Preliminary Results from the ROTATE-2013 Season

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During the spring of 2013, attempts were made to deploy DOWs and in-situ Tornado Pod instrumentation near and in several violent tornadoes during a reduced experimental season consisting of only a few IOPs. These include the EF-3 El Reno tornado, the EF-4 Rozel, Kansas tornado, the EF-4 Bennington, Kansas tornado, and the EF-2 Wichita, Kansas tornado. Very fine-scale radar observations, including rapid-scan (7-second volumes) and quick-scan (7-second sweeps) radar data reveal quickly-evolving structures, low level winds, and relationships with damage.

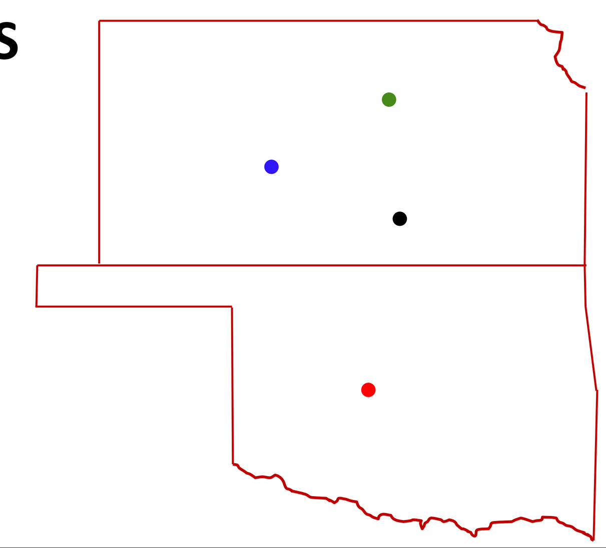
ROTATE 2013 TORNADOES

Rozel, KS (18 May 2013)

Wichita, KS (19 May 2012)

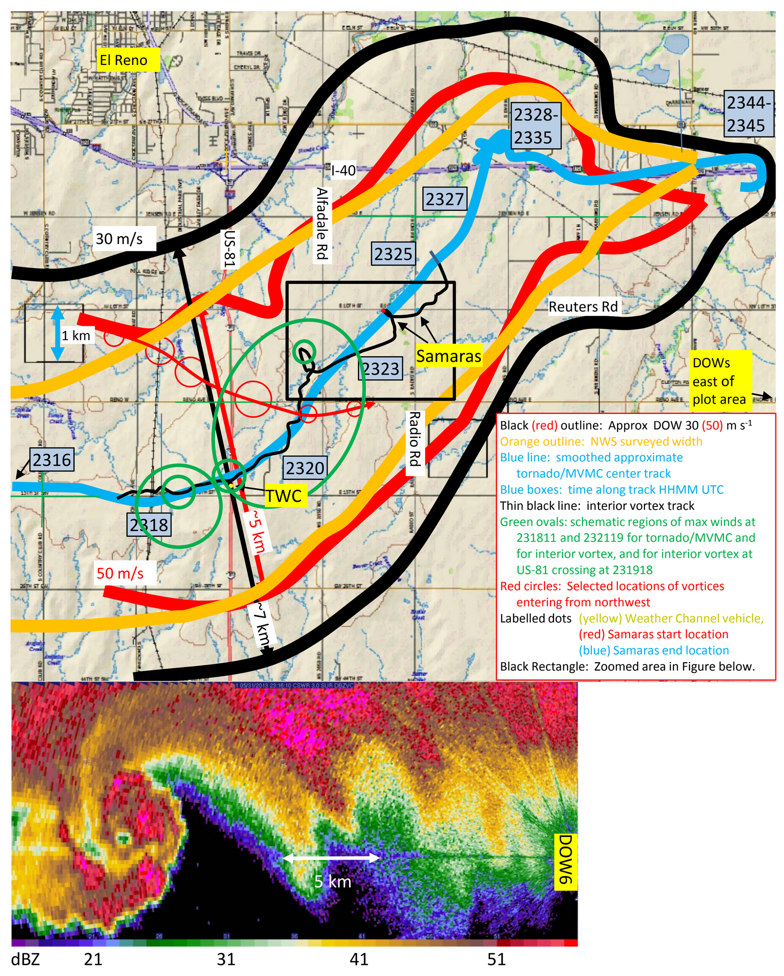
El Reno, OK (31 May 2013)

Bennington, KS (28 May 2013)

