Tornado
Structure and Risk

The DOW Perspective

Center for Severe Weather Research

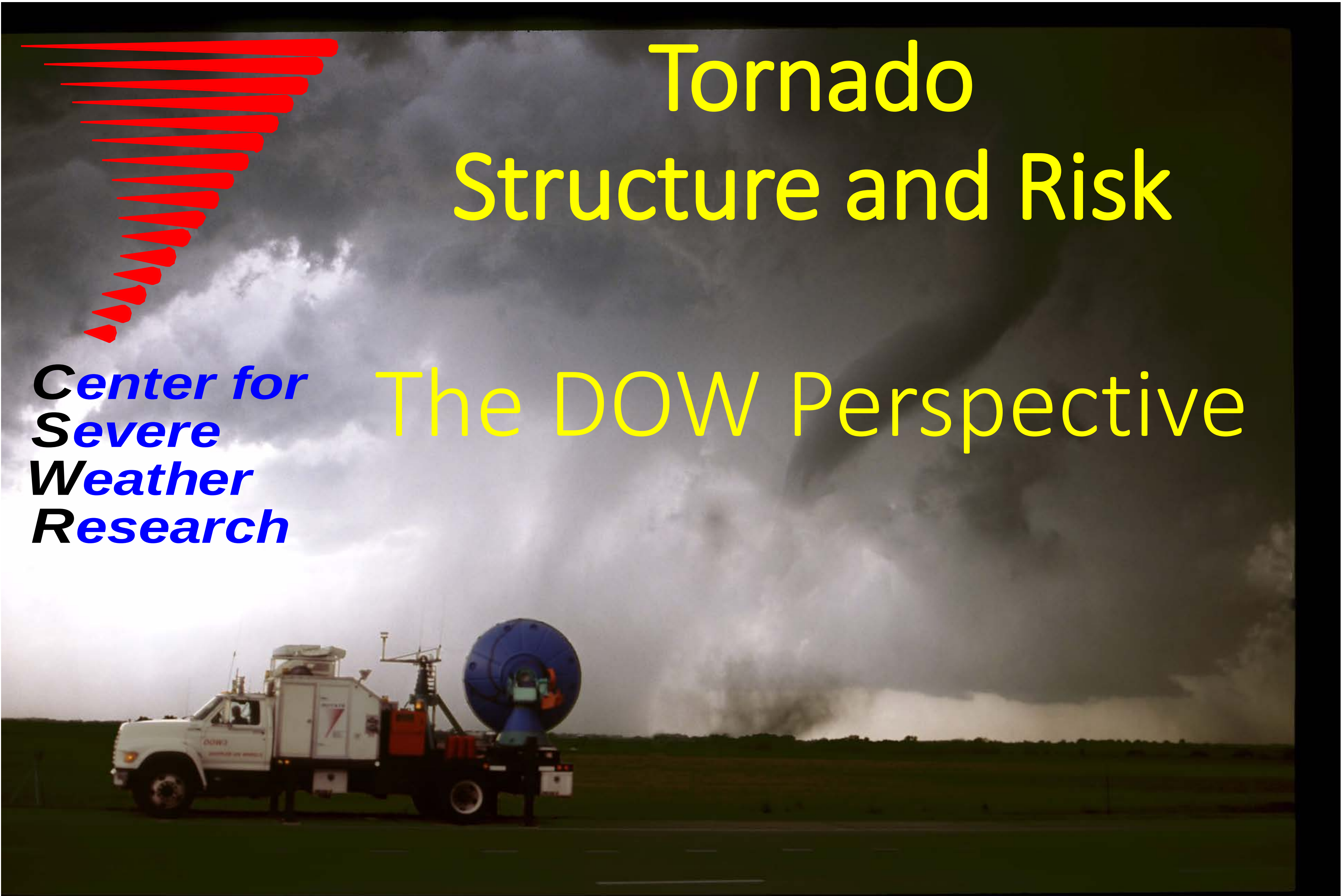
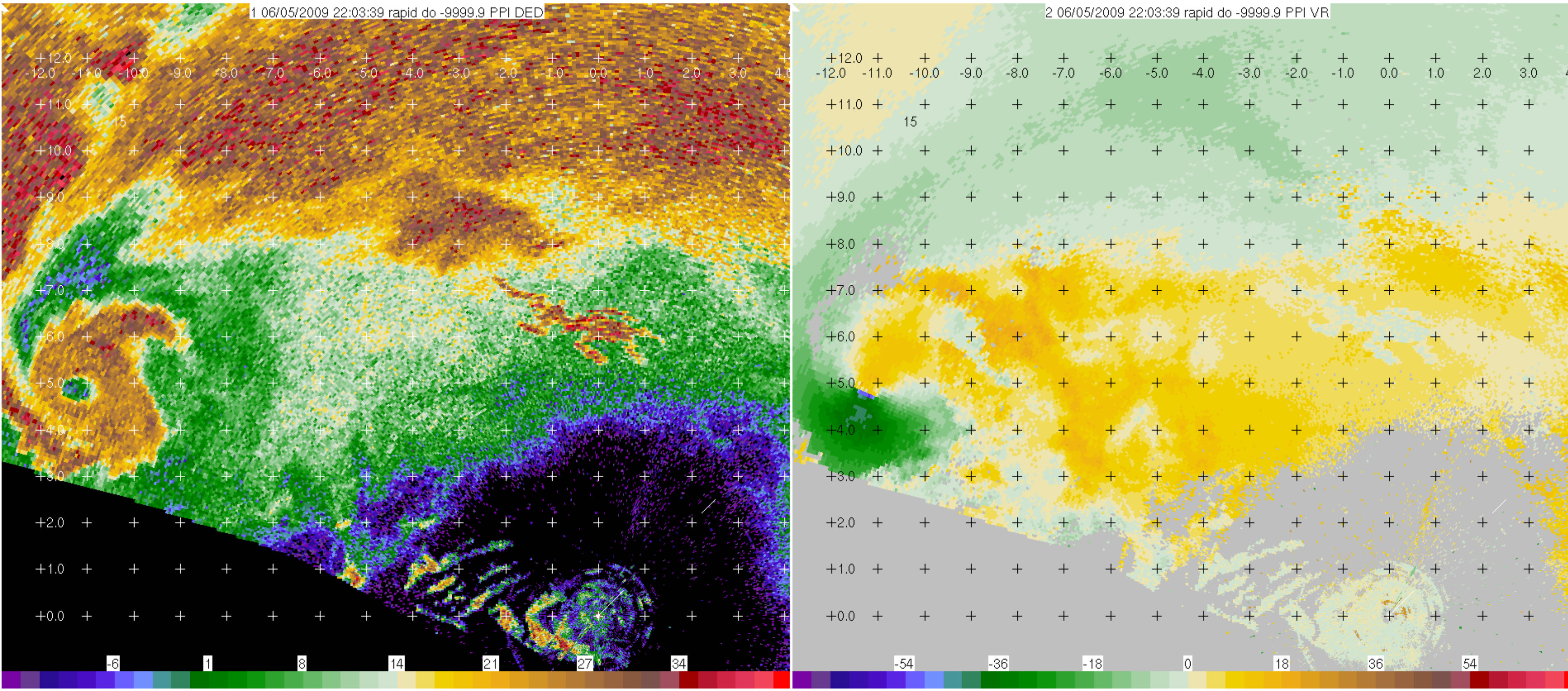


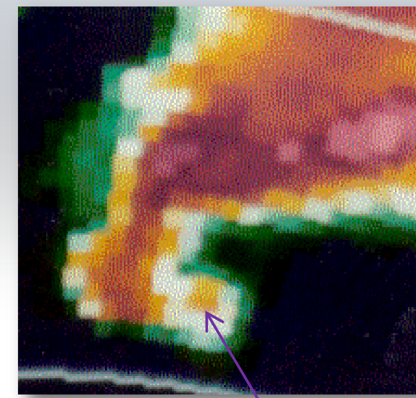
Photo by Herb Stein

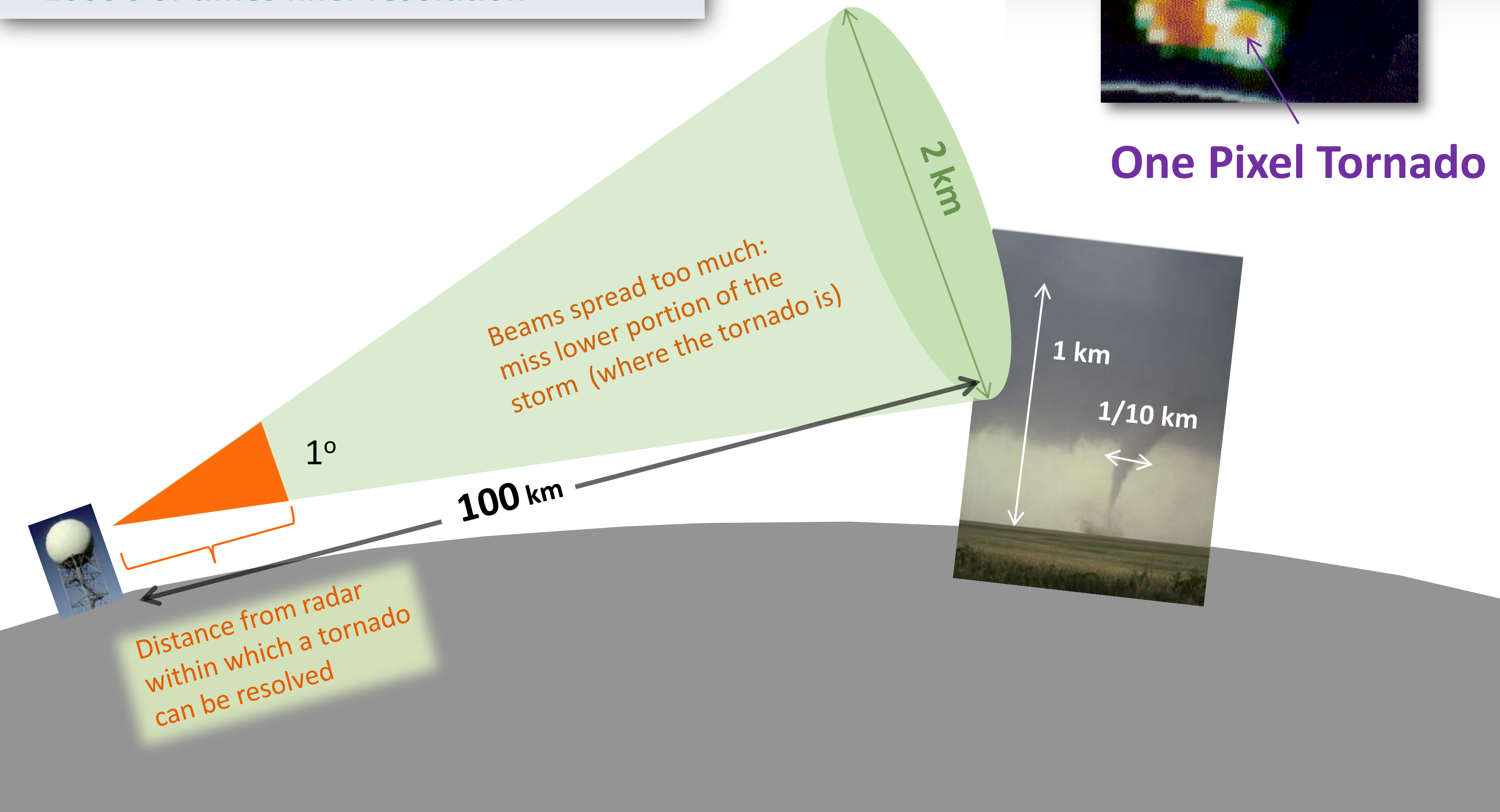

1 06/05/2009 22:03:39 rapid do -9999.9 PPI DED
-12.0 -11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 0.0 1.0 2.0 3.0
+12.0 +11.0 +10.0 +9.0 +8.0 +7.0 +6.0 +5.0 +4.0 +3.0 +2.0 +1.0 +0.0
15
-6 1 8 14 21 27 34
2 06/05/2009 22:03:39 rapid do -9999.9 PPI VR
-12.0 -11.0 -10.0 -9.0 -8.0 -7.0 -6.0 -5.0 -4.0 -3.0 -2.0 -1.0 0.0 1.0 2.0 3.0
+12.0 +11.0 +10.0 +9.0 +8.0 +7.0 +6.0 +5.0 +4.0 +3.0 +2.0 +1.0 +0.0
15
-54 -36 -18 0 18 36 54

Stationary Radars are too far away to resolve tornado structure

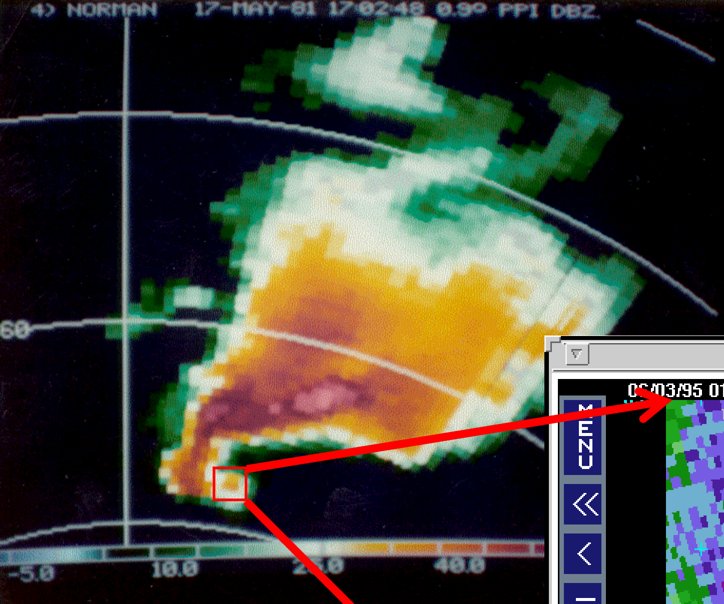
By getting 1-3 km away, DOWs have 1000's of times finer resolution

