INVESTIGATING THE VERTICAL STRUCTURE OF UPDRAFT HELICITY IN CONVECTION-ALLOWING MODELS

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I. INTRODUCTION

Updraft helicity (UH) is commonly used as a forecast parameter to identify rotating updrafts (Kain, et al., 2008). It is defined as:

$$UH = \int_{z1}^{z2} w\,\zeta\,dz$$

where z1 and z2 are the layer over which UH is calculated, w is vertical velocity and ζ is the vertical component of vorticity. UH essentially reduces a three-dimensional wind field into one number. This makes UH more useful for forecasters, but at the cost of potentially losing information contained in the three-dimensional wind field. Within numerical models, UH is calculated as:

$$UH \approx \sum_{z=2000m}^{z=5000m} \overline{w\zeta\Delta z}$$

The 2-5km above-ground layer was chosen "since the primary interest is on storm rotation in the lower to middle troposphere" (Kain, et al., 2008). When used as a surrogate for severe weather reports within a convection-allowing model (CAM), 2-5km UH shows utility in forecasting severe weather (Sobash, et al., 2011). The 2-5km UH forecasts from an ensemble have shown to be useful in forecasting tornado path lengths (Clark, et al., 2013). Filtering 2-5km UH with forecast environmental parameters has also demonstrated skill in forecasting tornadoes (Gallo, Clark, & Dembek, 2016).

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Low level UH (0-3km) has also been used as a proxy for low-level rotation in an attempt to help forecast tornadoes (Sobash, Romine, Schwartz, Gagne, & Weisman, 2016). When used in an ensemble, the 0-3km UH was more skillful than the 2-5km UH fore forecasting tornadoes.

There has been little, if any, research into the vertical structure of wζ. This paper will examine the vertical structure of wζ for two days on which tornadoes occurred.

II. DATA AND METHODS

To analyze the vertical structure of updraft helicity, WRF was run (configuration summarized in Table 1, as in the NSSL-WRF) for 15 February 2016 and 11 May 2014 with three-dimensional winds (u, v, and w) output every five minutes. The February case was chosen to represent a southeast cool-season event with high wind shear and low instability. The May case was chosen to represent a Great Plains springtime event with high shear and high instability. Each day had more than 30 tornado reports.

Table 1 WRF configuration

Model Version	WRFV3.4.1
Resolution	3km
Vertical levels	35
Time step	24s
Boundary Layer	MYJ
Microphysics	WSM6
Longwave	RRTM
Shortwave	Dudhia
LSM	Noah

For each hour in which there were model UH tracks, the locations of the ten highest grid-point

values of hourly maximum UH were identified. For each of these locations, a time-height cross section of wζ was created to identify the time at which the maximum UH occurred. Locations within the top 10 that occurred near each other in both space and time were then grouped and a time-normalized composite cross section was created. The composite cross sections were centered on the time of maximum UH for each location. The values were averaged for each time and for each height. To determine significance, bootstrap resampling was done at each time and for each height. Areas that had positive (negative) wζ at the 95% level are outlined in solid (dashed) lines. The resulting composite cross-section is Eulerian in nature. That is, the cross-section represents the vertical structure of wζ at a fixed point through time.

III. RESULTS

i. 15 February 2016 Case

The 15 February 2016 case had 39 tornado reports in the southeastern US, mostly resulting from linear storms (Figure 1). The environment was characterized by high shear and low instability, with both effective bulk wind shear and 0-6km wind shear above 50kts and CAPE near 1000J/kg, based on the Storm Prediction Center's mesoanalysis (not shown).
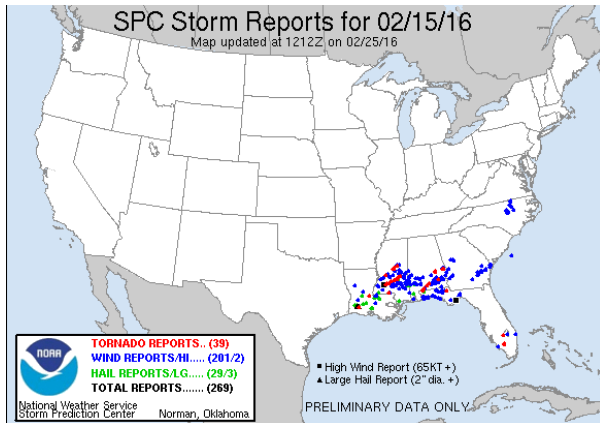