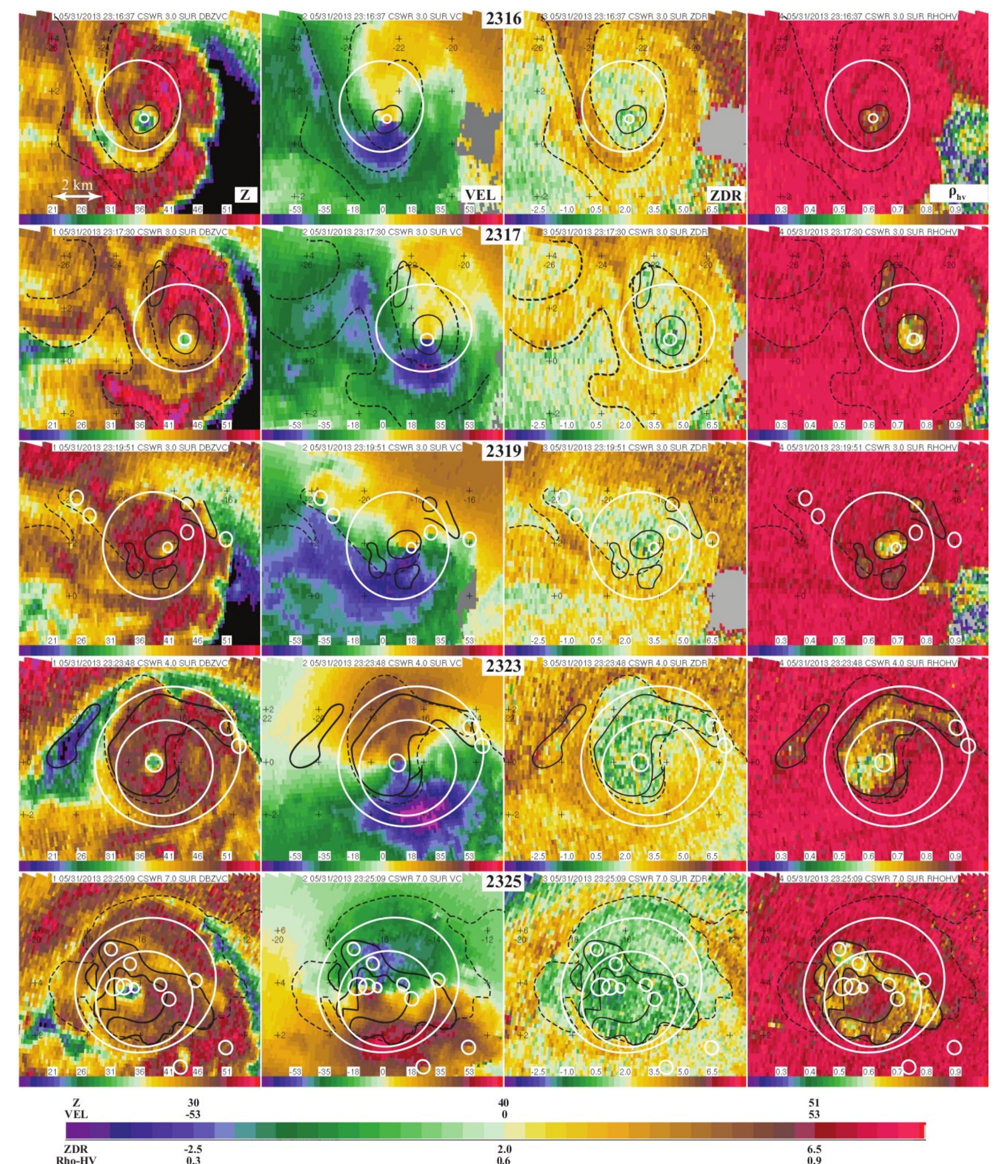


El Reno, OK:

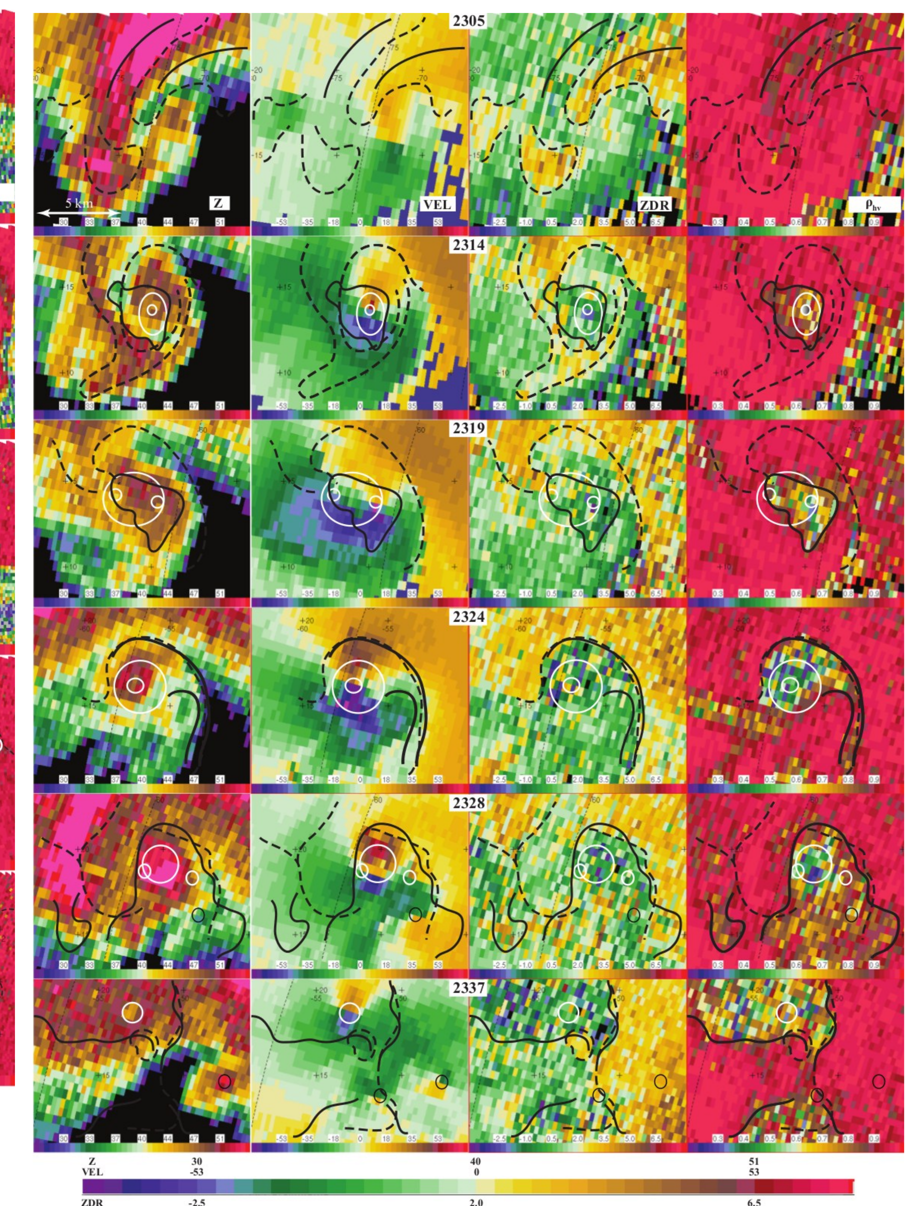
A large and violent tornado/multiple vortex mesocyclone (MVMC) tracked south and east of El Reno, Oklahoma on 31 May 2013, causing 8 fatalities, including storm-chaser/researchers attempting to deploy in-situ instrumentation. Transient and persistent sub-vortices moving within and near the MVMC were documented, some moving in trochoidal-like patterns inside the tornado/MVMC, with ground-relative translational velocities ranging from near zero to 79 m/s, the fastest ever documented. Winds measured by a DOW radar in one of these sub-vortices exceeded 115 m/s at 114 m AGL. If assumptions concerning radar-unobserved components of the velocity vector are made, peak wind speeds of 130-150 m/s are implied, comparable to the strongest ever measured. However only Enhanced Fujita Scale 3 (EF-3) damage was documented, likely due to a paucity of well-built structures in the path of the small, most-intense portions of sub-vortices and because the regions of most intense winds were very small, and translating extremely rapidly, resulting in 100 m AGL winds exceeding 120 m/s occurring for perhaps < 1 s over particular locations. The region enclosing the maximum winds of the MVMC extended ~2 km. DOW-measured winds >50 m/s (>30 m/s) extended outward from the radius of maximum winds (RMW) to cover a cross-track region extending > 5km (7km), comparable to the widest ever documented.