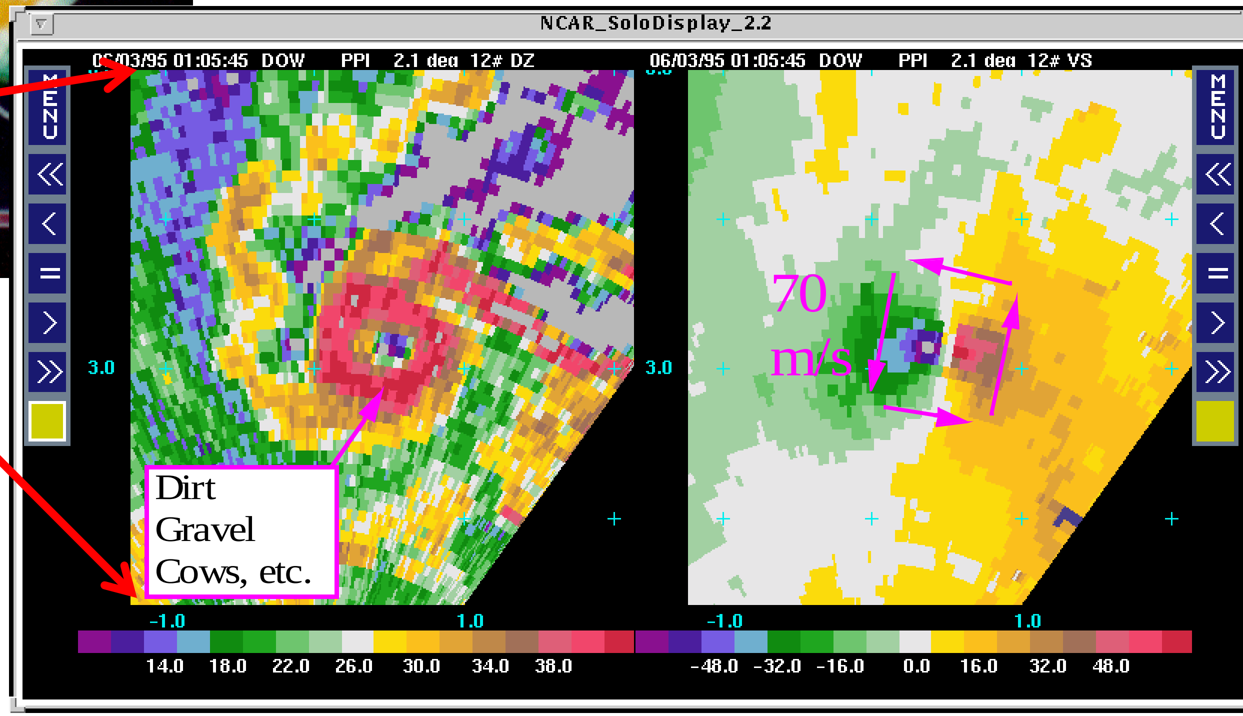
Blurry Image

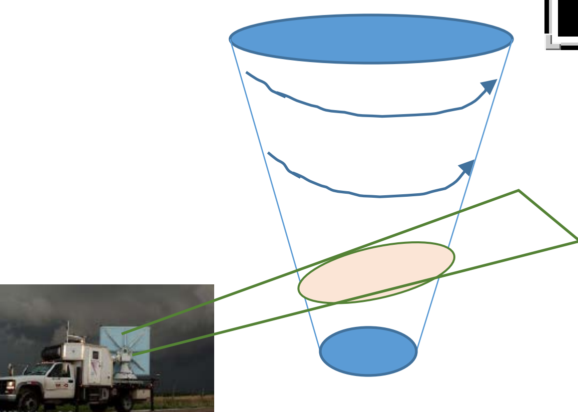




What do DOWs see inside tornadoes ?

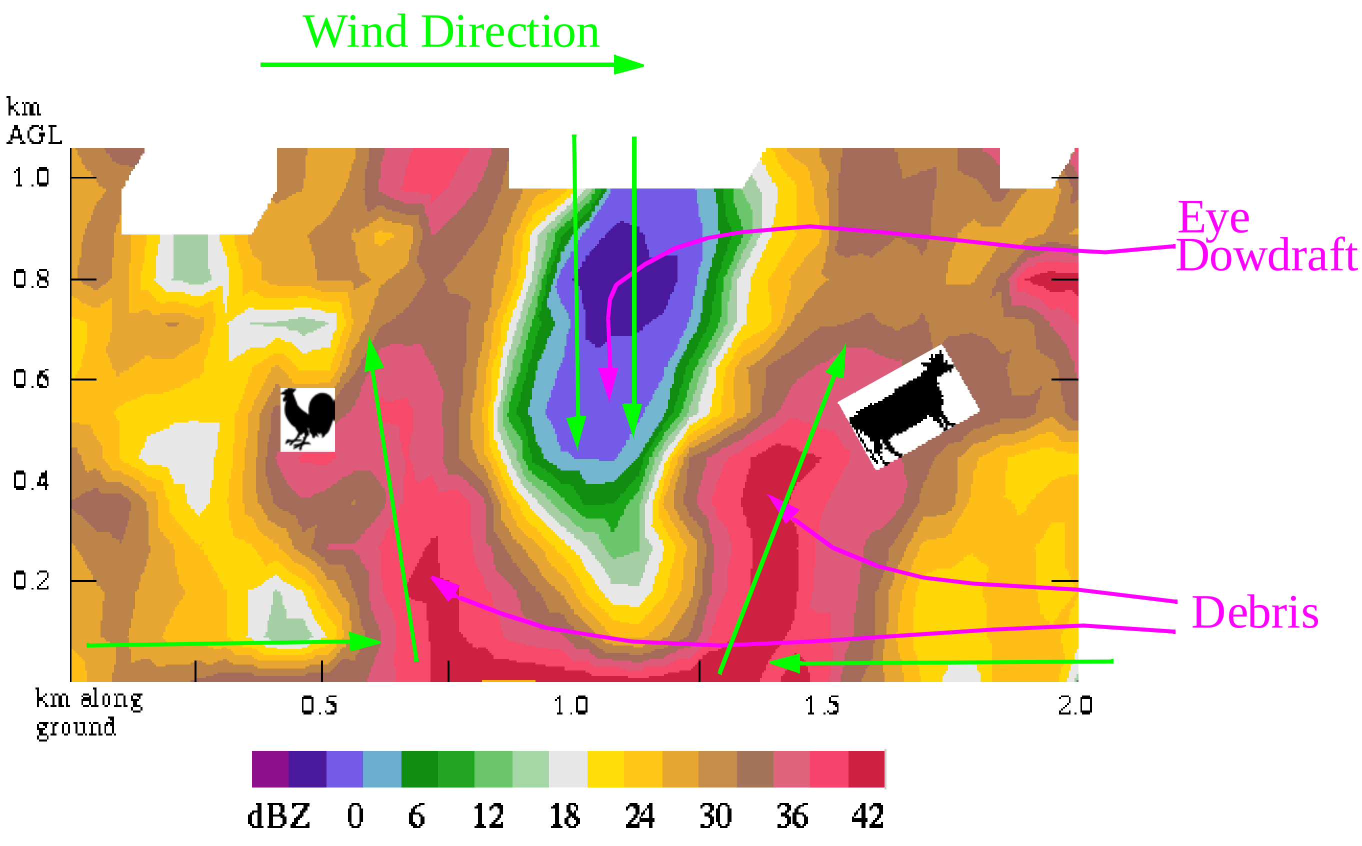






Reflectivity/Power sees debris/rain

Doppler velocity sees towards/away motion of debris/rain



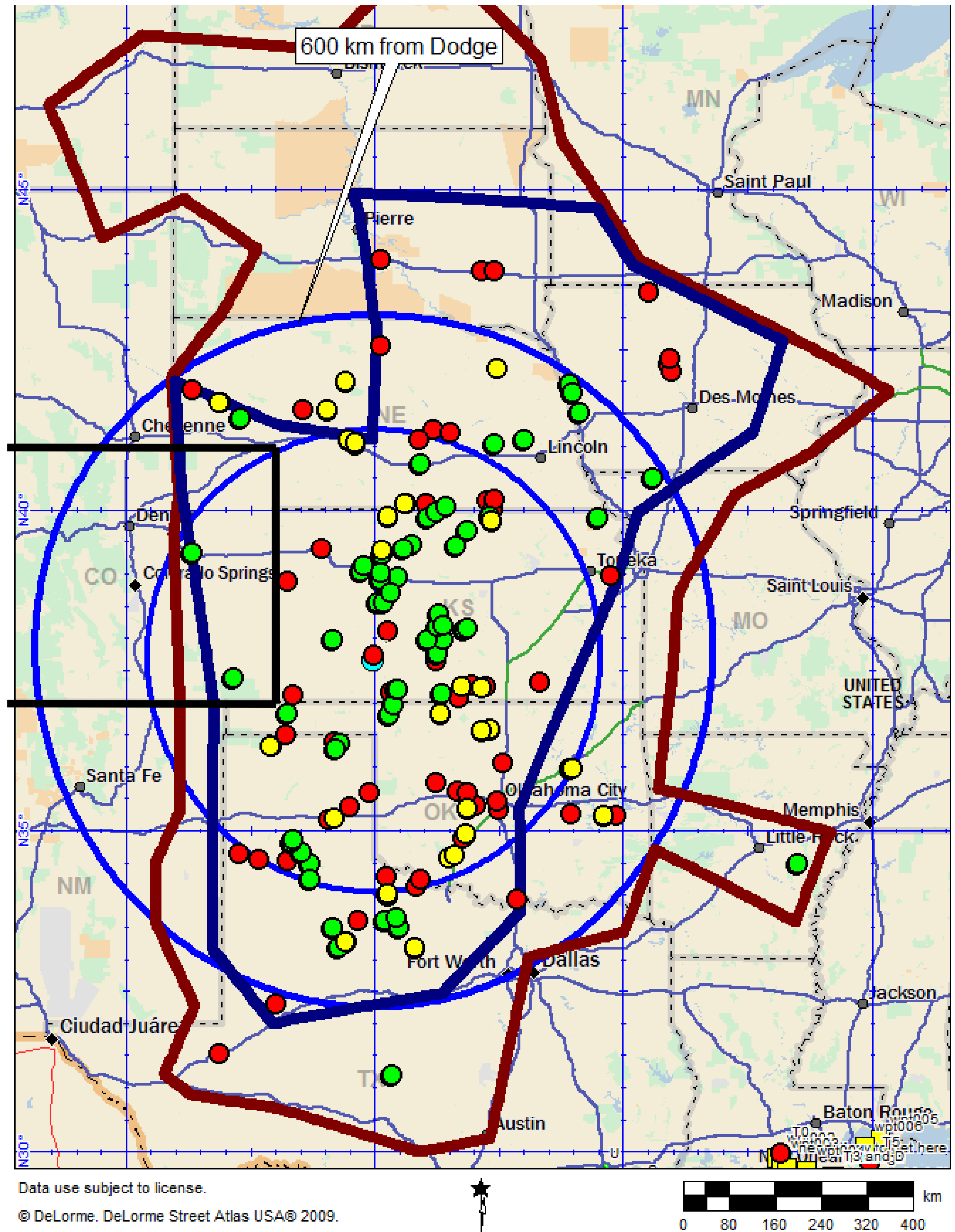
Vertical X-section through tornado

Distribution of DOW tornado observations through 2008

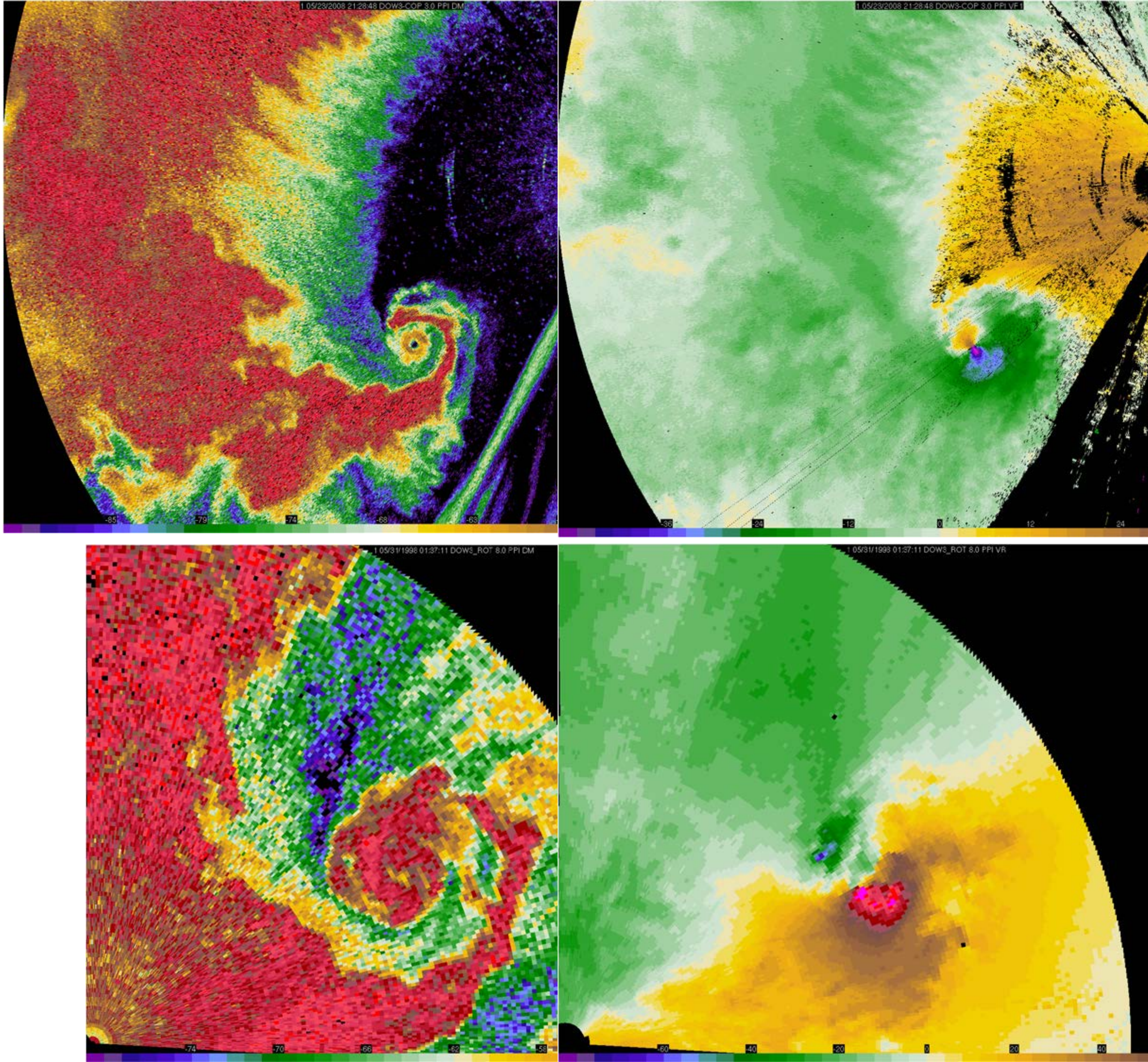
DOW Radars have observed about 200 tornadoes from 1995-2013

