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CONDITIONING AND EVOLUTION OF HIGH SHEAR, LOW CAPE SEVERE WEATHER ENVIRONMENTS

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1. INTRODUCTION

High shear, low CAPE (HSLC) severe weather events predominantly occur during the late evening, overnight and early morning hours, and are especially common throughout winter and early spring when CAPE is climatologically at its lowest (Guyer et al. 2006; Smith et al. 2008; Kis and Straka 2010). HSLC events primarily affect the Mississippi and Ohio Valleys as well as the Mid-Atlantic and Southeast portions of the U.S., and typically take the form of quasi-linear convective systems (QLCSs) and/or very small supercellular structures (Lane and Moore 2006; Schneider et al. 2006; Guyer and Dean 2010; Sherburn and Parker 2014). The small scale of HSLC events in addition to their common cool season and nocturnal occurrence leads to many forecasting challenges (Guyer and Dean 2010; Brotzge et al. 2011; Coleman and Dixon 2014). In an attempt to improve probabilities of detection and mitigate false alarms, recent research has focused on storm-scale evolution and radar detection of HSLC events (e.g., Sherburn and Parker 2014; Davis and Parker 2014).

Several recent studies have also begun to investigate how the larger scale environment influences smaller scale convective evolution throughout low CAPE events, finding that synoptic circulations may significantly modify environmental evolution by enhancing lift, and possibly providing a release of potential instability (e.g., Jewett and Wilhelmson 2006; Wheatley and Trapp 2008; Clark 2009; Dial et al. 2010; Evans 2010; Sherburn and Parker 2014). It has also been shown that advection of warm, moist air by low-level flow may be important for destabilization (Lackmann 2002; Trier et al. 2006; Tuttle and Davis 2006). The goal of this ongoing study is to focus on synoptic-to-mesoscale mechanisms by which destabilization may be occurring in the hours leading up to convection in low CAPE severe environments.

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2. METHODS

2.1 Model Description

Real-data numerical simulations of more than a dozen HSLC events have been performed, two of which will be discussed. These two cases were high impact severe events occurring during the evening and overnight hours in winter of 2013. The simulated events replicated the reflectivity structure of the observed events within reason. Comparisons were also made with observed soundings to ensure reasonable representation of the events.

Numerical simulations were performed using the fully compressible, non-hydrostatic Advanced Research Weather Research and Forecasting model (WRF-ARW; Skamarock et al. 2008), version 3.5.1. An outer domain at 9 km horizontal-grid spacing was one-way nested down to a 3 km domain, both of which had 50 vertical levels staggered to yield a high concentration of vertical levels near the surface. Each simulation was run for a minimum of 30 hours to account for the evolution of the synoptic environment. Initial and boundary conditions were supplied by the North American Mesoscale Model (NAM) 12 km analyses and were updated on 6 hour intervals. The Kain-Fritsch (Kain 2004) cumulus scheme was used to parameterize convection on the outer domain while convection on the inner domain was simulated explicitly. Microphysical and boundary layer processes were parameterized by the single moment WSM-6 class graupel scheme (Hong and Lim 2006) and the Yonsei University (YSU; Noh et al. 2003) non-local scheme, respectively.

2.2 Time Series Construction

Time series of simulated thermodynamic variables were constructed to determine how the simulated environment changed on a relatively small temporal scale. The time series were computed for a manually selected line of grid points for each case, dependent on the orientation of the simulated convection. For multiple evenly spaced grid points along the line, lowest model level potential temperature, water vapor mixing ratio and surface-based CAPE were recorded over 6 hours. The final time was defined as the time simulated surface-based

CAPE reached its maximum simultaneous with simulated reflectivity values of at least 50 dBZ.

In order to isolate the effects of changes in surface-based CAPE due to changes in near-surface temperature and moisture, 6 hour time series were created calculating surface-based CAPE while holding the entire profile constant and alternately updating: the lowest model level temperature only, the lowest model level mixing ratio only, and the lowest model level temperature and mixing ratio simultaneously with time.

3. DISCUSSION OF SIMULATED EVENTS

3.1 January 29-30, 2013

During the night of January 29-30, 2013, a QLCS moved through the central Mississippi Valley causing several significant tornadoes and a substantial amount of wind damage throughout Kentucky and Tennessee. An upper-level trough deepened while propagating eastward just upstream from the severe QLCS (Figure 1a, 1b). The sea-level pressure analyses (Figure 1c, 1d) show two pressure troughs moving toward the central Mississippi Valley. The pressure troughs correspond with a very strong outflow boundary ahead of a surface cold front, both of which likely had an influence on the severe convection that occurred.

Simulated composite reflectivity and lowest model level equivalent potential temperature (θ_e) and winds are displayed in Figure 2 at 06 and 10 UTC. Two boundaries are visible in the θ_e plot, representing the front and the outflow boundary seen in the sea-level pressure analyses. The QLCS propagated along the intense outflow boundary, surging ahead of the cold front. The environment ahead of the convective line became more warm and moist throughout the night as strong southerly winds persisted.