Figure 1 Storm reports for 15 February 2016

At 18 UTC, there were two areas of UH in the top 10 (Figure 2). The northwestern clustering (containing six of the top ten UH values) occurred between 1705 and 1710 UTC while the southeastern clustering (containing three of the other four) occurred between 1750 and 1755 UTC. Since the two clusters were separate in both space and time, separate composites were made for each.
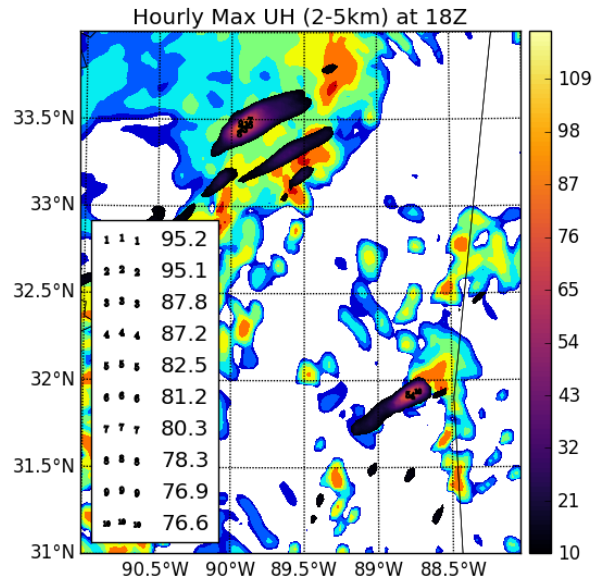

Figure 2 Hourly maximum UH for the hour ending at 18UTC with 1km AGL reflectivity at 18UTC.

The composite for the northwestern cluster is shown in Figure 3. A large area of positive wζ can be seen extending from 2km to 8km, but the deep positive area is most prevalent within five minutes of the maximum. A shallower area of positive wζ can be seen in the lowest 6km for the 15 minutes

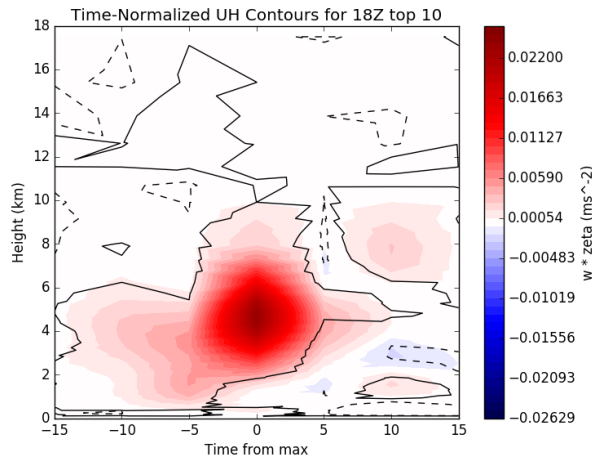before the maximum. After the time of the maximum, there is very little positive wζ.

Figure 3 Time-normalized composite cross section of wζ for the northwestern cluster of UH in the hour ending at 18UTC 15 February 2016. Solid lines outline areas of significantly positive wζ, and dashed areas outline areas of significantly negative wζ.

The composite cross-section for the southeastern clustering in the hour ending at 18UTC has a different structure from the northwestern clustering (Figure 4). At the time of maximum, there is a positive area of wζ between 2.5km and 7km, but it is above a 2km deep layer of negative wζ. The positive area appears to descend from aloft (8km) as the model simulated storm approaches.
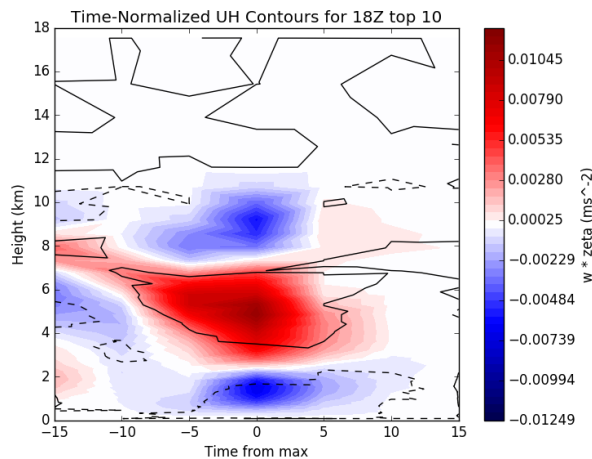

Figure 4 As Figure 3, but for the southeastern clustering.