Nearly all were supercell tornadoes

Several in Colorado



A wide Variety of Tornado

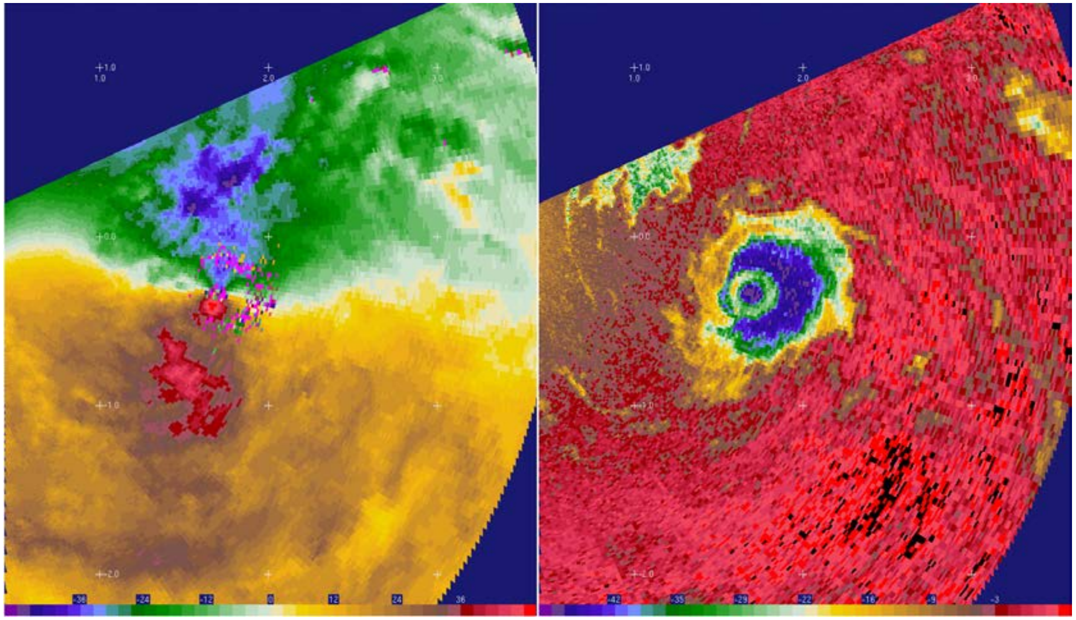


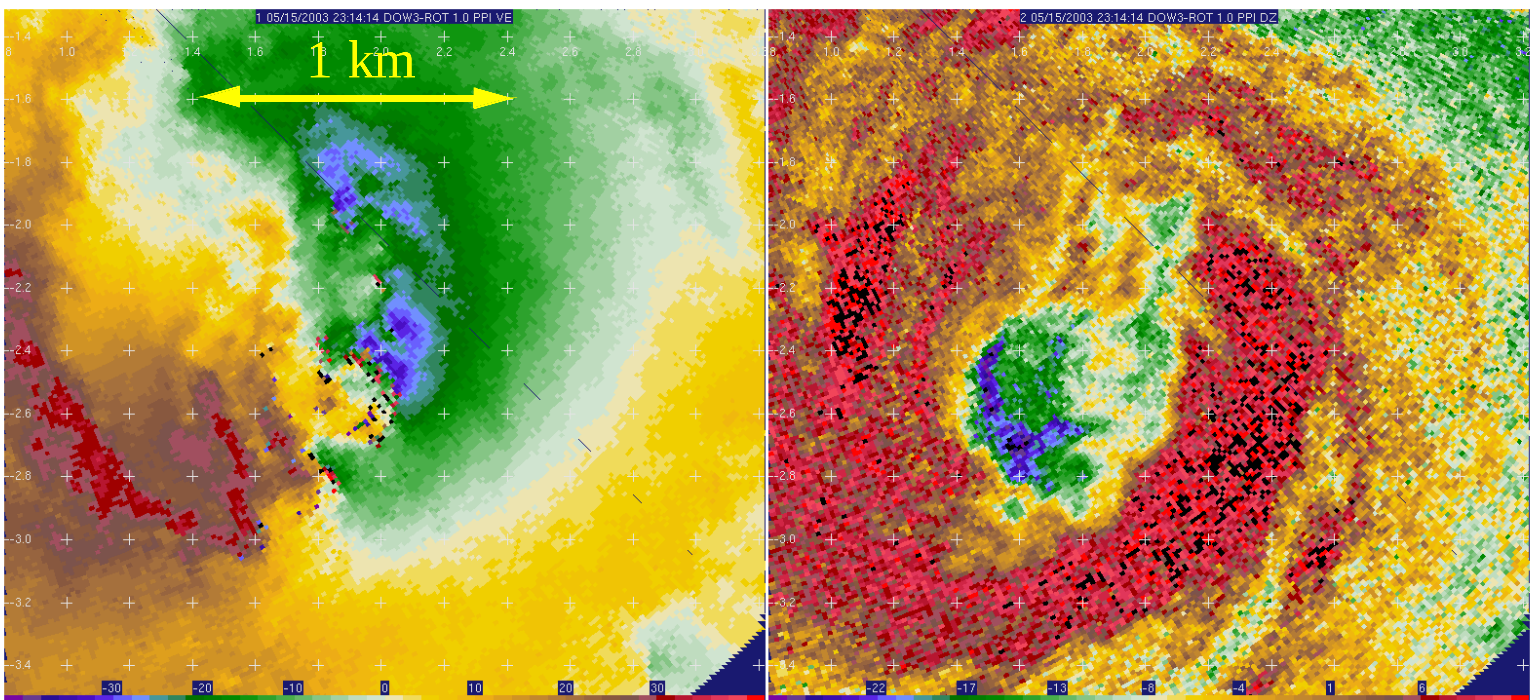
Sizes

Intensities

Structures

Very Complex Velocity Structures in Some Tornadoes





Quick Changes In Tornado Structure

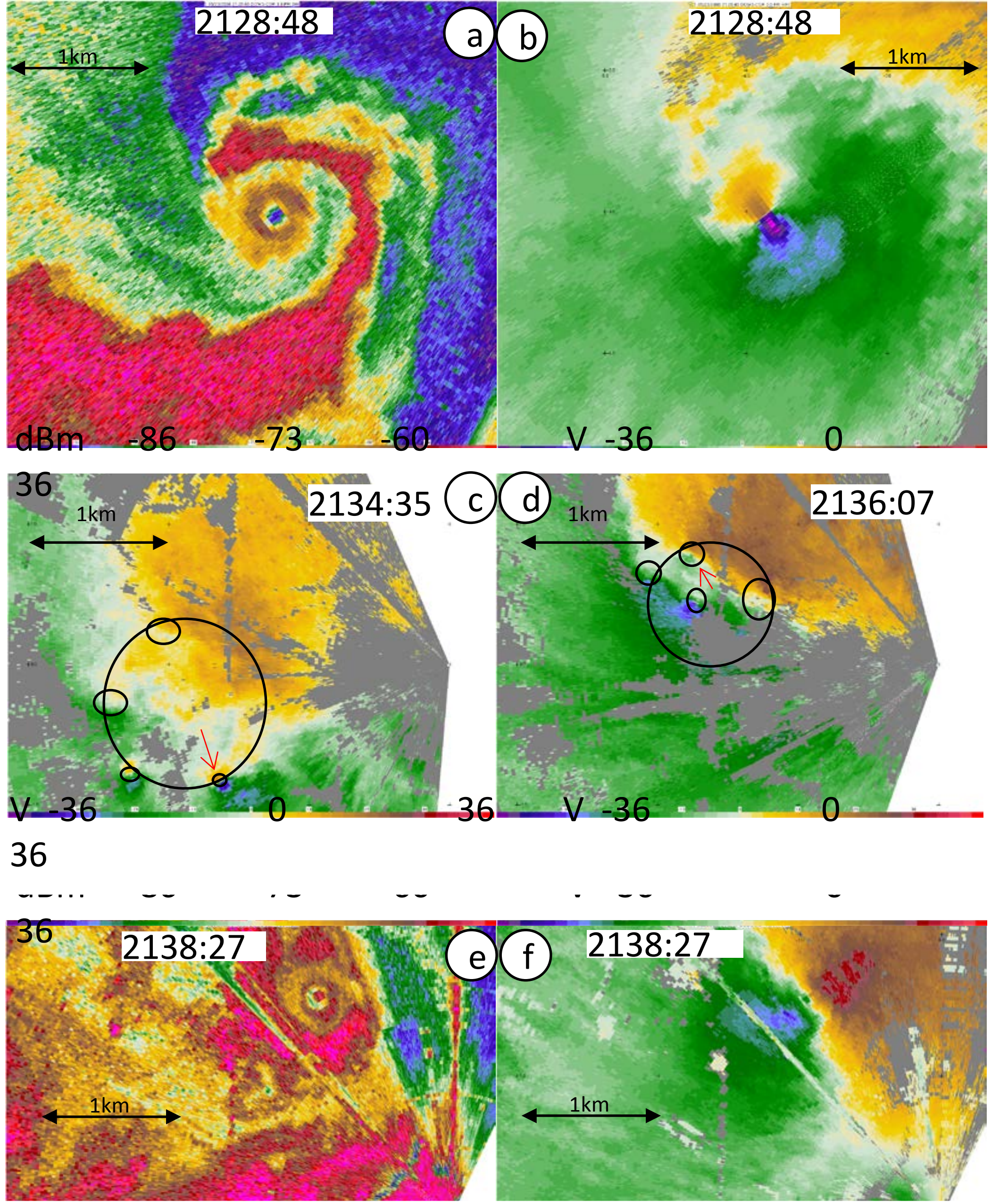
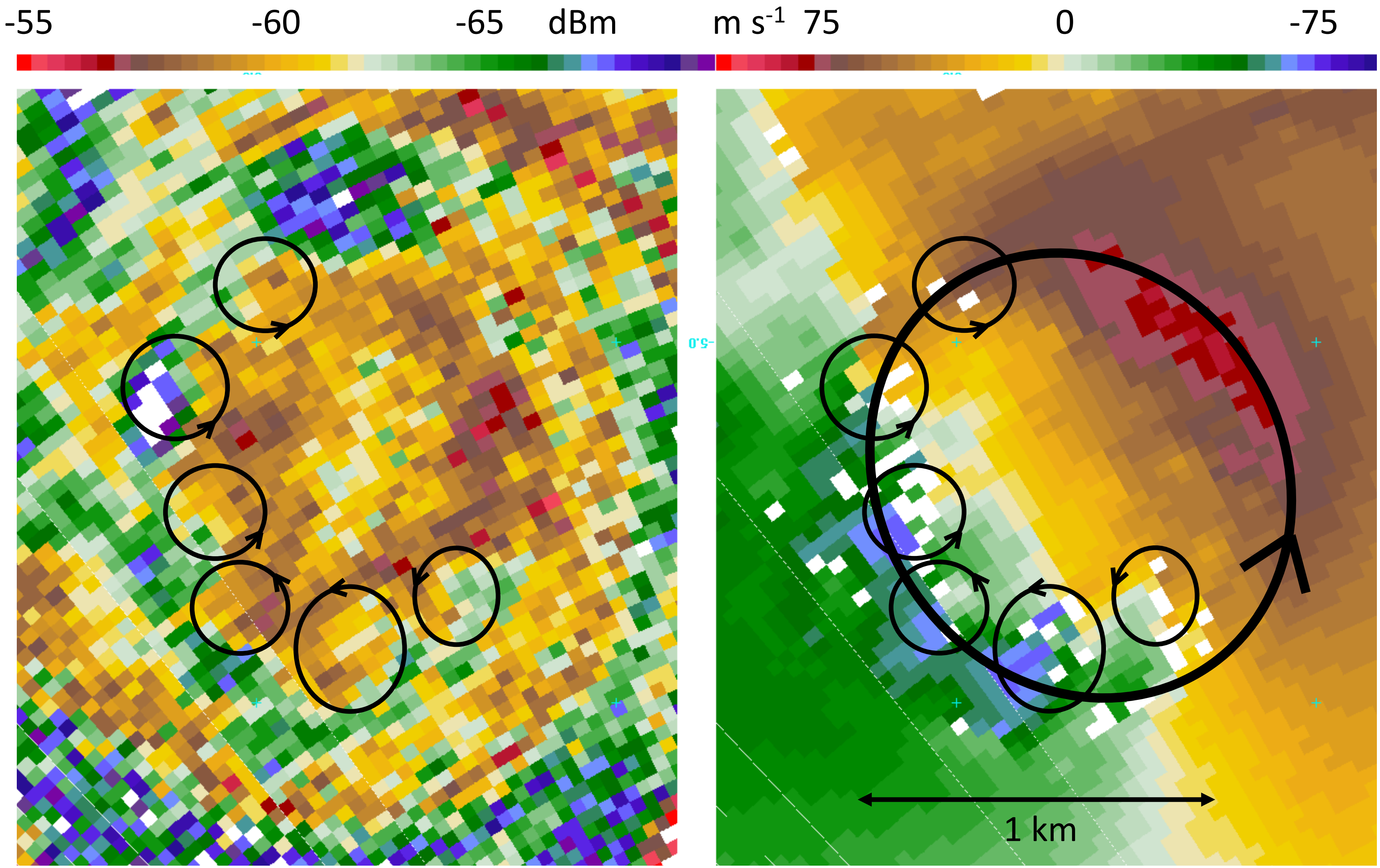


Figure 3: **Evolution of Multiple Vortex Mesocyclone (MVMC) from tornado to MVMC to new tornado.** Fields same as Fig. 1, except left panel (c) Doppler velocity. Times are HHMM:SS UTC (a,b) Weakening tornado with DR and LRE approaching Quinter, Kansas on 23 May 2008. (c,d) Additional vortices (small ovals) develop as vortex remnant of tornado (red arrow) weakens as it revolves around larger circulation (large ovals). (e,f) The circulation contracts, the vortices dissipate, and a new singlet tornado with a DB evolves.