0-500mb skew-t diagrams from the pre-convective environment at 5:55, 7:25 and 9:05 UTC (Figure 3) show minor increases in near-surface temperature and moisture as well as extremely strong low and mid-level winds (65 kts at 900 mb). The most noticeable change in the soundings over the 3.25 hours is the significant cooling and moistening in the 900-700 mb layer, destabilizing the environment. The bottom-up cooling/saturation that occurred is suggestive that potential instability was released as the convective line approached.

Time series were computed for several evenly spaced grid points as described in section 2.2 (Figure 4). An average of the simulated surface-based CAPE time series shows that the majority of the 273 J/kg increase occurred during the first hour and the final 2.5 hours prior to the passage of the QLCS. Increase in temperature and increase in moisture near the surface both generate a fairly linear increase in surface-based CAPE, though the temperature contributed more of an increase (87 J/kg) than moisture (60 J/kg). The lowest level temperature and moisture together provided an increase of ~140 J/kg, and thus the near-surface thermodynamics only accounted for about half of the total increase in CAPE over the 6 hours prior to convection in this simulation. The aforementioned release of potential instability due to synoptic forcing for ascent likely accounted for the additional increases in CAPE.

3.2 February 10, 2013

Throughout the late afternoon and into the evening on February 10, 2013, a QLCS moved into Mississippi from the west developing small, embedded supercells. Tornadoes, severe winds and some hail affected the southern and central portions of Mississippi and Alabama, including at least two extremely devastating EF-3 tornadoes. Sea-level pressure analyses (Figure 5c, 5d) show a deep surface cyclone over the North/Central Plains with an associated cold front extending southward into the Gulf states, providing convergence as southerly winds and warm, moist Gulf air collided with northwesterly winds and cool, dry air. A 500 mb closed low over the North/Central Plains influenced strong west-southwesterly flow in the mid-levels (Figure 4a, 4b).

Simulated composite reflectivity and θ_e (Figure 6) show intense convection propagating along a robust outflow boundary, much like in the previously discussed simulation. Lowest model level winds show strong flow from the Gulf of Mexico colliding with northwesterly flow behind the outflow boundary.

0-500 mb soundings from 20:40, 22:40 and 00:40 UTC (Figure 7) show modest increases in both temperature and moisture near the surface over 4 hours, likely owing to strong southerly winds in close proximity to the Gulf. In addition, intensification of southwesterly mid-level winds increased low-level wind shear in the simulated environment. In contrast with the soundings discussed in the previous section, substantial cooling does not occur in the mid and upper levels.

The average time series of CAPE (Figure 8) shows a significant increase of 702 J/kg over 6 hours. CAPE generated by increases in lowest model level temperature accounted for about 147 J/kg of the total increase, while the increases in lowest level mixing ratio provided an increase of 618 J/kg. The simultaneous changes in lowest level temperature and moisture actually increase CAPE more than the original progression in the simulation; thus, changes in the near-surface thermodynamics were primarily responsible for the destabilization of the environment in this case.

4. SUMMARY AND IMPLICATIONS

Both simulations demonstrated that instability can increase very quickly regardless of time of day. This is an extremely important forecasting consideration; what may not look like a severe storm environment may destabilize and produce very intense convection just a few hours later, even during the night. The pre-convective environments in both simulated events did show at least a partial increase in surface-based CAPE as a result of temperature and moisture increases near the surface; however, the January 29-30 case showed additional destabilization likely attributable to the release of potential instability due to large scale forcing for ascent.

Simulations of several case studies are being performed, including null events, to determine which mechanisms predominate in destabilizing low CAPE environments on short time scales (< 6 hours), and how the environmental evolution of severe events differ from that of null/non-severe events.

It is evident that increases in near-surface temperature and moisture are important for destabilization in the cases presented. Future work includes investigating mechanisms by which these increases may occur, including analysis of surface and boundary layer fluxes, as well as advection near the surface. In addition, investigations of the effect of upstream convection on enhancing low level flow will be performed via analysis of the generation of diabatic potential vorticity (e.g., Davis 1992, Lackmann 2002). This could have a significant effect in intensifying flow in the lowest levels, increasing low level temperature and moisture and influencing destabilization (Stoelinga 1996; Mahoney and Lackmann 2007; Gold and Nielson-Gammon 2008).

Another important mechanism that occurs in simulated events such as the event discussed in Section 3.1 is the release of potential instability. Detailed analysis of this mechanism will also be performed as this type of instability can account for more than half of the simulated CAPE increases occurring over a relatively short amount of time prior to severe convection in some events.

