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THE ROLE OF DIRECT INSOLATION AND NEAR-SURFACE MOISTURE ADVECTION IN THE RECOVERY OF CAPE ON 31 MARCH 2016 DURING VORTEX-SOUTHEAST

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I. Introduction

Tornadoes in the southeast United States occur under different conditions than what is typically seen in the Great Plains. For instance, severe storms have been observed to form when measured Convective Available Potential Energy (CAPE) is less than 500 J kg^{-1}, as opposed to 1000 J kg^{-1} which is what is generally accepted as needed for tornadic storms to develop (Sherburn and Parker 2014). It has been hypothesized that the low CAPE values are from inaccurate analysis, or that the environment generates CAPE on small spatial scales, allowing for these storms to develop.

We look to understand what allowed the northern Alabama storms of 31 March 2016, which occurred in a low CAPE environment, to form. We hypothesize that direct insolation and near-surface moisture advection allowed for the rapid recovery of CAPE over northern Alabama which then allowed for severe storms to develop.

We used VORTEX-Southeast observations (Koch and Rasmussen 2016) to examine relative roles of direct insolation and near-surface moisture advection. VORTEX-Southeast was a field program to study tornadoes and tornado environments in the Southeast United States. The observations were centered on a domain around Huntsville, Alabama that encompassed roughly the northern third of Alabama. In between the morning storms (Fig. 1) and the evening tornadic storms (Fig. 2), CAPE over the VORTEX-Southeast domain increased by at least 500 J kg^{-1} (Table 1). The University of Massachusetts (UMass) S-Band frequency-modulated, continuous-wave (FMCW) radar (Ince et al. 2003) and the Collaborative Lower Atmospheric Mobile Profiling System (CLAMPS) (Geerts et al 2016), which were collocated at Belle Mina, Alabama were used to look at thermodynamic and precipitation-related variables in the atmosphere, including temperature and moisture. The Atmospheric Emitted Radiance Interferometer (AERI; Blumberg et al. 2015), the principal instrument of the CLAMPS, is an operational ground based spectrometer that measures the downwelling infrared (3–19 µm) radiance emitted by the atmosphere at a high temporal and spectral resolution (Blumberg et al 2015).

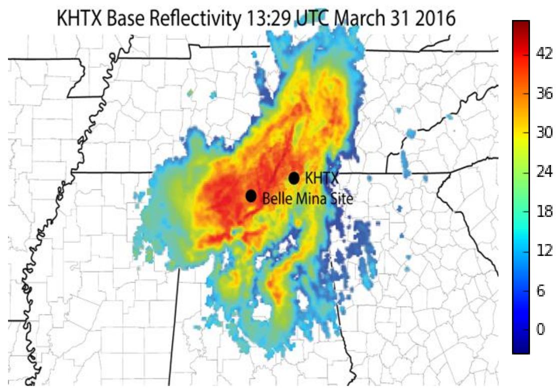


Fig. 1: 0.5° Reflectivity from KHTX at 13:29 UTC on 31 March 2016.

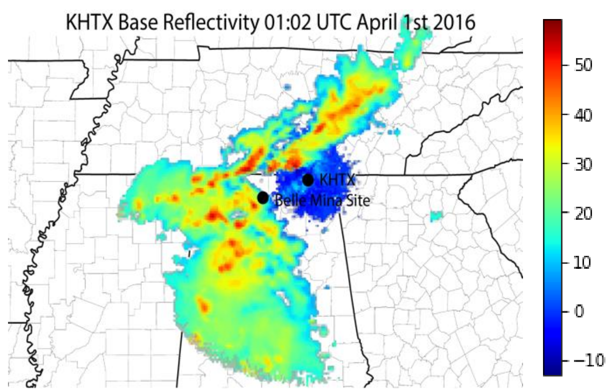


Fig. 2: 0.5° Reflectivity from KHTX at 01:02 UTC on 1 April 2016.

II. N. Alabama Environment

On 31 March 2016, the focus of the day was to study the rapid northward advection of warm, humid, near-surface air as a morning convective system departed, in hopes stronger convection would develop in the evening after the return of unstable air. What follows is a timeline of the days' events.

Storms moved through the VORTEX-SE domain early in the morning on 31 March. Fig. 3 depicts the rainfall as seen by the FMCW radar in Belle Mina, Alabama. This morning rain stabilized the air over northern Alabama, as seen by the stable boundary layer in figure 3b.