Multiple Vortices inside Tornadoes



Received Power and Doppler Velocity measured by a Doppler On Wheels radar in an extremely large (core flow diameter (DMW) > 1 km) on 04 May 1999 0316:38 UTC.

Complex
Multiple
Vortices

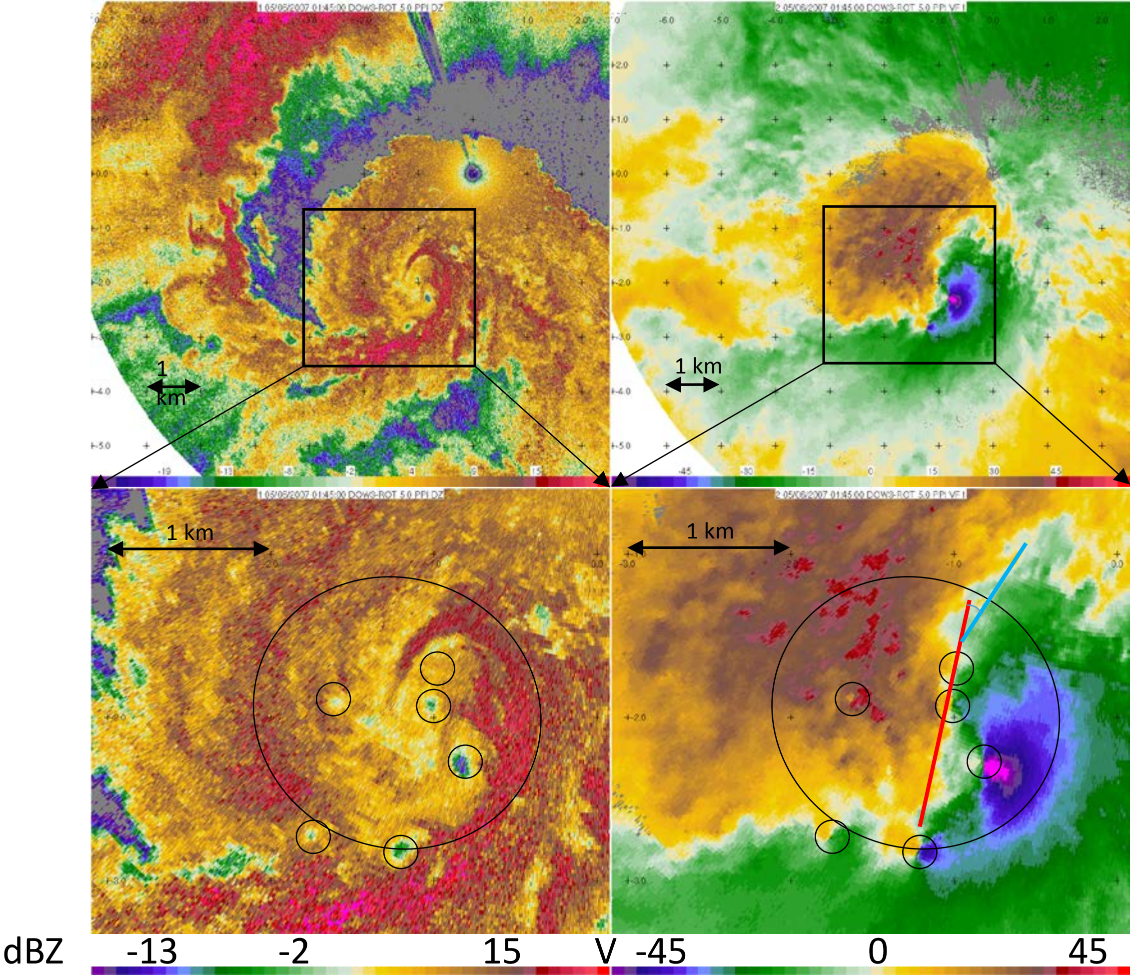


Figure 7: **Persistent intense MVMC structure with intense vortices**. Same as Fig. 1, except left panels are uncalibrated Reflectivity. MVMC observed near Seward, Kansas on 06 June 2007 in a high precipitation type supercell. Top panels display hook echo region, bottom panels are zoomed in in MVMC. Vortices (small ovals) with V_g up to 96 m s^{-1} and pronounced LREs revolve around ~ 1.5 km wide MVMC (large oval). MVMC exhibits broad weak LRE. Angle between radar observation direction (blue) and zero isodop line (red) through core of MVMC suggests divergence. This event, which occurred after dark in rural terrain, was rated by the NWS as a 250 yard wide EF1 tornado.

Intense vortices (“tornadoes”)
Inside larger “tornadoes”

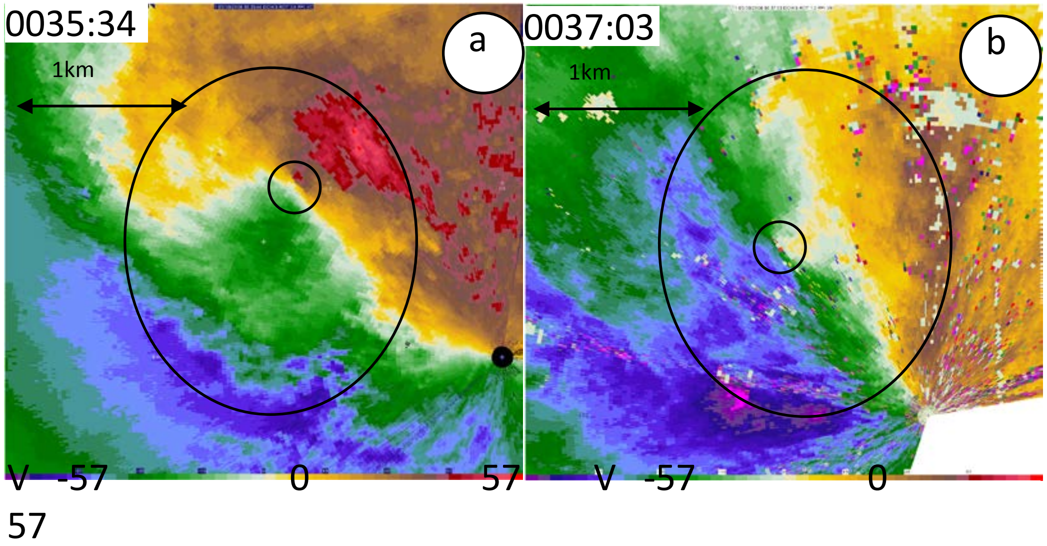


Figure 9: **Intense MVMC with internal vortex.** Doppler Velocity only, otherwise, plot layout same as Fig. 1. Times in HHMM:SS UTC. (a) Circulation with DX ~ 1.5 km (large oval), with an intense internal circulation observed near Geary, Oklahoma on 30 May 2004. Internal vortex (small oval), at 900 m range from DOW, exhibits peak V_g = 70 m s^{-1} . Which of these circulations were tornadoes? (b) Larger circulation impacted a DOW which measured V_g = 87 m s^{-1} at 12 m AGL.

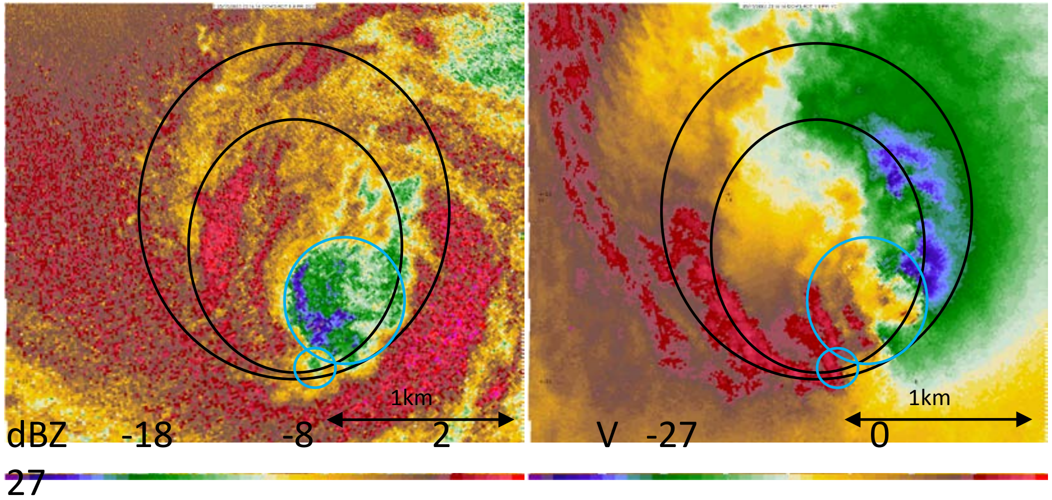


Figure **10 MVMC with complex structure**: Panel layout same as Fig. 1, except left panel is uncalibrated Reflectivity. An MVMC exhibiting complex structure including multiple embedded vortices and multiple wind field maxima near Stratford, Texas on 15 May 2003. Black ovals roughly outline rotation scales. Blue ovals outline LREs. Wind field features are not well correlated with reflectivity features.

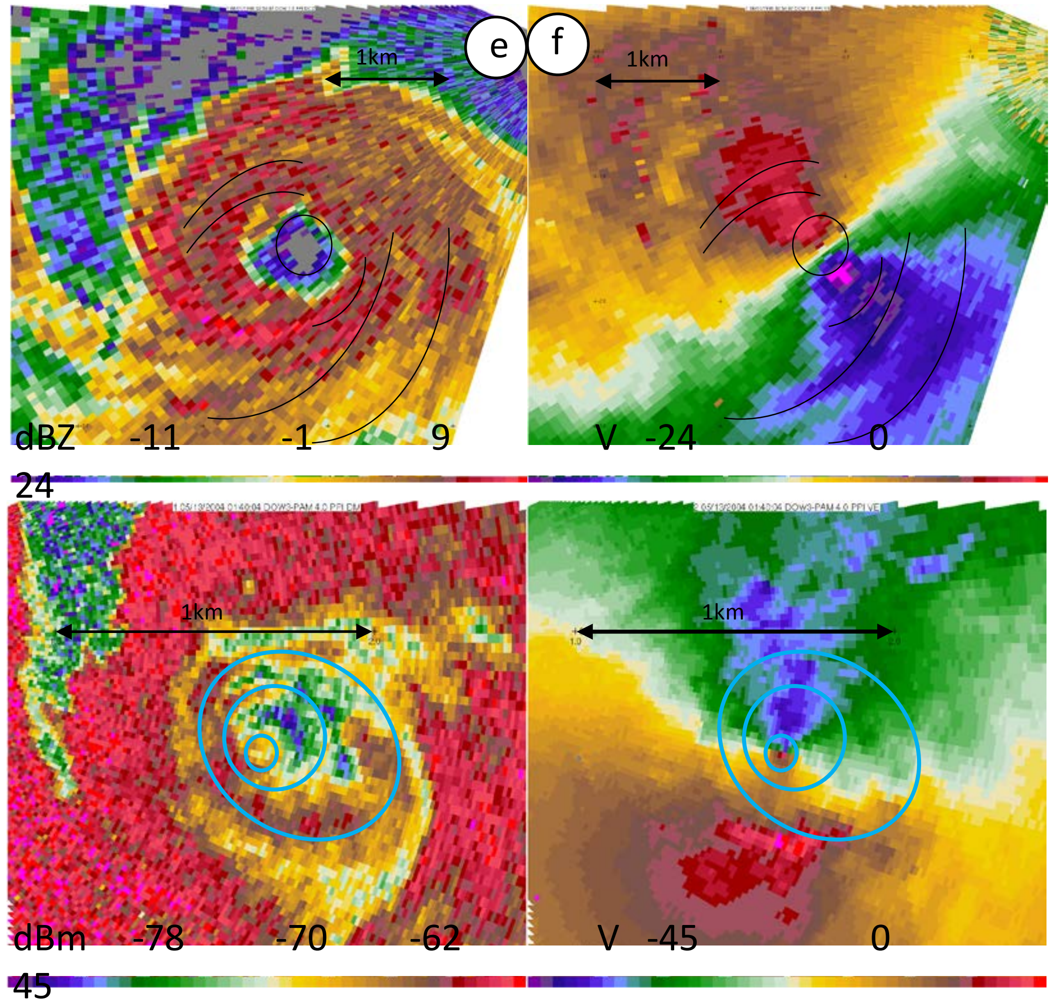


Figure 12: (top) A large weak tornado with **multiple wind speed maxima** near Rolla, Kansas on 01 June 1996. Doppler wind maxima do not correlate well with reflectivity maxima. (bottom) Intensifying tornado with very narrow central vortex and more intense outer wind speed maxima near Harper, Kansas on 13 May 2004. Rare multiple quasi-concentric LREs are present (blue ovals). Plot layout same as Fig. 1.

