radiosonde releases at 06Z and 09Z on the 15th. It should be noted that the KJAN radiosonde location is approximately 90 miles northwest of the general location where the tornadoes tracked between 0830 and 1057Z. However, it is apparent from both the 06z radiosonde (Fig. 5) and 09z radiosonde (Fig. 6) that the atmosphere across central and southern Mississippi has undergone significant low level destabilization during that time period.

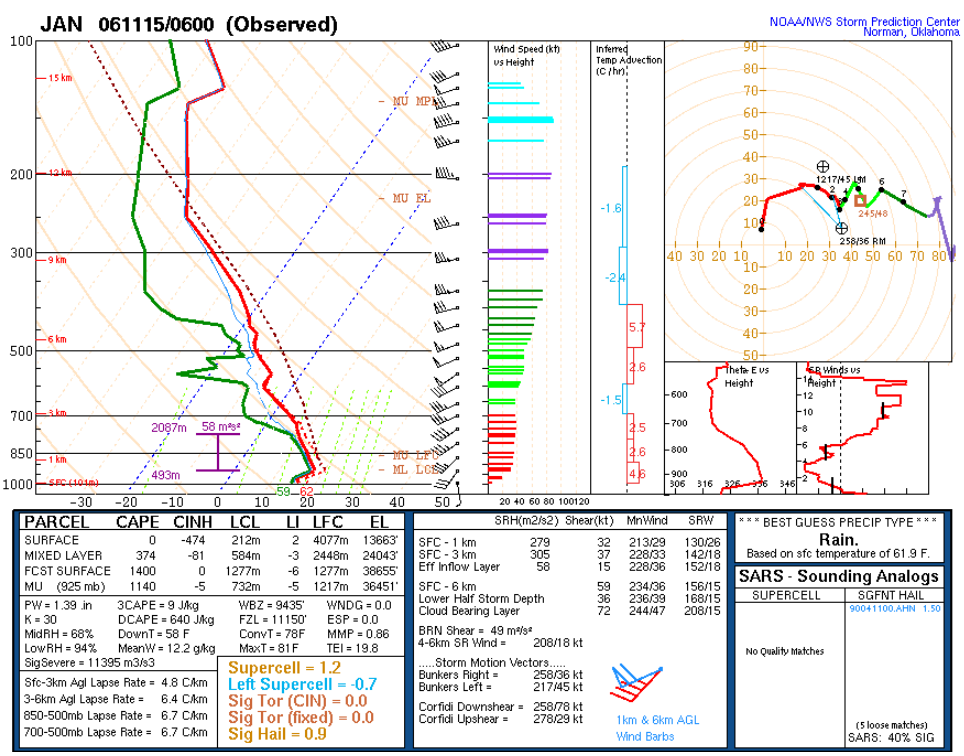

Fig. 5. KJAN radiosonde from 06z on November 15th, 2006

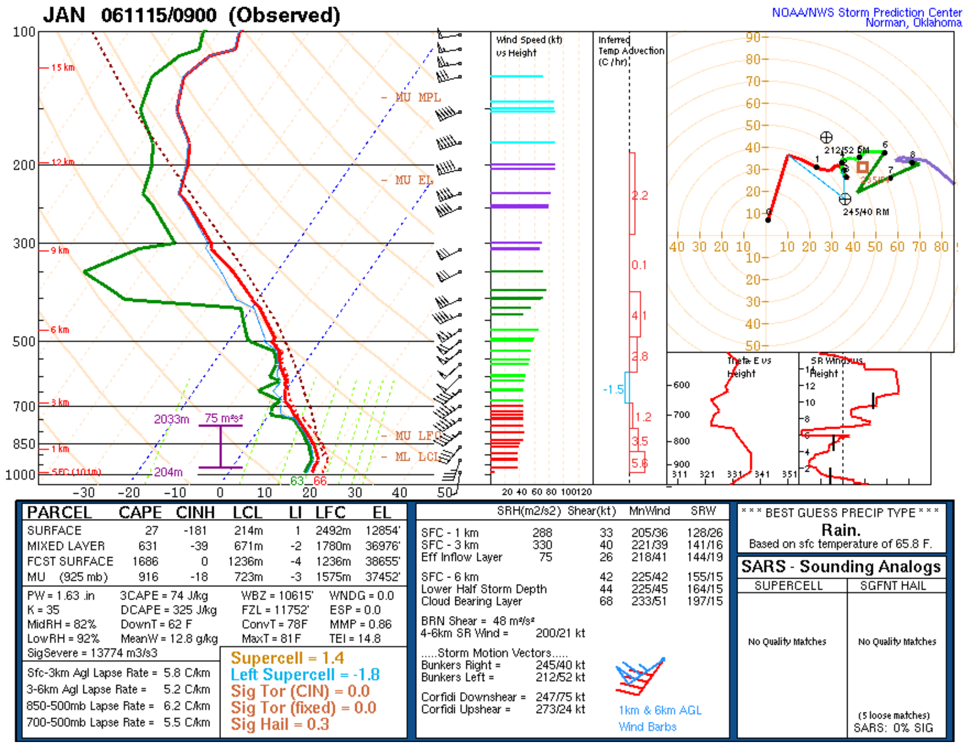

Fig. 6. KJAN radiosonde from 09z on November 15th, 2006

Specifically, the thermodynamic profile has been transformed from one with a noticeable stable inversion below 925 mb (with no surface based CAPE) to one with a marginally unstable layer near the surface. It is equally important