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FIGURES

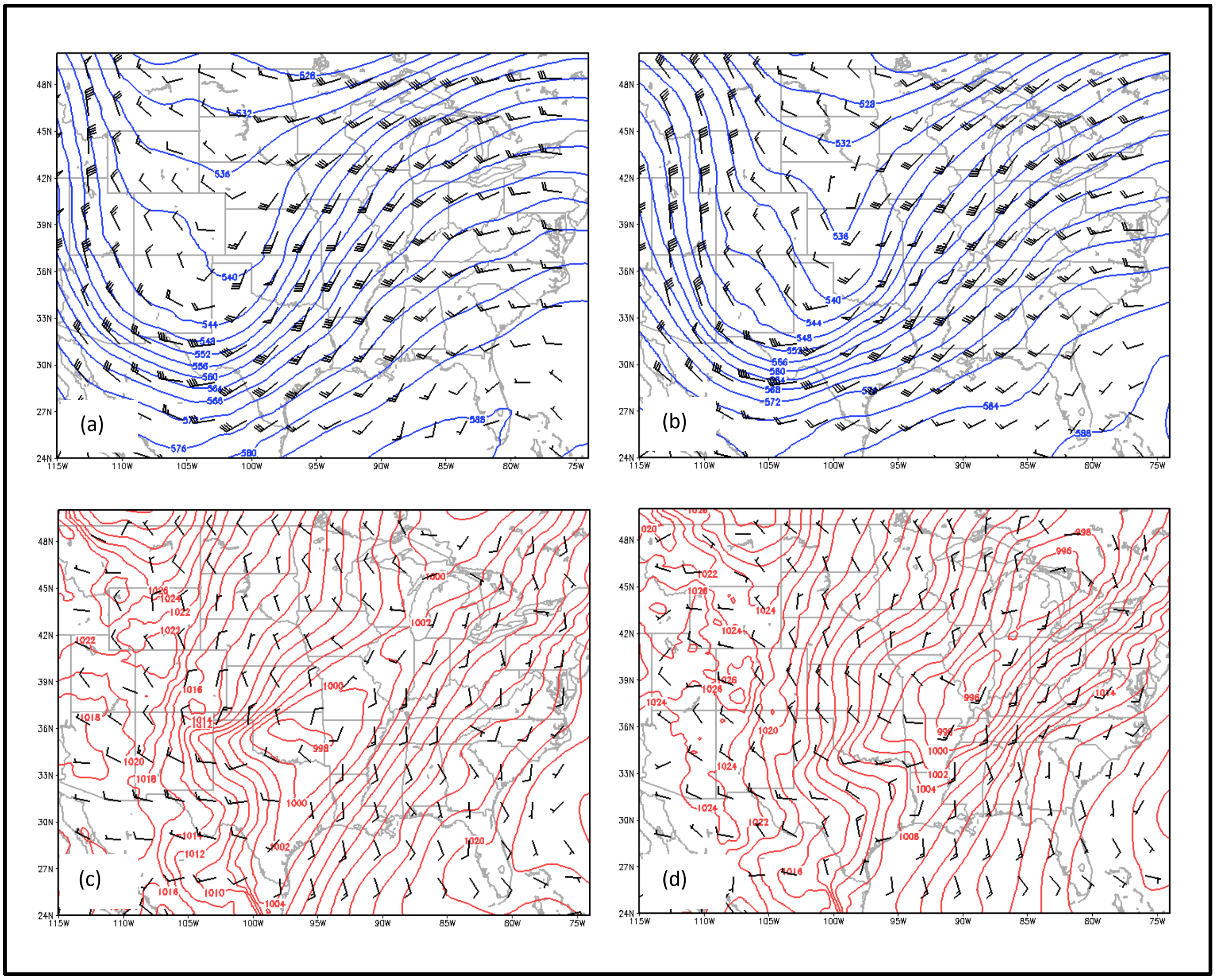

Figure 1: North American Regional Reanalysis (NARR) plots of: 500 mb heights and winds (a, b), and sea-level pressure and 10 m winds (c, d) for 00 UTC (a, c), and 06UTC (b, d) on January 30, 2013.

