Dual Doppler Radar Analysis of a Tornadic Quasi-Linear Convective System on 04 January 2015

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

SWIRLL Severe Weather Institute Radar & Lightning Laboratories

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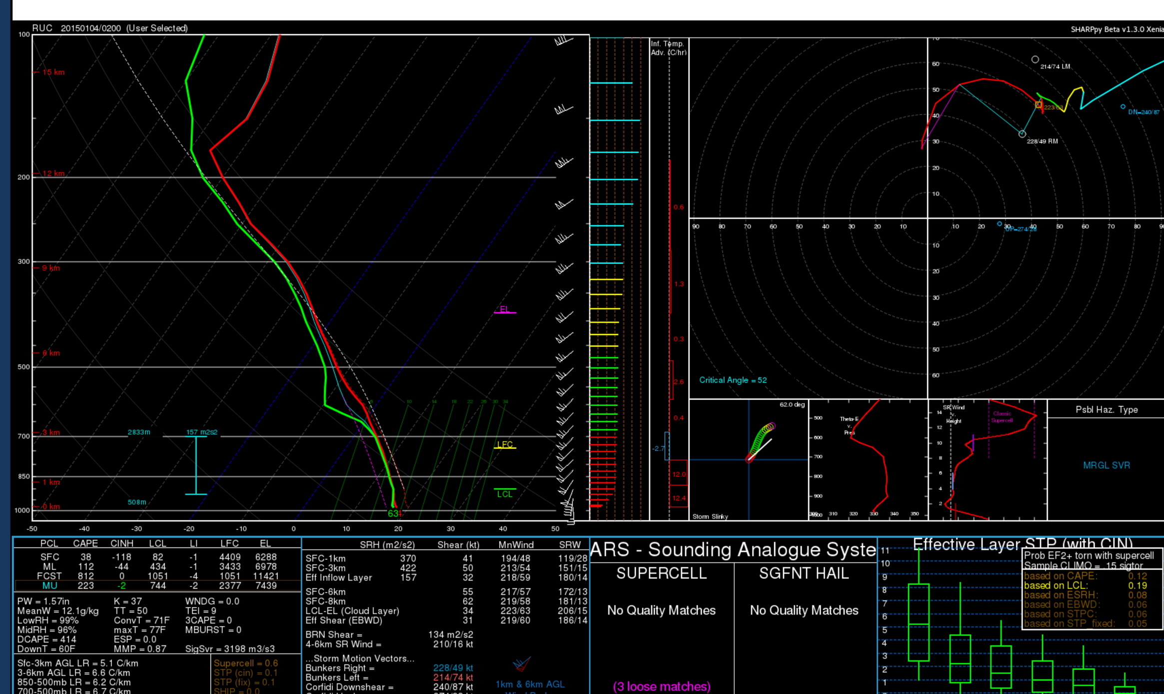
Background

On 4 January 2015, a quasi-linear convective system (QLCS) crossed North Alabama through the southern dual-Doppler lobe of the University of Alabama-Huntsville (UAH) Advanced Radar for Meteorological and Operational Research (ARMOR) and the National Weather Service Weather Surveillance Radar 1988-Doppler (WSR 88-D) in Hytop, AL (KHTX). Around 0140 UTC, the QLCS produced an EF-1 tornado for 10.3 km on the north side of Albertville, AL. The environment can best be characterized as a high shear-low CAPE environment. It is hypothesized that horizontal shearing instability (HSI) is responsible for vortexgenesis.



Above: RAP sounding for Albertville, AL. No in situ soundings were performed during this event and next closest observed sounding was not representative of wind profile in which the tornado occurred. Sounding reveals 50 kts of surface-3 km shear and 41 kts of surface-1km shear in addition to 38 J/kg of surface based CAPE.

Methodology

The ARMOR radar is a C-band (5.5 cm) wavelength radar with dual-polarization capabilities. The beam width is 1.0° and was operating in a 5-tilt rain one strategy with elevation angles at 0.7°, 1.3°, 2.0°, 2.7°, and 3.4°. KHTX is an S-band (10 cm) wavelength radar operated by the NWS in Huntsville, AL. The beam width is 0.95° and was operated in VCP 212.

