VORTEX-SE (VSE):

Improving radar wind retrievals and understanding local environmental influences on downdraft processes in potentially tornadic storms in the southeastern United States.

Center for Severe Weather Research

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OBJECTIVES:

USING DATA COLLECTED FROM 2017 VSE FIELD PHASE:

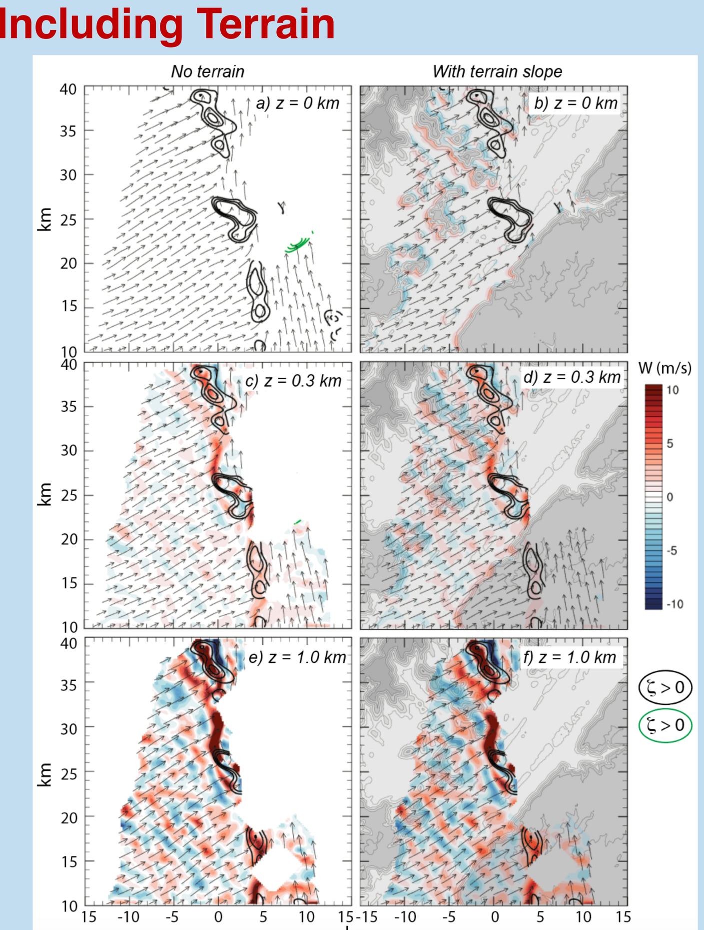
1. Refine dual-/multi-Doppler analysis techniques, with emphasis on the lower boundary condition, as applicable to areas of complex terrain and land use similar to the southeastern U.S.

2. Dual-Doppler, in situ, and environmental analysis of downdrafts associated with tornadic storms using instruments fielded in the northern Alabama VORTEX-SE domain

Improving Dual-Doppler Retrievals:

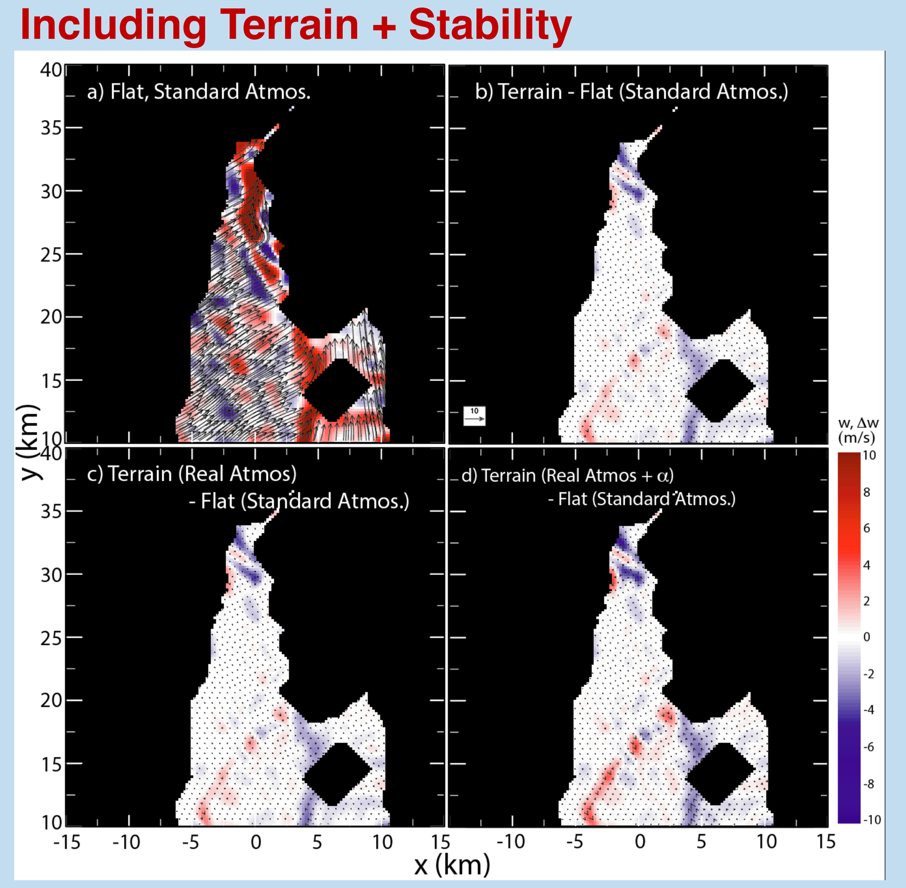
30 April 2017 event: Weakening QLCS with small/weak bowing segments over Sand Mt.