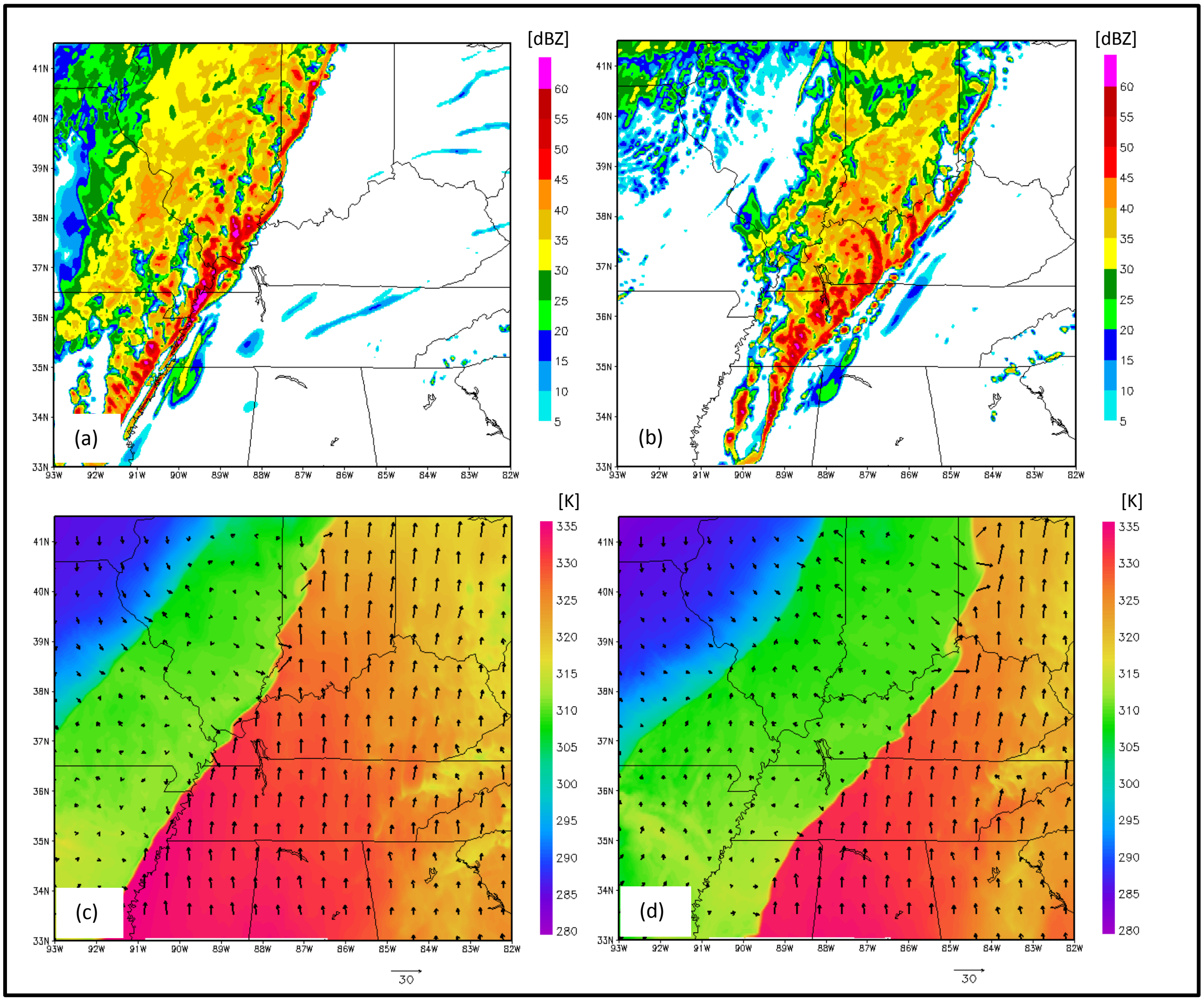

Figure 2: Simulated composite reflectivity (a, b) and lowest model level equivalent potential temperature and winds (c, d) at 06 UTC (a, c) and 10 UTC (b, d) on January 30, 2013.

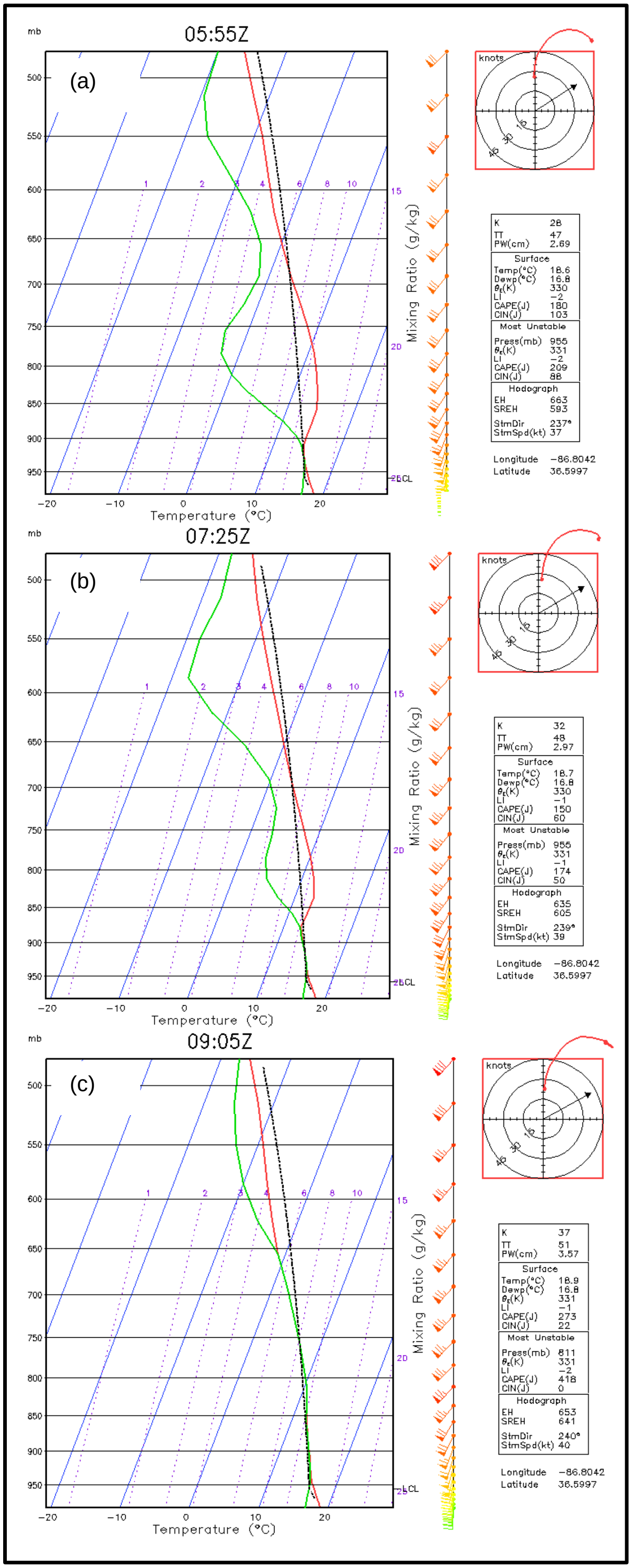

Figure 3: Example skew-t diagrams for (a) 5:55 UTC, (b) 7:25 UTC and (c) 9:05 UTC from the simulated pre-convective environment on January 30, 2013.