For the hour ending at 19 UTC (Figure 5), nine of the ten highest values of UH occurred between

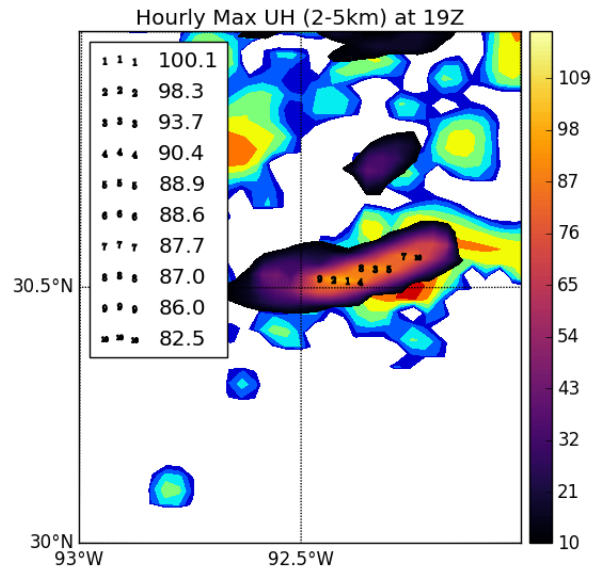1835 and 1855 UTC within close proximity to one another.

Figure 5 As Figure 2, but for 19UTC

The composite cross section for 19 UTC (Fig. 6) shows a shallow, weak area of positive wζ between 1km and 4km, with another, stronger positive area aloft between 8km and 12km. Between the two areas of positive wζ there is a weak area of negative wζ at 6km. The lower area of positive wζ is present for the 15 minutes before the maximum and for 10 minutes after the maximum, but the area appears less coherent after the maximum. The upper area of positive wζ is first seen 10 minutes before the maximum, and it dissipates within 5 minutes of the maximum occurring. The negative area in the middle appears 5 minutes

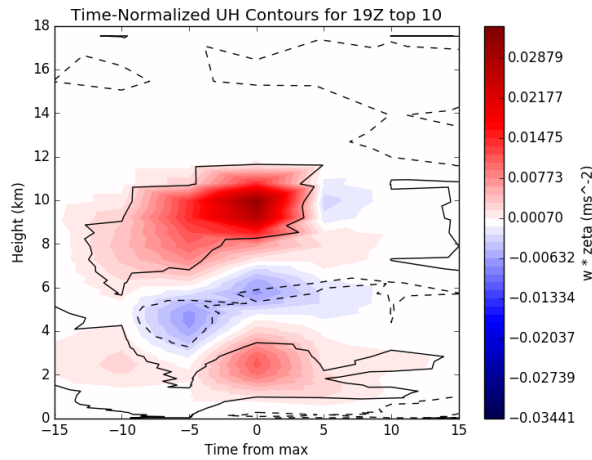before the maximum and persists weakly for 15 minutes after the maximum.

Figure 6 As Figure 3, but for 19UTC on 15 February 2016.

For the hour ending at 20UTC, only four of the top ten were clustered in space and time, with the time of maximum wζ between 1900 and 1910UTC (Figure 7).
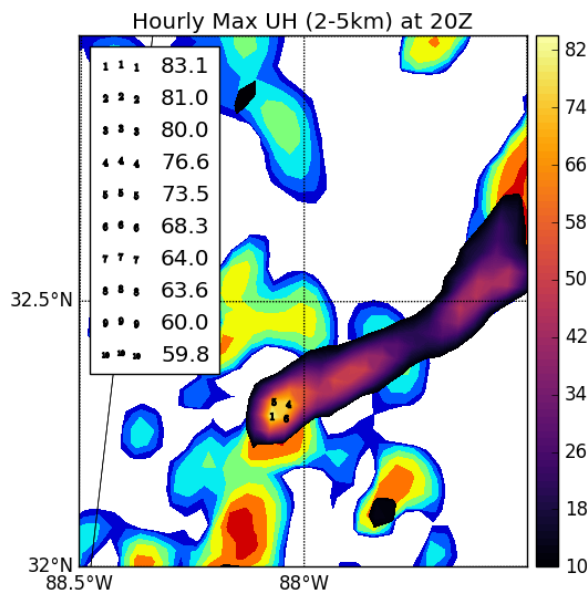

Figure 7 As Figure 2, but 20UTC on 15 February 2016.

