Multiple Doppler Radar Analysis of External Environmental and Topographical Influences on a QLCS Tornado Event

Anthony W. Lyza, Todd A. Murphy, Ryan A. Wade, Timothy A. Coleman, Kevin R. Knupp

Severe Weather Institute-Radar and Lightning Laboratories (SWIRLL)

University of Alabama in Huntsville, Huntsville, AL

Overview

- Two EF1-rated tornadoes formed from a QLCS across Redstone Arsenal and the south side of Huntsville, AL, along with additional tornadoes and wind damage in northern and northwestern Alabama
- ***The paths of the two tornadoes were bisected by Huntsville Mountain, an approximately 280-m rise above the surrounding terrain***
- Tornadogenesis of EF1 "Lily Flagg Rd." tornado occurred at approximately 2120 UTC
- First tornado was associated with typical peak in pre-genesis convergence, followed by significant rise in rotational velocity/axisymmetric vertical vorticity during/after tornadogenesis
- The Advanced Radar for Meteorological and Observational Research (ARMOR) indicated a tornado debris signature (TDS; Ryzhkov et al. 2005, Schultz et al. 2012) from 2120-2128 UTC
- Second tornado ("Dug Hill Rd." tornado) formed at 2132 UTC at the eastern foot of Huntsville Mountain
- Even though the second tornado produced slightly more intense damage, the circulation appeared much weaker in ARMOR data, with no TDS
- To the north of the tornadoes, an intriguing gust front structure was observed, with notable pressure drop associated with temperature drop, likely caused by effects of old, decaying bookend vortex
- Gust front passage at University of Alabama in Huntsville (UAH) occurred at approx. 2114 UTC
- Initial passage of gust front marked by wind shift, temperature drop, and pressure ***drop***
- Pressure dropped a total of 1.25 hPa between 21:14:40 UTC and 21:22:00 UTC
- A decaying bookend vortex approached UAH around 2122-2125 UTC
- Pressure rose from 978.02 hPa to 981.27 hPa (3.25 hPa rise) between 21:22:40 UTC and 21:27:00 UTC
- Initial density current depth of ~0.8 km observed with X-band, vertically-pointed radar
- Similar temperature and pressure progression was recorded at Madison COOP site
- ***Both unique internal (bookend vortex) and external (terrain) influences played significant role in evolution and properties of the QLCS and associated tornadoes in/near Huntsville***