A Wide Variety of Intense Vortices Associated With Tornadoes

Multiple Vortices Inside Other Multiple Vortices

Cyclonic Anticyclonic Twin Tornadoes

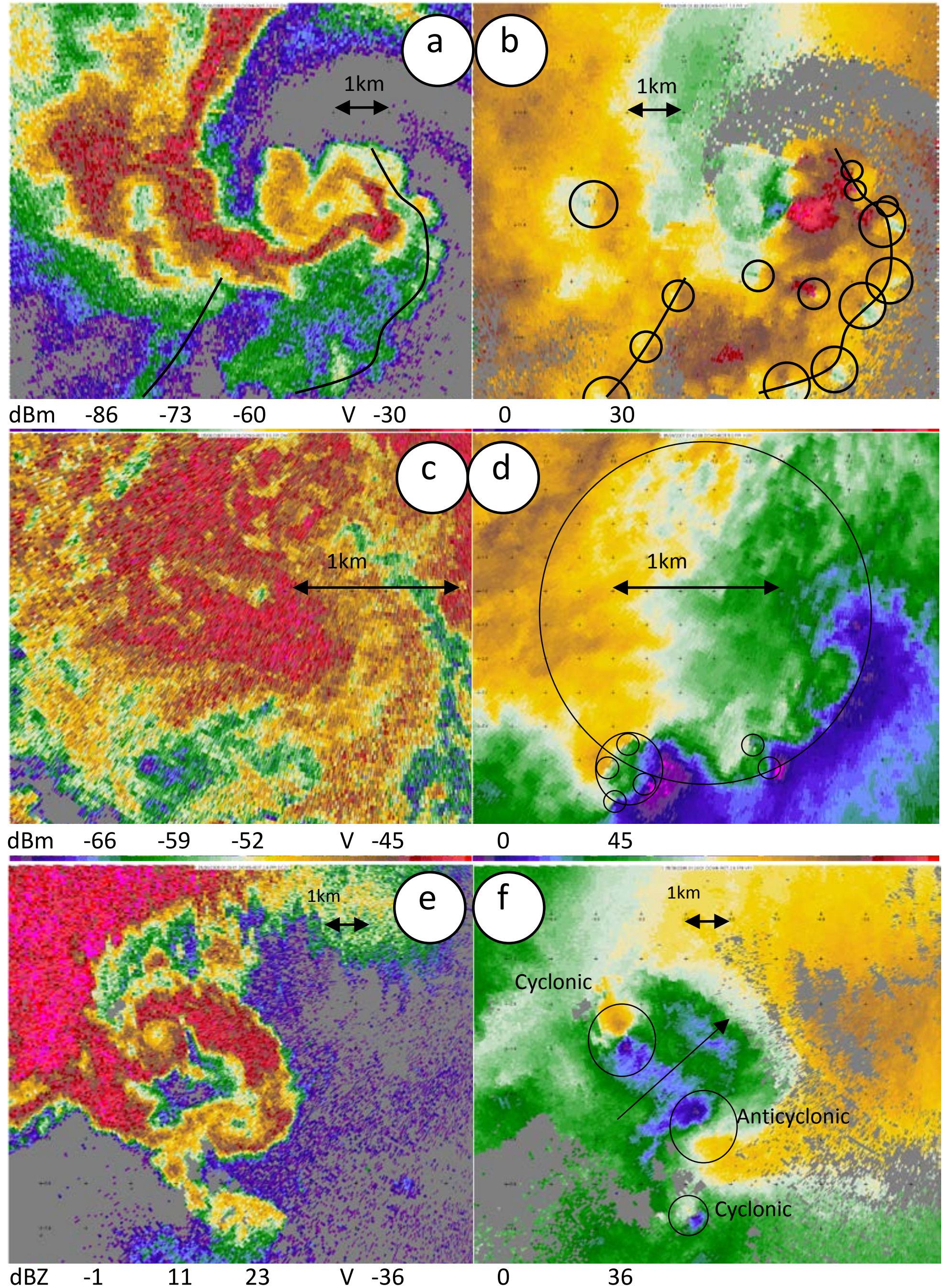


Figure 13: (a,b) Lines of **anticyclonic and cyclonic vortices near a tornado** near Jewell, Kansas on 30 May 2008. (c,d) **Multiple-vortices (small ovals) within a multiple vortex** (medium sized oval) of a large tornado or MVMC (largest oval) near Seward, Kansas on 06 May 2007. (e,f) **Cyclonic / anticyclonic tornado pair** near Glen Elder, Kansas on 30 May 2008. Enhanced inbound Doppler velocities associated with the rear flank downdraft are annotated with an arrow in (f). Panel layout same as Fig. 1, except field in (e) is Reflectivity.

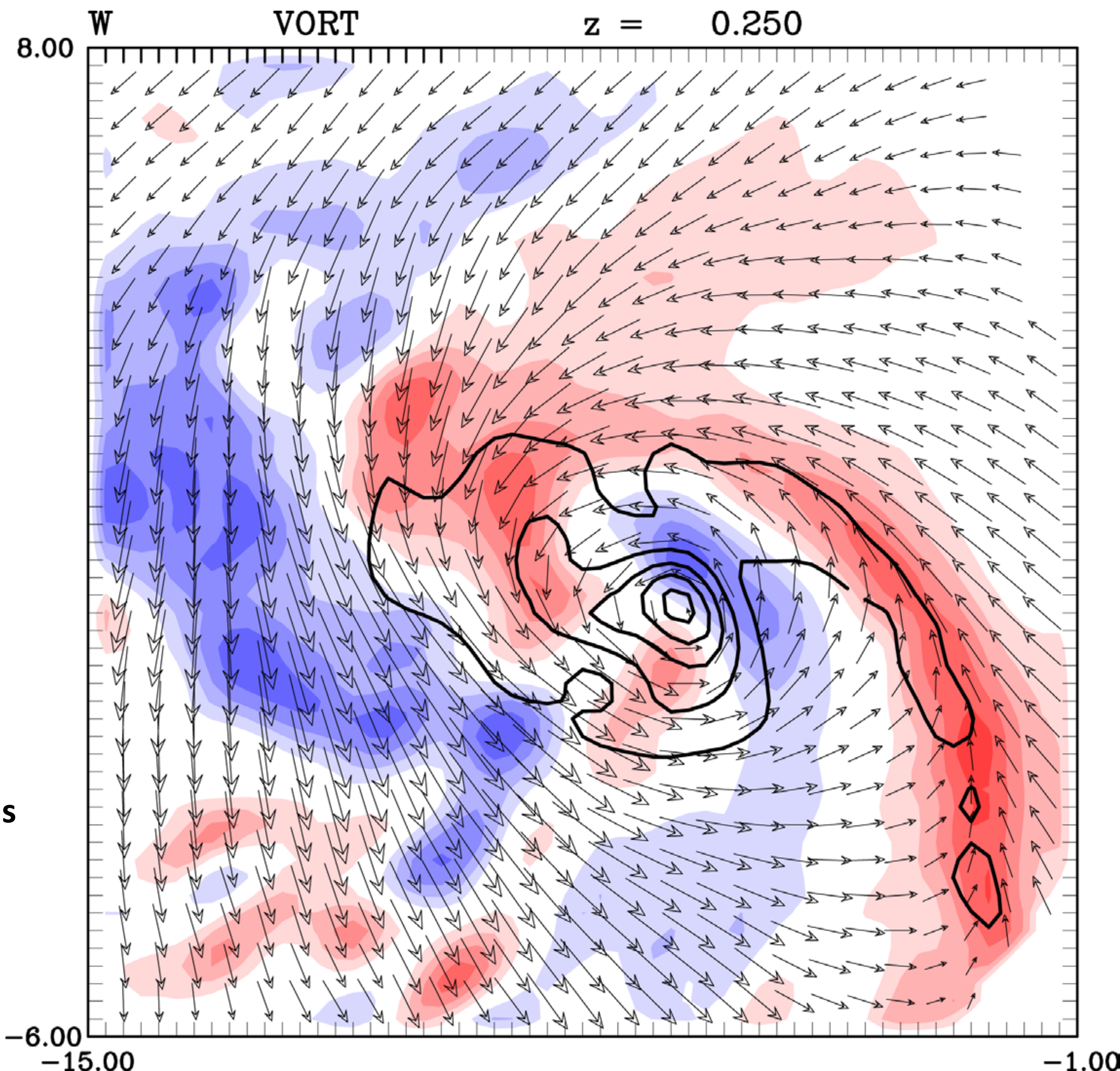
Vector Winds

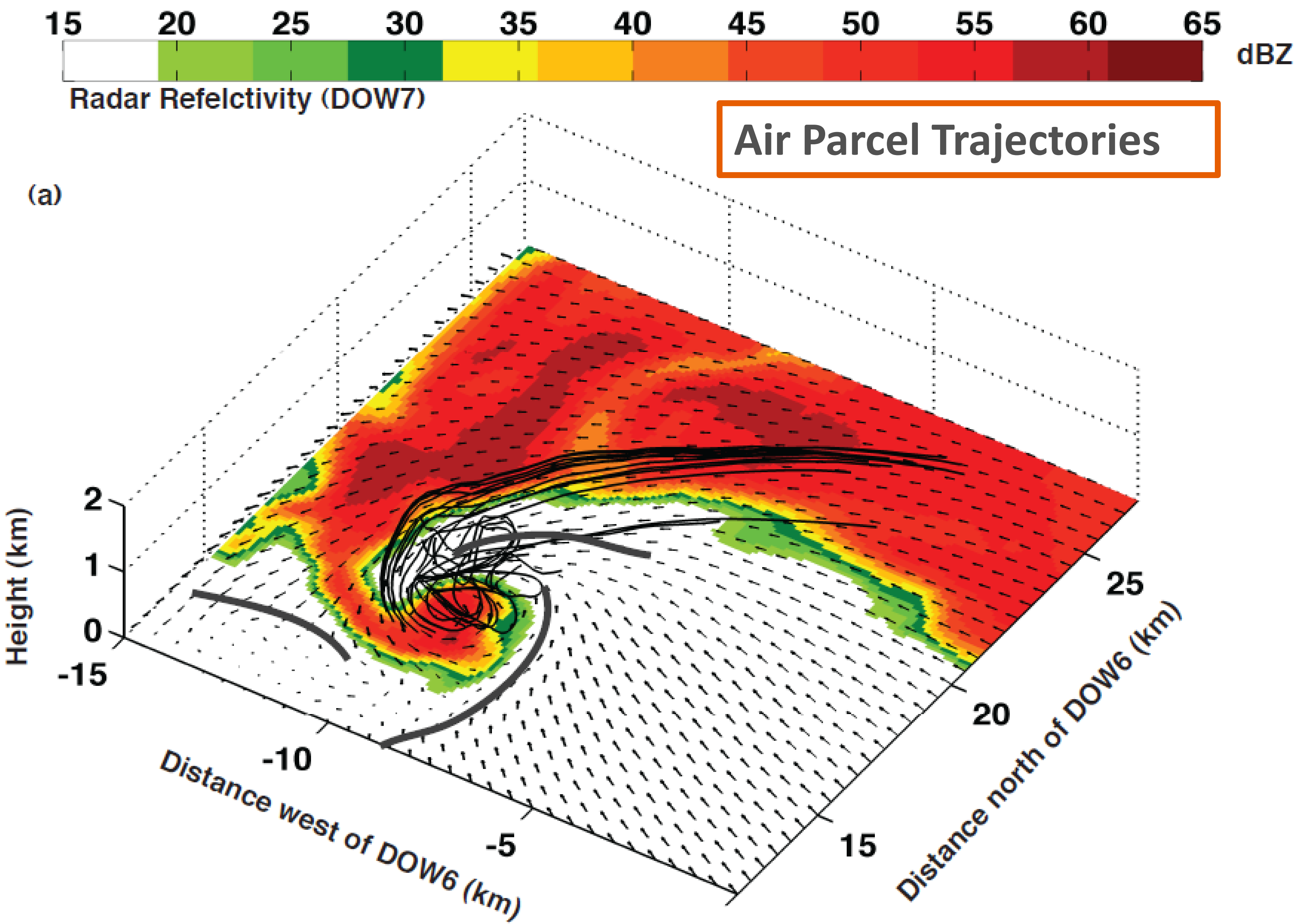
(can do trajectories)

Divergence shaded

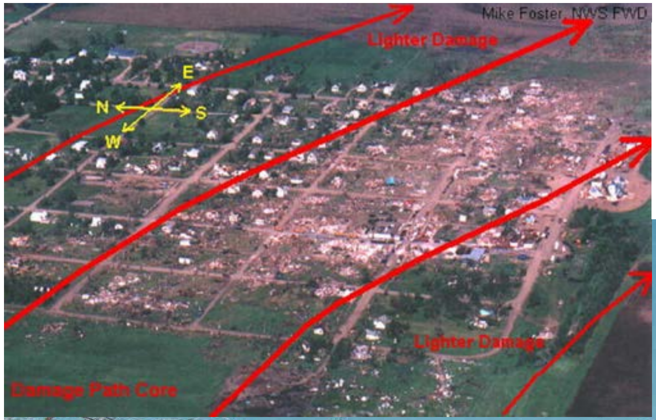
Vorticity contoured

05 June 2001, Kansas
(Dowell et al. 2003)

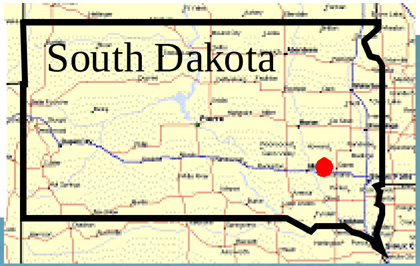



15
20
25
30
35
40
45
50
55
60
65
dBZ
Radar Refelctivity (DOW7)
Air Parcel Trajectories
(a)
Height (km)
2
1
0
-15
-10
-5
Distance west of DOW6 (km)
15
20
25
Distance north of DOW6 (km)