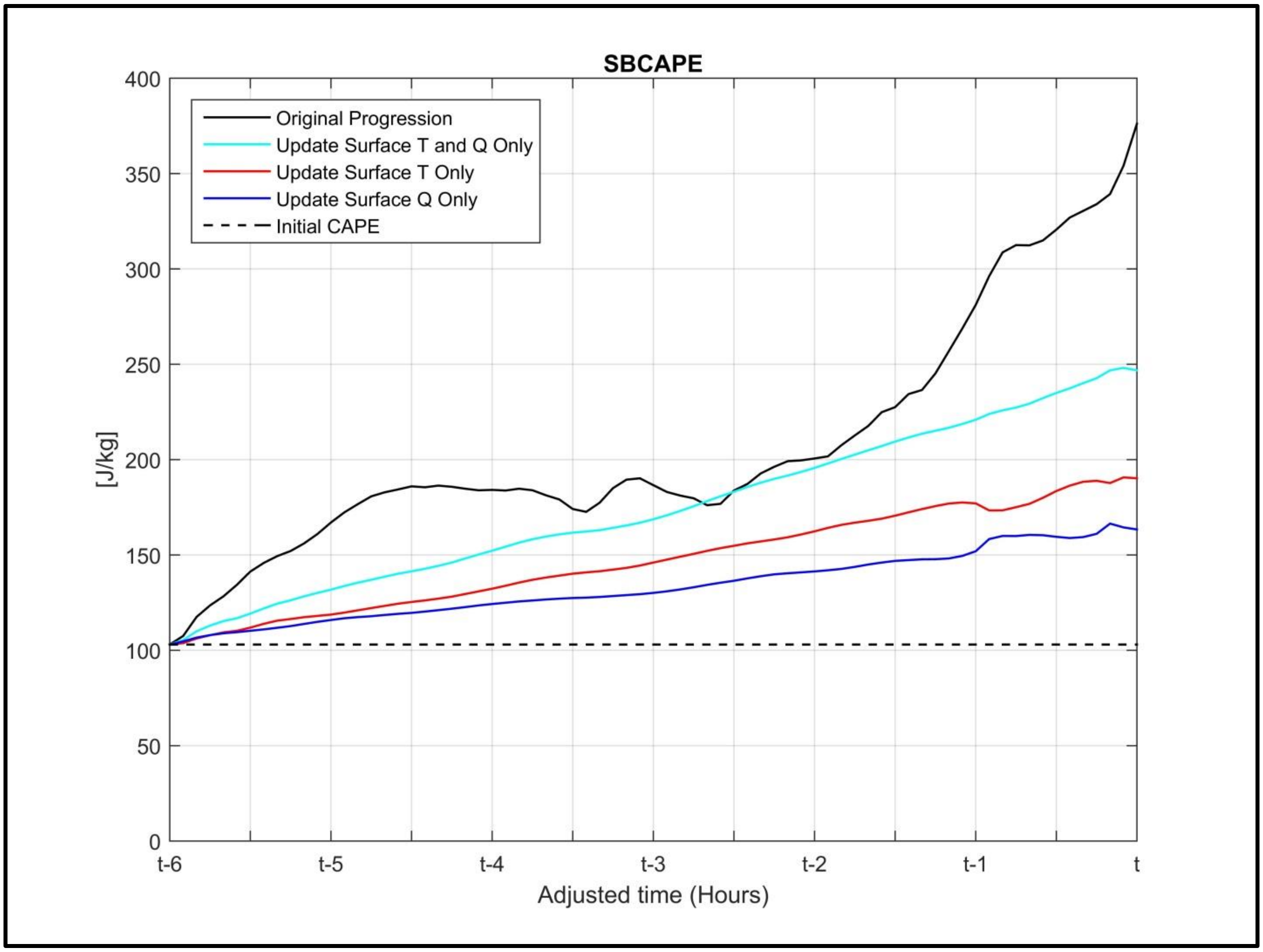

Figure 4: CAPE time series calculated as described in section 2.2, averaged for the January 29-30, 2013 simulation. Original Surface-based CAPE over 6 hours is plotted in black. Surface-based CAPE updating lowest model level temperature and mixing ratio simultaneously is plotted in cyan. Surface-based CAPE updating lowest model level temperature alone and lowest model level mixing ratio alone are plotted in red and blue, respectively. The average final time is (t) 7:25 UTC, or 1:25 AM local.