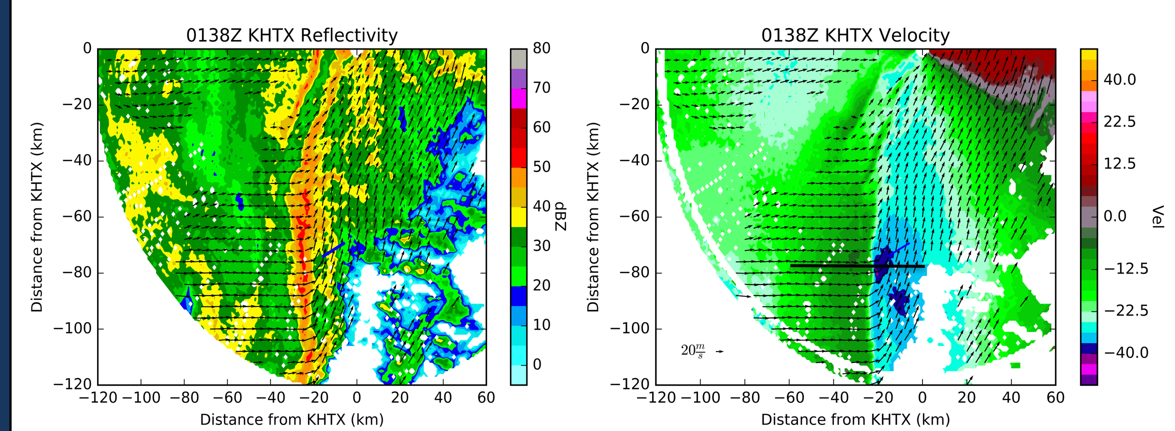
Data were edited using Solo3 software. Areas of ground clutter and noise were manually determined from the reflectivity, radial velocity, and correlation coefficient (RHOHV) fields and were removed. Manual unfolding of radial velocity was performed on ARMOR and KHTX.

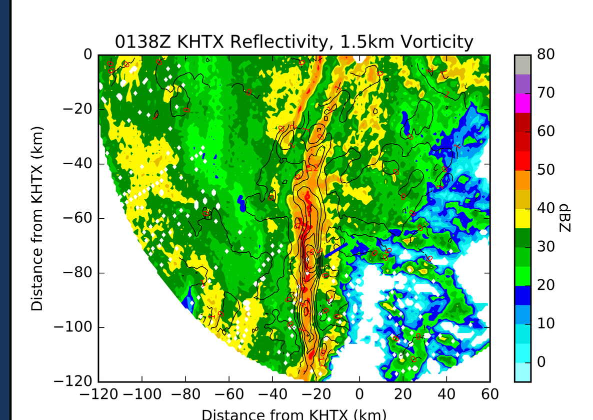
Data were mapped to a regular Cartesian grid using a Cressman analysis. A 1-point linear interpolation was used. For all analyses, the horizontal grid spacing is 1000 m and the vertical grid spacing is 500 m.

Dual-Doppler (DD) wind syntheses were performed using CEDRIC. To reduce errors in the DD analyses, only ARMOR volume scans that were fully within a KHTX volume scan were used for the wind syntheses.