Tornado Wind Versus Damage Studies

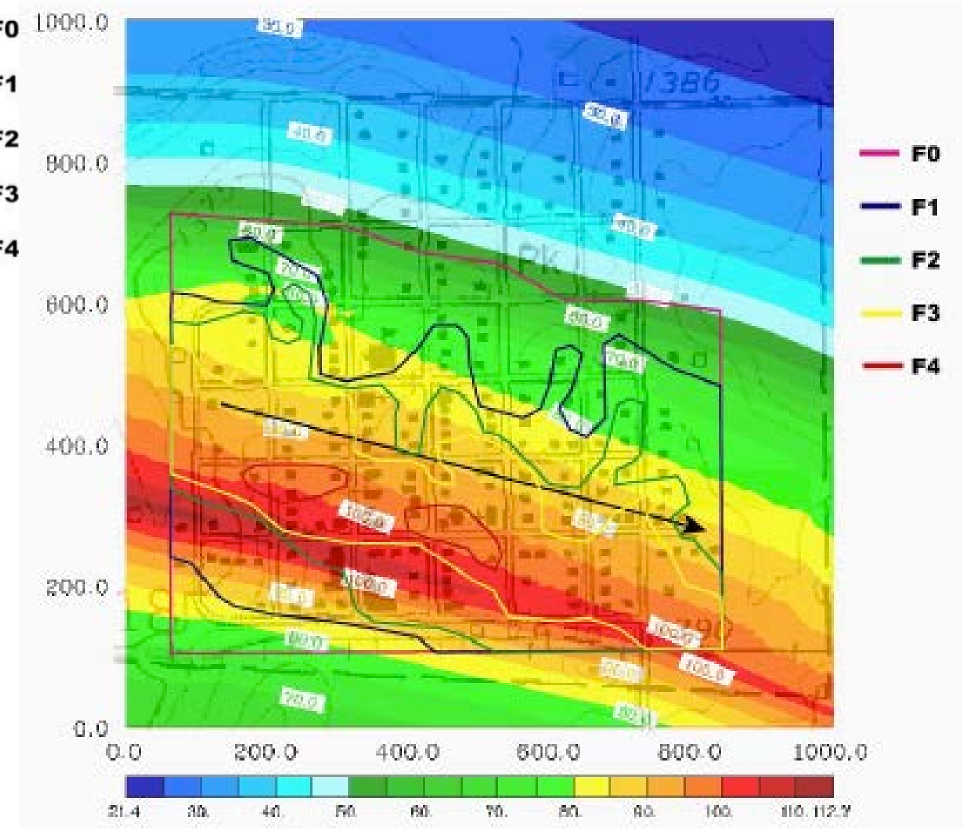


Spencer, South Dakota
Tornado, 31 May 1998
Damage and Winds Measured



Damage Survey F-Scale

Radar peak ¼ mile winds



From Wurman and Alexander (2005)

Is damage f(3-second wind)? f(airborne debris)? f(other?)

And, even if damage = f(3-second wind), what is the relationship?
F5 = 261 mph EF5 = 200 mph

4 May 2007: Greensburg, Kansas

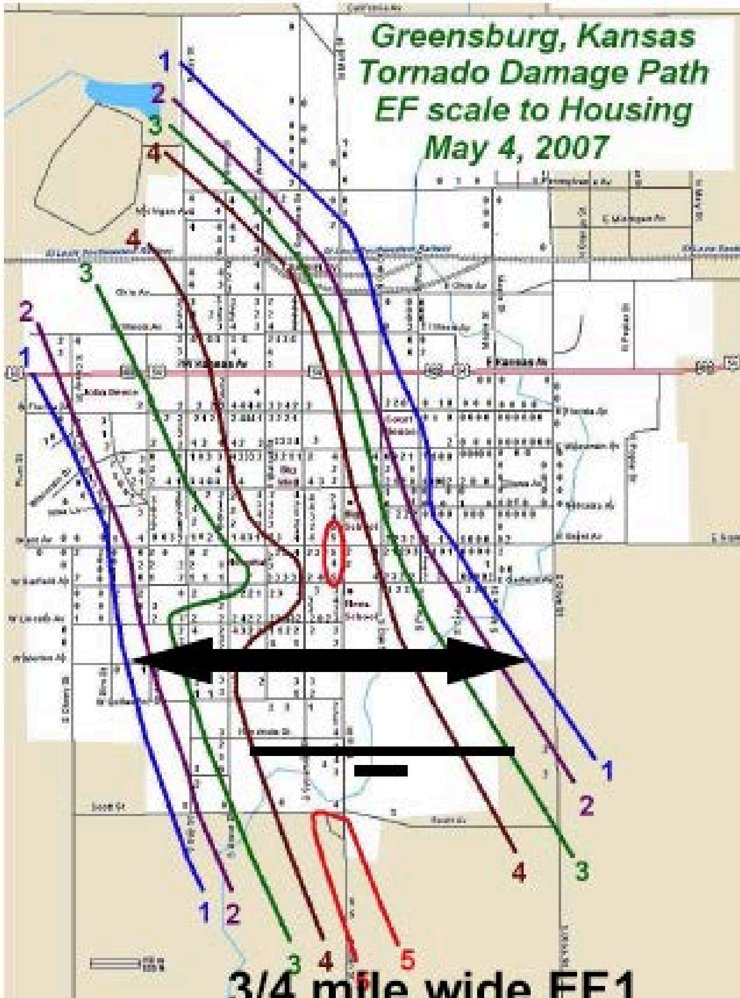
Spencer-type tornado windfield model

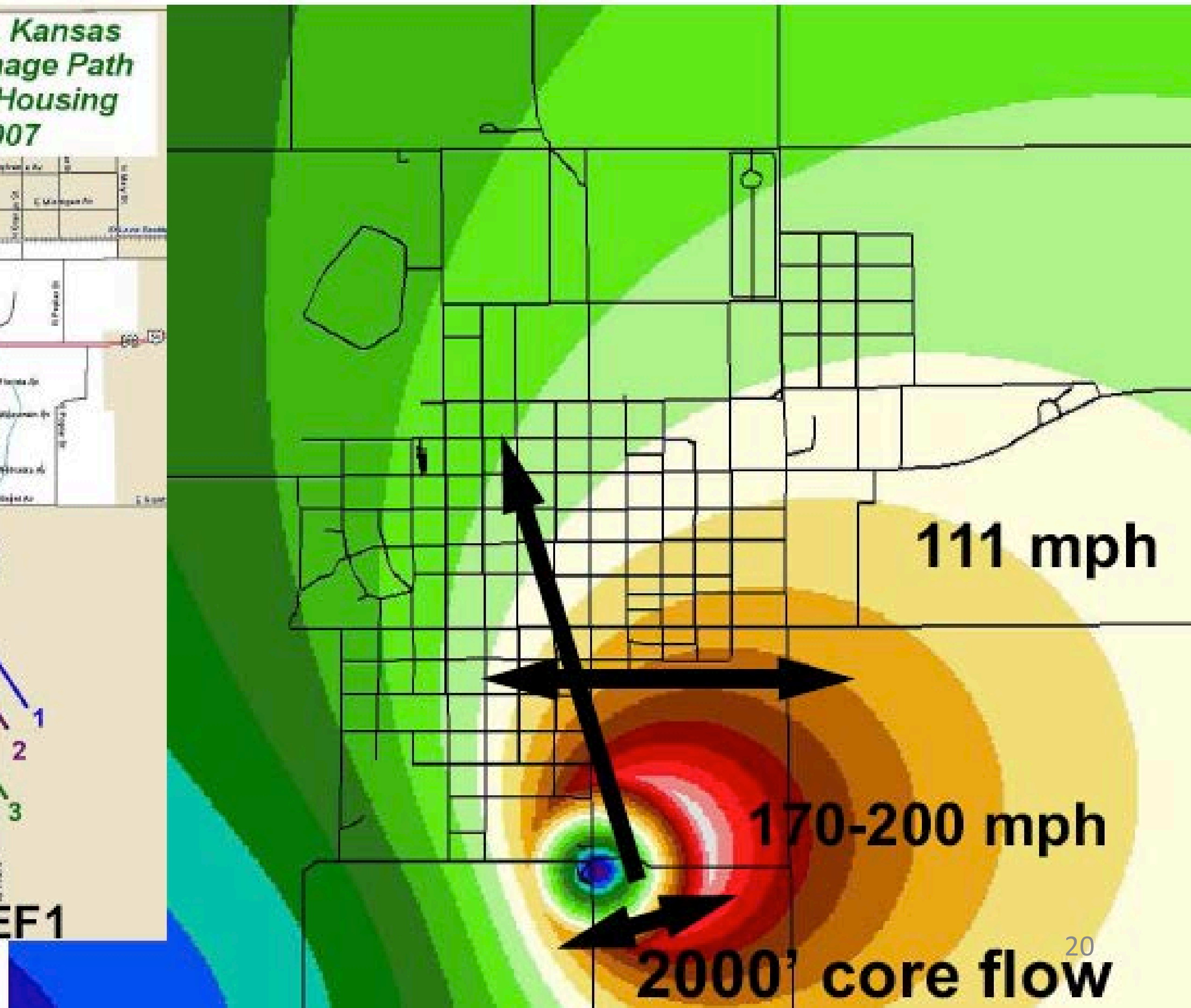
Used to deduce: damage, speed size and intensity of tornado vortex

EF1 Swath = 0.75 miles

Inferred core flow diameter = 2000 feet

V(rot) = 74 m/s, V(trans) = 19 m/s, D = 600 m



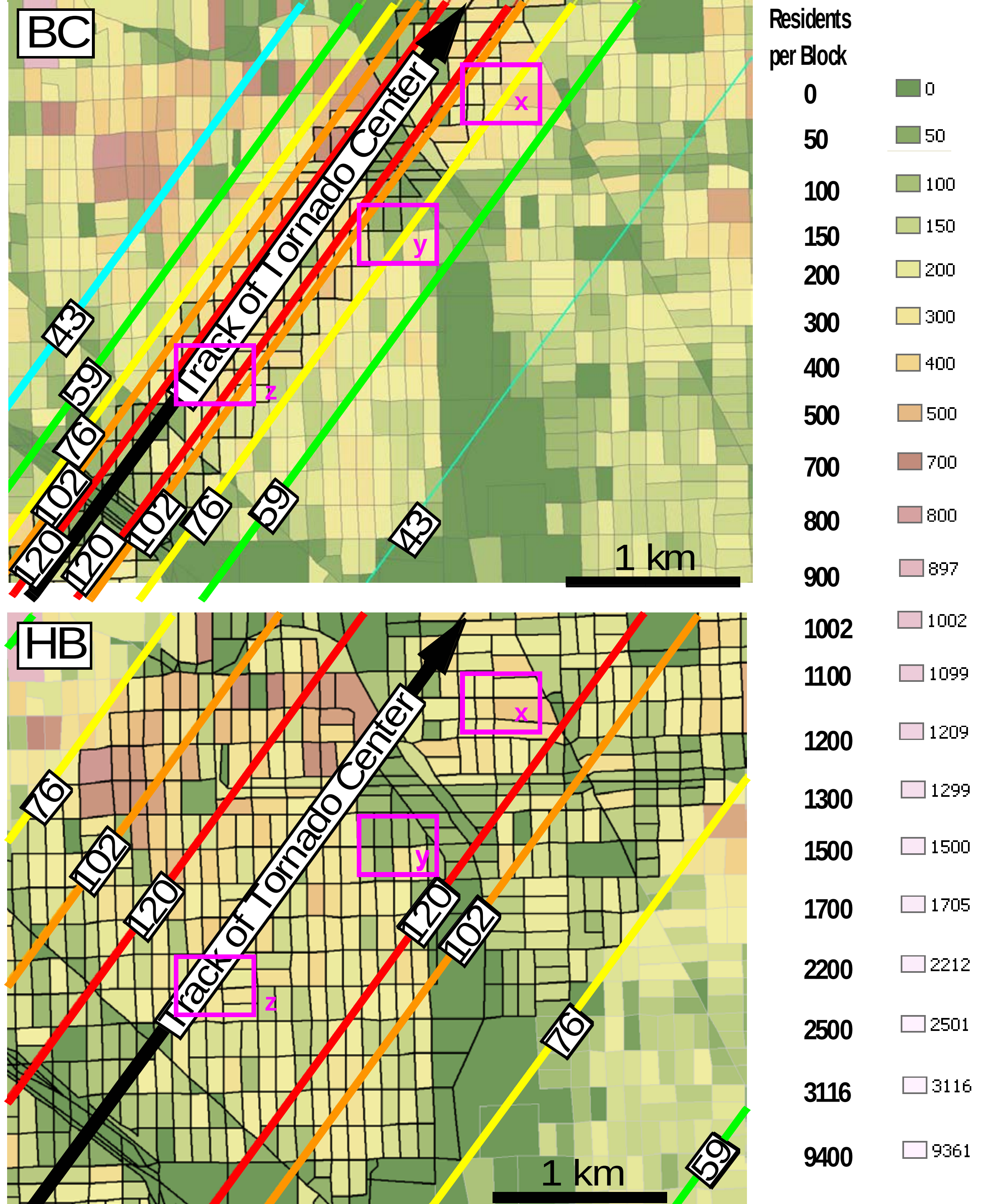


Using US Census Data

Count: # of houses
# of people
# of whatever

inside 120 m/s
102 m/s
76 m/s
59 m/s
43 m/s

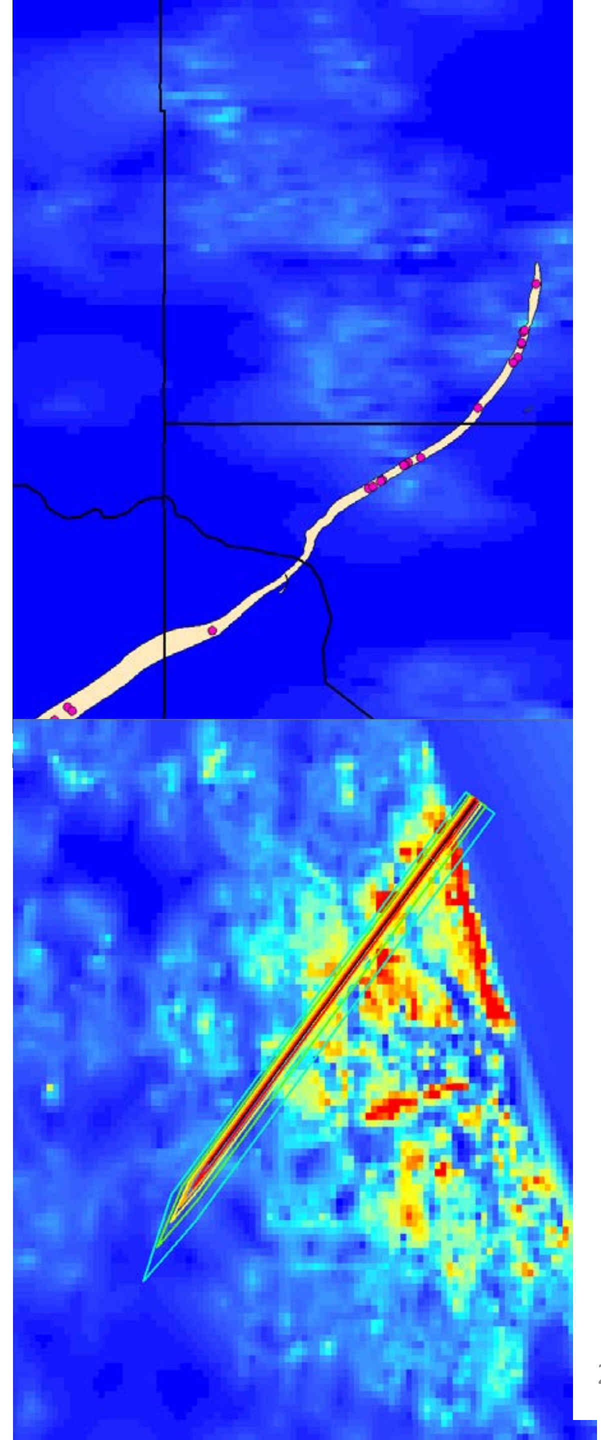
Thresholds corresponding to EF-Scale damage categories for houses

