The Fluid Dynamics of Tornadoes

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Lecture 1: Tornado Observations

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A tornado is a rapidly rotating column of air that occurs in association with a cumuliform cloud.

Tornado Damage

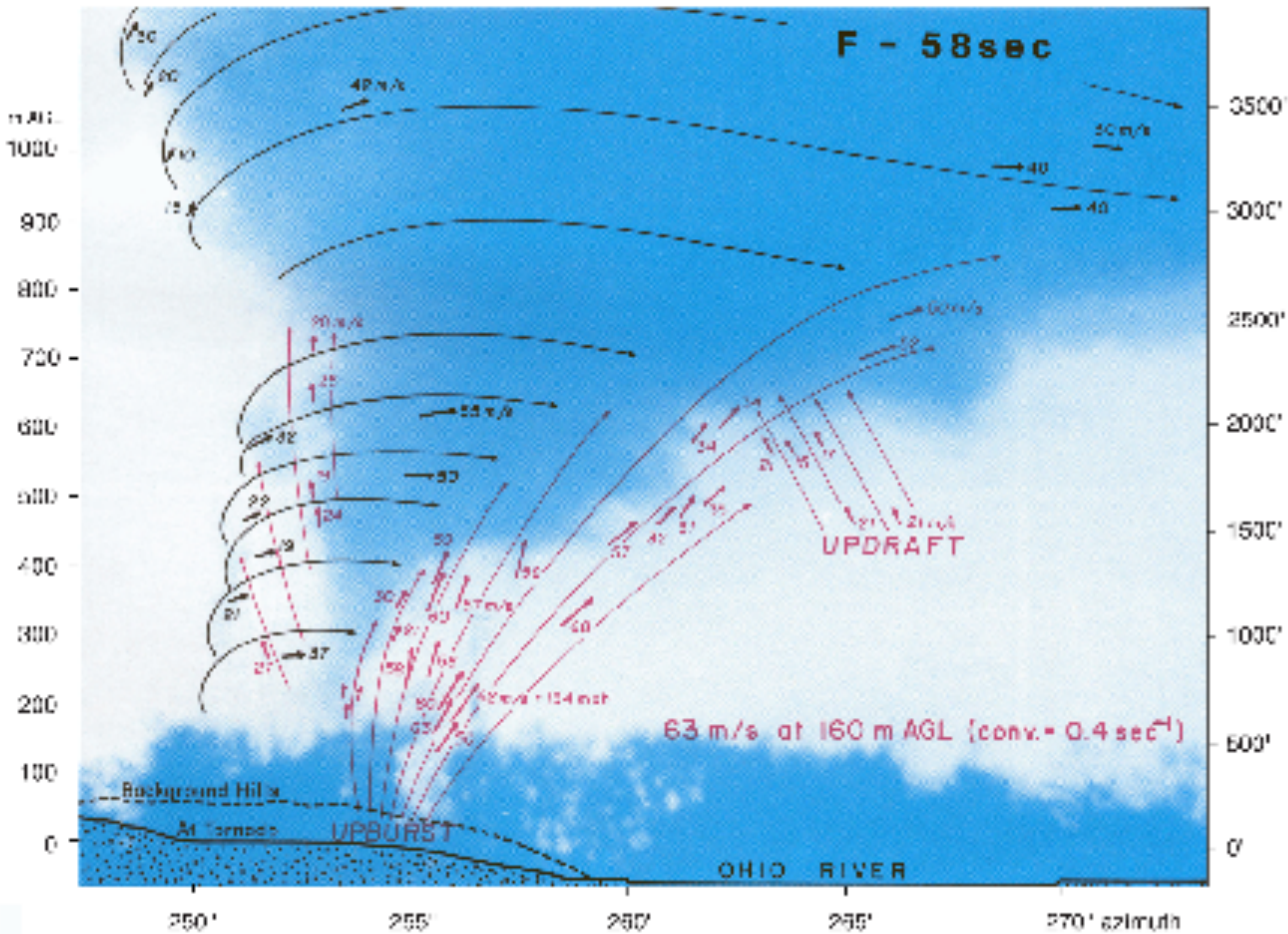
Moore, OK
May 3, 1999

flying cow

chicken without feathers

Old methods for inferring tornado wind speeds

Photogrammetric Analysis of Tornado (Saylor Park, OH, 3 April 1974)



Fujita (1992, U Chicago Tech Report)

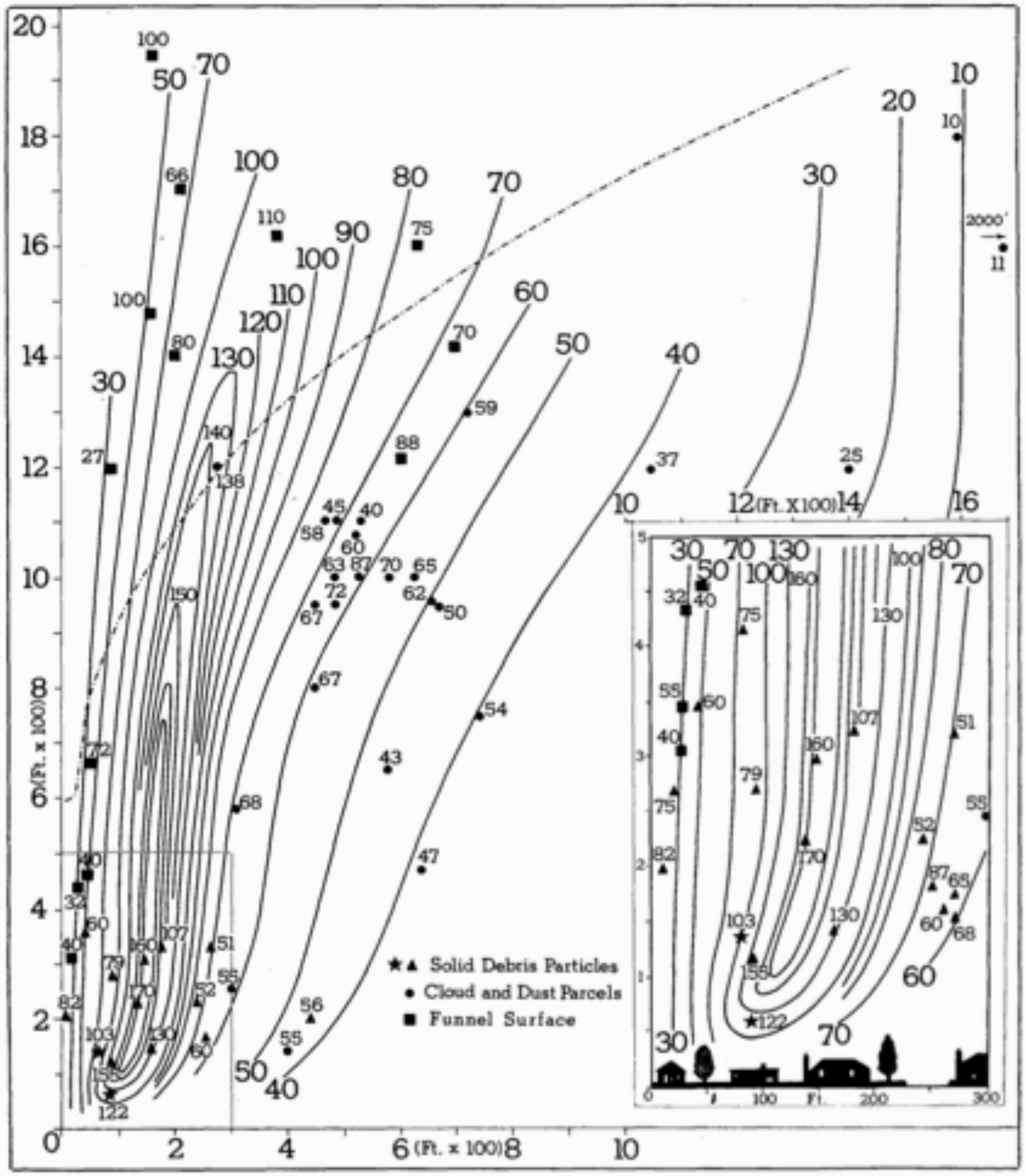


FIGURE 2.—Distribution of derived tangential speed from the center of the tornado to a radius of 2000 ft. and from near the ground to about 1800 ft. in elevation.

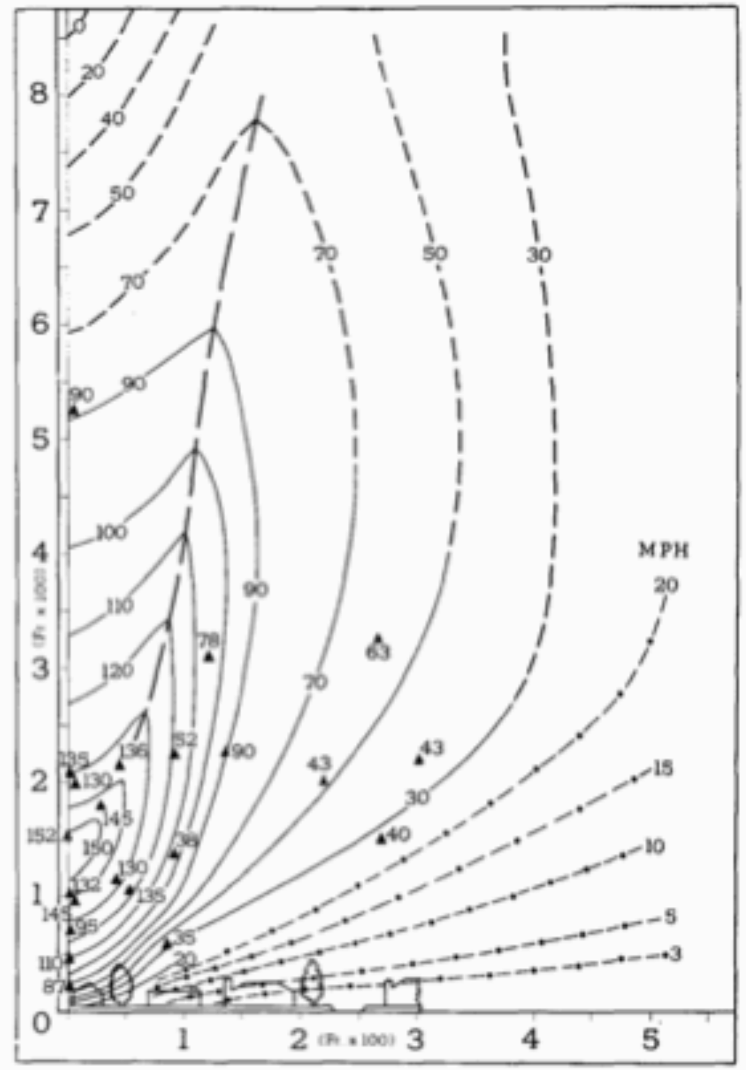


FIGURE 6.—Detailed version of distribution of upward speeds. Only the lower 900 ft. and the inner 500 ft. are shown.