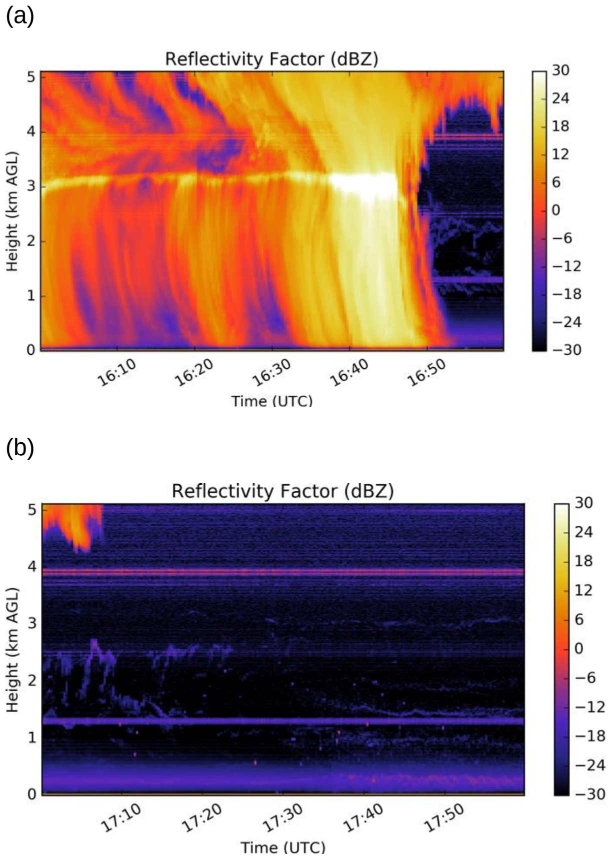


Fig. 3: Reflectivity factor (in dBZ) observed by the FMCW radar during the morning rain from (a) 1600-1659 UTC and (b) 1700 – 1759 UTC.

After the cessation of rainfall at around 1650 UTC (Fig. 3a), the mixed boundary layer immediately began to redevelop, reaching a depth of about 500m by 1740 UTC (Fig. 3b) and 1 km by 2000 UTC (not shown), as made evident in the refractive index turbulence detected by the FMCW.

At 1900 UTC, thunderstorms developed over north central Mississippi (not shown). These then moved rapidly to the northeast (Fig. 2), with some exhibiting weak shear. They then moved into air that was generally considered too cool to support low-level rotation. By 2100 UTC, the Storm Prediction Center (SPC) released a mesoscale discussion about these cells and their surrounding environment. All mesoscale discussions for that day can be found at http://www.spc.noaa.gov/cgi-bin-spc/getmd.pl. The morning convection had left a large-scale outflow boundary over northern Mississippi and central Alabama, an area which now exhibited strong speed shear in the mid- and upper levels and 0-to-1 km bulk shear around 200 $m^2 s^{-2}$.

At 2200 UTC storms with persistent low-level rotation had reached the Alabama-Tennessee border, despite surface conditions being fairly cool and stable. At 2300 UTC, the SPC issued a tornado watch over northern Alabama and south-central Tennessee, citing supercells capable of hail, locally damaging winds, and tornadoes were expected to develop and move east to east-northeast across the area overnight. The SPC released two more mesoscale discussions over the next hour, at 2352 UTC on 31 March 2016 and 0041 UTC on 1 April 2016, respectively, mentioning developing discrete cells on the Alabama-Tennessee border. The cells had developed into a mix of discrete supercells and clusters. This setup appeared to be supporting a longer tornado risk across northern Alabama. The surrounding environment was characterized by backing and strengthening winds above 1 km MSL, 0-1 km storm relative helicity (SRH) of 250 $m^2 s^{-2}$-300 $m^2 s^{-2}$, 18 to 21 °C surface dewpoints everywhere but northern Alabama, and mixed layer CAPE (MLCAPE) of 1000 J kg^{-1}. Low-level warm air advection (WAA) was also present closer to the Alabama-Georgia border.

Over the next few hours, the northern Alabama storms (Fig. 2) continued to show low-level rotation. They moved over the VORTEX-SE domain, generating a tornado near Priceville, Alabama at 0300 UTC. The tornado touched down just northeast of Hartselle, Alabama and moved northeast dissipating just northeast of Priceville, Alabama. The tornado was rated an EF-2 with max winds of 69 m s^{-1}. Its track was 13.7 km long, and 182 m wide.

VORTEX-Southeast stopped collecting data at 0300 UTC, because the storms had moved away from the Huntsville domain. However, convective storm activity continued in central and eastern Alabama late into the morning of 1 April.

III. CAPE Development

Following the morning rain on 31 March, CAPE values grew to over 1200 J kg^{-1}, as evidenced by hourly radiosonde soundings (Lee et al. 2016b) taken at Belle Mina, Alabama (where UMass FMCW and CLAMPS were collocated). Some of these soundings, launched from 2000 on 31 March 2016 to 0200 UTC on 1 April 2016, are shown in Table 1. The parameters shown in Table 1 were calculated using SHARPpy (Blumberg et al. 2017).