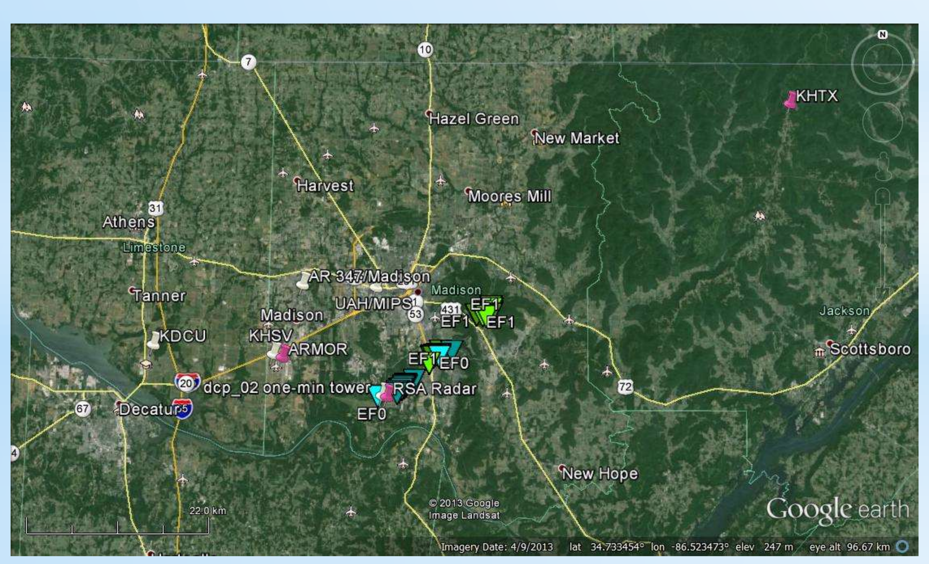

Fig. 1: Overview map for 11 April 2013, containing the locations of the Huntsville (KHSV) and Decatur (KDCU) ASOS sites, the WSR-88D radar at Hytop, AL (KHTX), the Advanced Radar for Meteorological and Observations research (ARMOR), the Redstone Arsenal S-band Doppler radar (RSA Radar), and the location of the UAH surface station and Mobile Integrated Profiling System (UAH/MIPS). National Weather Service Huntsville survey points for the 11 April 2013 tornadoes are indicated by the blue and green triangles. Image produced on Google Earth.

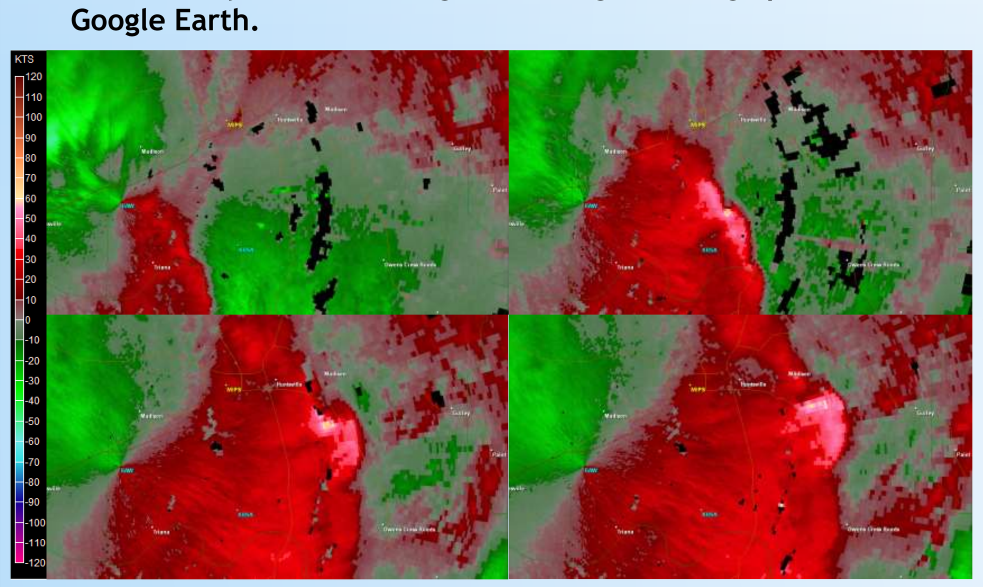

Fig. 2: Four-panel overview of base velocity from ARMOR at 2116 UTC (top-left), 2123 UTC (top-right), 2131 UTC (bottom-left), and 2134 UTC (bottom-right) on 11 April 2013.