to note the rapid increase in the Mixed Layer CAPE (from 374 to 631 J/kg) and the associated decrease in Mixed Layer CIN (from -81 to -39 J/kg). Recall from the Davies (2004) study that over 80% of all tornadoes occurred when the Mixed Layer CIN (MLCIN) was less than 50 J/kg.

A quick review of the RUC CAPE analysis also shows the destabilizing nature of the atmosphere in advance of the tornadogenesis across southeast Mississippi that night. As previously mentioned, the initial tornado touched down near Sumrall, MS in northwest Lamar County at 0830Z. Figures 7 and 8 show the RUC CAPE analyses from 08z and 09z respectively. During that one hour period, the CAPE increased by 40% with the nose of the higher CAPE extending into Lamar and Forrest counties.

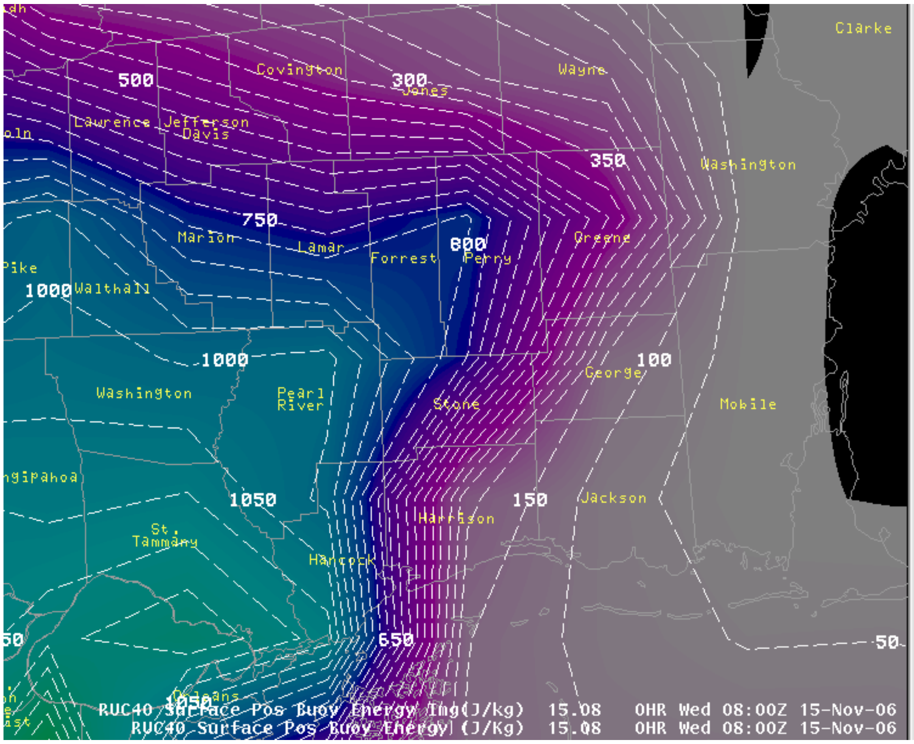

Fig. 7. RUC40 model forecast of CAPE for 08z on November 15th.