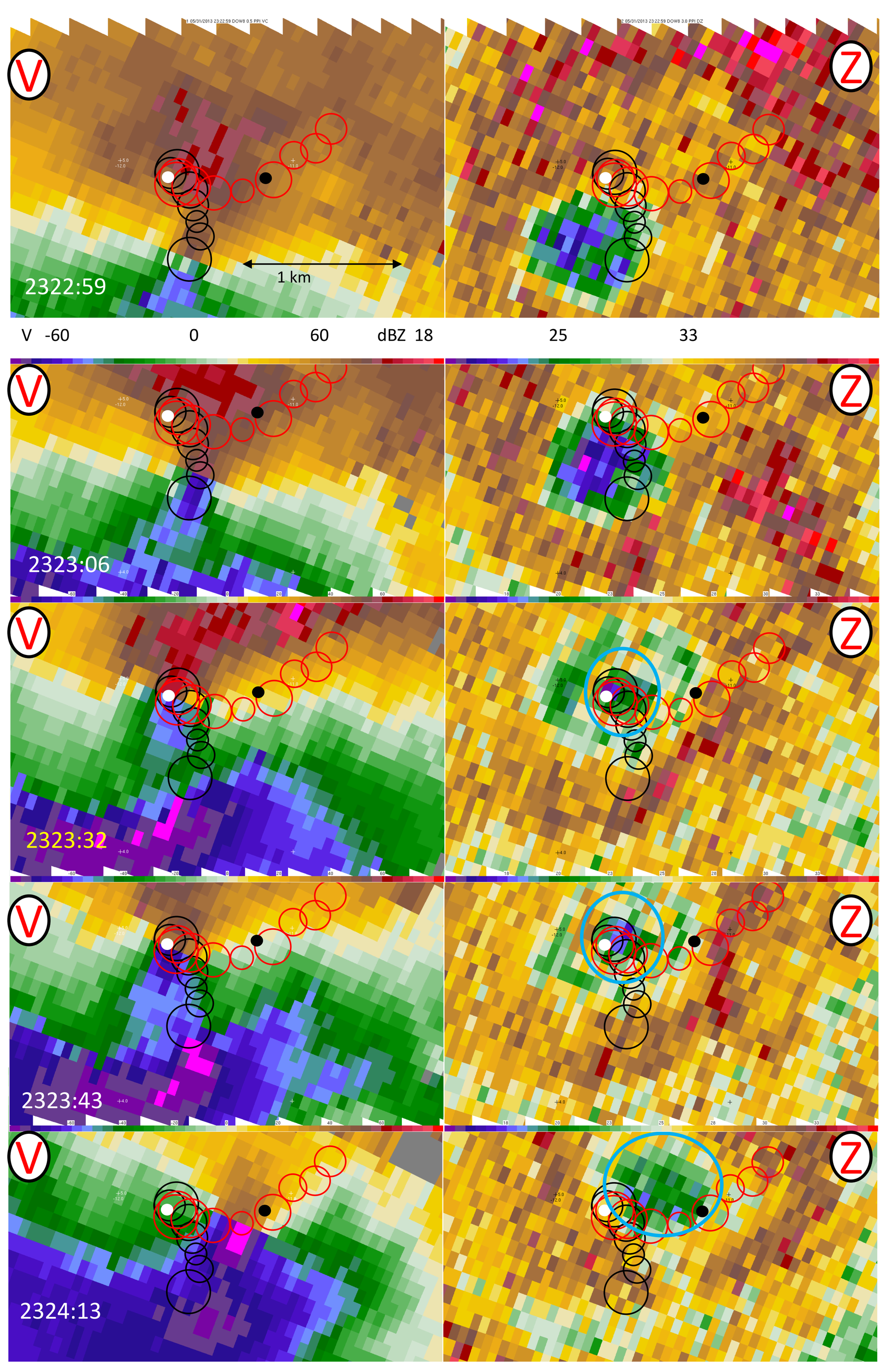
Above. (top) Track of tornado/MVMC, internal sub-vortex impacting research team, and other vortices near El Reno, Oklahoma on 31 May 2013. Very wide path and complex and intense multiple vortex structure combined to make this tornado particularly hazardous. (bottom) Reflectivity in the supercell thunderstorm as measured by DOW6 at 3 degrees, approximately 1 km AGL at 2316 UTC.