Including Terrain



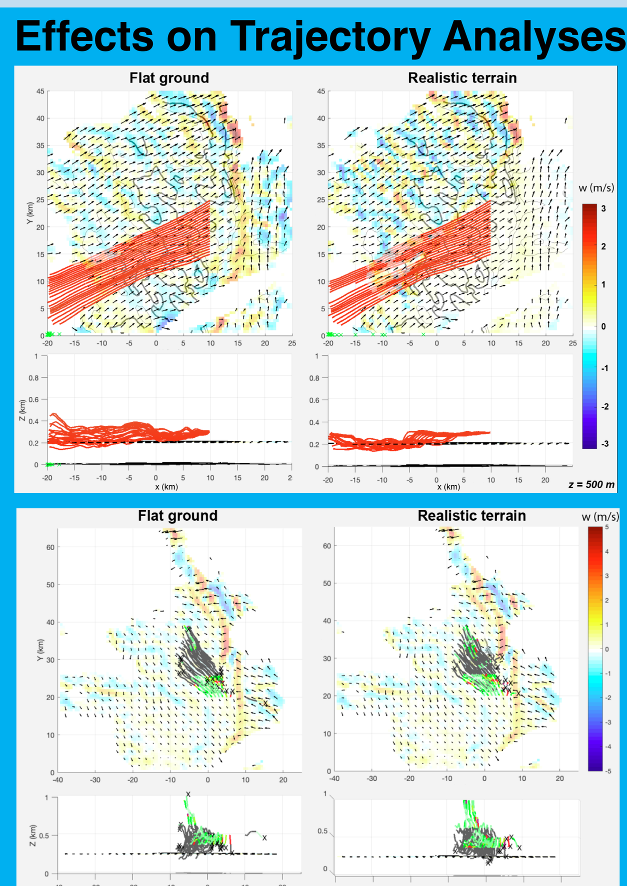
Dual-Doppler wind syntheses (horizontal winds are vectors, vertical velocity is shaded) at various levels above the bottom of the grid (at z = 0, 300, 1000m) that assume: flat ground at z = 0 km (left) and sloped terrain (right). Fields are overlaid on top of USGS topography (gray shaded).

Including Terrain + Stability



Comparison of dual-Doppler wind syntheses from four experiments, two assuming standard atmospheric conditions with i) flat ground or ii) realistic terrain (with $\alpha = 1$ everywhere; i.e., our Froude number effect is disengaged), and two with terrain that also include iii) realistic sounding-measured $\rho(z)$, and iv) the Froude number term described above. Vertical acceleration by terrain slope itself ($W_{terr} \neq 0$) in a standard atmosphere produced the largest overall difference from the flat ground and standard atmosphere experiments (**a-b**). Using a realistic $\rho(z)$ in (1), measured from a sounding collected behind the gust front produced virtually no difference in dual-Doppler vertical velocity (**c**). Further modification of the surface vertical velocity by the $\alpha = 1 - z(k_{terr})/h_{max}$ term increased the perturbation in vertical velocity located along terrain gradients by up to ~ 0.5 m/s (**d**), but these perturbations are typically weaker than those forced by the terrain itself.