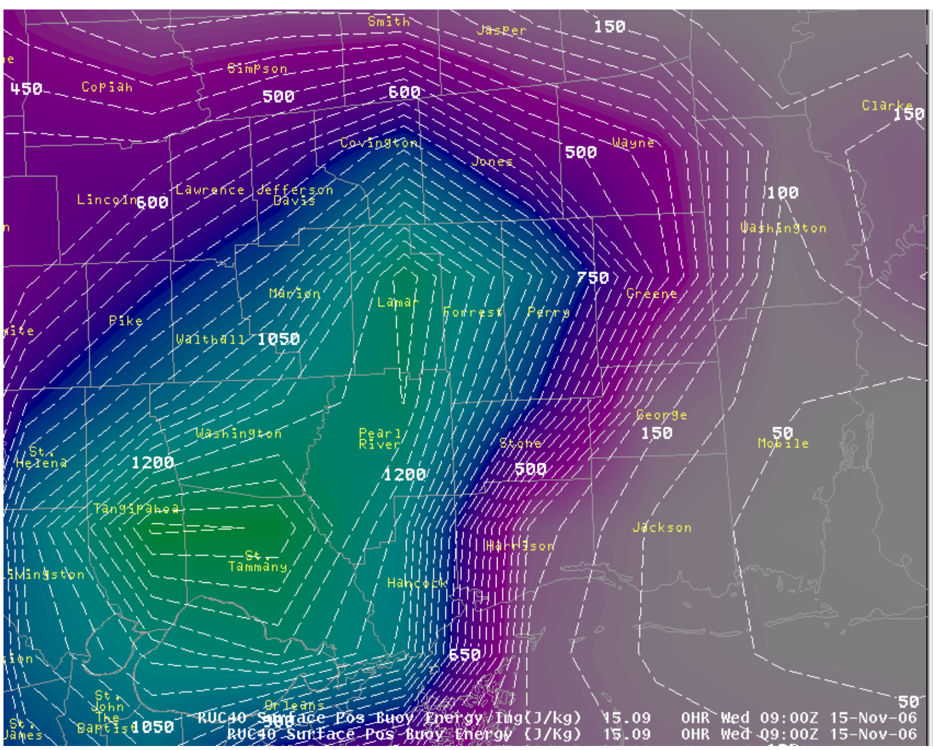

Fig. 8. RUC40 model forecast of CAPE for 09z on November 15th.

During this review, it was also of interest to review the point information available via the Sounding Toolkit application. This application can be accessed on both the WES for case studies and also on the operational AWIPS for mesoscale analysis and forecasting purposes. The Sounding Toolkit can analyze both radiosonde data and model sounding data for specified points. In this case, a point was analyzed for 08z (Fig. 9) near Sumrall, where the initial F3 tornado occurred.

The RUC40 forecast sounding output (Fig. 10) from this particular time period does reveal some interesting details beyond the already discussed CAPE calculations. Of specific note are the impressive values for the EHI_{0-1} (1.6), SRH_{0-1} (115 m^2/s^2), and the favorable LFC heights of 1492 meters. All these variables fit well into the thresholds for significant tornado potential, and should be “red flags” for a warning forecaster.

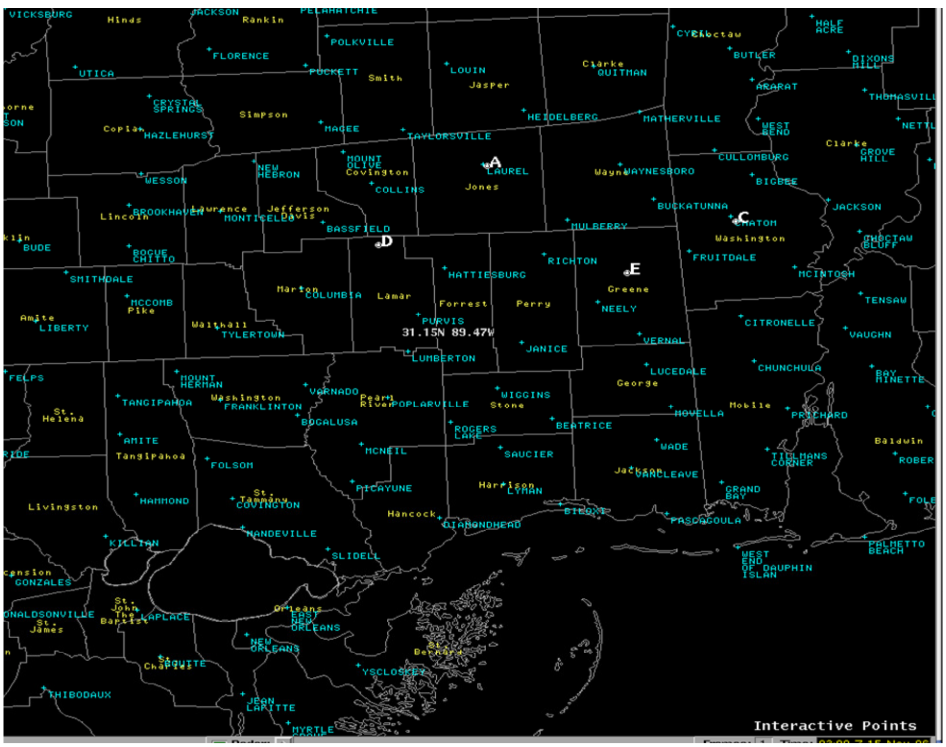

Fig. 9. Map of Interactive Points used for Sounding Toolkit. Note point D is located in northern Lamar County near site of first MS tornado.