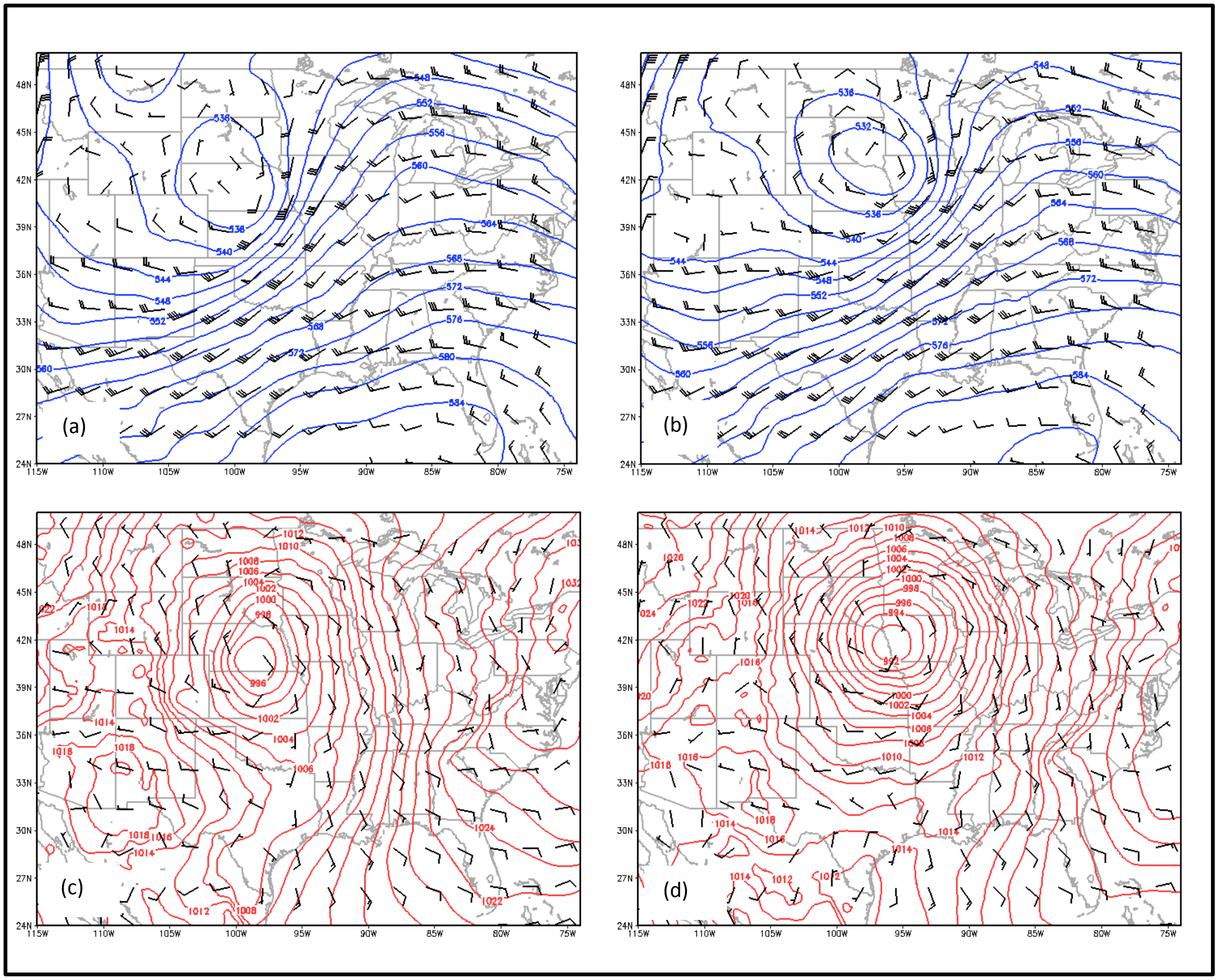

Figure 5: North American Regional Reanalysis (NARR) plots of: 500 mb heights and winds (a, b), and sea-level pressure and 10 m winds (c, d) for 12 UTC (a, c), and 18 UTC (b, d) on February 10, 2013.