Effects on Trajectory Analyses

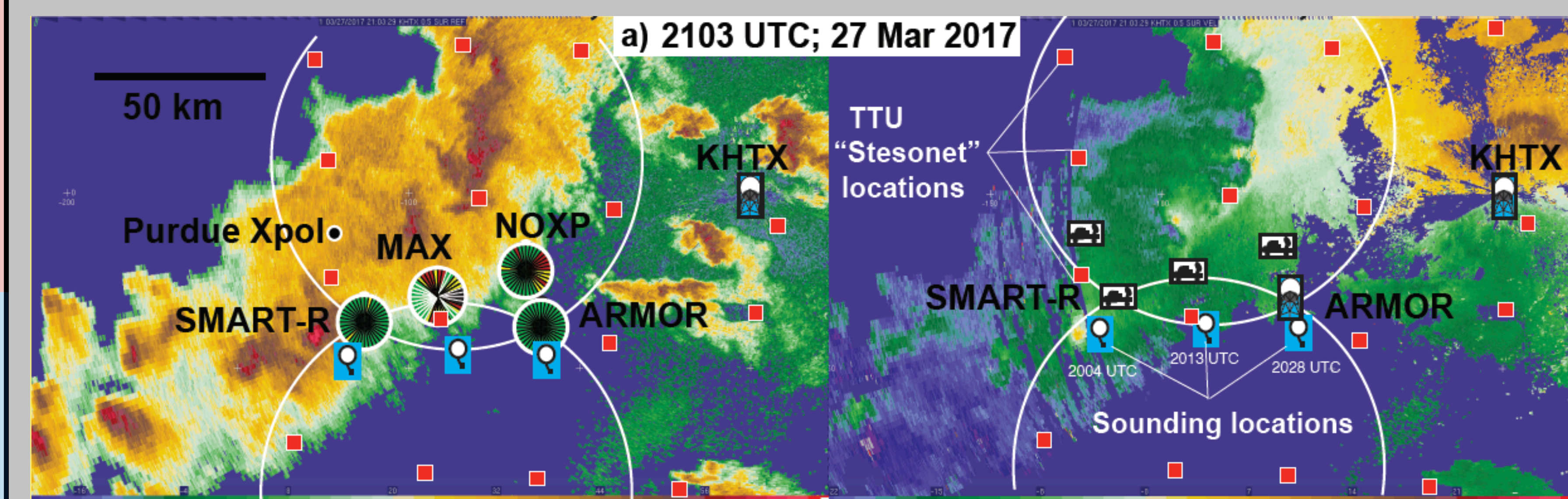


TOP. 3D parcel trajectories traversing Sand Mountain, calculated from two sets of dual-Doppler experiments: left) assuming flat terrain at the lower boundary with a standard atmosphere; and right) using realistic terrain and a standard atmosphere. Parcels are integrated backward in time from 2050 UTC (located at x, y, z = 10, 15-25, 0.3 km) to 2020 UTC. Top) Projection of these 3D trajectories in the x-y plane (view from above); bottom) projection of these trajectories into the x-z plane (view from the south). Shaded field is w at z = 500m.