1000 ft =305m , 100 mph = 45 m/s

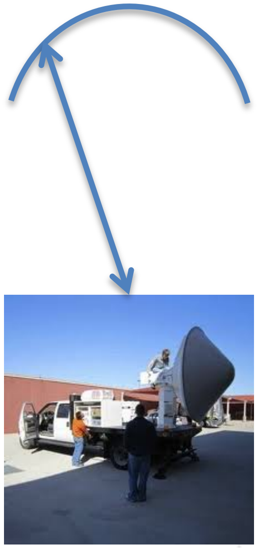
Hoecker 1960

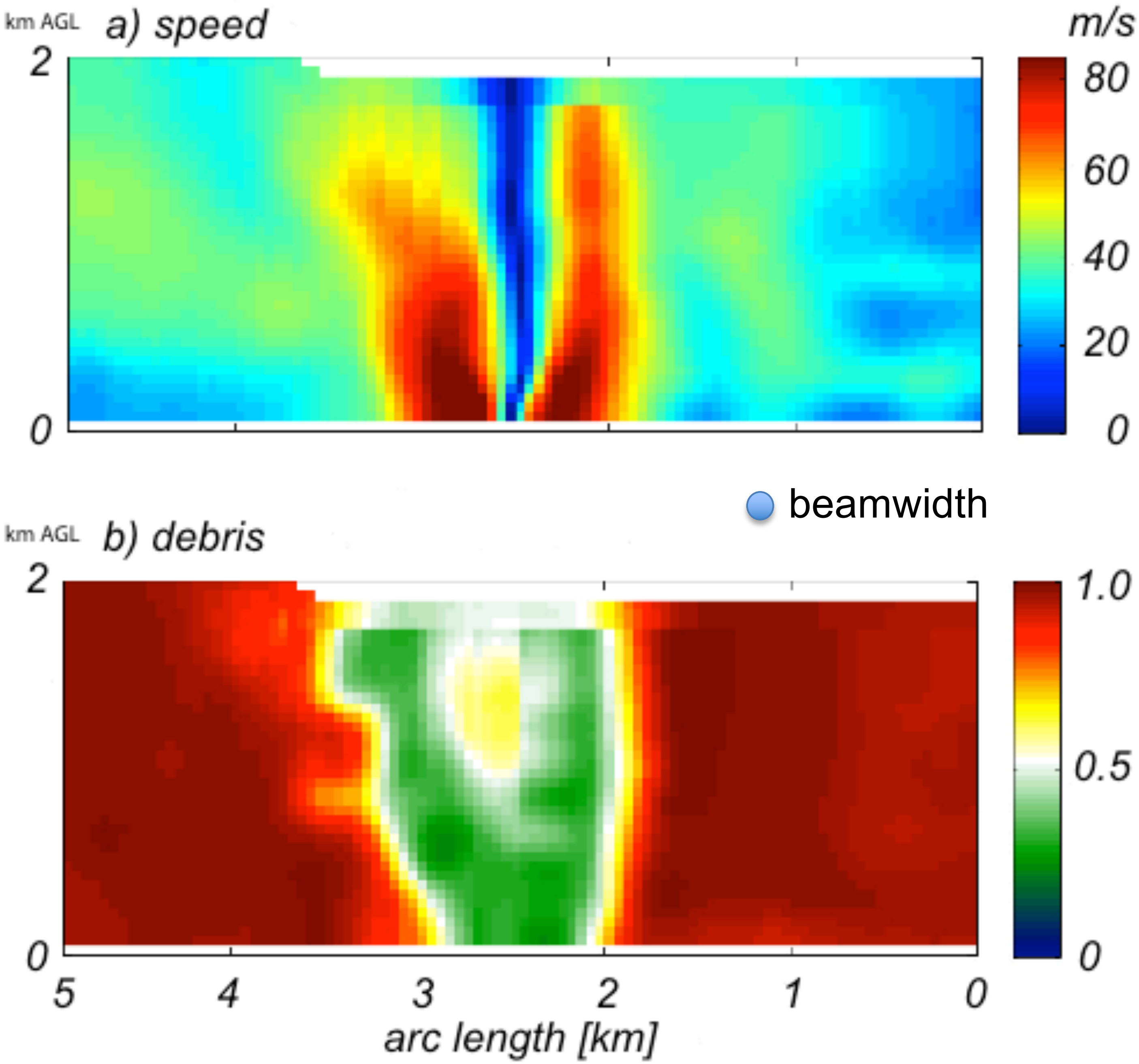
Dallas tornado 2 April 1957

Mobile Doppler Radar

Wurman et al. (1997, *JAOT*)

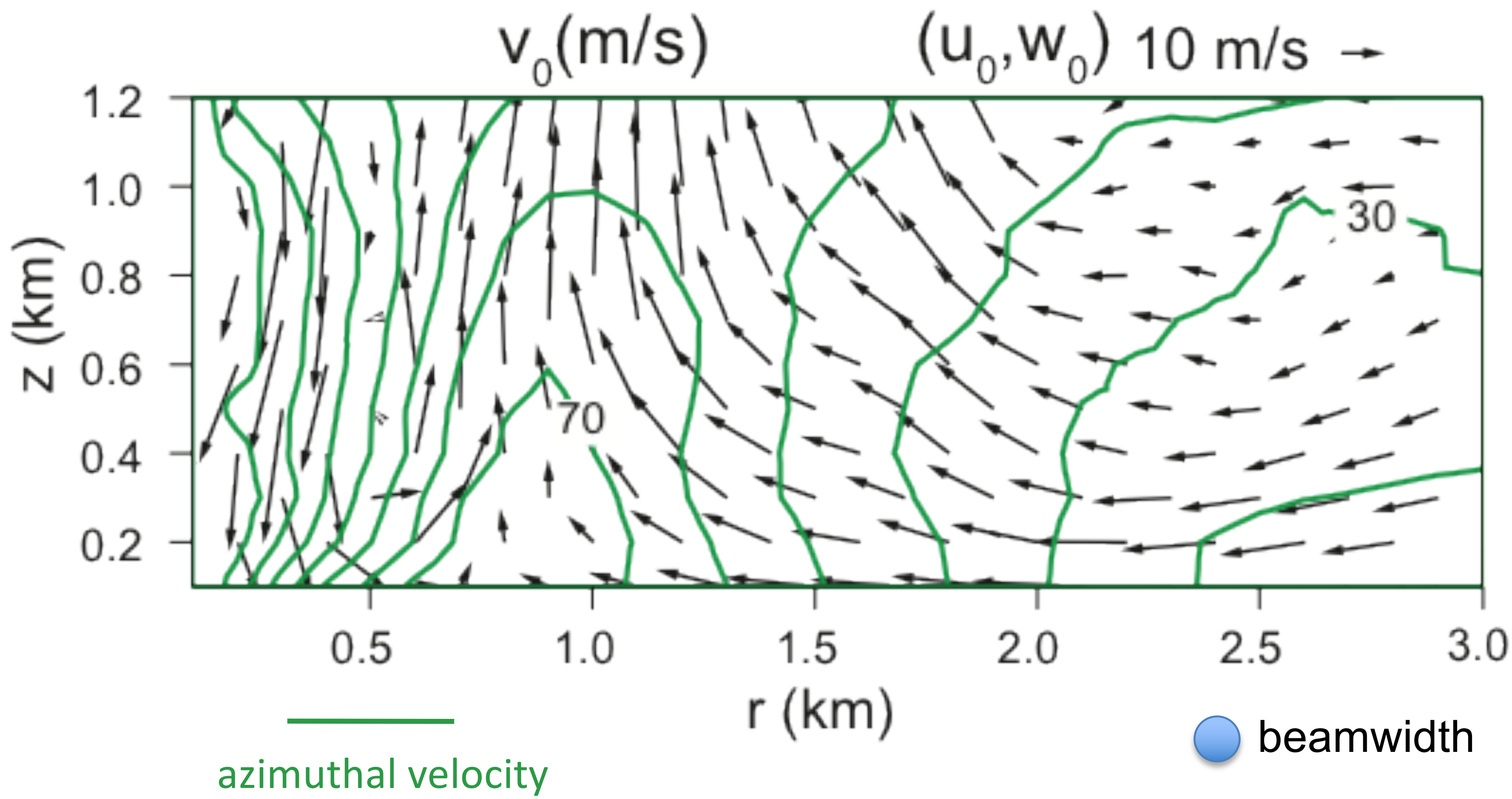
Mobile Doppler-Radar Observations of Tornado (El Reno, OK, 24 May 2011)





Courtesy J. Hauser and H. Bluestein

Analysis of Axisymmetric Components of Tornado Velocity from Doppler on Wheels (Mulhall, TX, 3 May 1999)