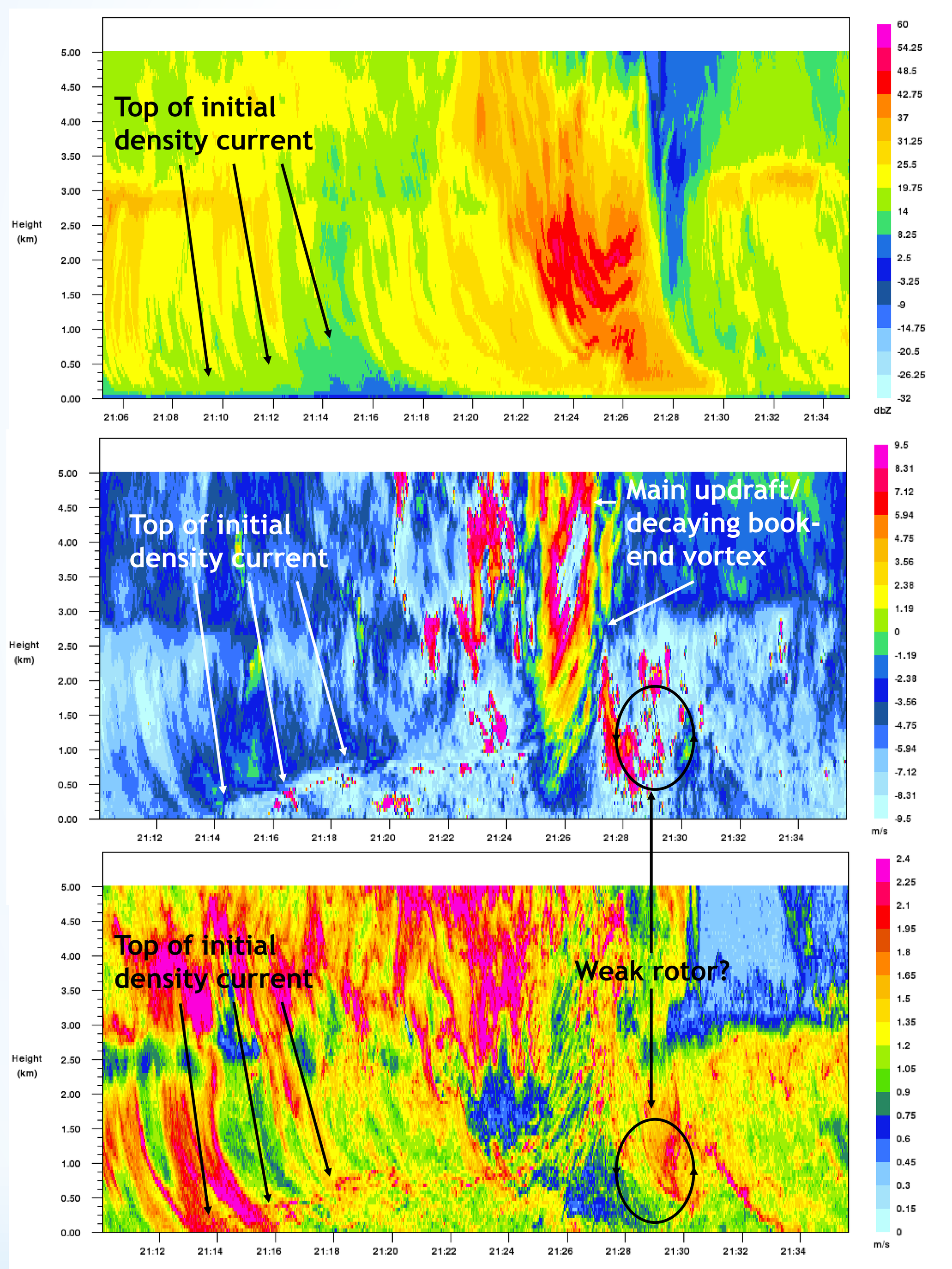

Fig. 3: Uncorrected reflectivity (Z), particle vertical velocity (W), and spectrum width time-height cross-sections from the X-band, vertically-pointed radar (XPR) for 0-5 km depth, 2110-2135 UTC 11 April 2013. Nyquist velocity is 9.5 m s^{-1}.