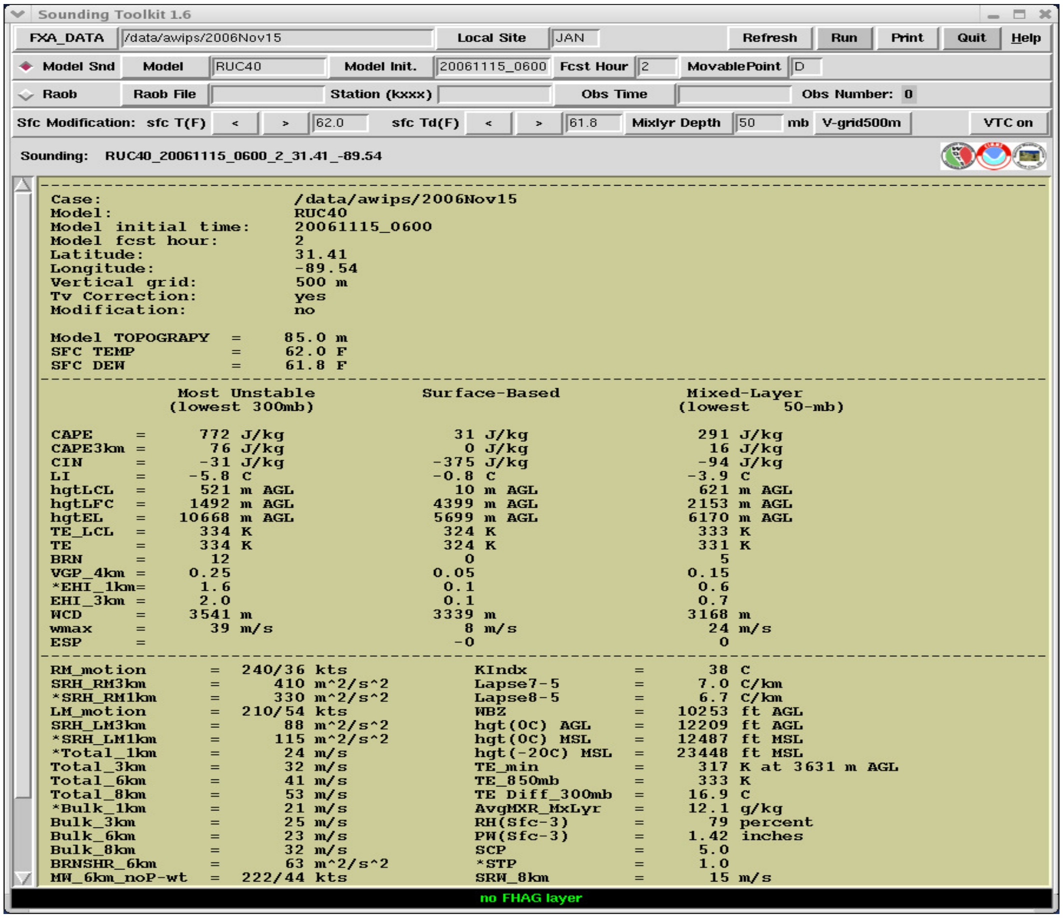

Fig.10. Sounding Toolkit Calculations for Lamar County MS (Point D) for 08z on November 15th.

IV. Alabama Tornadoes

On the morning of November 15th, additional tornadoes developed and moved across southern Alabama. All totaled, 5 tornadoes touched down across Alabama with one F2 and four F1s being reported. As was the case with the events earlier in the night across Mississippi, these tornadoes were associated with a rapidly destabilizing airmass across southern sections of the state. In fact, all five events were associated with a marked increase in low level CAPE and associated decrease in boundary layer CIN in advance of the tornado touchdowns.

One specific example of this was the F2 tornado that touched down near Montgomery Alabama around 1625z. Between 14Z and 16Z, the CAPE values near Montgomery (graphic not shown) increased from approximately 309 J/kg to 640 J/kg according to the RUC40. $EHI_{0\text{-}1}$ also increased to a value of 1.4 near the time of the tornado touchdown.