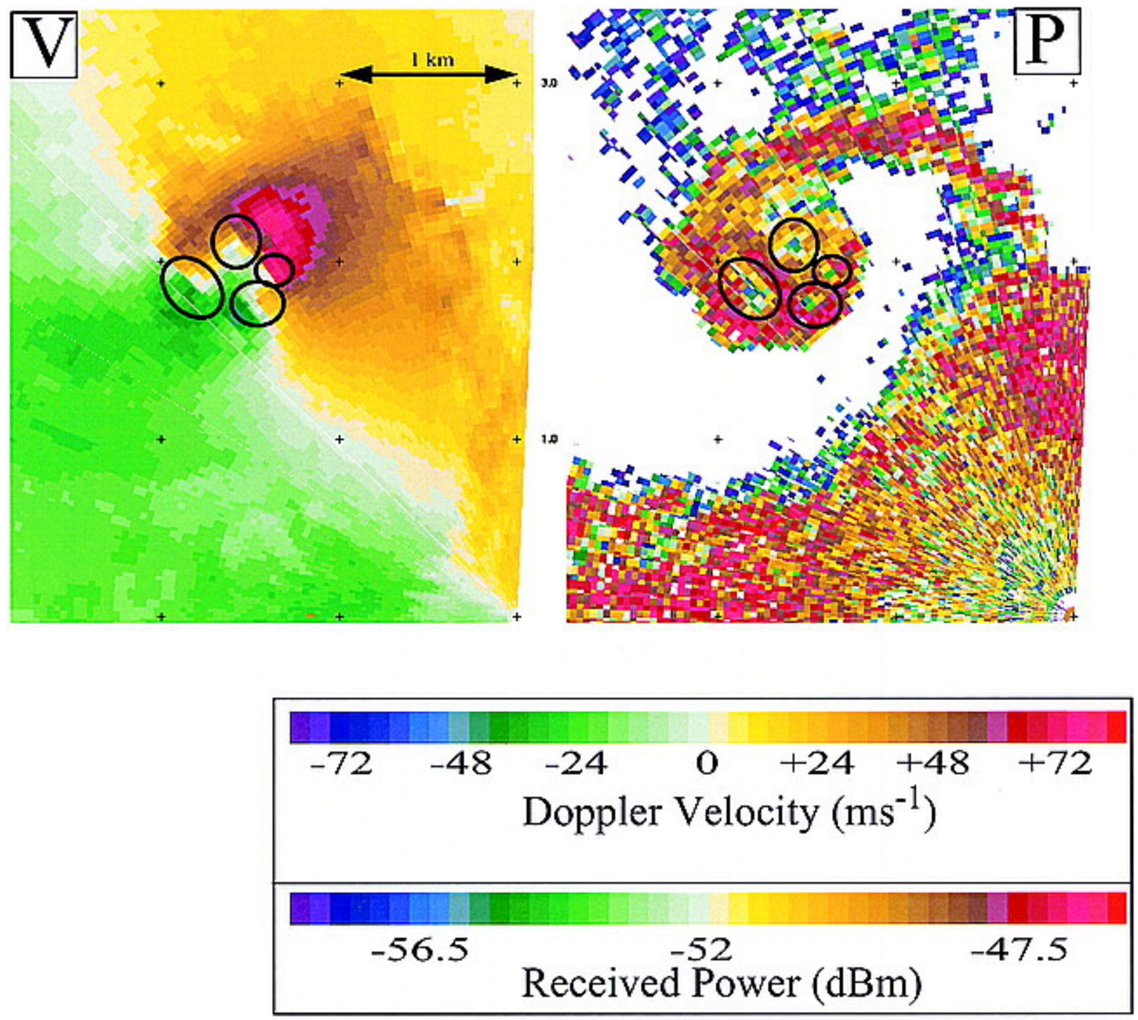


Adapted from Lee & Wurman (2005, *JAS*)

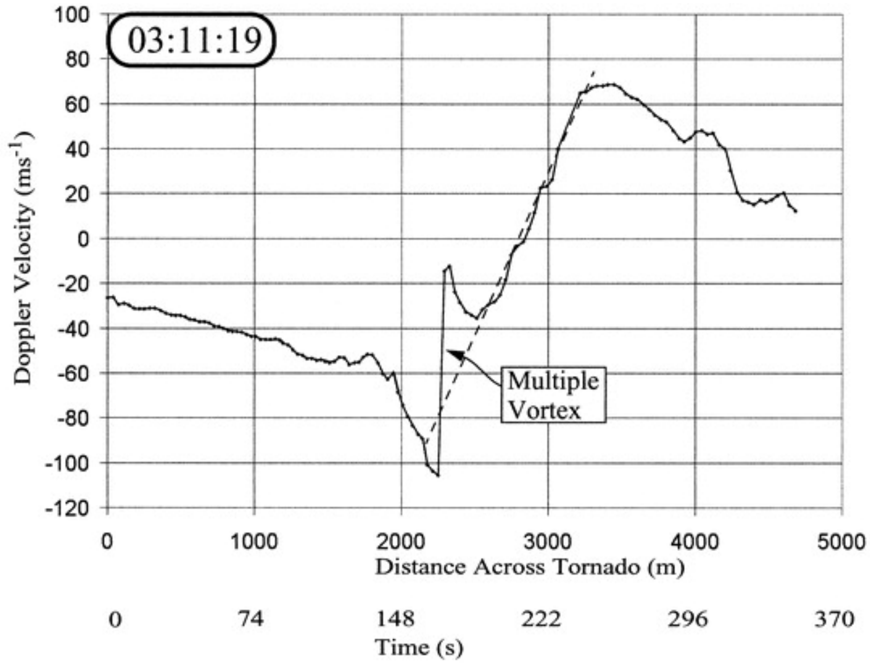
Multiple-Vortex Tornado

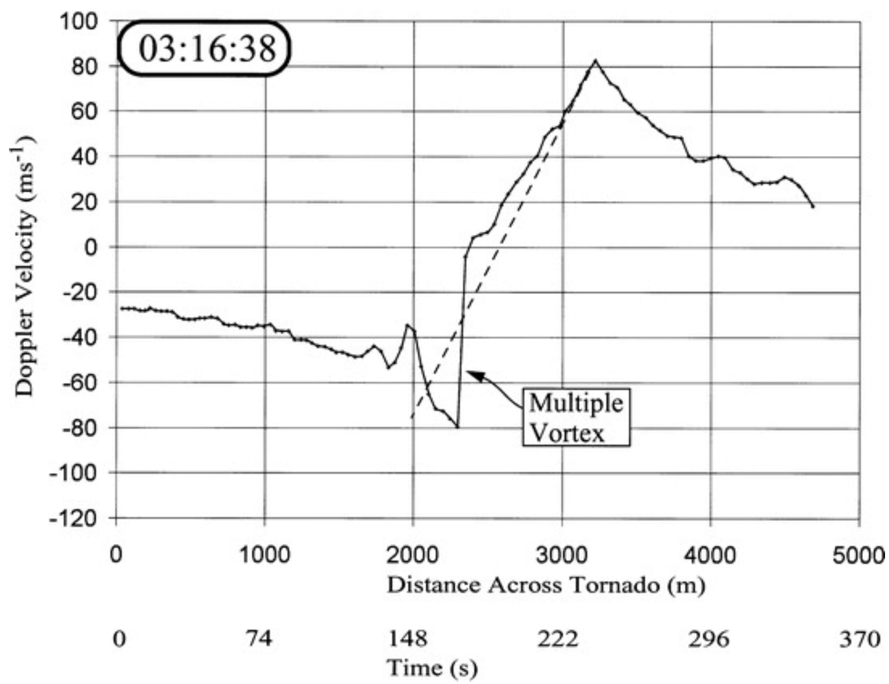
Photo by H. Bluestein

Doppler Velocity & Reflectivity



Wurman (2002, *WAF*)





Wurman (2002, *WAF*)

Doppler-Derived Tornado Statistics

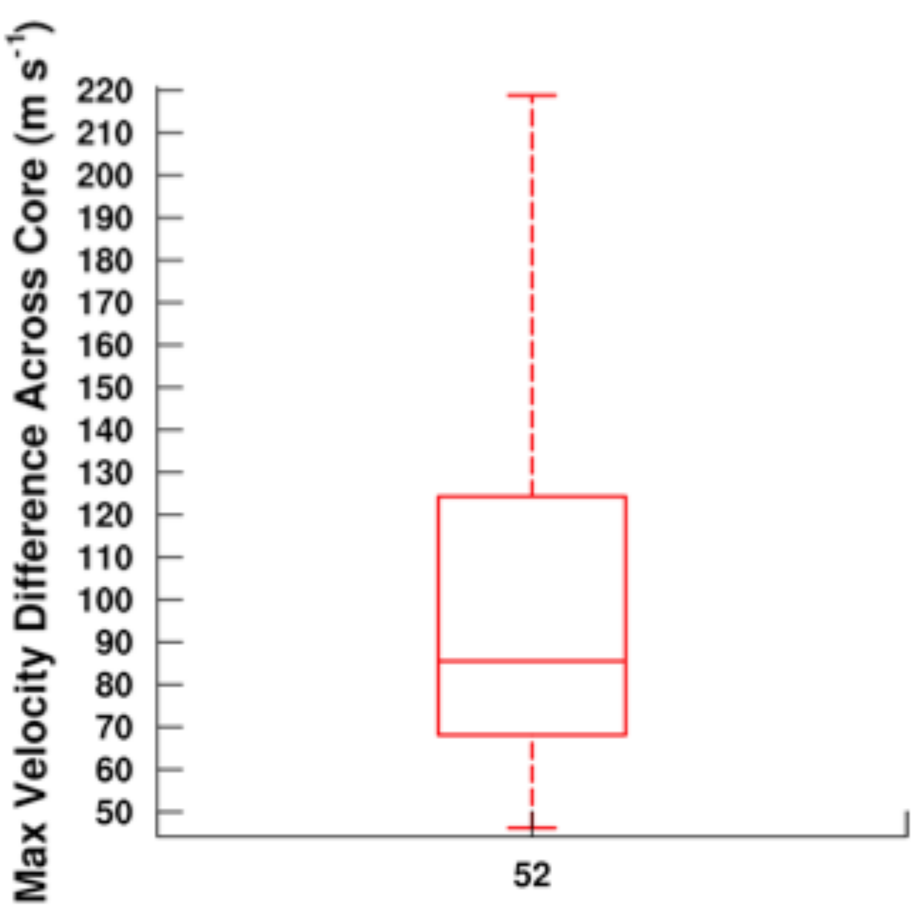


Fig. 5. Distribution of the maximum velocity difference in 52 tornadoes as observed by the DOWs below 500 m AGL showing minimum, 25th percentile, median, 75th percentile and maximum values.