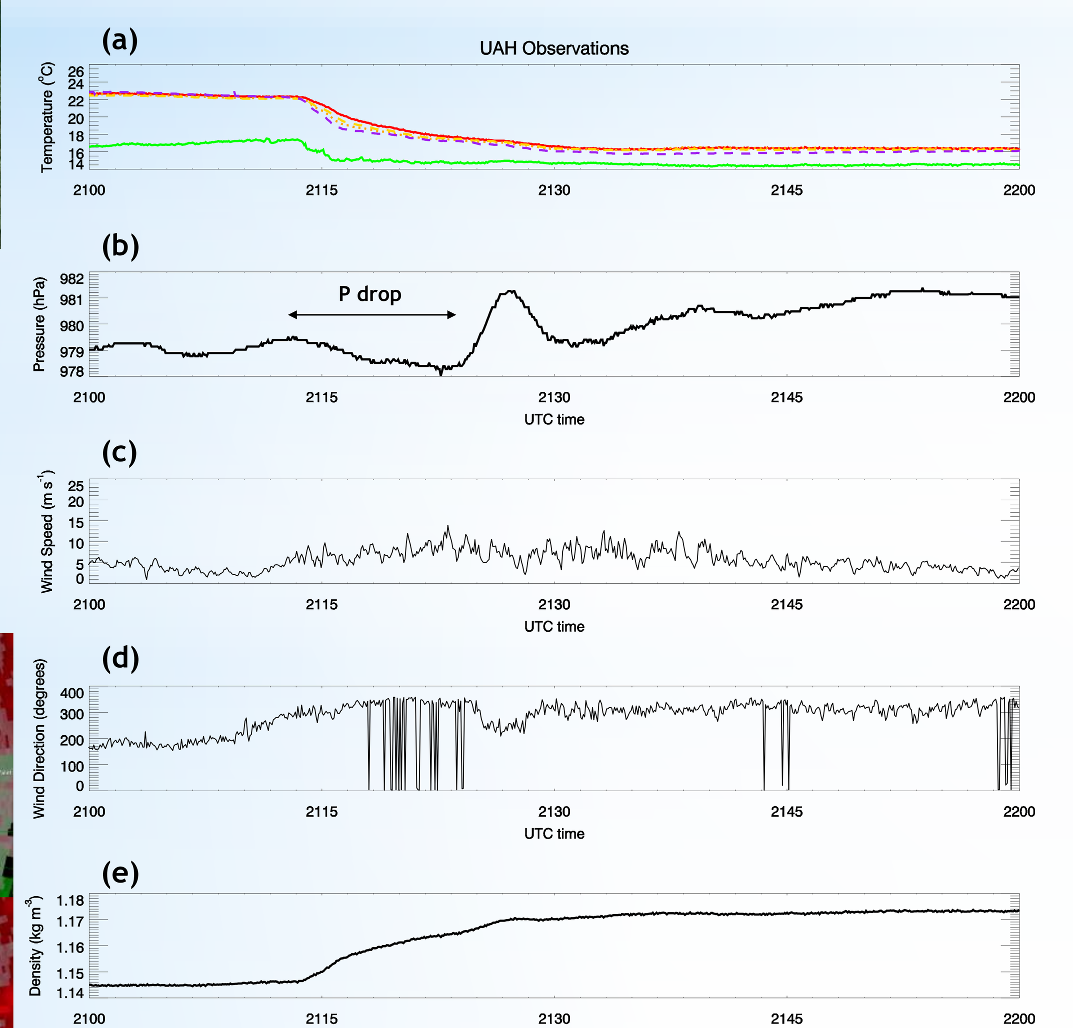

Fig. 4: 5-sec. resolution data from UAH observation site of a) 0.5-m (gold), 1.0-m (orange), 2-m (red), and 10-m (purple) temperatures (°C) with 2-m dewpoint (°C; green); b) 2-m pressure (hPa), c) 10-m wind speed (m s^{-1}), d) 10-m wind direction (degrees), and e) 2-m density (kg m^{-3}).