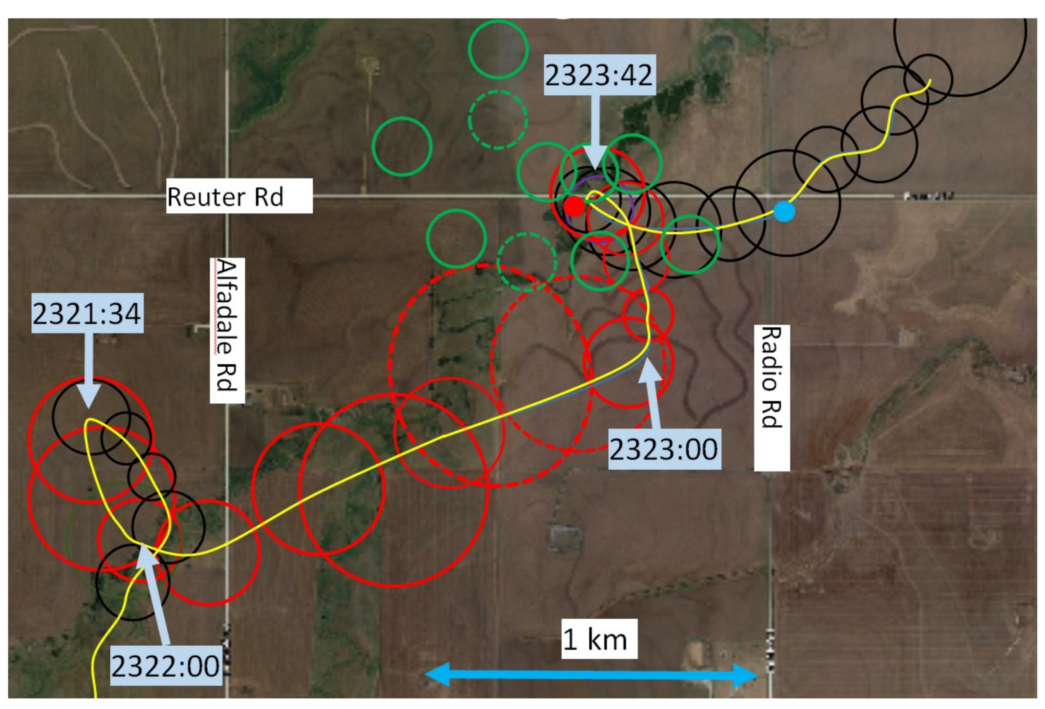
Above. El Reno tornado as observed by DOW6. Columns from left to right: Reflectivity (Z), Doppler Velocity (VEL), Differential Reflectivity (ZDR), and the cross-correlation coefficient (ρ_{hv}). Stippled (Solid) lines indicate regions of interest in the ZDR (ρ_{hv}) field(s).



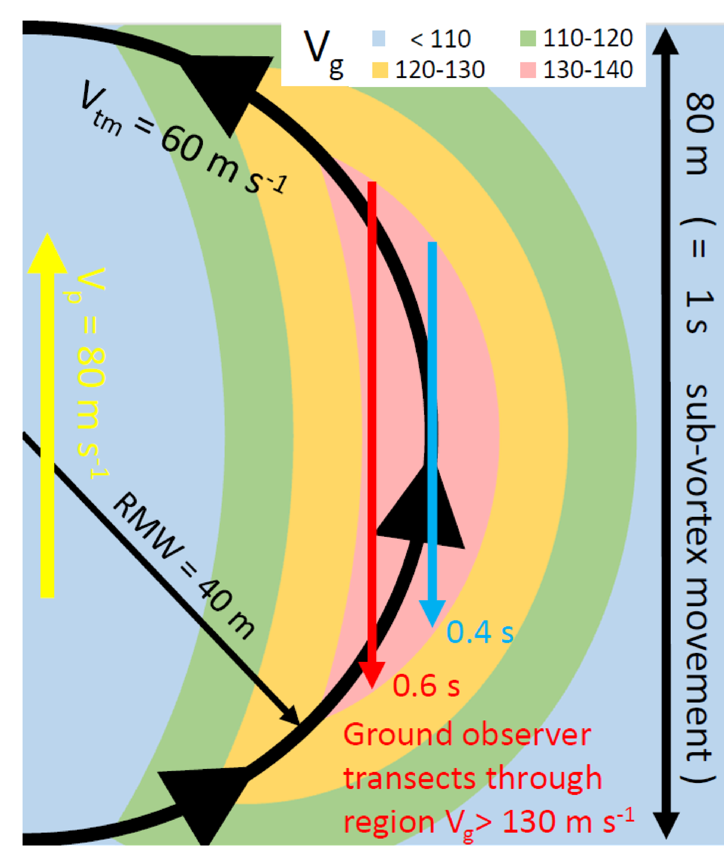
Above. El Reno tornado and anticyclonic tornado as observed by KTLX. Columns from left to right: Reflectivity (Z), Doppler Velocity (VEL), Differential Reflectivity (ZDR), and the cross-correlation coefficient (ρ_{hv}). Prominent vortices, including the large tornado/MVMC, visible internal vortices are outlined in yellow. Anticyclonic vortices, one of which is a tornado, in black. Stippled (Solid) lines indicate regions of interest in the ZDR (ρ_{hv}) field(s).



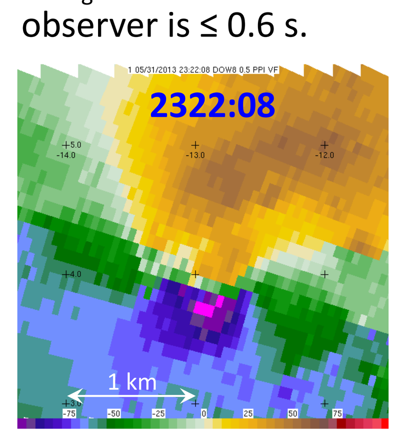
Above. Doppler Velocity (left) and Reflectivity (right). DOW sweeps at selected times illustrating path of sub-vortex which impacted Samaras research team. Red and black rings are schematic indications of region enclosing maximum winds. Times are HHMM:SS UTC. Blue ring (right panels) annotates widening debris ring echo (DRE). White/Black dots are start/end location of vehicle. Beginning at ~2323:32, vehicle was transported south, then east about southern side of the sub-vortex.