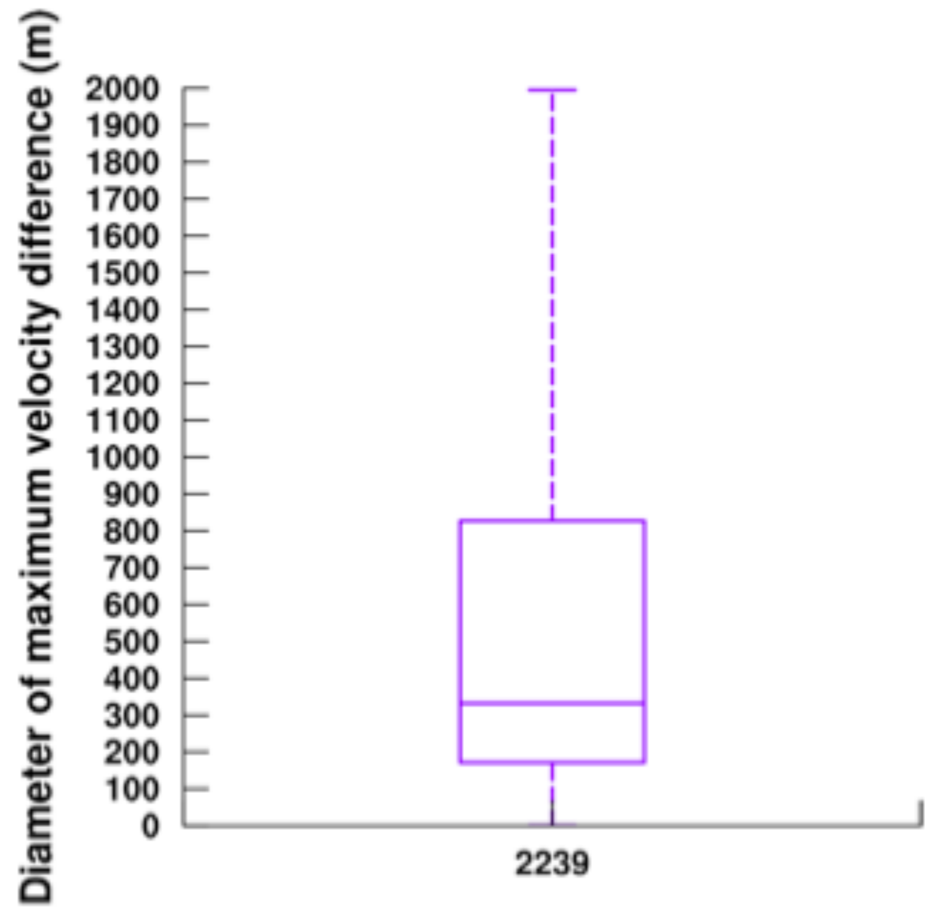


Fig. 4. Distribution of tornado core diameters as observed by the DOWs showing minimum, 25th percentile, median, 75th percentile and maximum values for 2239 scans below 500 m AGL.

Alexander&Wurman (2008, 24th *Conf SLC*)

Doppler-Derived Tornado Statistics

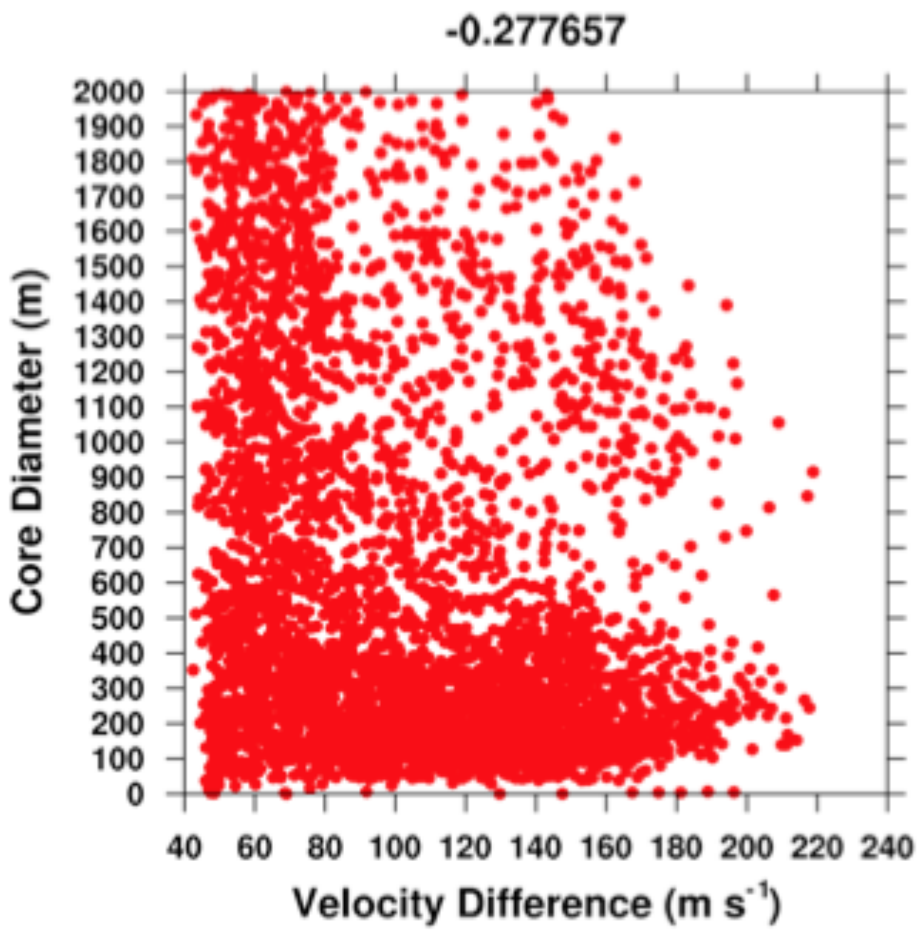


Fig. 11. Scatter plot of the DOW-observed velocity difference when paired with the diameter of the velocity difference for all scans across 69 tornadoes. The R-squared value is shown above the plot.

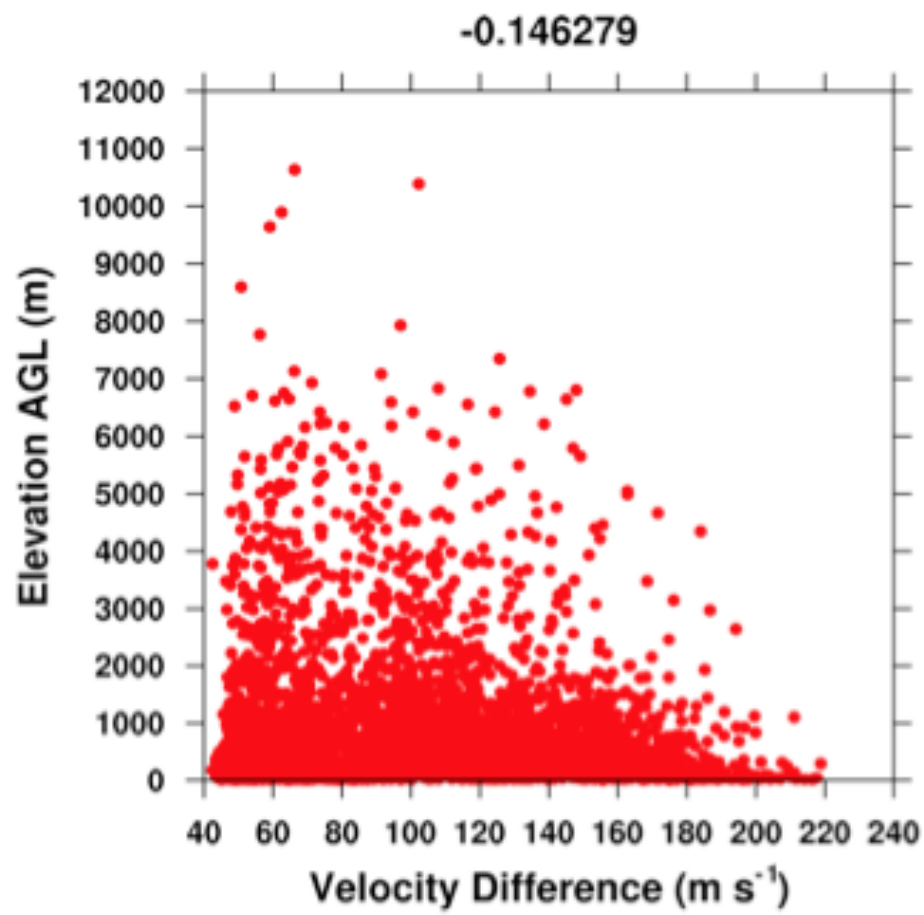
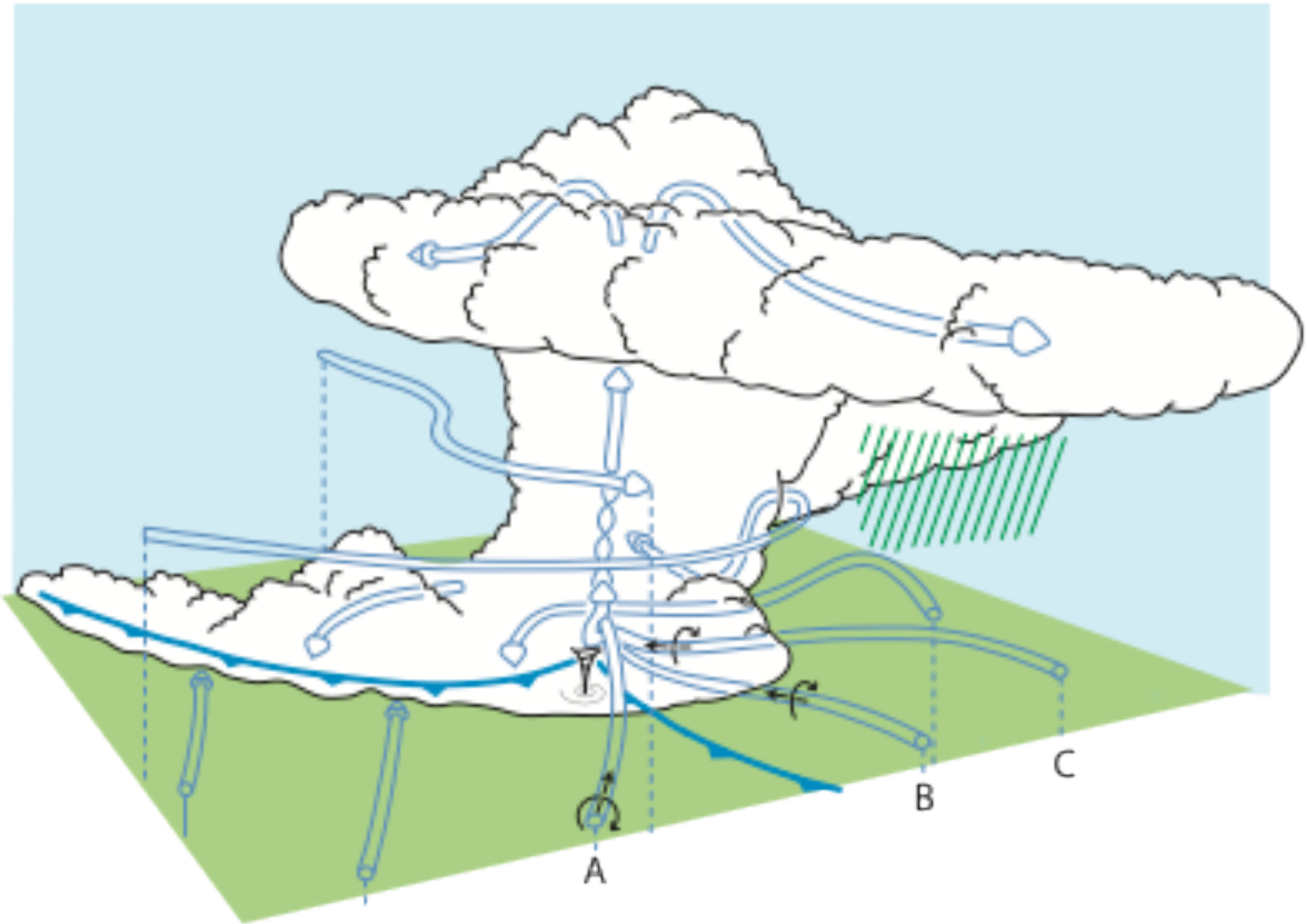