Table 1: Surface-based, mixed layer, and most unstable CAPE and CIN values from three soundings.

Time	20 UTC	21 UTC	22 UTC
SBCAPE (J kg^{-1})	119	1282	558
SBCIN (J kg^{-1})	-102	0	-16
MLCAPE (J kg^{-1})	61	149	367
MLCIN (J kg^{-1})	-120	-62	-37
MUCAPE (J kg^{-1})	592	1282	668
MUCIN (J kg^{-1})	-1	0	-10

The greatest CAPE increase occurred between 2000 UTC and 2100 UTC on 31 March 2016 (Table 1). During that particular hour, solar insolation increased over the Belle Mina site (Fig. 4), resulting in more surface heating over the area. This insolation increase corresponded with a slight increase in surface temperatures, shown in Fig. 5 UMass FMCW reflectivity observations (Fig. 6) show that the boundary layer deepened and became more convectively active during this period. A program using an extended Kalman filter was used to identify the boundary layer heights over this time period. Boundary layer heights reached 600 m by ~2130 UTC.

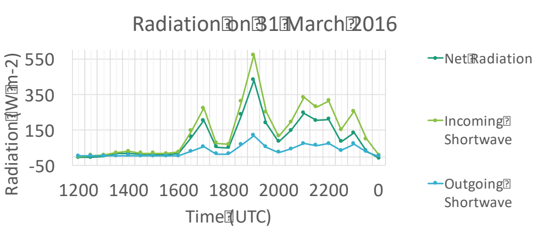


Fig. 4: Radiation data from a 2.5 m AGL meteorological tower at Belle Mina, Alabama. Data from Lee et al. (2016a).

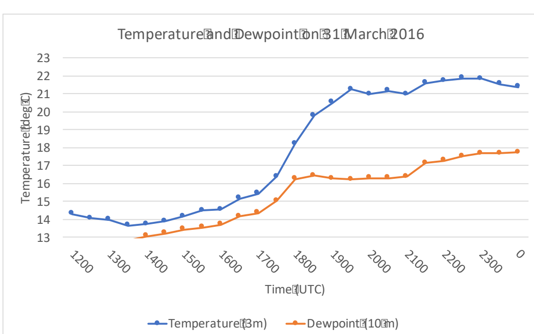


Fig. 5: Temperature data from 3 m AGL meteorological tower at Belle Mina, Alabama. Data from Lee et al. (2016a).

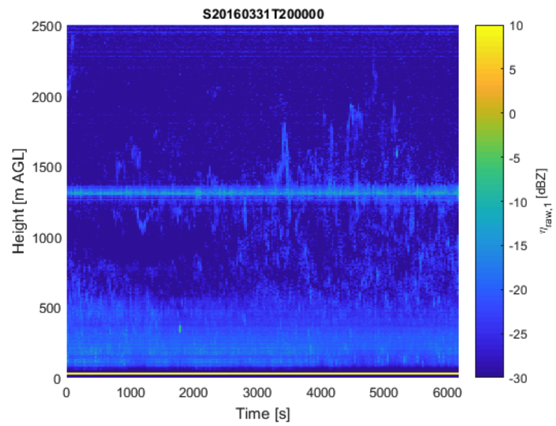
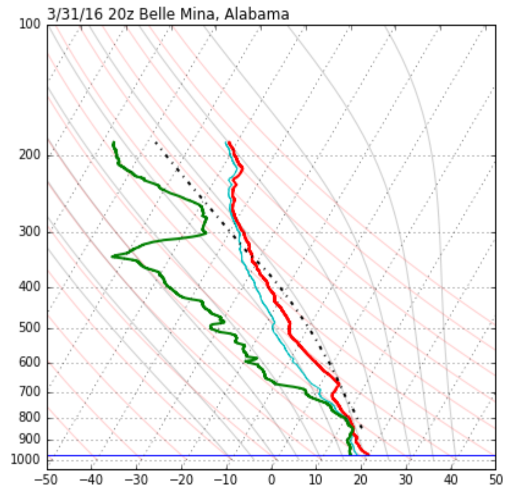


Fig. 6: FMCW reflectivity from 2000 UTC to 2100 UTC on 31 Mar 2016.