It should also be noted that 4 of the 5 tornadoes that occurred across Alabama on the 15th were associated with the same storm (the Montgomery supercell). The 5th tornado was the same storm that produced the tornado near Sand Hill, MS before moving into

Washington County around 1144z. The 16z surface analysis (Fig. 11) shows the marked dewpoint contrast from south to north with upper 60s to near 70 degree dewpoints feeding into the storms approaching Montgomery County. This low level moisture convergence no doubt enhanced the surface based instability and should be monitored in real-time by the warning and mesoscale forecasters.

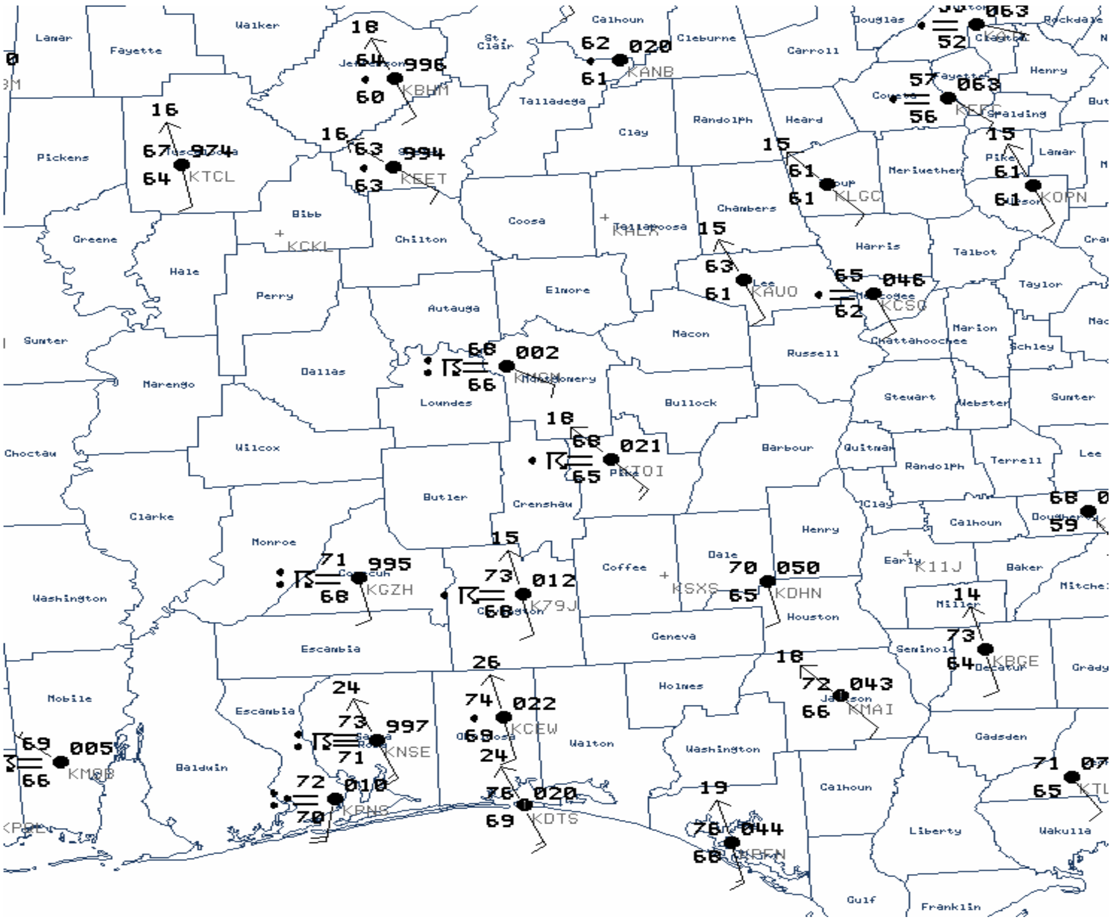

Figure 11. 16z Surface Analysis along the Gulf Coast on November 15th, 2006..

V. Carolinas Tornadoes

As the same storm system tracked eastward toward the mid atlantic region, two additional tornadoes touched down across the Carolinas during the morning hours on November 16th. One tornado, F1 in intensity, touched down near Manning, SC around 0619z. The town of Manning is situated along Interstate 95 approximately 20 miles southeast of Sumter.

Although this tornado occurred shortly after 100 AM EST in the morning, the atmosphere across the eastern half of the state was quite unstable and primed for severe weather considering the time of year. Once again, the RUC proximity sounding (Fig. 12) showed that the critical parameters we've been discussing during this paper were in place for tornadic potential across the area. Specifically, the combination of the EHI_{0-1}, SRH_{0-1}, substantial MLCAPE, and low LFC heights, were all favorable for tornadic development.