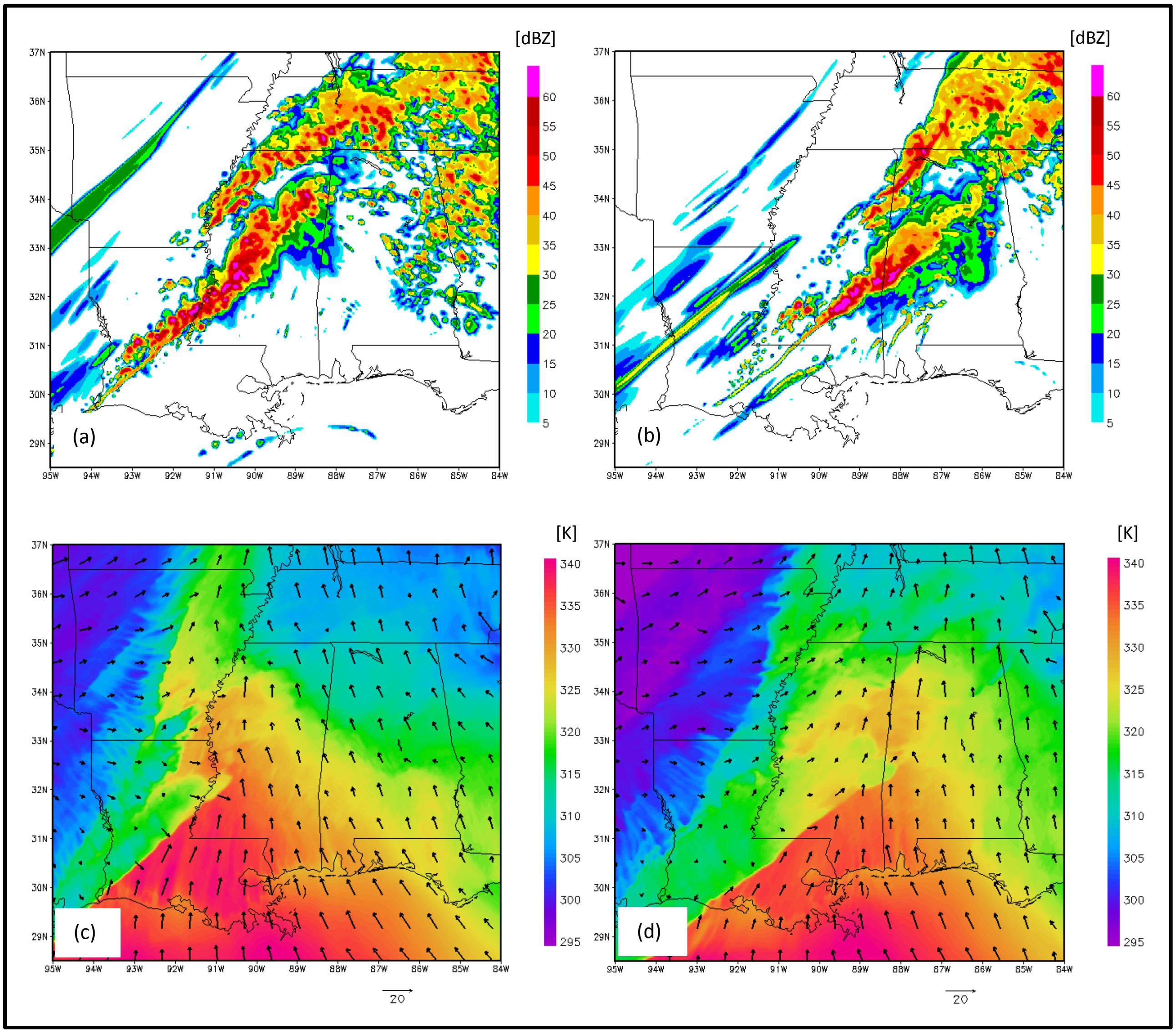

Figure 6: Simulated composite reflectivity (a, b) and lowest model level equivalent potential temperature and winds (c, d) at 22 UTC on February 10, 2013 (a, c), and 02 UTC on February 11, 2013 (b, d).