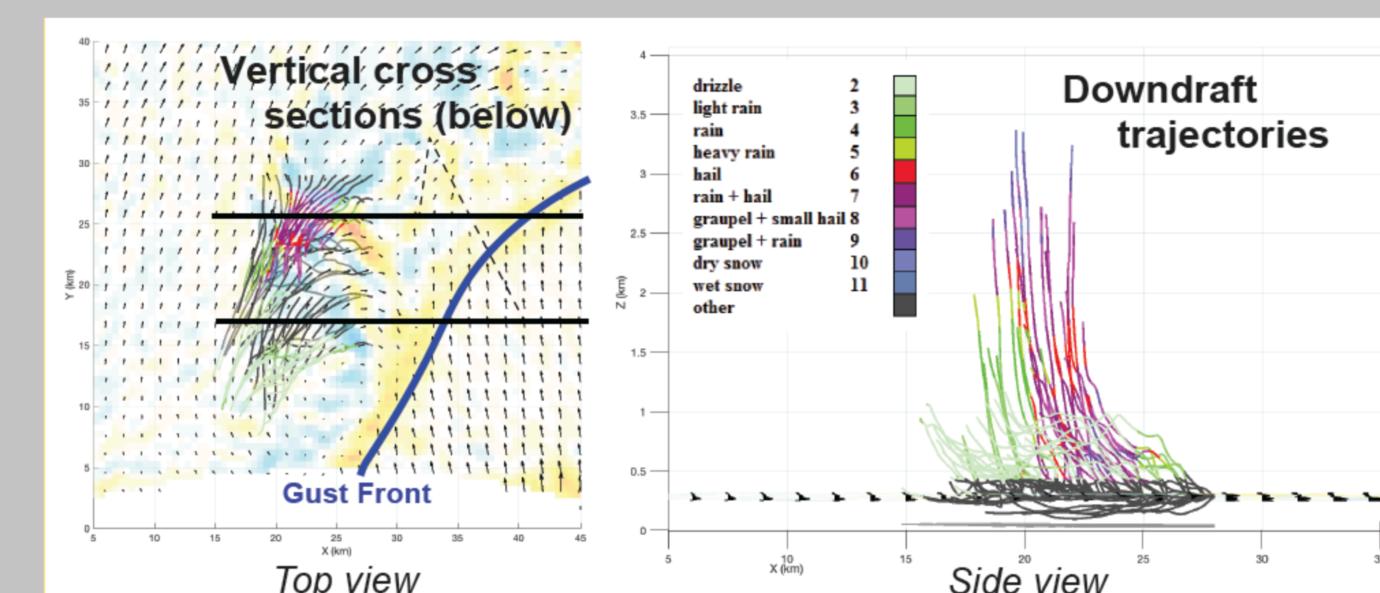
BOTTOM. Trajectories originating at z = 500 m within a region of downdraft behind the QLCS gust front.

27 March 2017: Downdraft Processes

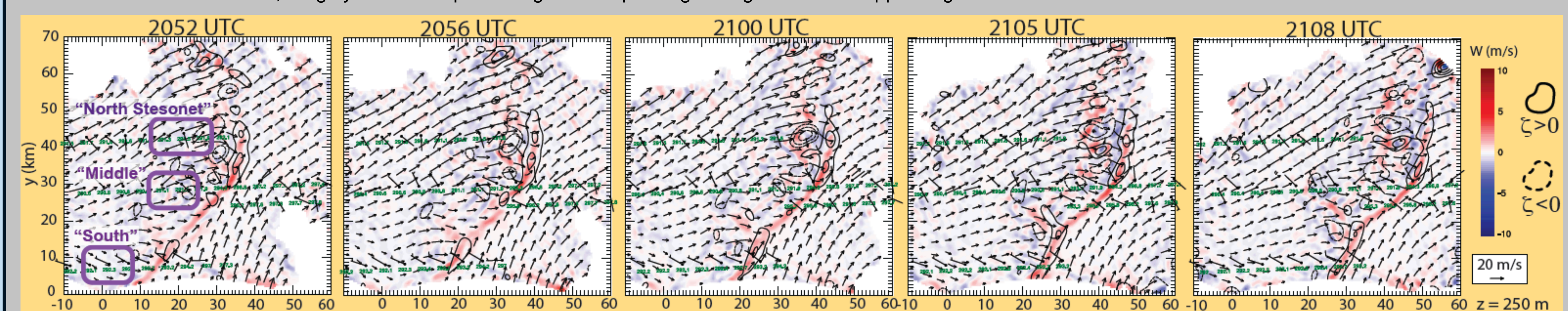
Dual-Doppler, surface (sticknet or "stesonet"), and sounding observations collected in multiple 2017 storms targeted by VORTEX-SE are examined to determine environmental sensitivities of downdraft properties in severe convective storms in the Southeast United States. Two QLCS storms, a storm type commonly associated with tornadoes in the SE U.S., were analyzed, 27 March and 30 April 2017. The 27 March case is the focus because of the superior observation density ahead of and within the storm. Current focus is to relate surface outflow temperature, downdraft strength, and hydrometeor types in downdrafts to environmental profiles and heterogeneity in the SE U.S. Focus on relating surface outflow temperature, downdraft strength, and hydrometeor types in downdrafts to environmental profiles and heterogeneity in the SE U.S.