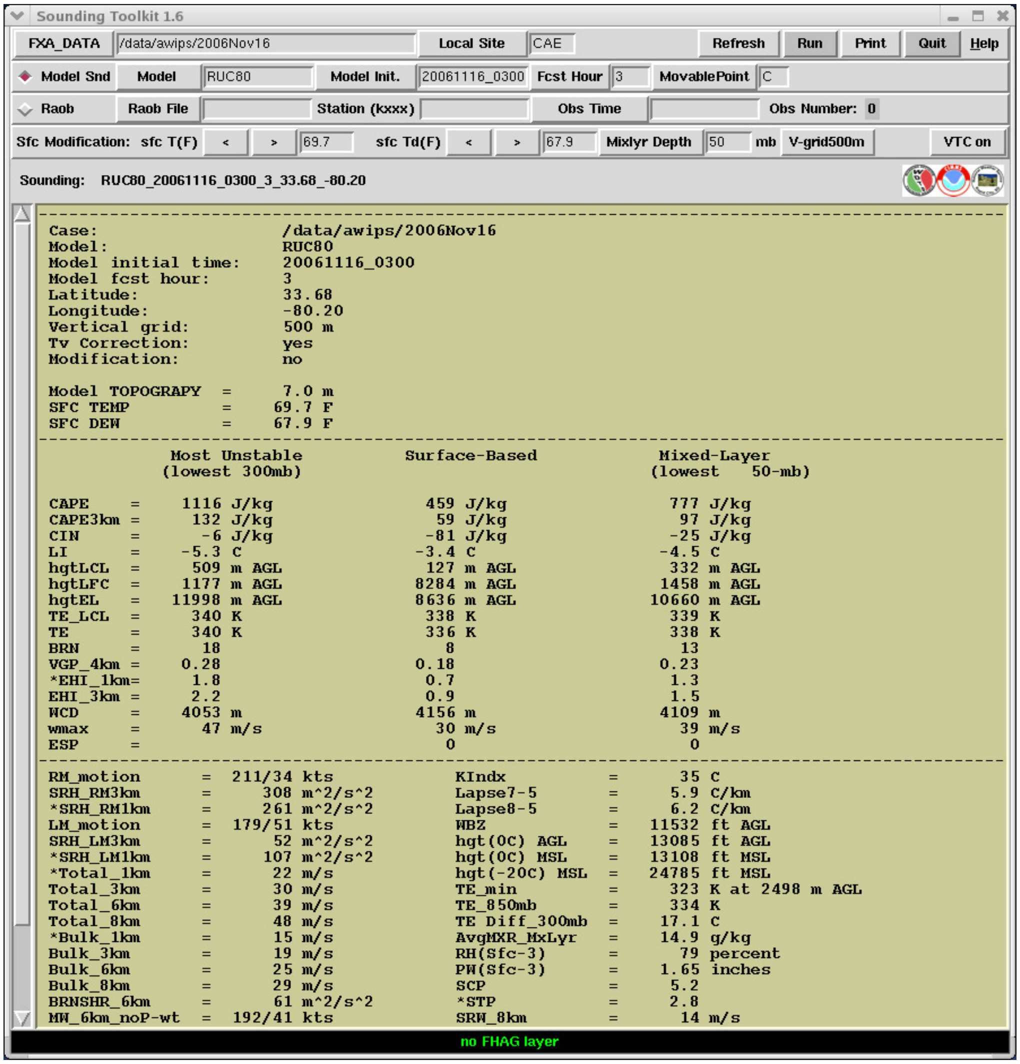

Figure 12. RUC proximity sounding data for 06z on November 16th.

The most high profile and costliest tornado of this severe weather event occurred around daybreak near Riegelwood North Carolina on November 16th. An F3 tornado hit a densely populated mobile home park around 1137z causing 8 fatalities and 20 injuries. The tornado had a maximum width of 300 yards with a damage path of nearly 7 miles. Although a tornado warning was issued 8 minutes prior to the tornado touchdown, many residents did not flee their mobile home for more secure shelter.

The Riegelwood tornado was another case where the atmosphere destabilized rapidly in advance of the tornado touchdown. The supercell that spawned the tornado developed rapidly over the coastal waters south of Wilmington and raced northward onshore. The data from the RUC proximity sounding (Figures 13 and 14) just northwest of

Wilmington, in the vicinity of Riegelwood, show the destabilization of that area from 09z to 12z on the morning of the 16th.