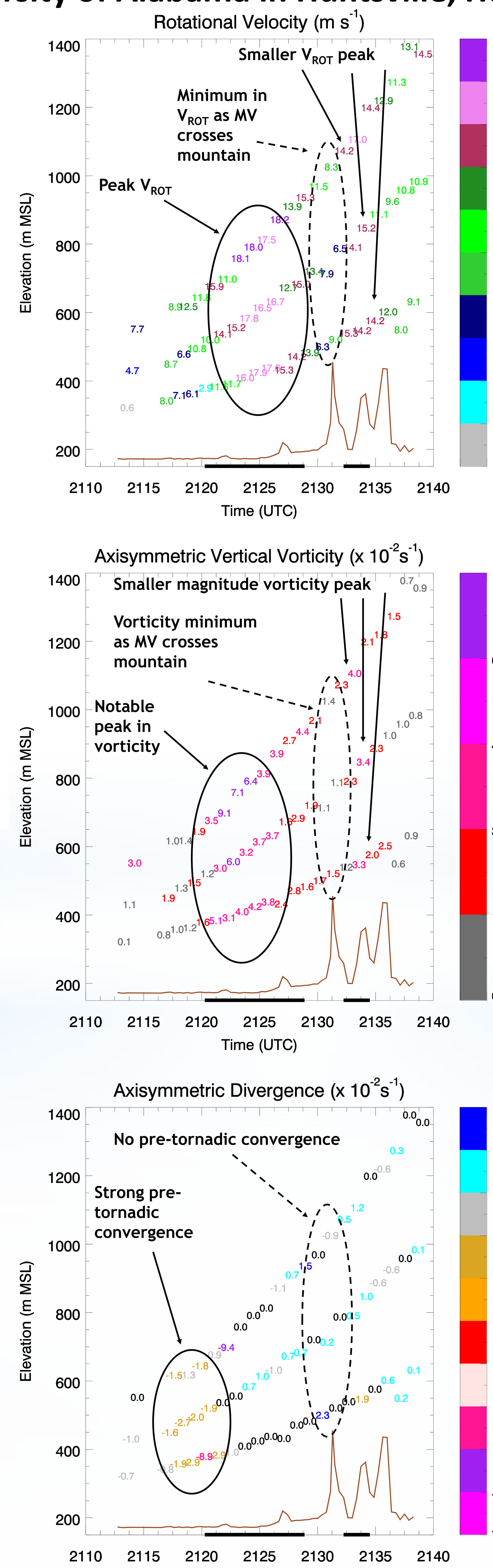

Fig. 5: Rotational velocity (V_{ROT}; top), axisymmetric vertical vorticity (middle) and axisymmetric divergence (bottom) of the Huntsville tornadic mesovortex (MV) from 2116-2136 UTC 11 April 2013, as estimated from ARMOR data. The brown line indicates land surface elevation underneath the center of the mesovortex at each time indicated, and the bold black lines along the time axis indicate the Storm Data times of tornado occurrence. Rotational velocity, vorticity, and divergence were calculated assuming a Rankine combined vortex, which assumes a circular, axisymmetric velocity profile (Brown and Wood 1991). Limitations of radar location, scanning height, and steady-state assumption for the mesovortex precluded the employment of a dual-Doppler or synthetic/pseudo-dual-Doppler technique.