ABOVE. Deployment diagram of the 27 March case. A QLCS with weak surface vertical vorticity and bowing segments passed through the northern portion of the radar and sur-face observing network. Although a multitude of mobile and fixed radars were coordinated, tree and building blockage at most radar sites precluded dual-Doppler coverage in most parts of the storm (green/yellow/red pie charts in the left-most panel indicate quality of data within each azimuth sector). The best dual-Doppler coverage of this storm utilizes the SMART-R and ARMOR radars, with a large baseline of approximately 50 km. Mobile soundings were launched in an E-W-oriented line near the SMART-R/ARMOR baseline, roughly 45-60 min prior the gust front passing through the dual-Doppler region.



ABOVE. 4D airflow is probed via calculations of parcel trajectories within the strongest downdrafts located near areas of low-level rotation. Trajectories are traced backward in time from 2108-2052 UTC. Among the tested regions, parcels display two primary downward vertical excursions during the 16 min integration period: 1) from z > 3 km (which could be higher, given the large amount of smoothing of Doppler velocities during objective analysis owing to the range from each radar), or 2) from much shallower depths, z < 1.5 km. Parcels descending from the higher altitudes contain larger rain and hail (dual-pol-retrieved) than those descending from lower altitudes.

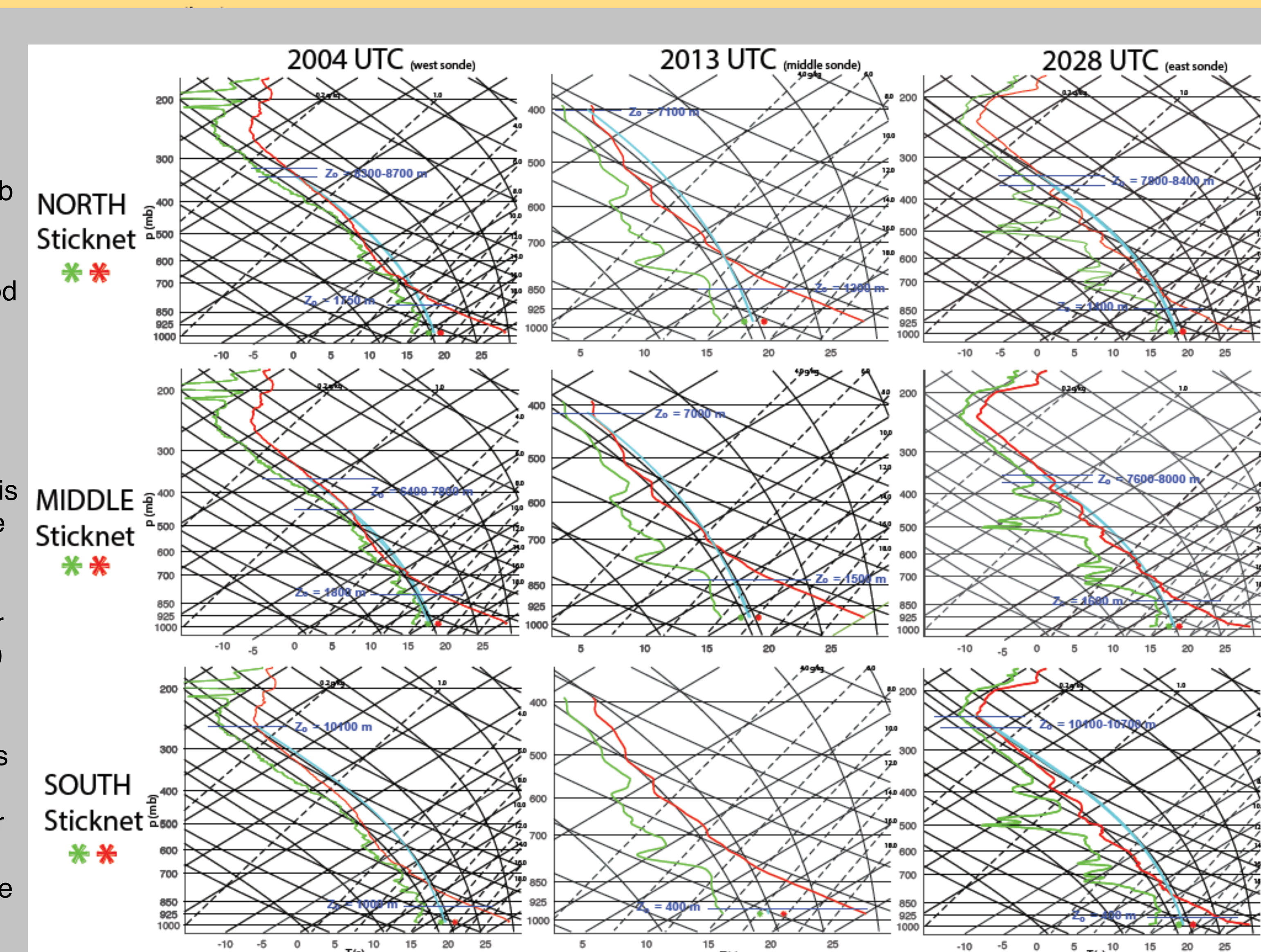


LEFT. 3D Dual-Doppler wind syntheses are performed using an upward integration of mass continuity. Radar velocity coefficients are assumed constant between the lowest radar beam and the ground to implement the lower BC (w = 0 m/s at z = 0 m). Wind syntheses illustrate updraft/downdraft structure and near-surface vertical vorticity located near the gust front. A few areas of enhanced downdraft are seen near the ground behind bowing segments of the line (e.g., y ~ 20 km and ~40 km). Areas of positive and negative vertical vorticity are relatively weak, but these are likely underestimates of the true value owing to the relatively coarse resolution of the radar data.

Winds and thermodynamic observations from the "stesonet" are shown (time-space corrected, using a mean gust front motion, within a +/- 45 min window). These analyses indicate outflow air with a 5-7 K temperature deficit from the environment. Low-level winds observed by the stesonet typically are significantly weaker and directionally-different from the dual-Doppler winds at the lowest common radar level.