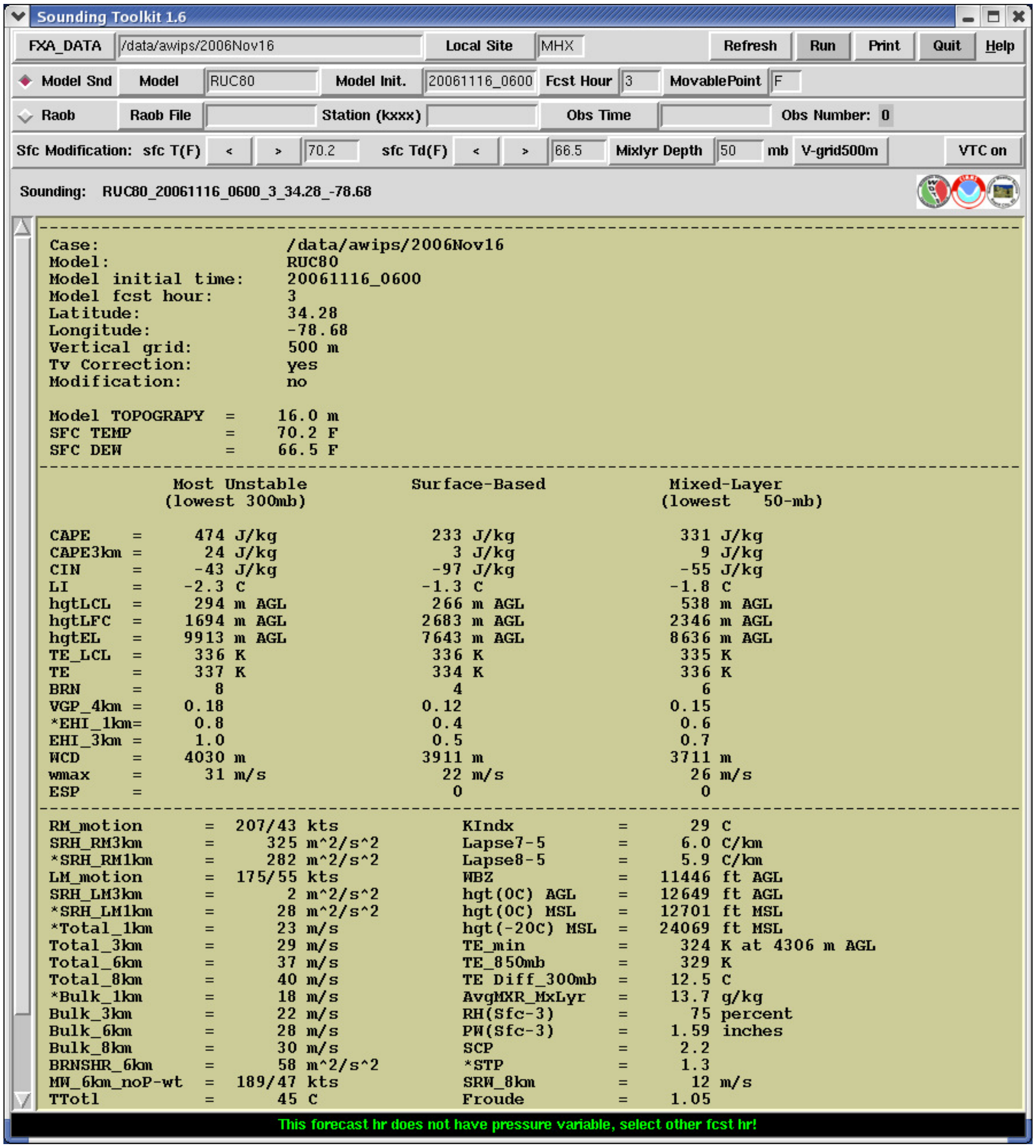

Fig. 13. RUC Proximity Sounding for Riegelwood - 09Z on November 16th, 2006

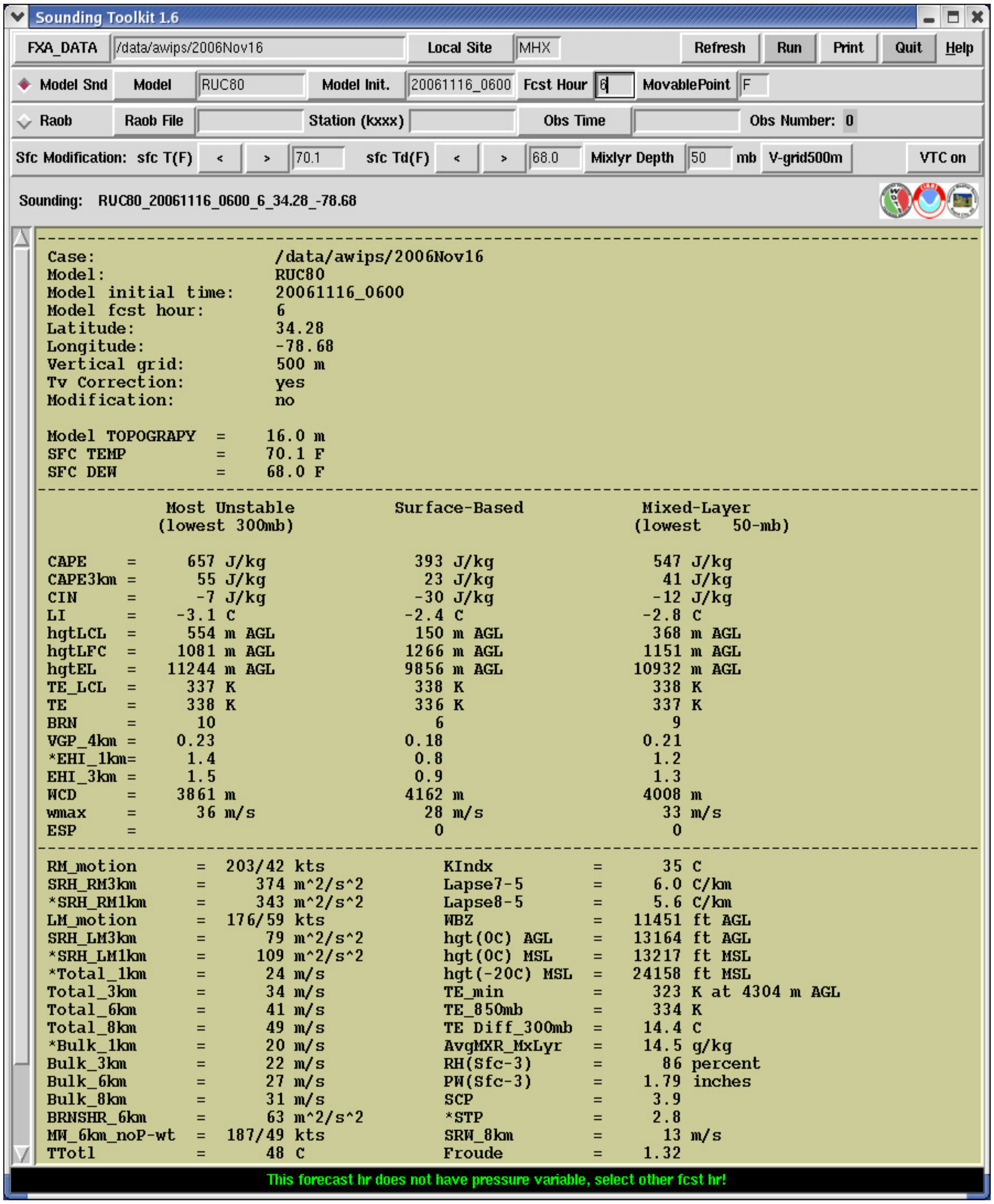

Fig. 14. RUC Proximity Sounding for Riegelwood - 12Z on November 16th, 2006

As can be seen in the previous two figures, the overall characteristic of the thermodynamic environment became much more favorable for rotating supercells and tornado potential between 09z and 12z. Specifically, the low level CAPE (0-3 km) nearly doubled, the SRH_{0-1} increased substantially, the resultant EHI_{0-1} increased significantly, and the near-storm LFC heights lowered to approximately 1150 meters. During this time period, the characteristics of the storm transitioned dramatically from strong to life threatening.

VI. Research Summary

The full suite of radar products, along with real-time spotter reports, have always been the backbone of the warning decision making process. However, as we learn more about the storm scale processes that are essential to severe convective events it is apparent that radar interrogation alone is not sufficient to discern all types of severe weather occurrences. Nor is it sufficient to provide the adequate lead times that all types of event planners and mission critical decision makers require.

Due to various field experiments over the past two decades, and as evidenced by the large Tornado Warning False Alarm Rate, it is apparent that there is much more to tornadogenesis than the development and strengthening of a parent mesocyclone. To that end, researchers and operational meteorologists have conducted many studies correlating near-storm environment parameters to tornado occurrences. As the science has progressed, so have the overriding conclusions of these studies.

The most recent research points toward the thermodynamic and kinematic characteristics of the lower tropospheric layer, and chiefly the boundary layer, of the atmosphere as the key discriminator between tornadic and non-tornadic environments. It is hoped that this paper has helped to highlight some of the parameters and indices that may be of utility to the operational meteorologists when tasked with making critical warning and forecast decisions.

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