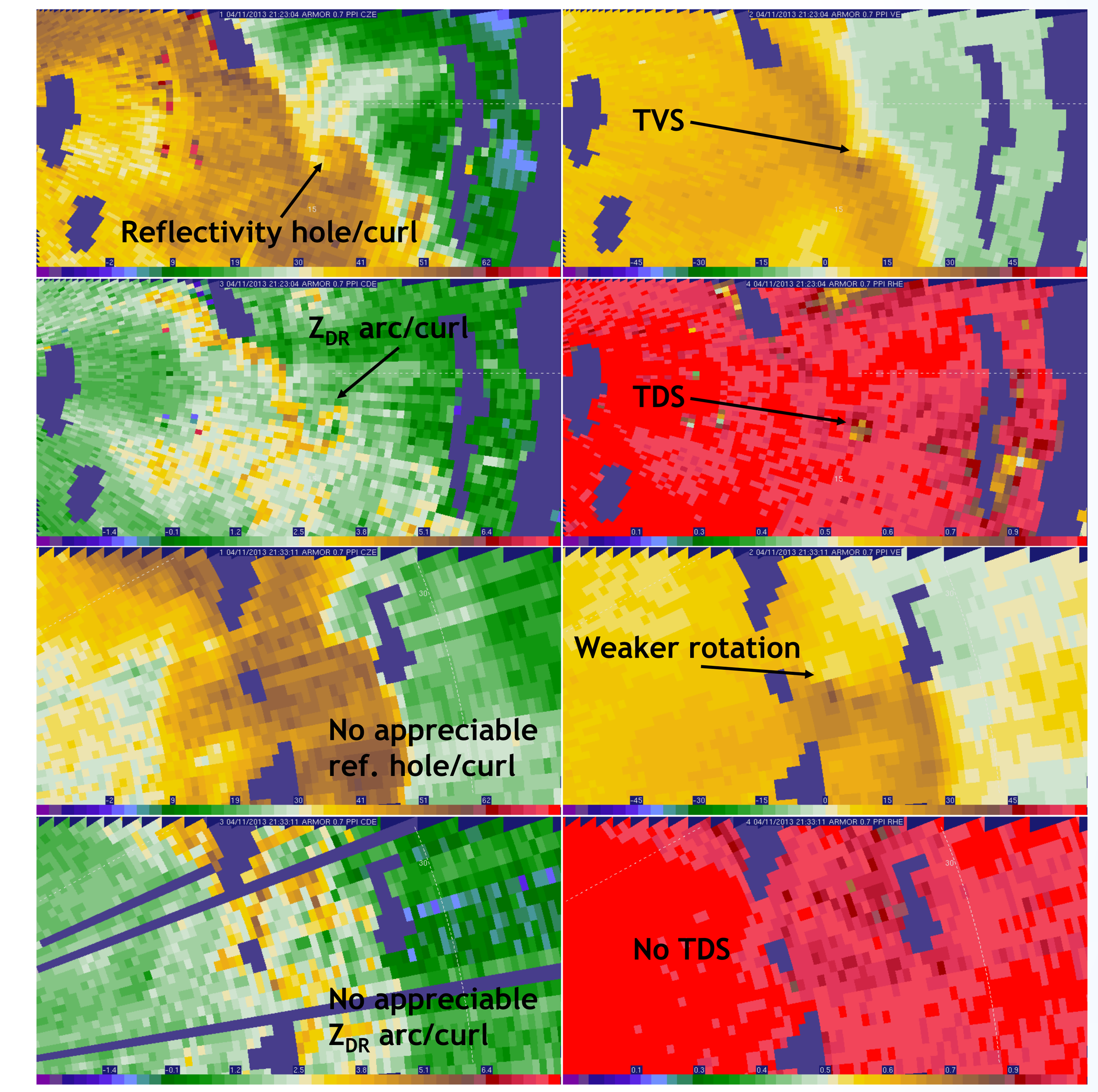

Fig. 6: Four-panel plots of corrected reflectivity (dBZ; upper-left), dealiased base velocity (m s-1; upper-right), corrected differential reflectivity (dB; lower-left) and correlation coefficient (lower-right) at 0.7° from ARMOR at 21:23:04 UTC (top) and 21:33:11 UTC (bottom), at about the respective times of peak intensity for the Lily Flagg Rd. and Dug Hill Rd. tornadoes.