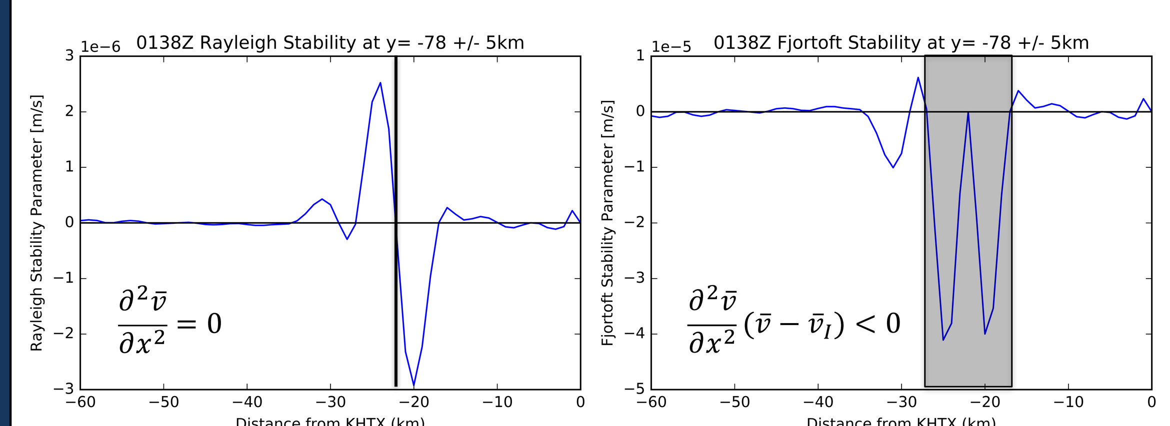
Radar Objective Analyses

Tornadic Vortex at 0138 UTC



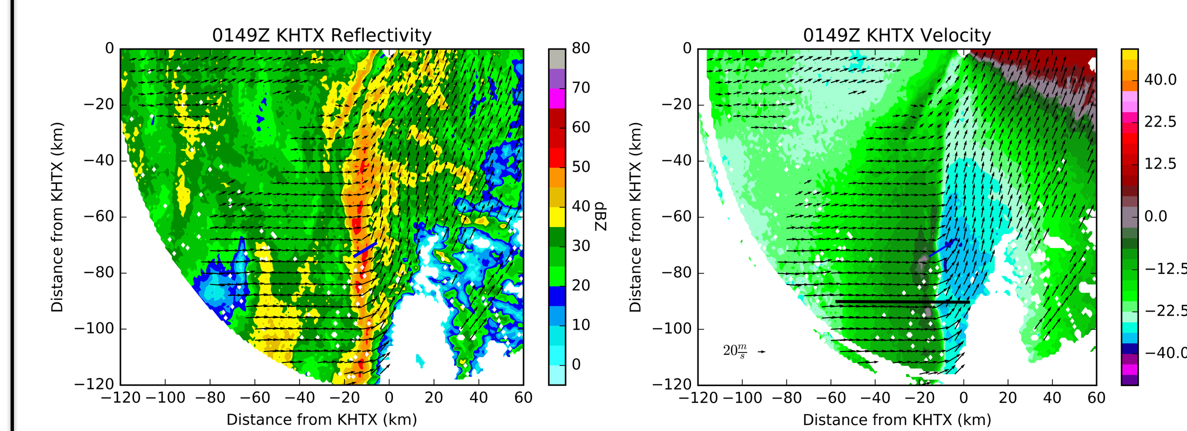


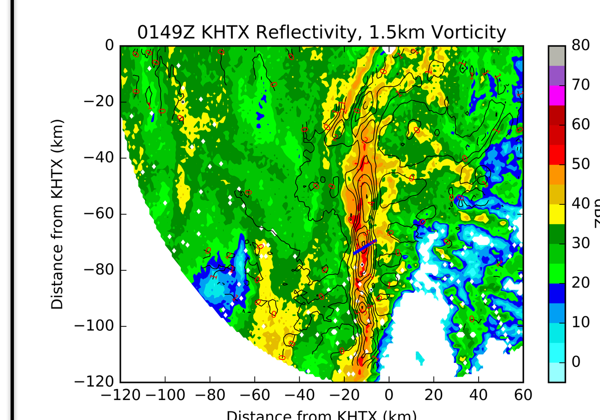
Above: Objectively-analyzed radar reflectivity factor (top left), vorticity (left) and radial velocity (m s^{-1}; top right) from KHTX at 0138 UTC at 1500 m above ground level (AGL). Vorticity is contoured at an interval of 1x10^{-3} s^{-1}. At this time, there were strong pre- and post-QLCS winds with a wind shift of almost 90° at the gust front. The tornadic vortex is located near (x = -25 km, y = -78 km). Blue line indicates tornado track.