Fig. 12. Scatter plot of the DOW-observed velocity difference when paired with the elevation of the velocity difference for all scans across 69 tornadoes. The R-squared value is shown above the plot.

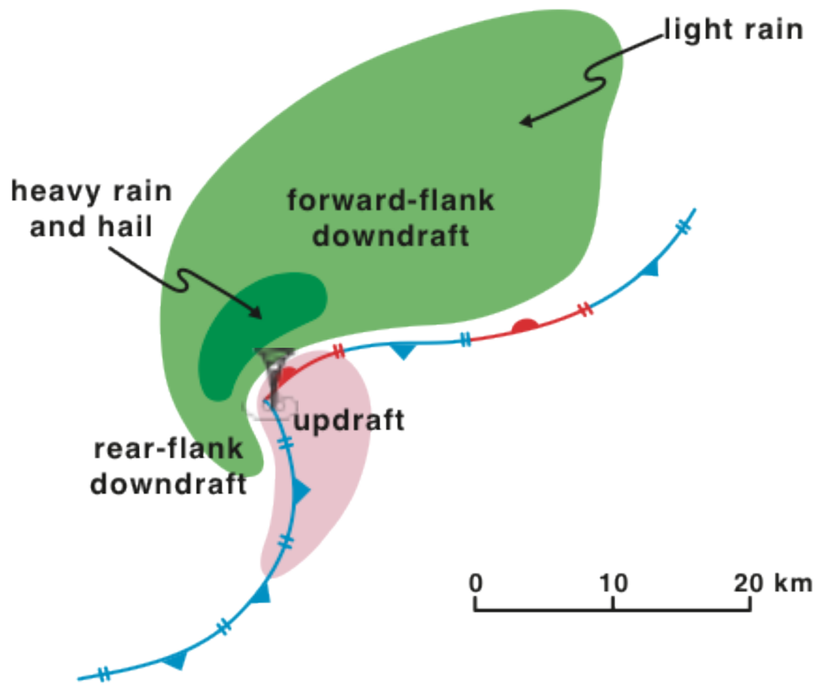
Alexander&Wurman (2008, 24th *Conf SLC*)

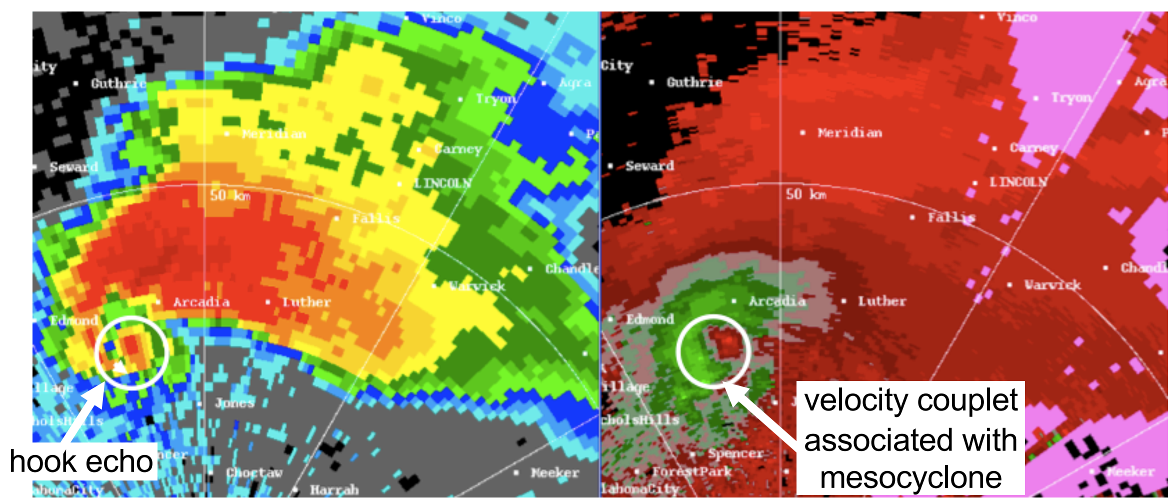
Supercell Thunderstorm with Tornado



Adapted from Klemp (1987, *Ann. Rev. Fluid Mech.*)

Supercell Surface Features



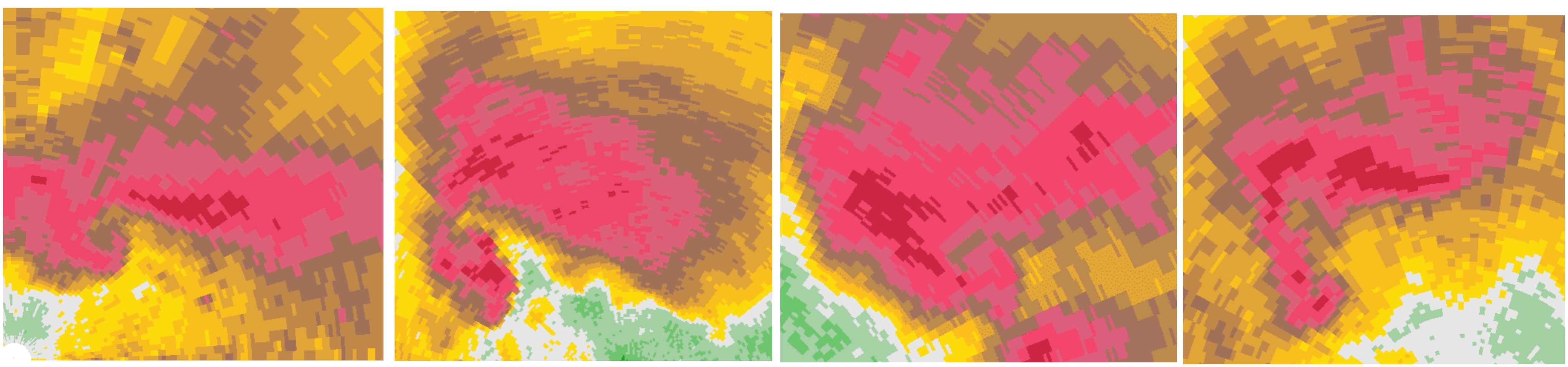


Outstanding Research/Operational Issue

Although most significant tornadoes are associated with supercell thunderstorms, most supercells are *not* tornadic