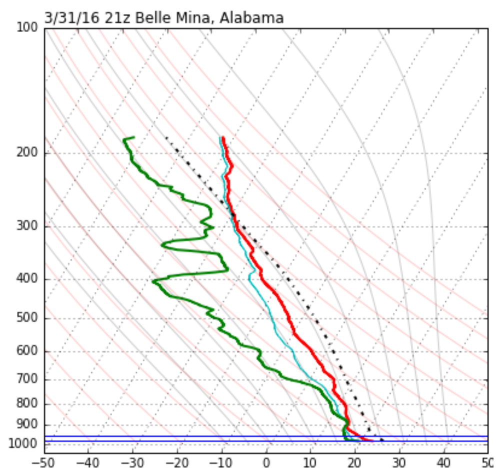
All of these data were used together to estimate the amount CAPE we would expect to see from the increased solar insolation versus moisture advection. There was a rapid increase in surface temperature between 1700 and 1900 UTC (Fig. 5) which corresponds with an increase in solar insolation (Fig. 4). We assumed that solar insolation was the only factor contributing to the change in temperature, while moisture advection was the only factor contributing to the change in the dewpoint profile. We modified the 2000 UTC soundings by replacing either the temperature or dewpoint profile with that from the 2100 UTC sounding, then recalculated CAPE in order to estimate the changes in CAPE values due to insolation and moisture advection, respectively. Using this technique, we found that solar insolation should have increased CAPE values by approximately 1822 J kg^{-1} and moisture advection by approximately 141 J kg^{-1}.

To examine moisture advection more closely, we used the Advanced Regional Prediction System (ARPS, Xue et al. 2000) model to simulate the weather conditions of the day from 12 UTC on 31 March 2016 to 0300 UTC on 1 April 2016. These simulations were run with 6 km horizontal grid spacing, and initial conditions nested inside the 12z NAM. These simulations had southerly winds and increasing equivalent potential temperature over northern Alabama over the course of the afternoon. The simulations also captured the rainfall from the morning event, and convective initiation later in the afternoon. From the simulations, we found low level moisture at the Belle Mina site did increase during this time, However, at altitudes at and above 500 m, there were layers of drying, or little to no moisture advection. These qualities are evident in the soundings (Fig. 7a-c) and the plot of the moisture advection (Fig. 8) calculated from simulations of the day's weather.

(a)



(b)



(c)

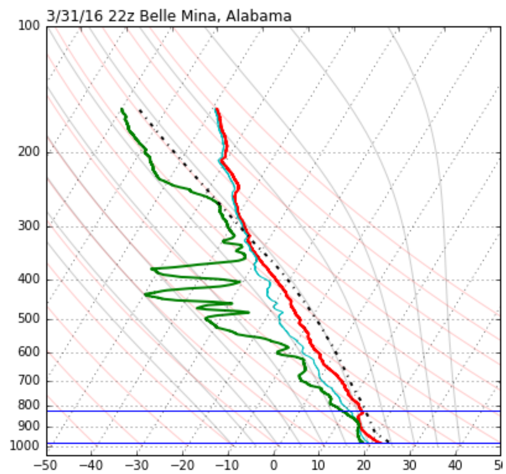


Fig. 7: Skew-T log-p plots of the radiosonde soundings from (a) 2000, (b) 2100, and (c) 2200 UTC at Belle Mina, Alabama.

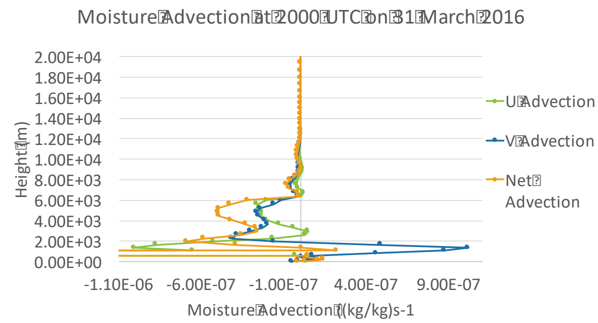


Fig. 8: Plot of the moisture advection around the FMCW area calculated from ARPS simulations.

IV. Results and Conclusions

Both solar insolation and moisture advection likely played a role in increasing CAPE in Belle Mina, Alabama on 31 March 2016, with solar radiation playing by far the largest role of the two (by a factor of 10 or more).

Calculated CAPE increase (1822 J kg^{-1} and 141 J kg^{-1} from solar radiation and moisture advection, respectively) suggest that CAPE should have increased more than the observed 1163 J kg^{-1}, which leads to the conclusion that some other mechanism was present that modulated CAPE values. This mechanism may be radiational cooling of the column, as that is one of the terms in the time tendency of CAPE equation that can reduce CAPE values (Emanuel 1994). In the future, we will investigate what possibly modulated CAPE values during the afternoon. We will also continue to examine the evolution of CAPE values in more detail using the CLAMPS data, and work with the simulation data to refine our estimates of moisture advection. Additionally, we will examine the boundary layer growth in more detail using an extended Kalman filter technique (Lange et al. 2015) to objectively identify the top of the boundary layer.

Acknowledgments

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