The composite cross-section for the hour ending at 20UTC has significance issues due to the smaller sample size (Figure 8). There is a significant area of positive wζ extending from the surface to 2km. This area first appears five minutes before the time

of maximum and dissipates within five minutes. Between 2km and 4km, there is another area of significantly positive wζ that appears five minutes after the time of maximum and persists until at least fifteen minutes after the time of maximum.
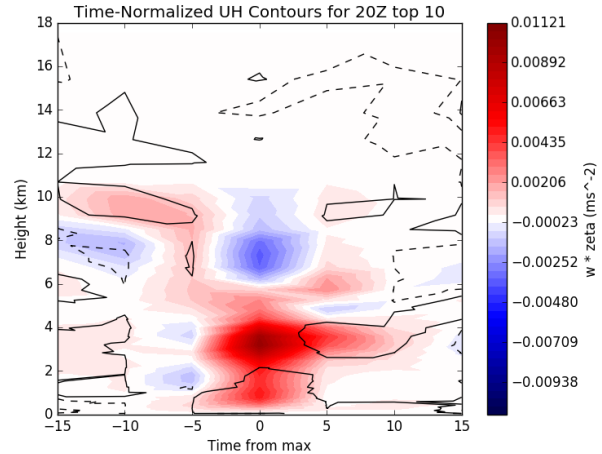

Figure 8 As Figure 3, but for 20UTC

ii. 11 May 2014 Case

The 11 May 2014 case had 46 tornado reports in the Great Plains, mostly resulting from discrete supercells (Figure 9). This was a high instability, high shear event. Effective wind shear and 0-6km wind shear was above 50kts, and surface-based CAPE was above 3000J/kg, based on Storm Prediction Center's mesoanalysis (not shown).
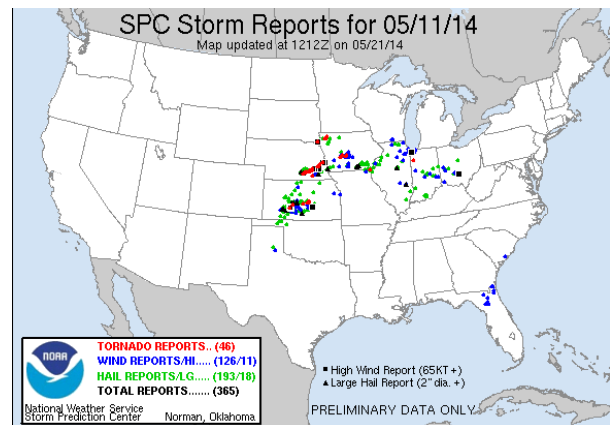

Figure 9 As Figure 1, but for 11 May 2014

For this event, the only forecast hours with significant UH tracks were 22UTC and 00UTC (each hour covering the preceding hour). For the hour

ending at 22UTC, eight of the ten highest values of UH for the hour occurred between 2125 and 2145UTC. These eight all occurred within a swath, as seen on Figure 10.
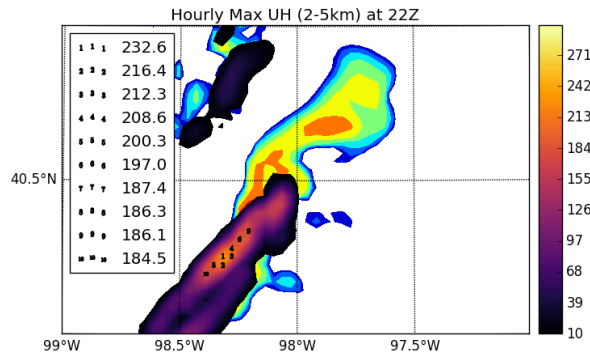

Figure 10 As Figure 2, but for 22UTC on 11 May 2014.