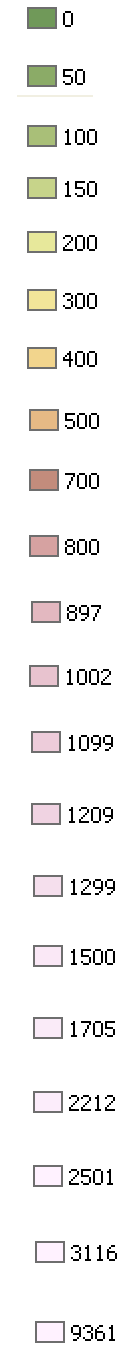


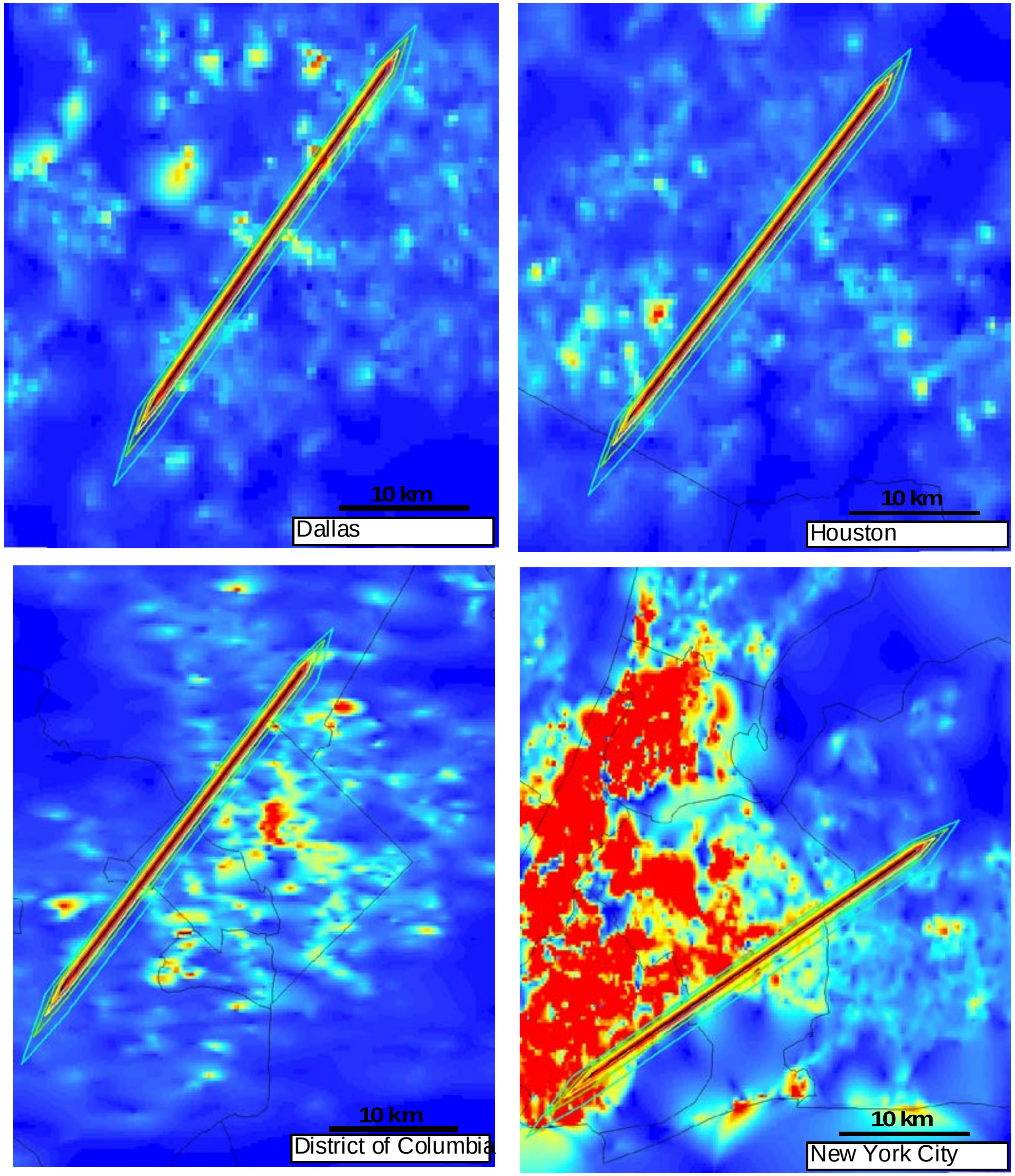
Actual 03 May 1999 tornado track across Oklahoma City

Simulated tornado tracks across Chicago

Note the differences in population density



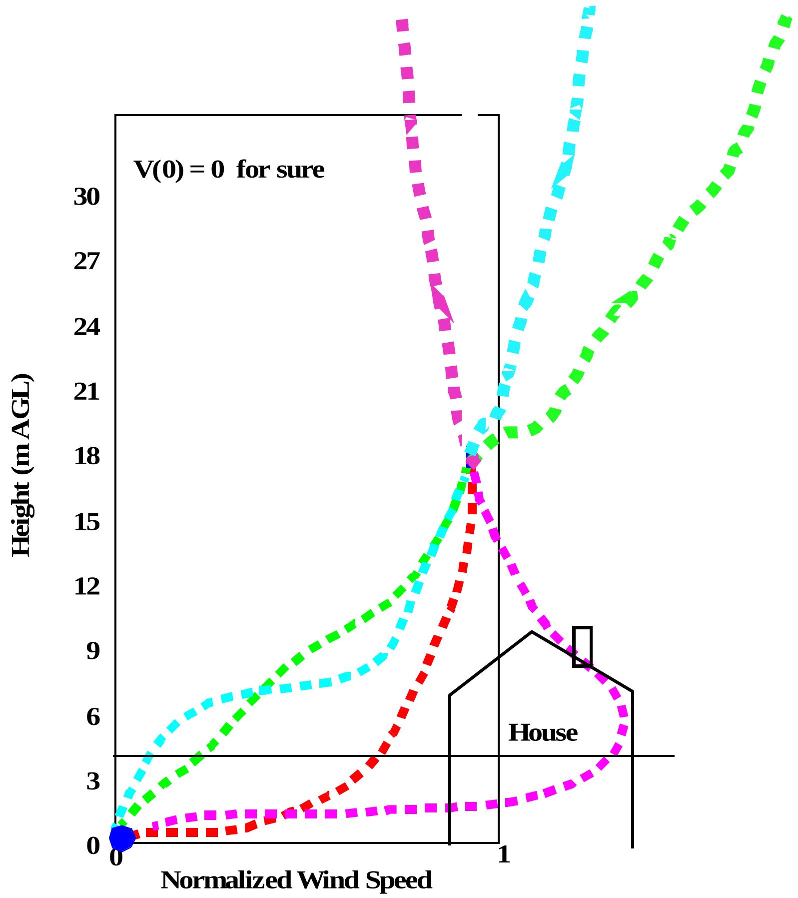




Any DOW observed tornado windfield can be dragged across any section of any city.

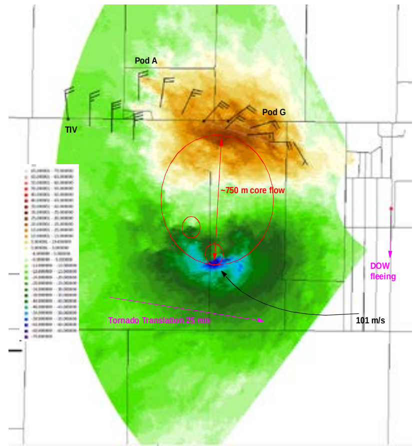
We chose suburban city edges rather than downtowns.

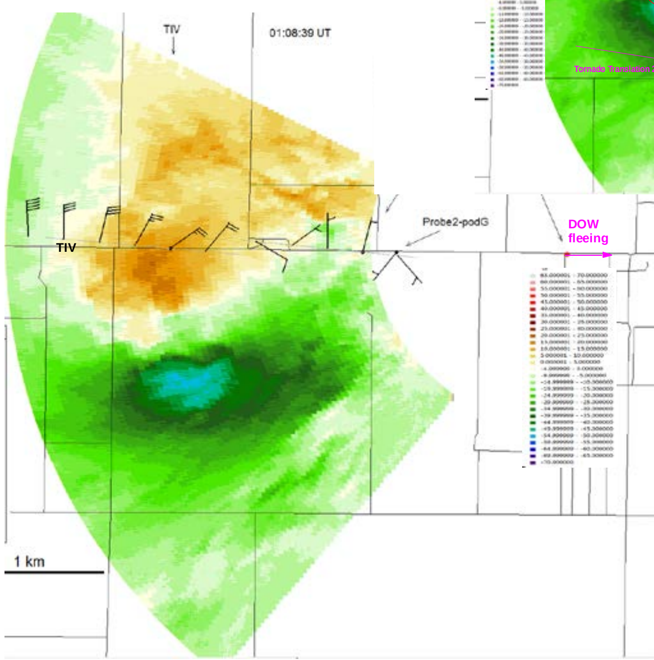
How do radar measurements at XX m AGL compare to 10 m AGL?

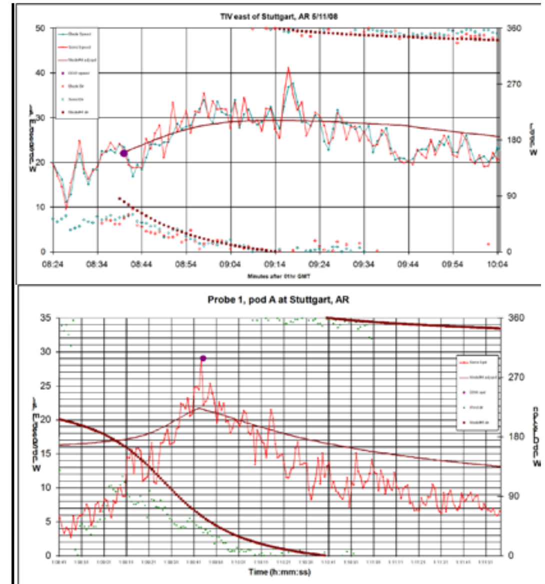


Radar + 1-3.5 m AGL

Observations in Stuttgart, Arkansas, 2008 tornado **DOW EF-5**







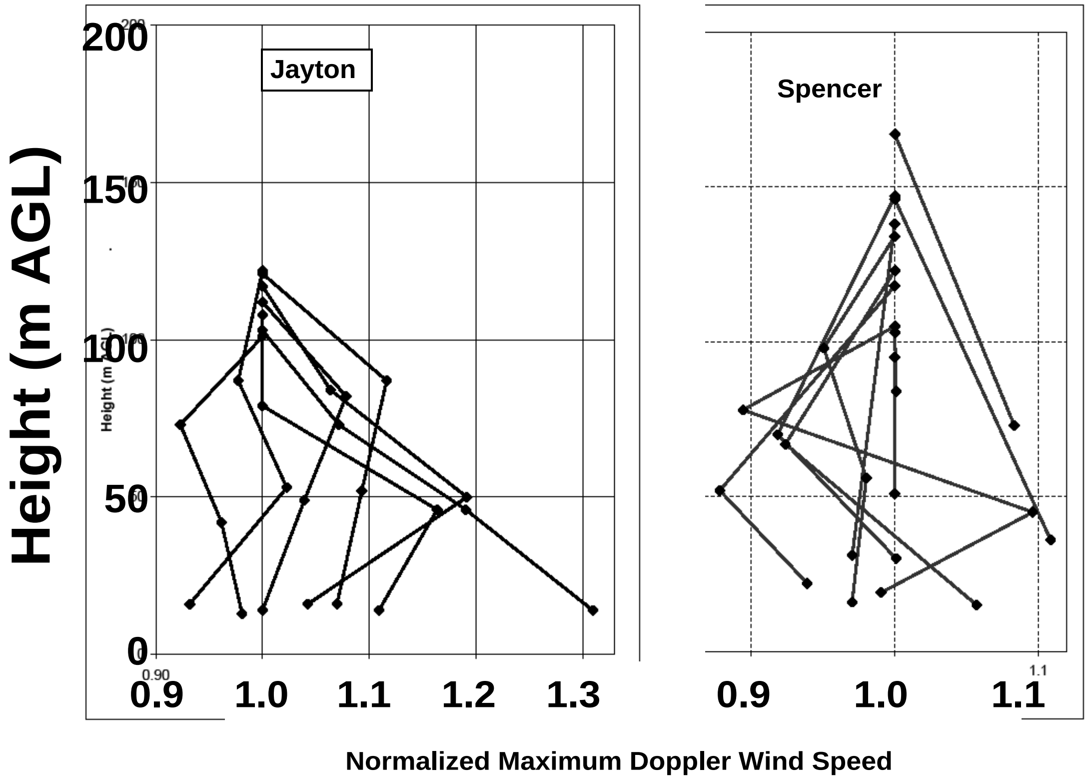
(Vmax = 102 m/s)