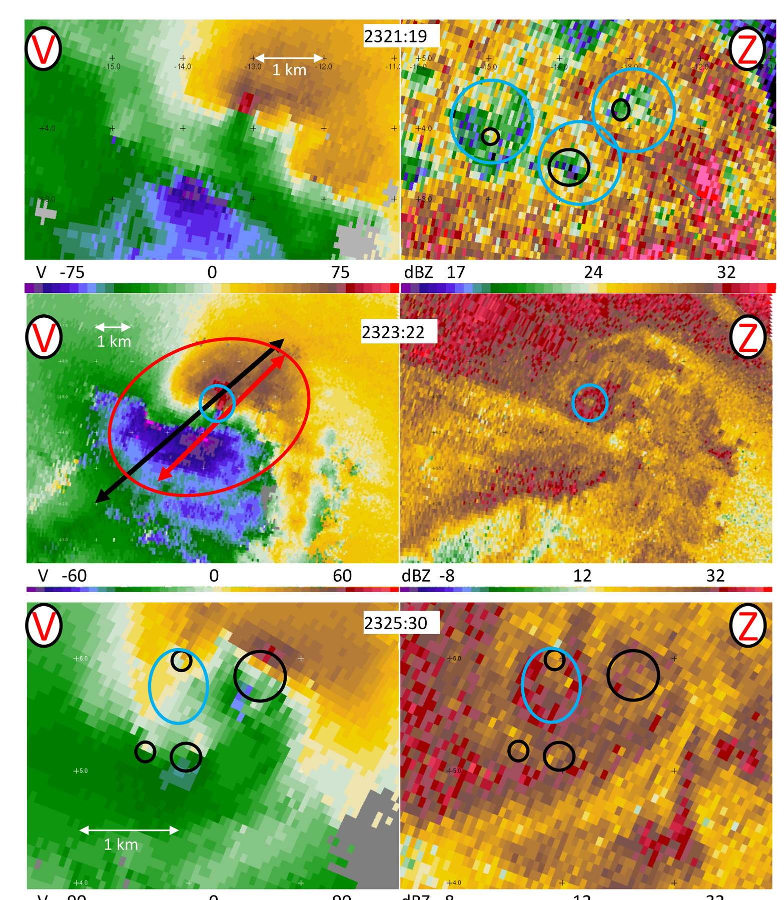
Above. Smoothed track of interior sub-vortex as measured by the Rapid-Scan DOW. Yellow line is approximate center of circulation. Red and black circles delineate, at selected times, the approximate region enclosing the maximum tangential velocity, V_{tm}. Blue boxes label selected times along the track in HHMM:SS UTC. Red (blue) dots represent start (end) locations of the Samaras team's vehicle. Green circles delineate vortices impacting the same area shortly afterwards. The vortex loops at 2321:34, moves rapidly east-northeast from 2322:00 until 2323:00, then more slowly north-northwestward, becoming stationary over Reuters road and the vehicle, then moves east-northeastward again.



Above. Schematic of strong V_g side of rapidly moving sub-vortex. Very fast V_p = 80 m s^{-1}, adds to peak tangential winds V_{tm} = 60 m s^{-1}, at and near the radius of maximum winds resulting in peak V_g = 140 m s^{-1}. However, due to very fast V_p, the duration of V_g > 130 m s^{-1} over a stationary object or observer is ≤ 0.6 s.



Left. Doppler velocity (RSDOW) 120m AGL during time of peak area >90 m s^{-1} (darkest blue to magenta) not in a sub vortex. Some points could have experienced >90 m s^{-1} for >15s.



Above. Doppler Velocity (left) and Reflectivity (right). (top) strong vortices, exterior vortex, with LRE and DS/DRE signatures (blue rings). (middle) Large along-track width of 30 m s^{-1} and 50 m s^{-1} radar winds, ~ 2km diameter circulation and strong interior vortex. (bottom) several sub-vortices. Blue rings schematically illustrate debris ring echoes (DRE). Black rings denote velocity signatures of sub-vortices.