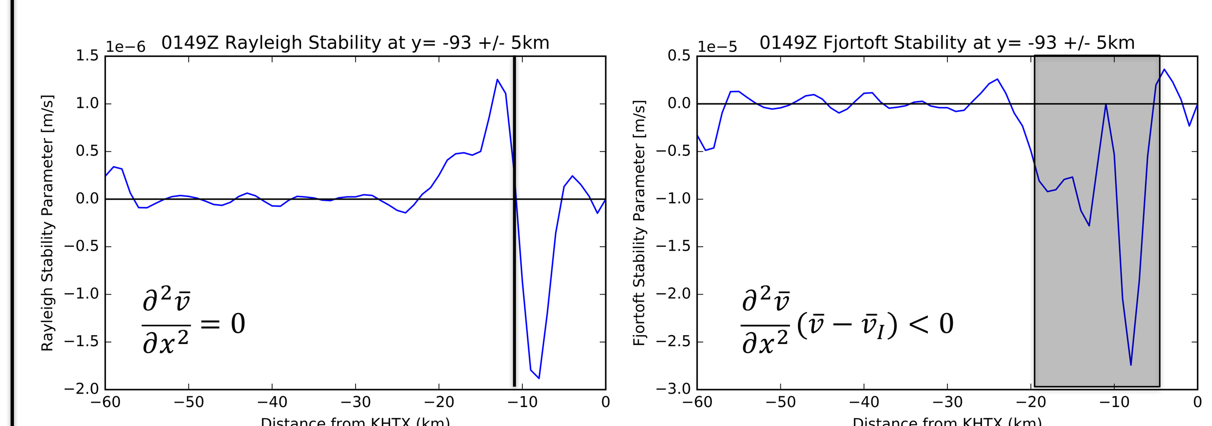
Above: Rayleigh and Fjortoft stability criteria calculated along black line through the tornadic vortex (78 km south of KHTX) in velocity image above. $\bar{v}$ is average meridional wind and $\bar{v}_I$ is meridional wind at the inflection point. Change in sign of Rayleigh stability criterion indicates inflection point is present and is necessary but insufficient condition for horizontal shear instability (HSI) to occur. Negative Fjortoft parameter reveals that the vortex is not near the boundaries (Marchioro and Pulvirenti 1994) and is also necessary but insufficient for HSI.