Radar Reflectivity

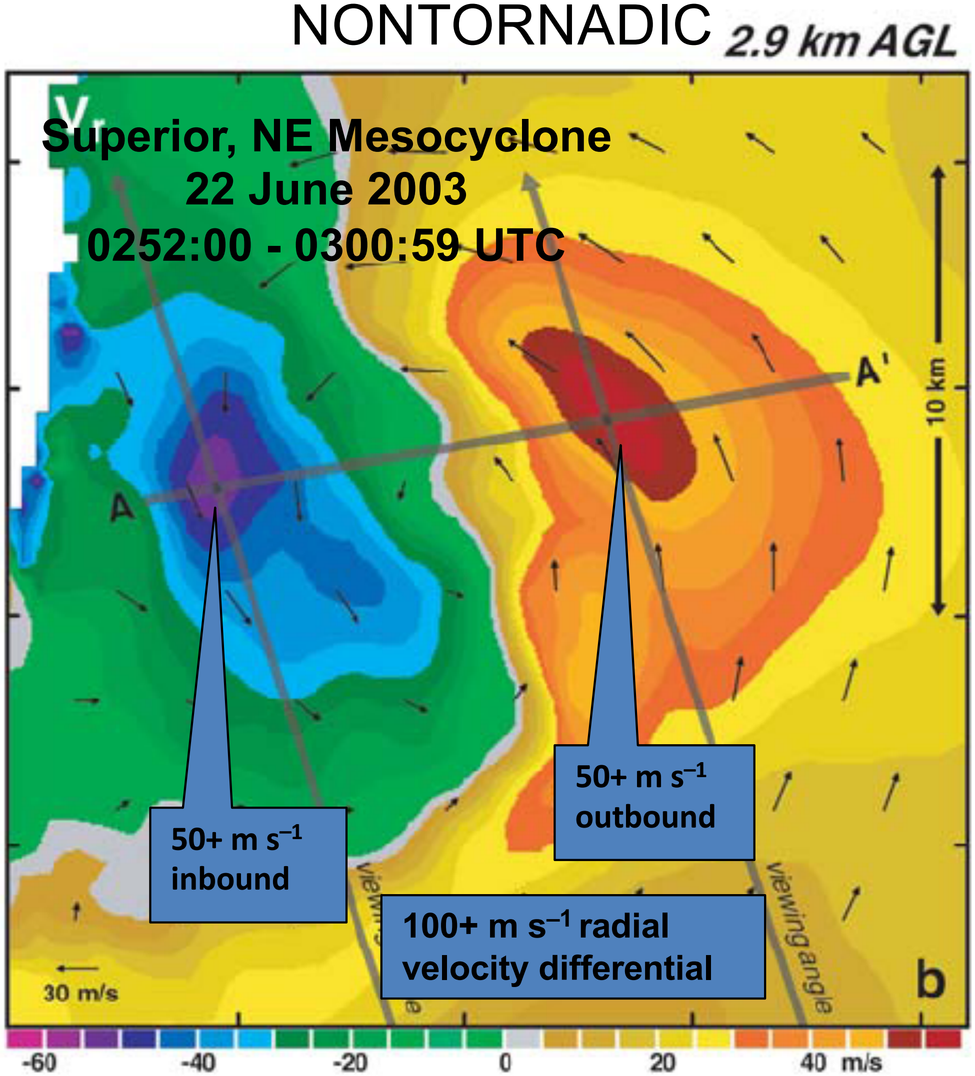
nontornadic ***nontornadic*** ***tornadic*** ***nontornadic***



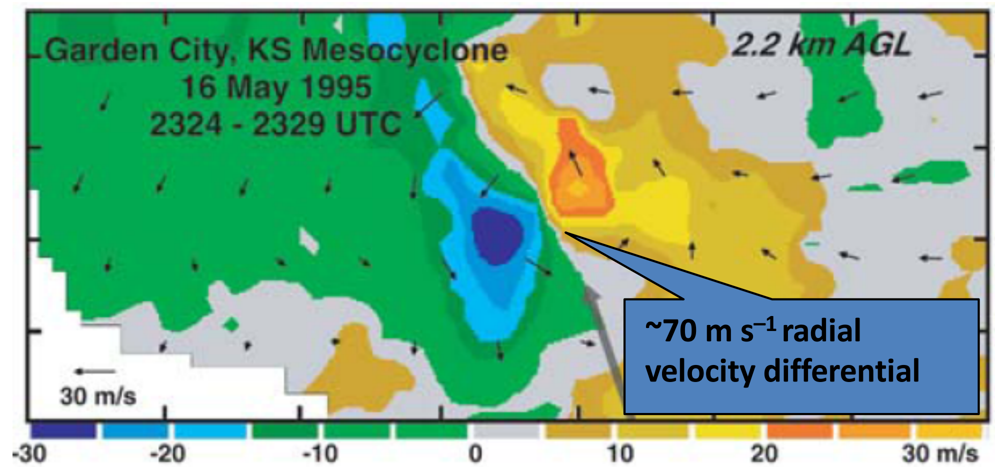
Outstanding Research/Operational Issue

spatial scales are the same in all 3 images

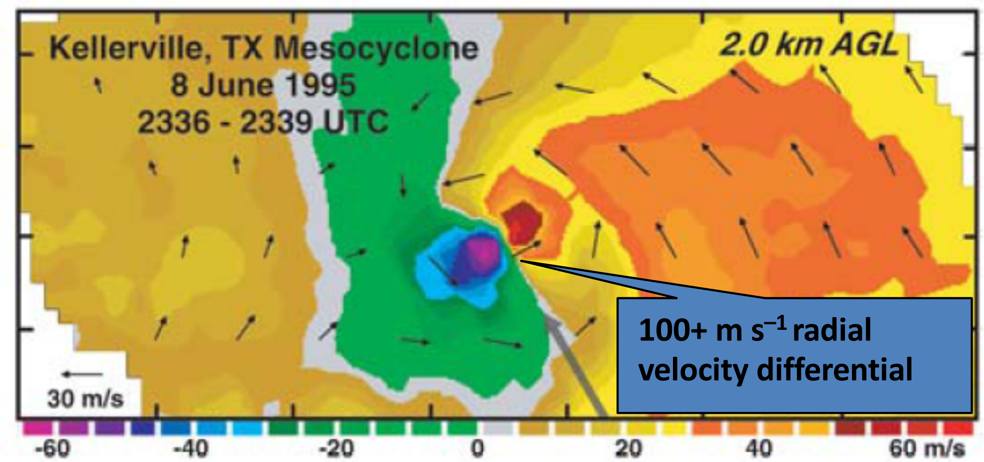
NONTORNADIC



TORNADIC

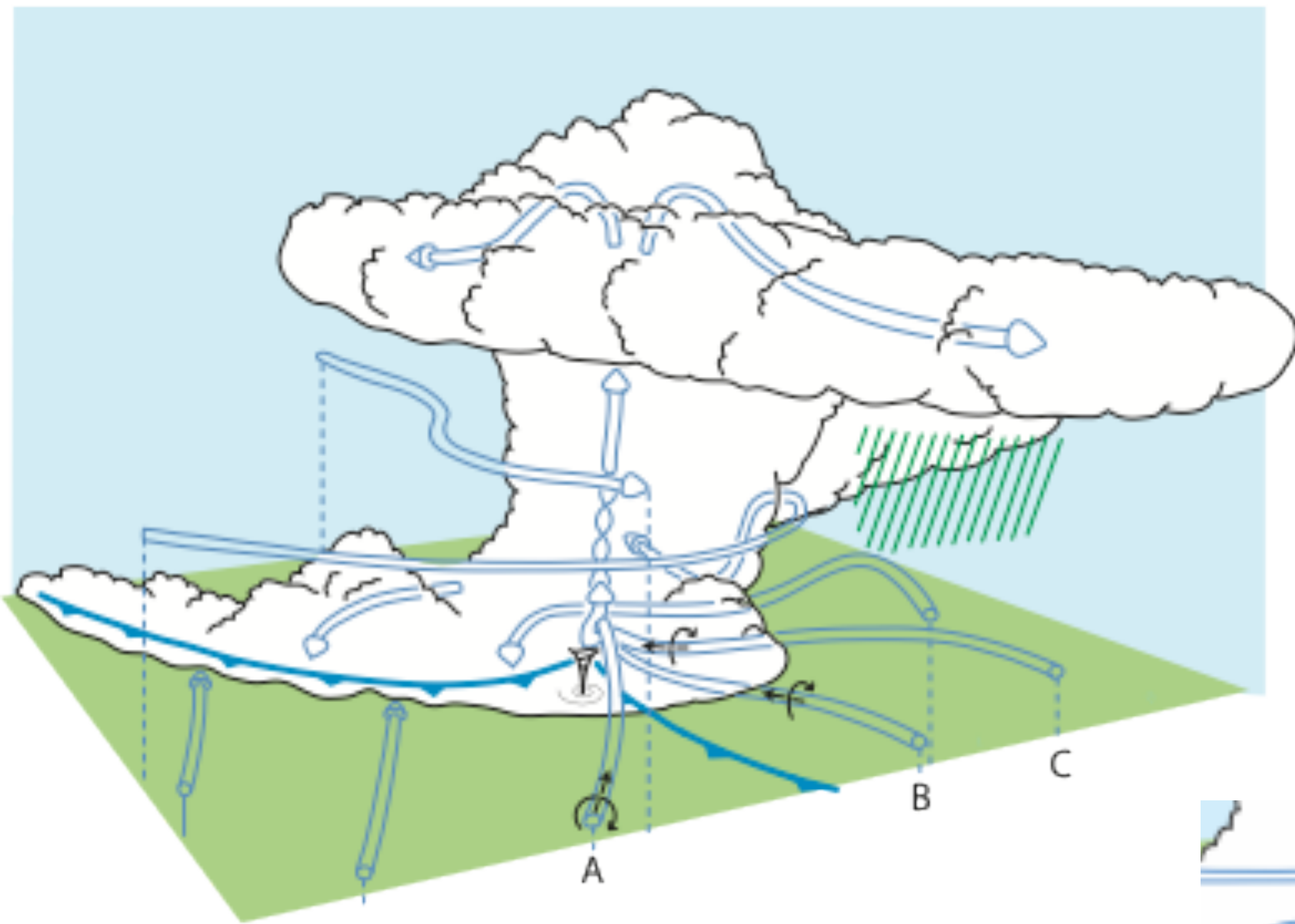


TORNADIC



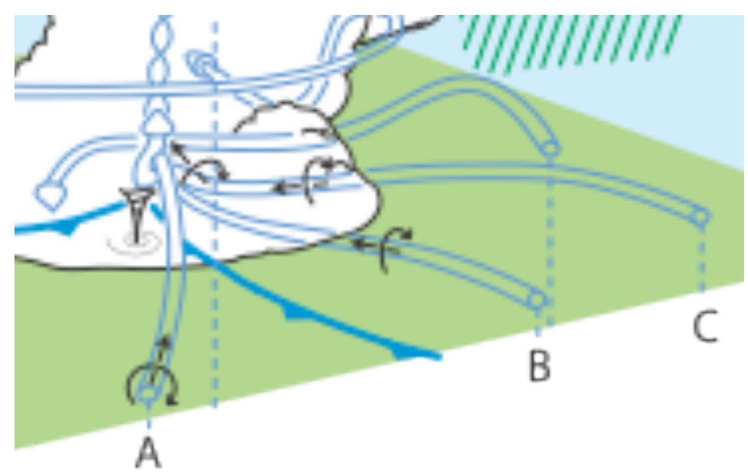
Wakimoto et al. (2004)