The composite cross-section for the hour ending at 22UTC has an area of significantly positive wζ at the time of maximum between 1km and 6km (Figure 11). This area exists below 2km for 10 minutes before the maximum, but it dissipates after the maximum. There is a large area of strong significantly negative wζ between 8km and 16km at the time of maximum. This area exists aloft for 15 minutes before the maximum but dissipates after the maximum.
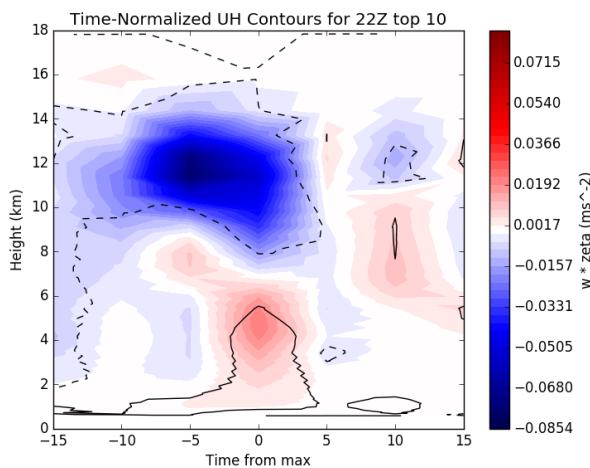

Figure 11 As Figure 3, but for 22UTC on 11 May 2014.

For the hour ending at 00UTC on 12 May 2014, all of the ten highest values of UH occurred between 2305 and 2325UTC within close proximity to each
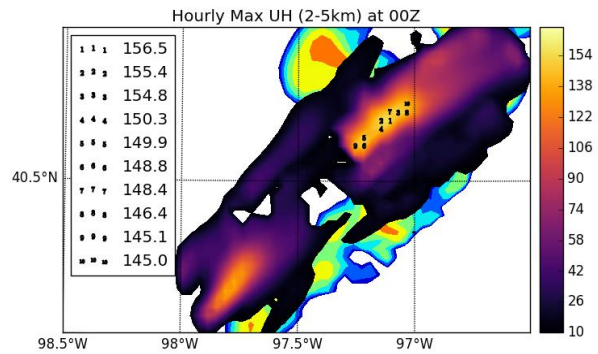
other (Figure 12).

Figure 12 As Figure 2, but for the hour ending at 00UTC on 12 May 2014.

The composite cross-section for the hour ending at 00Z has a very deep (0km-11km) layer of significantly positive wζ (Figure 13). This area only appears five minutes before the time of maximum but persists below 6km for 15 minutes after the time of maximum. There are no notable areas of significantly negative wζ, though the (non-significant) negative area aloft is seen, both significantly and non-significantly, in other composite cross sections.
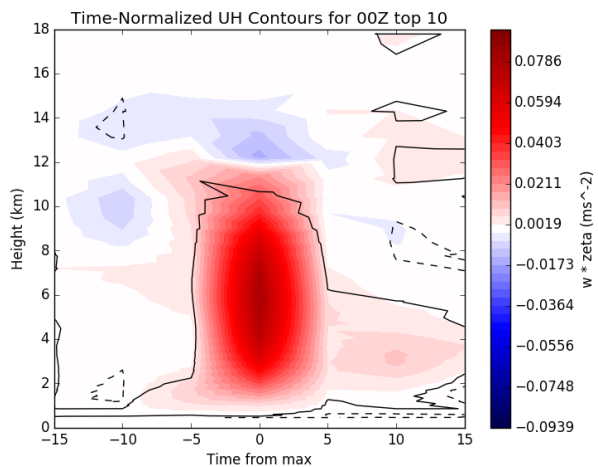

Figure 13 As Figure 3, but for the hour ending at 00UTC on 12 May 2014.

IV. CONCLUSIONS

From the composite cross-sections, it can be seen that wζ extends vertically beyond the usual 2km-5km layer used to calculate updraft helicity. There also exists considerable variations in the vertical

structure of wζ. Some cross-sections showed large areas of positive wζ, while others had more varied structures, with areas of both positive and negative wζ. These variations in structure may provide additional information that could aid in forecasting.

Work is ongoing to develop a method of tracking UH maxima to enable Lagrangian cross-sections. Further work will explore sensitivity to both horizontal and vertical resolution, which will be especially important as forecast models move to higher resolutions. The eventual goal of this work is to develop an effective layer UH calculation that would estimate organized updraft rotation regardless of the vertical structure of wζ.

V. REFERENCES

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