Nontornadic Vortex at 0149 UTC



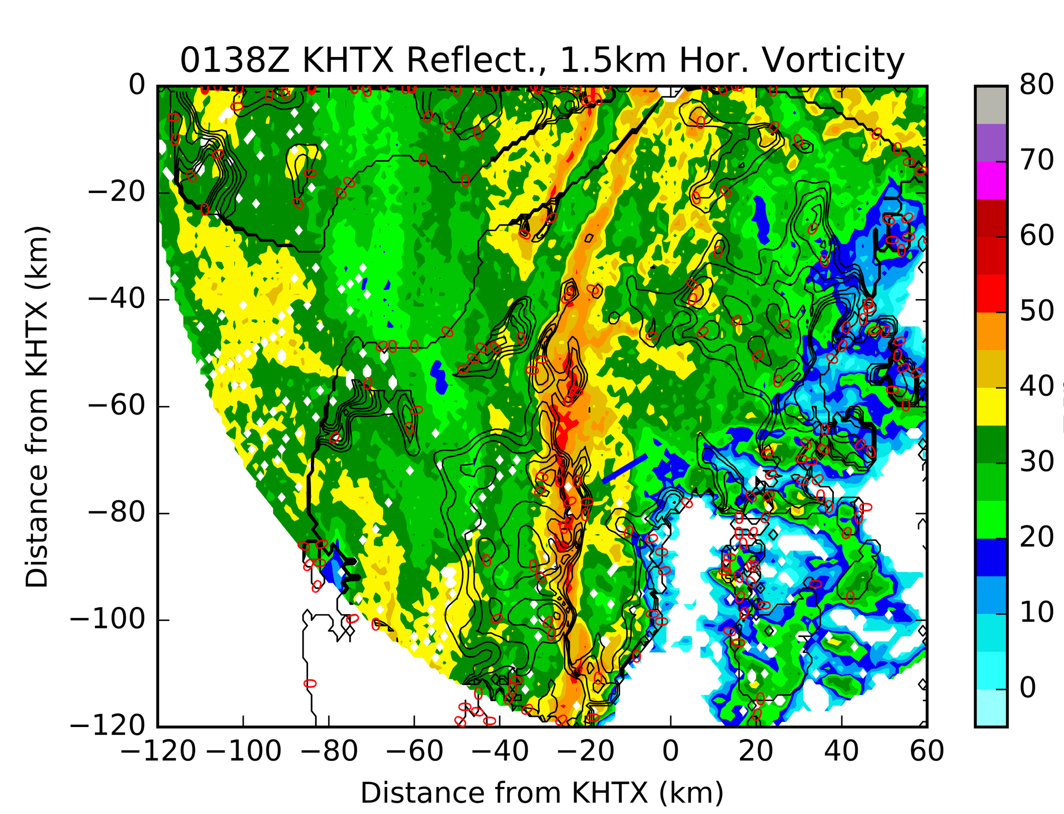


Above: Objectively-analyzed radar reflectivity factor (top left), vorticity (left) and radial velocity (m s^{-1}; top right) from KHTX at 0149 UTC at 1500 m above ground level (AGL). Vorticity is contoured at an interval of 1x10^{-3} s^{-1}. Wind shift is broader with slightly weaker winds ahead of the QLCS. Nontornadic vortex is located near (x = -18 km, y = -93 km). Blue line indicates tornado track.

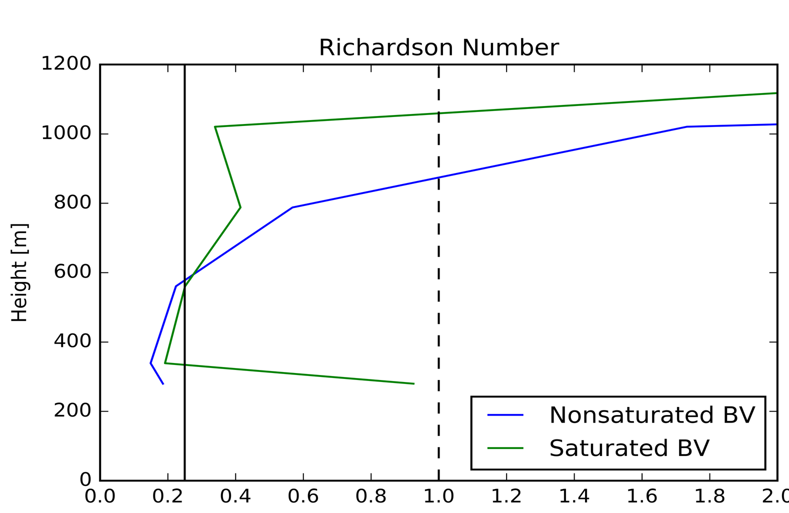


Above: Rayleigh and Fjortoft stability criteria calculated along black line through the nontornadic vortex (93 km south of KHTX) in velocity image above. $\bar{v}$ is average meridional wind and $\bar{v}_I$ is meridional wind at the inflection point. Change of sign in Rayleigh stability criterion and negative values of Fjortoft stability criterion are necessary but insufficient conditions for HSI. Magnitude of criteria at this time are less than that of the northern vortex.

Wave Interaction



Above: Objectively-analyzed radar reflectivity factor from KHTX at 1.5 km AGL at 0138 UTC. Horizontal vorticity is contoured at an interval of 1x10^{-3} s^{-1}. The quasi-linear light reflectivity structures may have been caused by gravity waves; quantitative analysis regarding the presence of these waves can be found to the right. Blue line indicates tornado track.