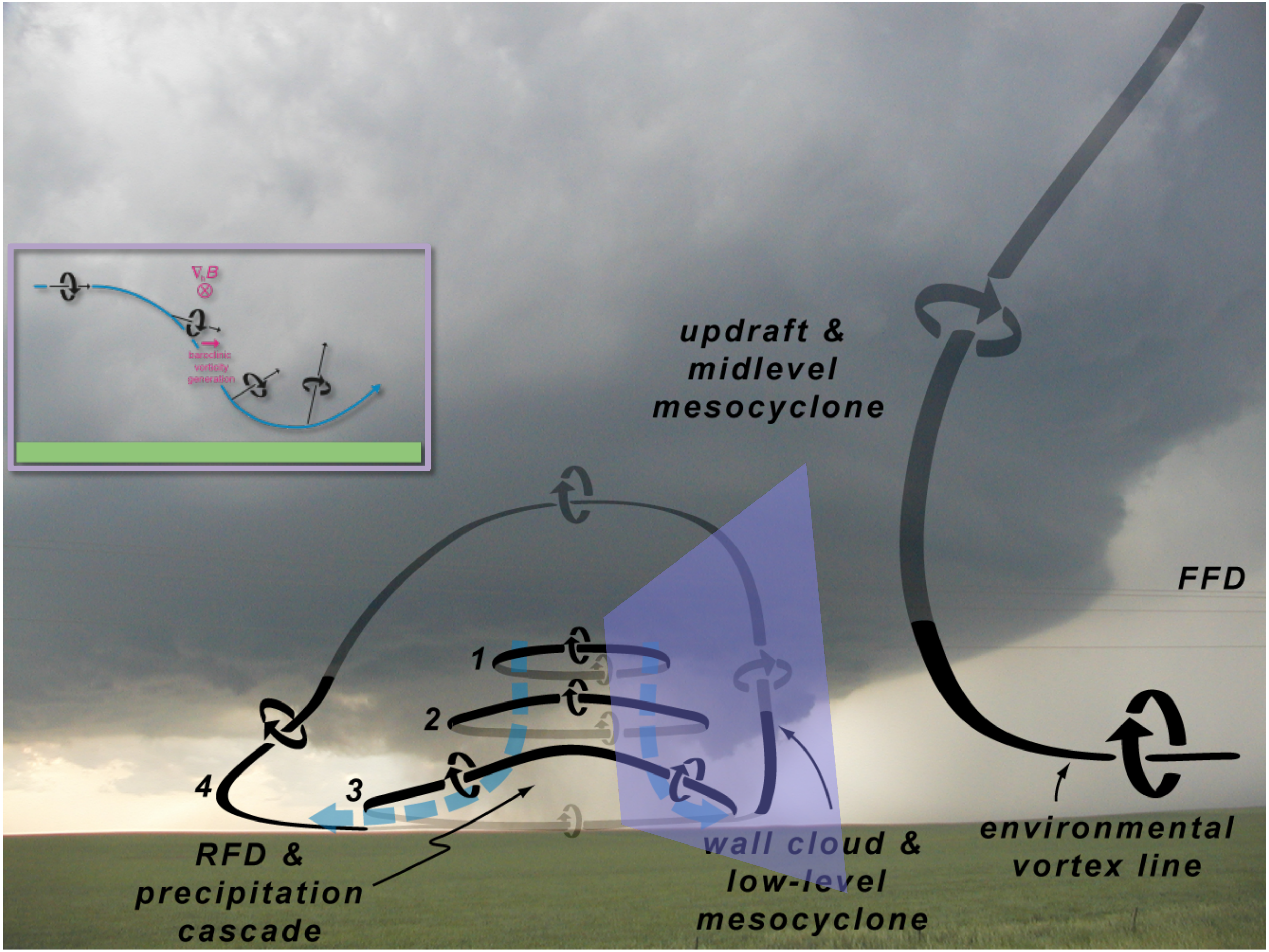
Low-Level Rotation



Rotunno&Klemp(1985) : "…as the air approaches from the northeast, it first acquires horizontal vorticity directed towards the southwest from baroclinic generation along the cold air boundary. The horizontal vorticity is then tilted upward to produce cyclonic vertical vorticity as the air encounters the updraft."

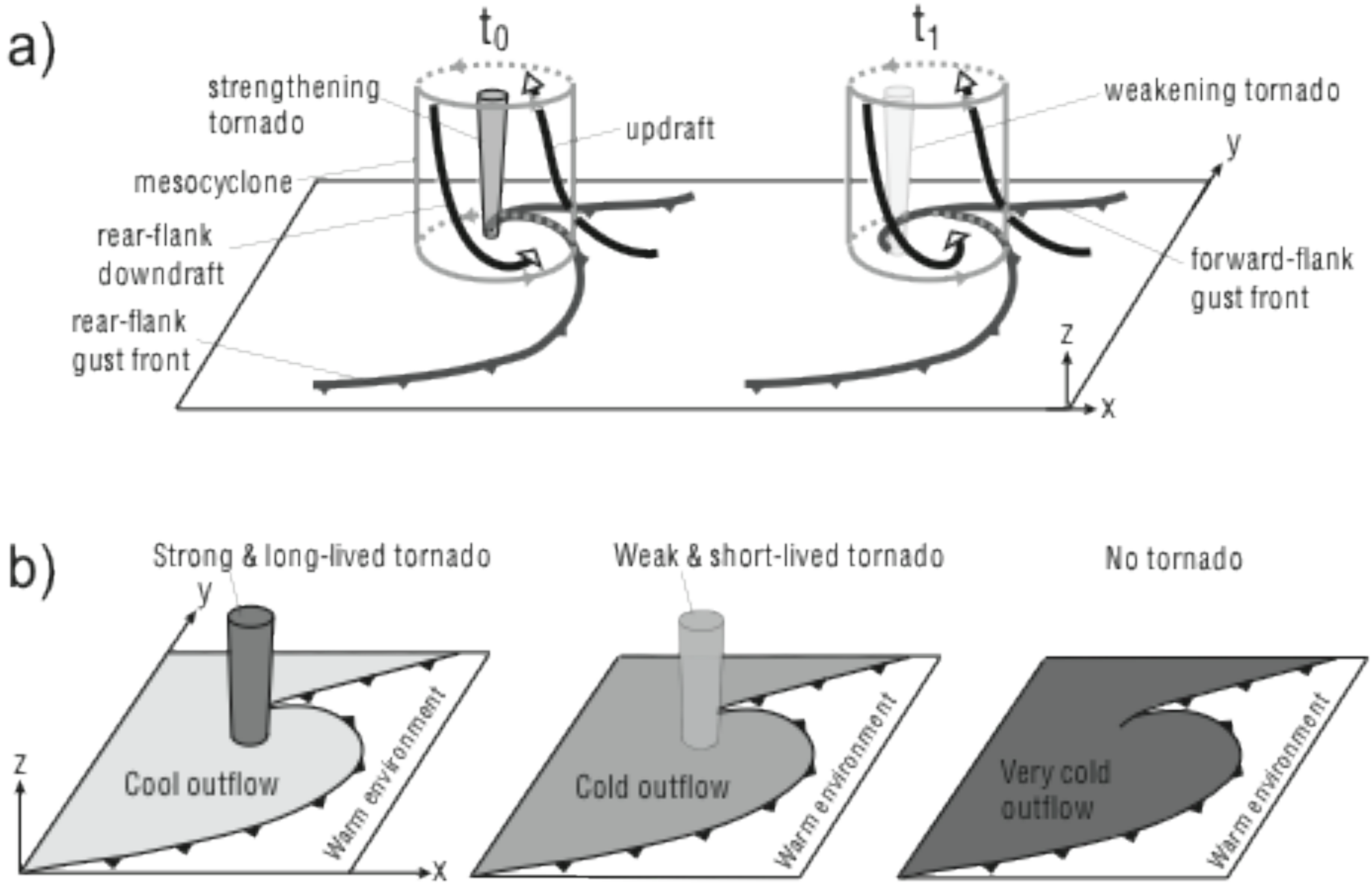
Davies-Jones & Brooks (1993): "…the horizontal vorticity generation forcing introduces 'slippage' between the (descending) fluid and vortex lines…"





Markowski, P. M., J. M. Straka, E. N. Rasmussen, R. P. Davies-Jones, Y. Richardson, and J. Trapp, 2008: Vortex lines within low-level mesocyclones obtained from pseudo-dual-Doppler radar observations. *Mon. Wea. Rev.*, **136**, 3513–3535.