RIGHT. A combination of 3 proximity soundings in the near-storm inflow and 3 stesonet surface observations of outflow thermodynamics are used to constrain and pinpoint possible downdraft origin heights in the QLCS, and to address the sensitivity of these estimations to different environmental base states. Wet-bulb potential temperature is calculated for a variety of heights on each sounding and parcels brought down to the surface pseudo-moist-adiabatically for comparison with stesonet observations. This method utilizes typical parcel theory assumptions (e.g., neglects mixing of environmental/cloudy air, pressure gradient forces) to estimate downdraft/outflow thermodynamics, constrained by surface observations.

A variety of possible downdraft origin heights are identified using this method. In general, downdrafts initiated from two main regions have thermodynamic properties that are consistent with surface observations: 1) from certain heights within the boundary layer (approximately 400-1800 m AGL), or 2) from various layers at upper levels (6.5-10 km AGL). Saturated air from mid-levels (~2.0 km - 6.0 km) is much colder at the ground than surface observations. Air originating from the upper most of the identified layers (z ~ 6.5-10 km) are positively buoyant for a deep layer aloft, suggesting that this air does not reach the surface as a downdraft (without significant downward-oriented pressure gradient forces present). Downdraft air with thermodynamics consistent with surface data from the "Middle" and "North" stesonet stations have similar origin altitudes; thus, there is only subtle outflow heterogeneity on the northern half of the dual-Doppler coverage region. However, parcel-theory-determined altitudes generally are lower for the "South" stesonet station.



Downdrafts proximal to near-surface vorticity in the 27 March 2017 case, interrogated with backwards parcel trajectory analysis, indicated along-QLCS downdraft heterogeneity, and origins from generally two altitudes (from within the lowest kilometer and from > 3 km AGL). As a second method of downdraft origin estimation, pseudo-equivalent potential temperatures from various proximity soundings that yield thermodynamic conditions at the surface consistent with stesonet observations suggest that air descended from within the lowest 2 km of the atmosphere, or from the mid-upper levels (> 6 km AGL); however the vertical distribution of DCAPE suggests the former. It is possible that a combination of significant hydrometeor loading and significant downward-oriented pressure gradient forces could force descent of positively buoyant air from mid-upper levels. It is unclear to what degree down-draft temperature and origin altitude varies by environment in the along-QLCS direction on scales < 30 km owing to a limited surface and sounding network; however, sensitivities of downdraft properties estimated by parcel theory are subtle based on the use of 3 different soundings, and hydrometeor observations may point to intra-storm heterogeneity to explain variable downdraft strength rather than heterogeneities of the environment.