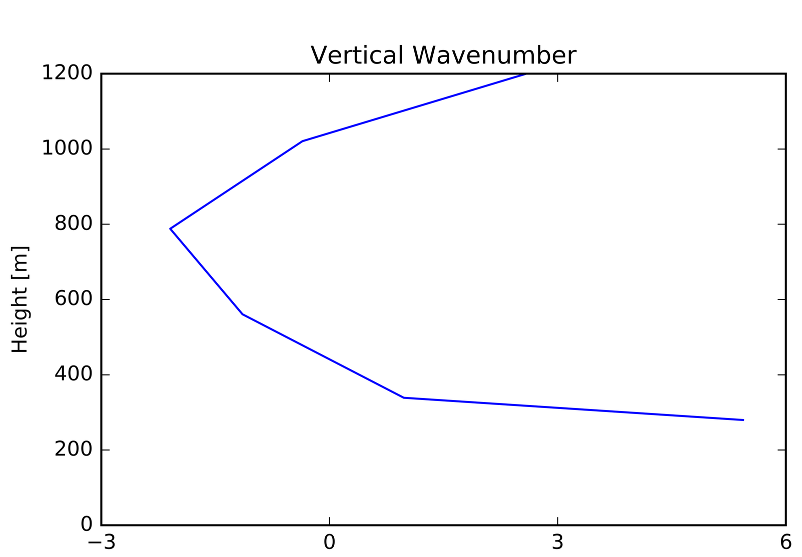


Left: Profile of Richardson Number calculated from the RAP sounding using saturated and non-saturated Brunt-Vaisala frequency. Values below 0.25 (1.0) are supportive for generation (maintenance) of Kelvin-Helmholtz waves. u is wind speed in direction of wave motion.

$$N^2 = \frac{g}{\theta}\frac{\partial \theta}{\partial z}$$

$$N_s{}^2 = \frac{g}{\theta_{z_0}}\left[\frac{\theta_{e_{(z_0)}} - \theta_{es_{(z_1)}}}{h_{z_0} - h_{z_1}}\right]$$

$$Ri = \frac{N^2}{\left(\frac{du}{dz}\right)^2}$$



Left: Profile of vertical wavenumber determined from equation below using RAP sounding. Gravity waves can be reflected by the ground and by layers of decreasing m² (Coleman and Knupp 08). u is wind speed in direction of wave motion.

$$m^2 = \frac{N^2}{(c-u)^2} + \frac{\frac{\partial^2 u}{\partial z^2}}{(c-u)} - k^2$$

$$k^2 = \left(\frac{2\pi}{\lambda_h}\right)^2$$

Conclusions

Dual-Doppler wind synthesis at two separate times reveal a well-defined wind shift located along the leading edge of the QLCS. The sharpness of the wind shift and pre- and post-QLCS intensity of the winds are consistent with the results of Clark and Parker (2014), who demonstrated that a wind shift >> 45° and strong pre- and post-frontal winds in a narrow cold frontal rainband are supportive of tornadoes. Calculation of the Rayleigh Stability parameter shows that for both the northern and southern vortex, an inflection point was present. The more stringent Fjortoft Stability Parameter reveals that the relative maximum in vertical vorticity is away from the boundary (Marchioro and Pulvirenti 1994). Therefore, we hypothesize that HSI is the primary formation mechanism for these vortices.

Shortly before tornadogenesis, reflectivity structures propagate perpendicular to the leading edge of the QLCS. It is hypothesized that these segments are indicative of a wave-like feature, and the subsequent tilting of horizontal vorticity into the mesocyclone led to an increase in vertical vorticity and tornadogenesis. The environment depicted by the model sounding is supportive of the formation and maintenance of gravity and Kelvin-Helmholtz waves. A lack of surface observations over the area of interest, in addition to low resolution dual-Doppler data, does not allow for validation of a possible wave, however.

Future Work

Similar analyses will be explored on other events that occurred within the North Alabama domain with improved radar coverage. Trajectory analyses will be performed with the Weather Research and Forecasting model to track parcel paths within the circulations and along the leading edge of potential wavelike features.

Acknowledgments

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References

Clark, M. R. and D. J. Parker, 2014: On the mesoscale structure of surface wind and pressure fields near tornadic and nontornadic cold fronts. *Mon. Wea. Rev.*, **142**, 3560–3585, doi:10.1175/MWR-D-13-00395.1.

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Marchioro, C. and M. Pulvirenti. *Mathematical Theory of Incompressible Nonviscous Fluids*. Springer-Verlag, 1994.