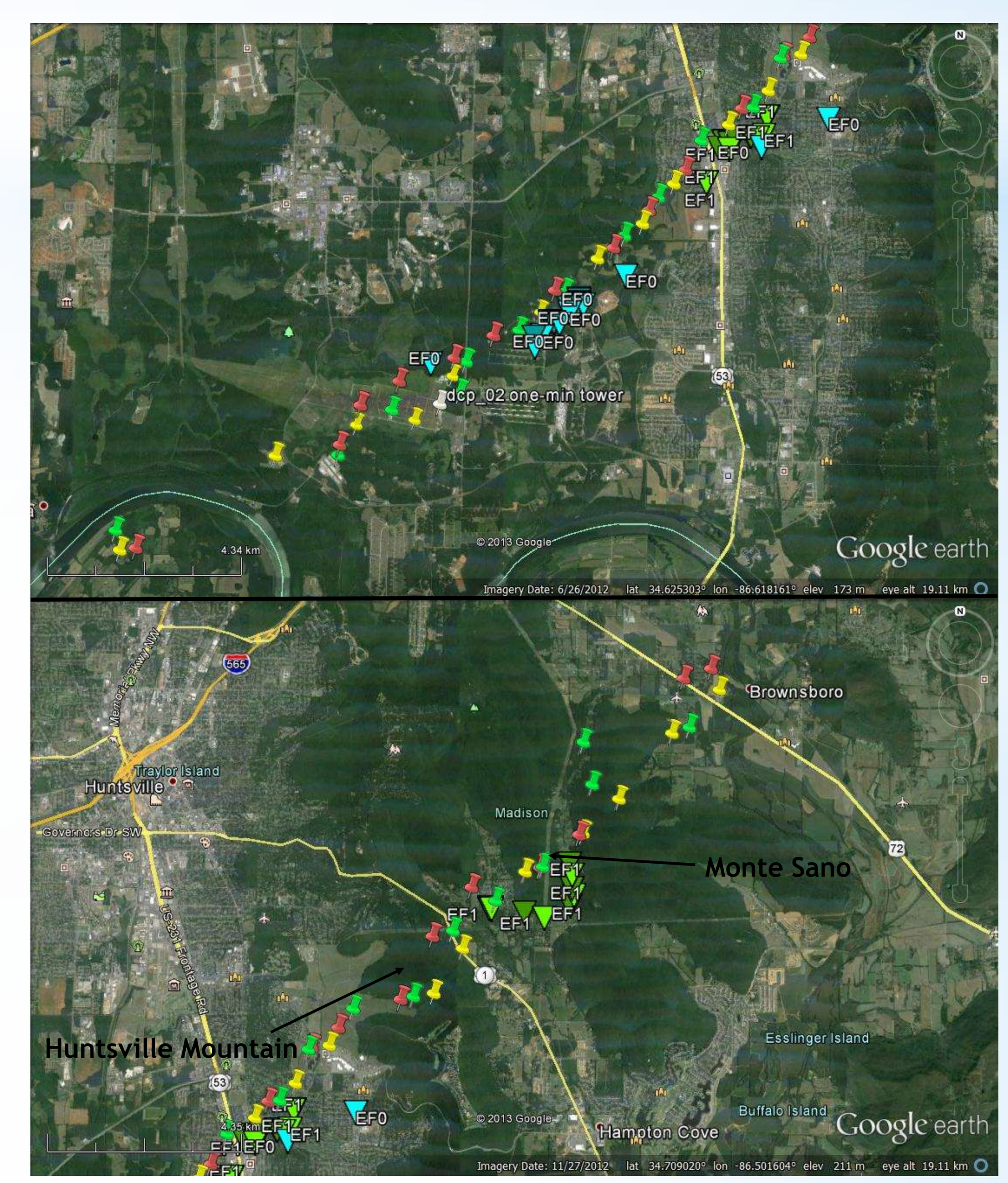

Fig. 7: Zoomed-in view of the Lily Flagg Rd. (top) and Dug Hill Rd. (bottom) tornado tracks as surveyed by NWS Huntsville (triangles), and the center-points of the mesovortex as estimated by ARMOR (green = 0.7°, yellow = 1.3°, red = 2.0°).