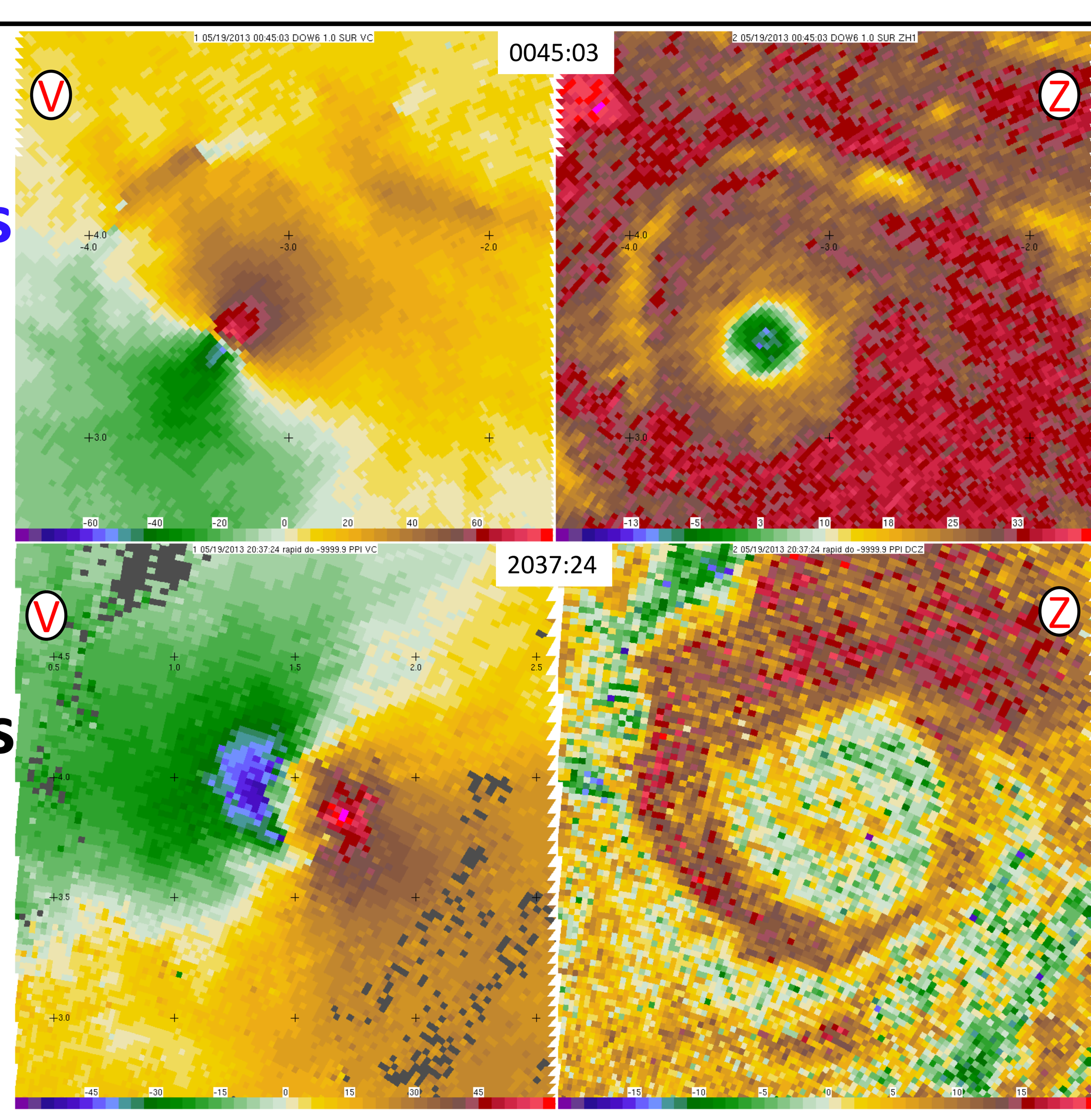
Wurman, J., K. A. Kosiba, P. Robinson, and T. Marshall, 2013: The Role of Multiple Vortex Tornado Structure in Causing Storm Researcher Fatalities. Accepted to *Wea. and Forecasting*.