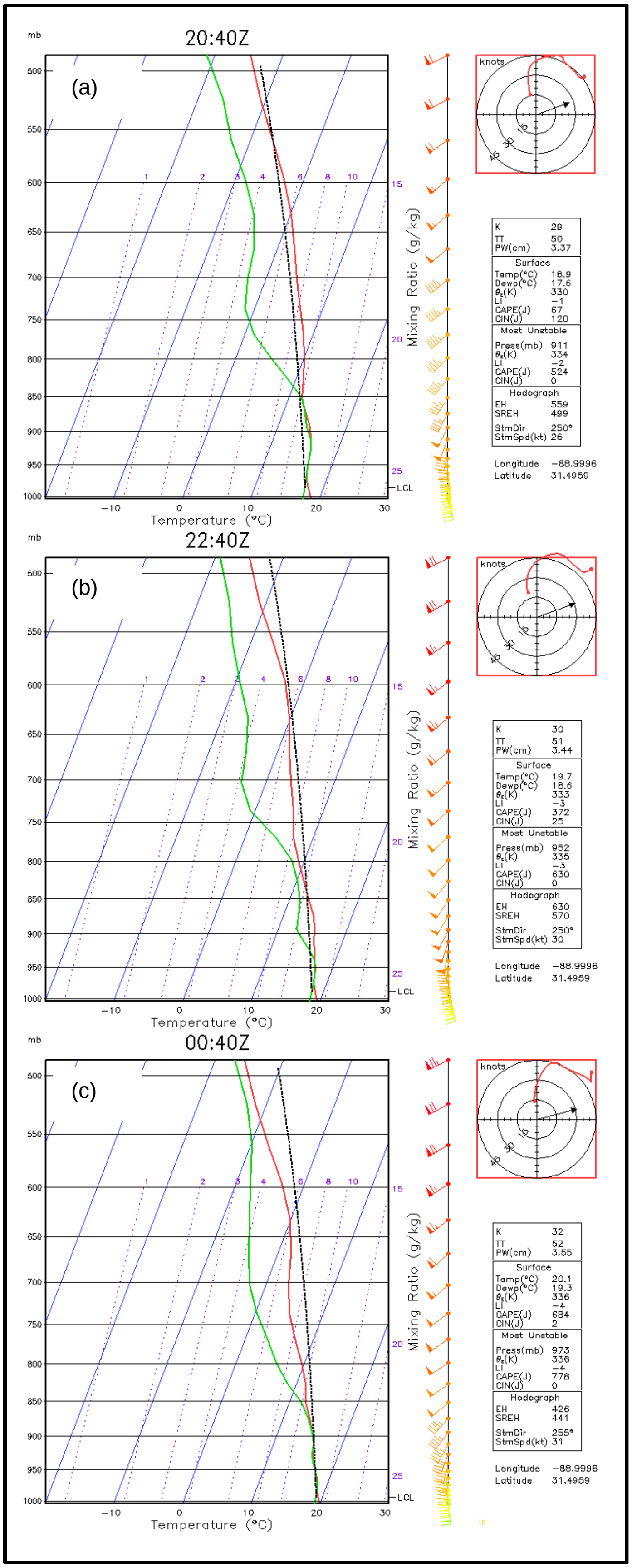

Figure 7: Example skew-t diagrams for (a) 20:40 UTC, (b) 22:40 UTC and (c) 00:40 UTC from the simulated pre-convective environment on February 10-11, 2013.

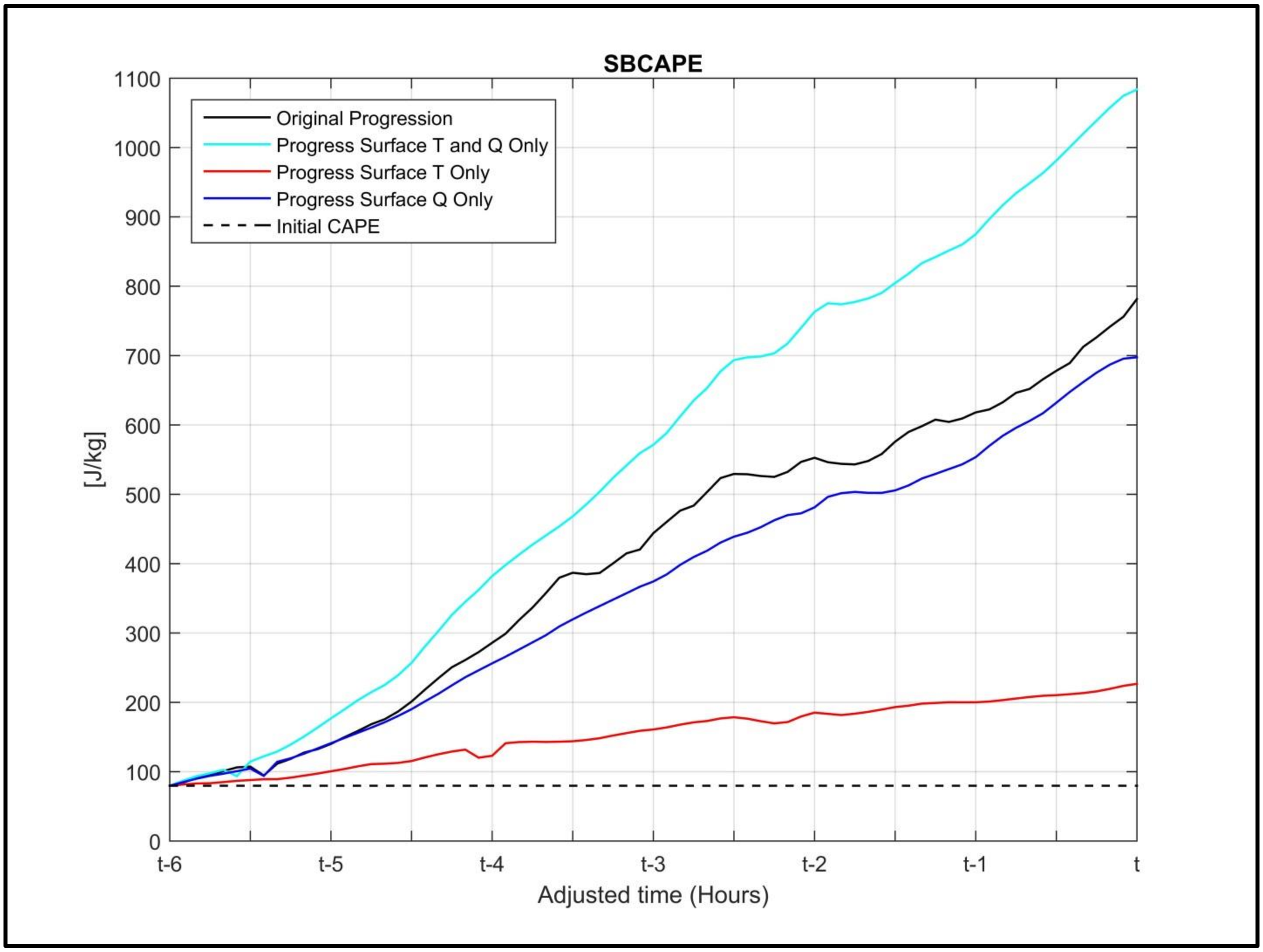

Figure 8: CAPE time series calculated as described in section 2.2, averaged for the February 10-11, 2013 simulation. Original Surface-based CAPE over 6 hours is plotted in black. Surface-based CAPE updating lowest model level temperature and mixing ratio simultaneously is plotted in cyan. Surface-based CAPE updating lowest model level temperature alone and lowest model level mixing ratio alone are plotted in red and blue, respectively. The average final time is (t) 00:10 UTC, or 7:10 PM local.