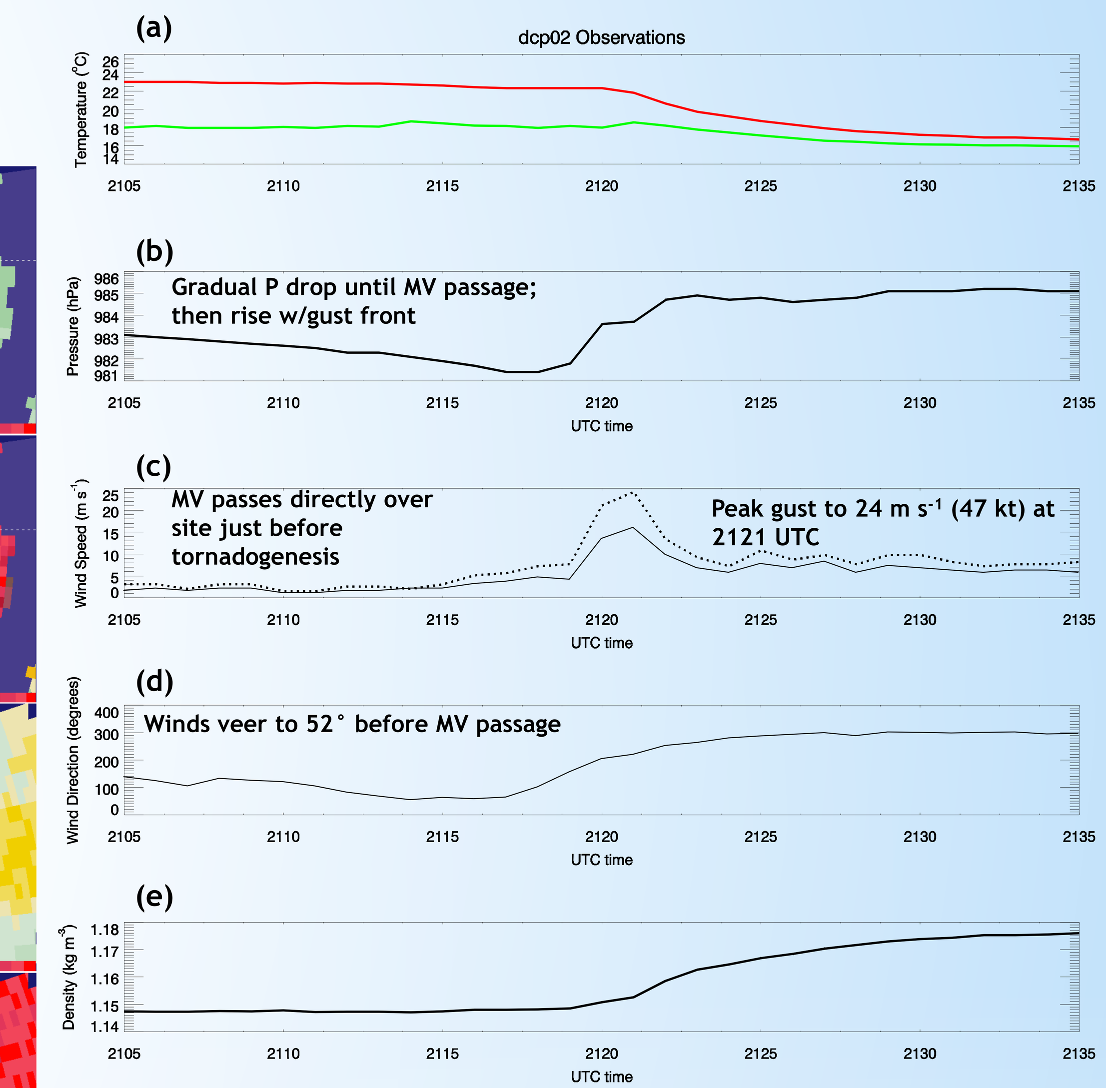

Fig. 8: 1-min. resolution data from Redstone observation site dcp02 of a) 2-m temperature (°C; red) with 2-m dewpoint (°C; green); b) 2-m pressure (hPa), c) 2-m wind speed (m s^{-1}; solid) and peak gust (m s^{-1}; dashed, d) 2-m wind direction (degrees), and e) 2-m density (kg m^{-3}).

Preliminary Results

- Gust front propagation and pressure characteristics appeared to be influenced by decaying bookend vortex over UAH and Madison sites
- Shallow depth of density current evident in XPR, wind profiler, and WSR-88D data
- Mathematically, negative pressure perturbation from 2114-2123 UTC is predicted by the following equation (derived from Markowski and Richardson 2004):

$$p'(H) = \rho o(0.5c^2 - gH((\rho 2 - \rho 1)/\rho 1))$$

where

$p'(H)$ = perturbation pressure as a function of density current depth
ρo = a background density
c = propagation speed of the density current
g = 9.81 m s^{-2}
H = depth of the density current
$\rho 1$ = density within the density current
$\rho 2$ = density outside the density current

- Observed pressure perturbation (-1.25 hPa) is larger than perturbation predicted by above equation (-0.654 hPa)
- ***Mesovortex becomes noticeably less organized in vicinity of Huntsville Mtn., momentarily stalls and then either jumps/reforms on the other side of the mtn.***
- ***ARMOR rotational velocity, vorticity, and divergence plots indicate that the mesovortex never regained the intensity it had prior to mountain interaction, even though the damage on the eastern base of the mountain was slightly more intense, as estimated from both NWS and UAH surveys***
- Near-surface corner flow collapse (Lewellen and Lewellen 2007, Lewellen 2012) may have occurred on the downslope of Huntsville Mountain, a phenomenon predicted numerically by Lewellen (2012) in tornadoes that descend mountains; this would have lead to very-near-surface strengthening and would explain lack of TDS or significant strengthening aloft

References/Acknowledgements

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