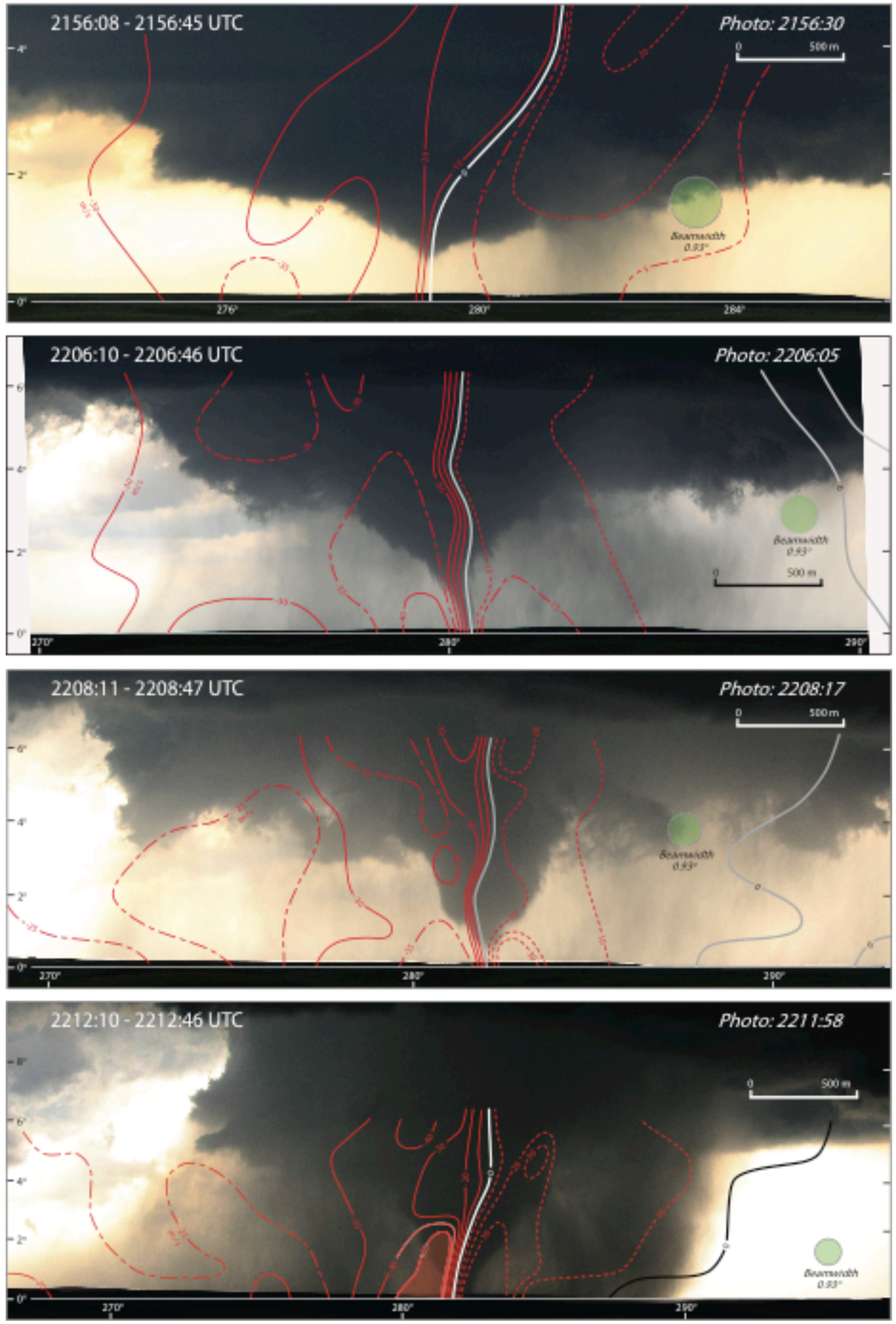
Tornadoes at the Cool-Air Boundary in a Supercell



Adapted from Marquis et al (2012, *MWR*)

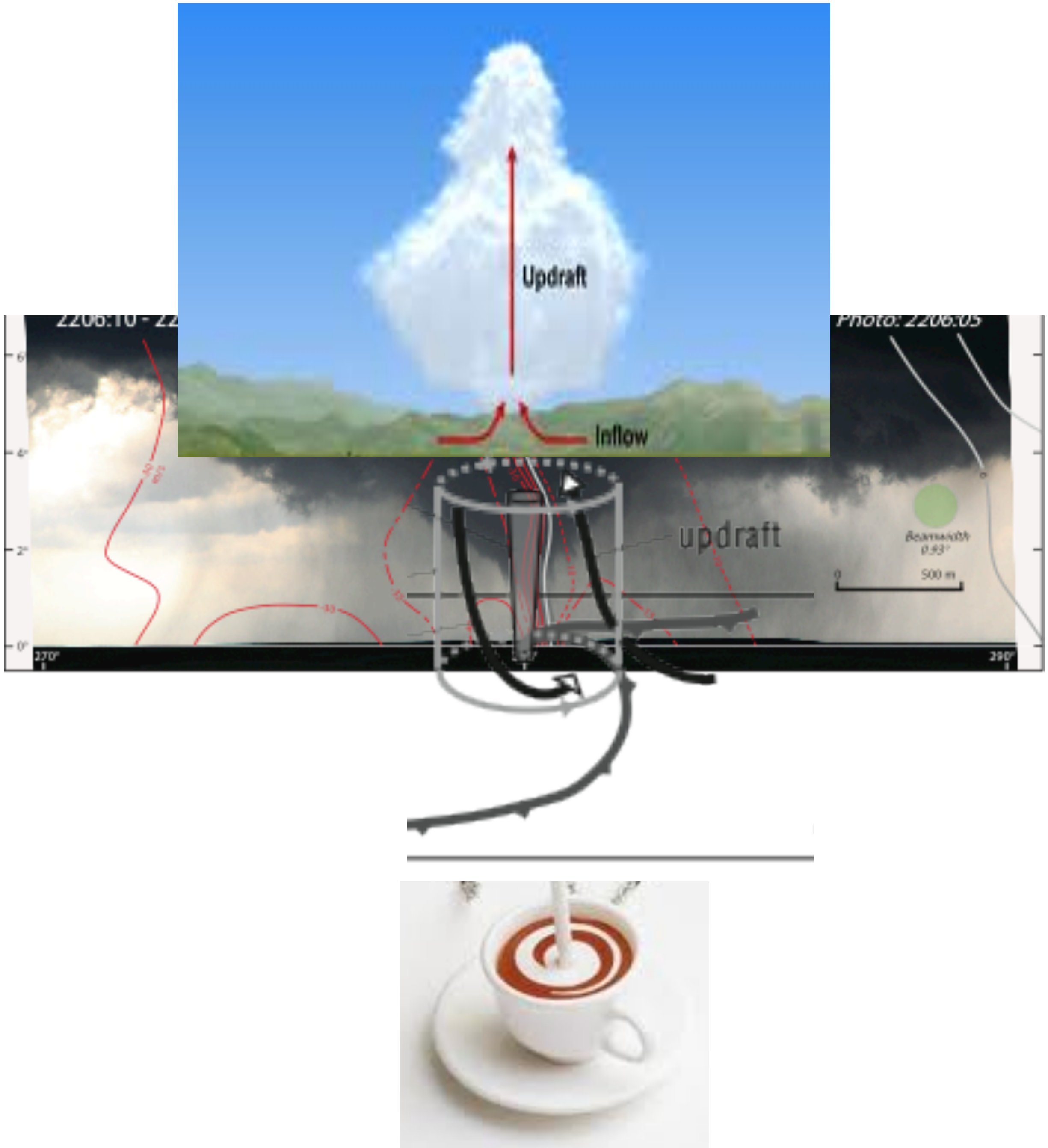
Tornadogenesis in a Supercell (LaGrange, WY, 5 June2009)

Visual +
Doppler on Wheels

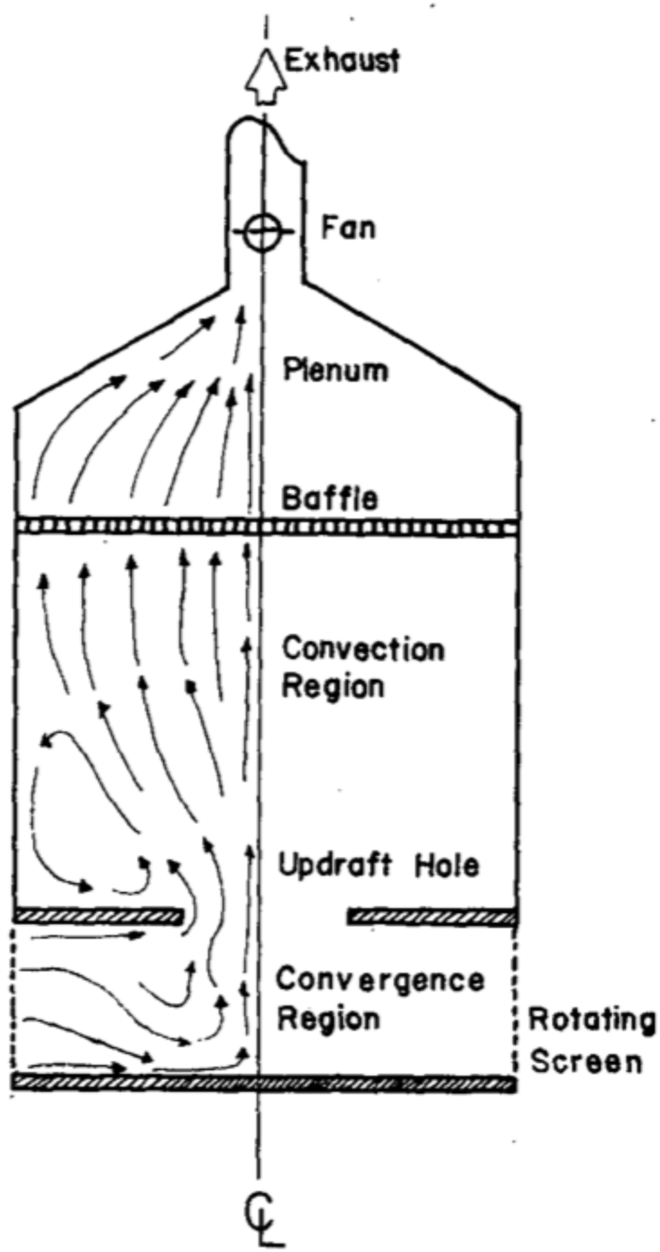


Adapted from Wakimoto et al (2011, *MWR*)

Idealization for Tornado Study



Tornado Vortex Simulation



Tornado Observations Summary

1. Intensity
2. Structure
3. Supercell → Tornadoes
4. Importance of Cold Air
5. Idealization