Rozel, KS: EF-4*

DOW-Measured winds of 78-83 m/s

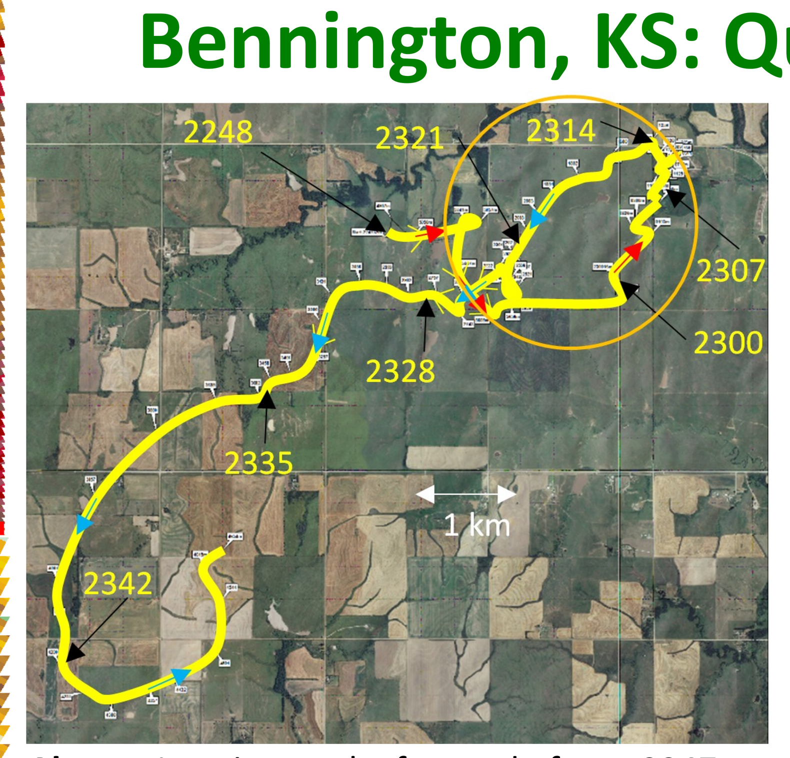
Wichita, KS: EF-2*

DOW-Measured winds of 60-64 m/s

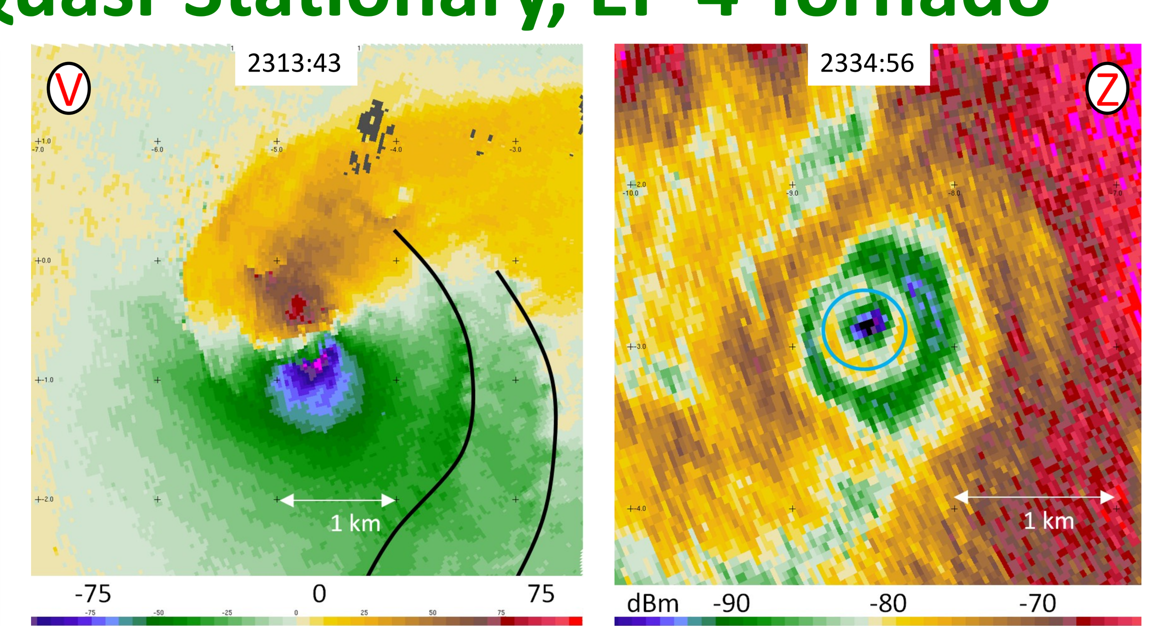


*DOW-Influenced Preliminary Ratings

Bennington, KS: Quasi-Stationary, EF-4 Tornado



Above. Looping track of tornado from 2247-2347 UTC. Tornado formed before 2247, but DOW-based locations are less precise since the DOW was in motion. Tornado was nearly stationary from 2308-2313, moving less than 80 m over 300 s, and traced multiple loops during that and other periods, remaining within a 2.5 km diameter circle (orange) for 2000 s.



Above. Doppler Velocity (left) and Received Power (right)showing Discontinuous debris ring echo (DRE) as tornado passes over region with trees, in Bennington, Kansas tornado on 28 May 2013. Winds exceeded 118 m s^{-1} at 47 m AGL. Black lines indicate two RFD surges.

Analysis supported by NSF-ATM-1211132
DOWs supported by NSF-ATM-0734001