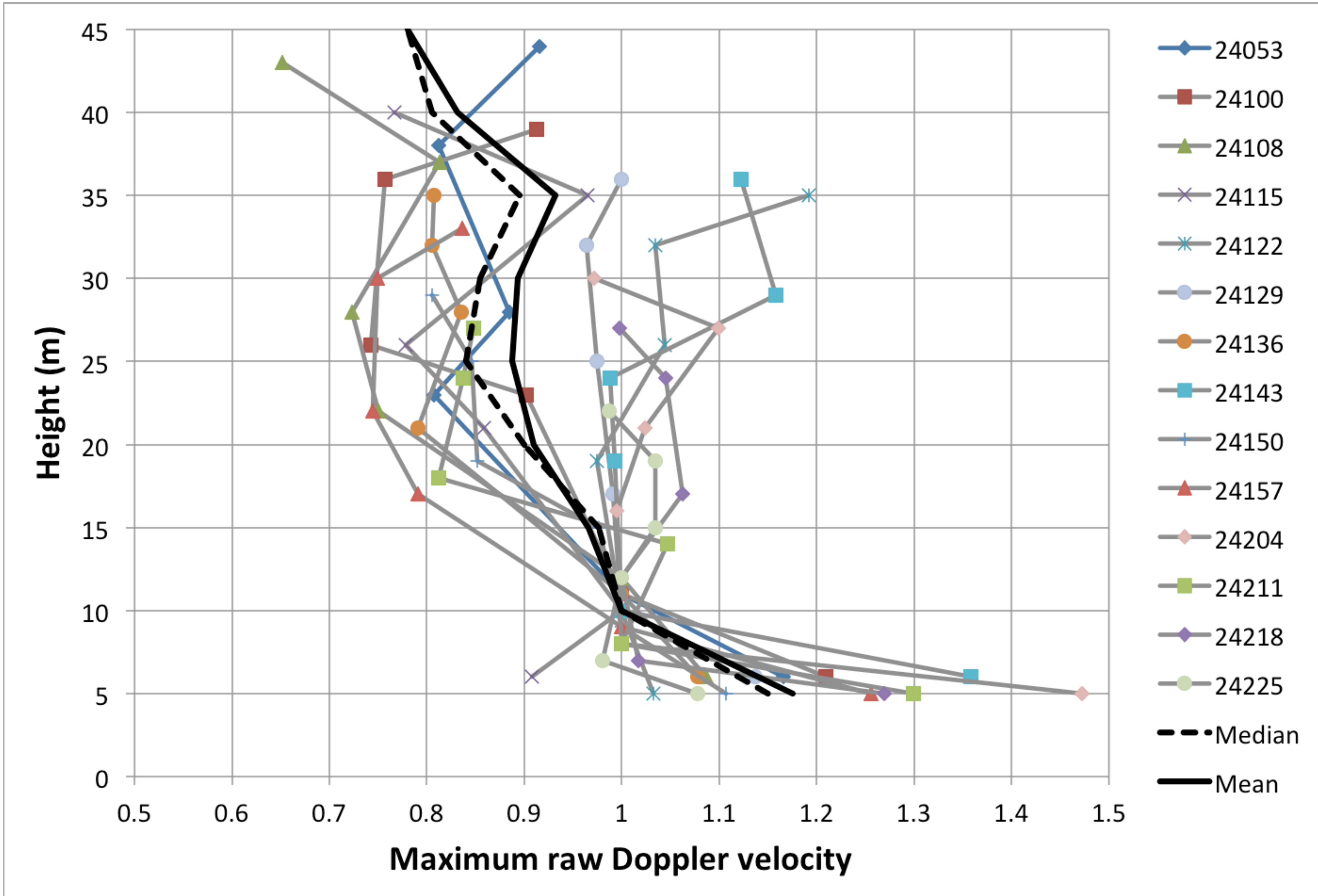
TIV 3-m winds 90% as intense as DOW 250 m winds. No apparent inward turning of winds in sector sampled by TIV.

Pod 1-m winds 50-60% as intense as DOW winds. 40-50 degree inward turning in this sector.

Study of two tornadoes found no strong dependence dVmax/dZ ~ 0 for 15 m < Z < 100 m

Wurman, J., C. Alexander, P. Robinson, and Y. Richardson, 2007c: Low Level Winds in Tornadoes and Potential Catastrophic Tornado Impacts in Urban Areas. *Bull. Amer. Meteor. Soc.* **88**, 31-46.



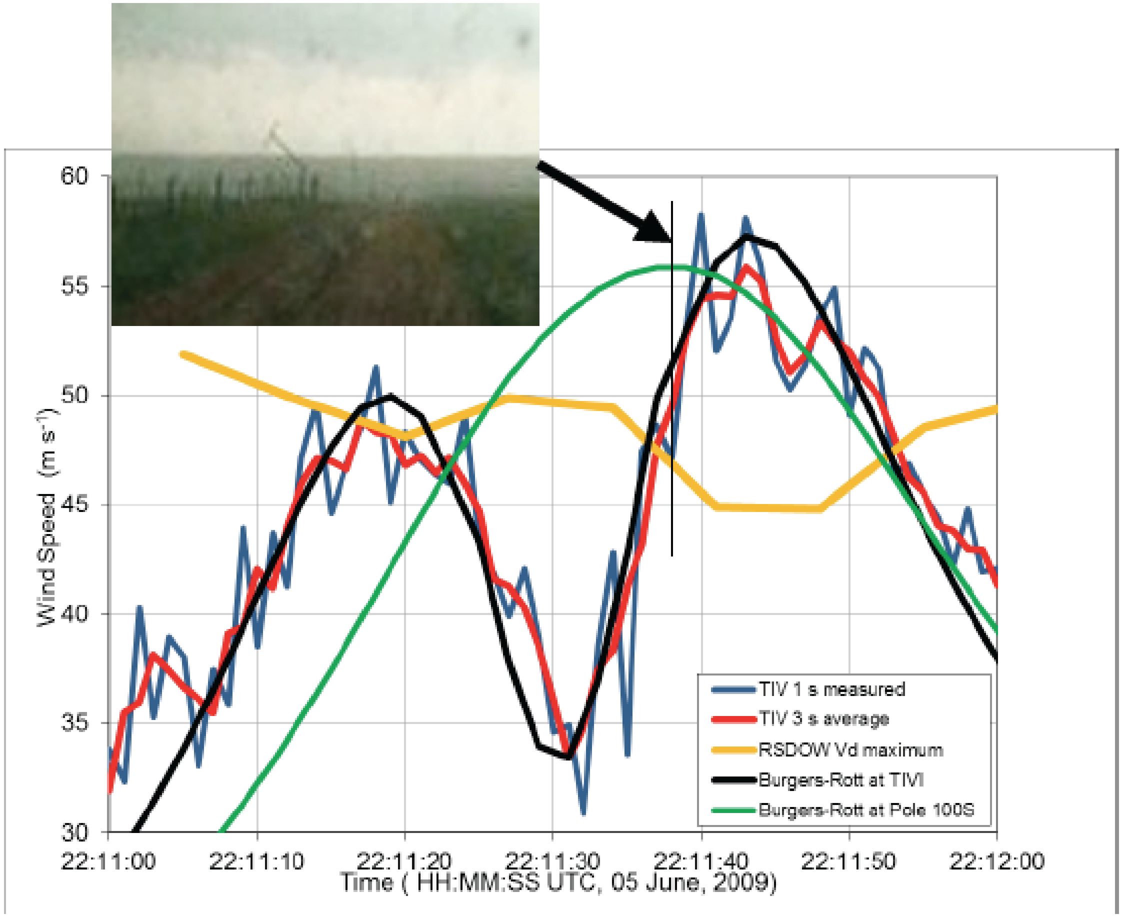


Height (m)
Maximum raw Doppler velocity
45
40
35
30
25
20
15
10
5
0
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
24053
24100
24108
24115
24122
24129
24136
24143
24150
24157
24204
24211
24218
24225
Median
Mean

Winds observed by TIV anemometer in Goshen County, Wyoming, 2009, tornado

V (3 m AGL) > Vdoppler (30-100 m AGL)

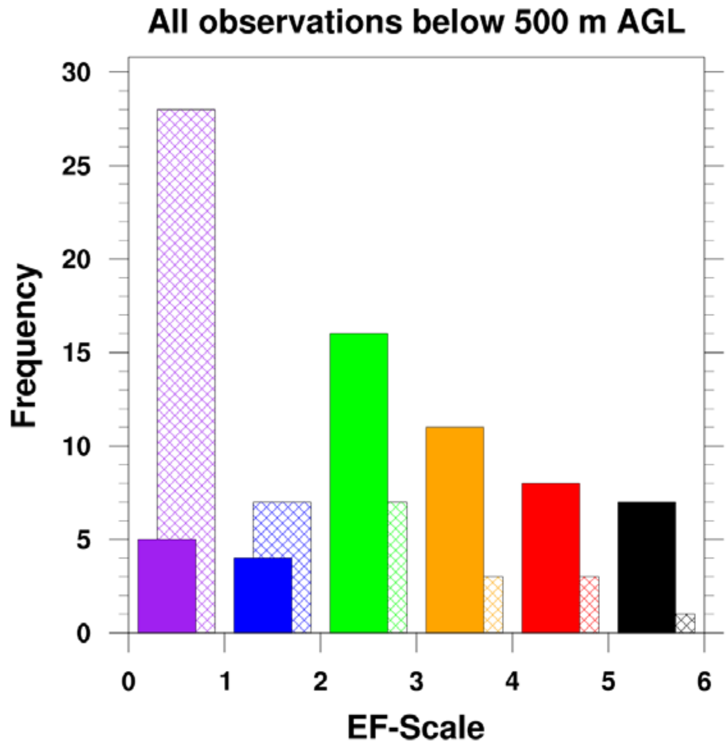
Wind measurements compared to real-time damage documention

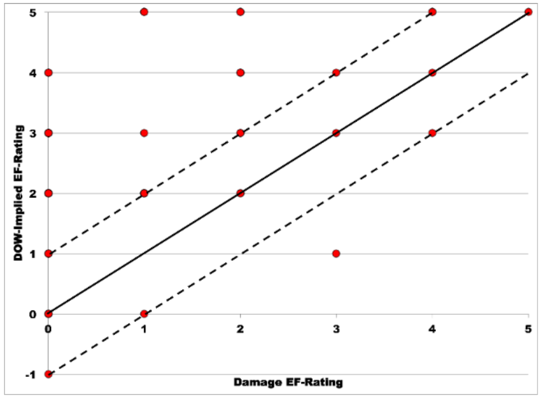


TIV wind transect data fit to Burgers-Rott profiles

DOW EF usually > NWS EF
DOW EF >= NWS EF + 2 in 40% of tornadoes

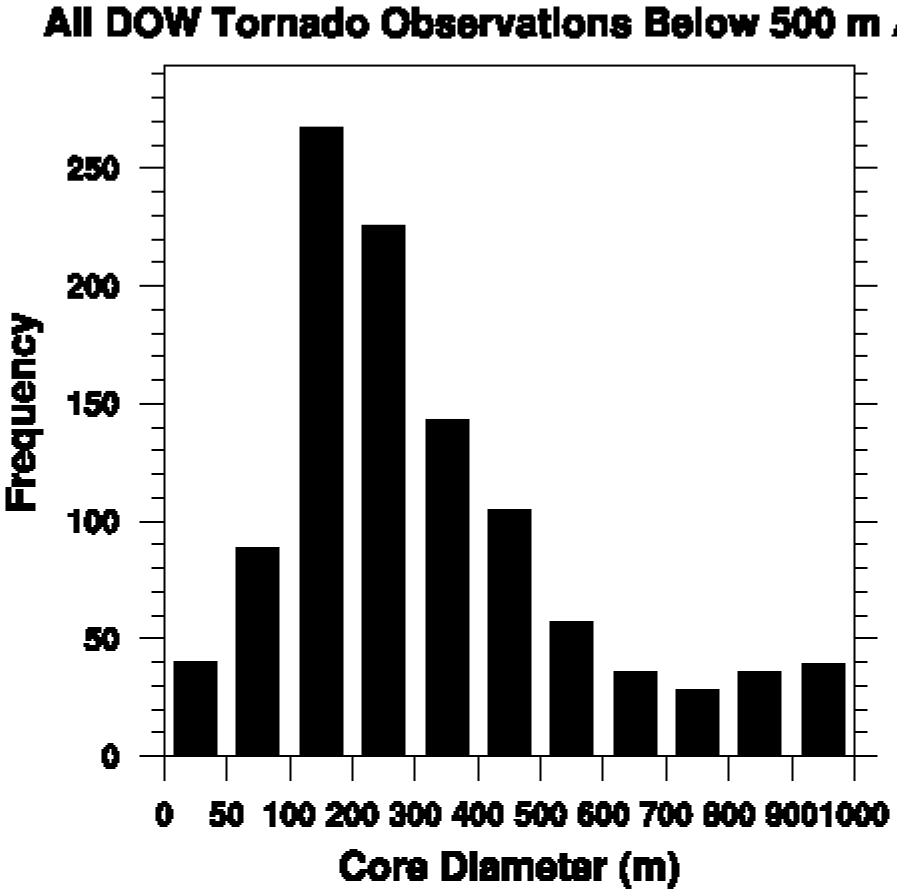
Tornadoes have a preferred intensity: EF2-3



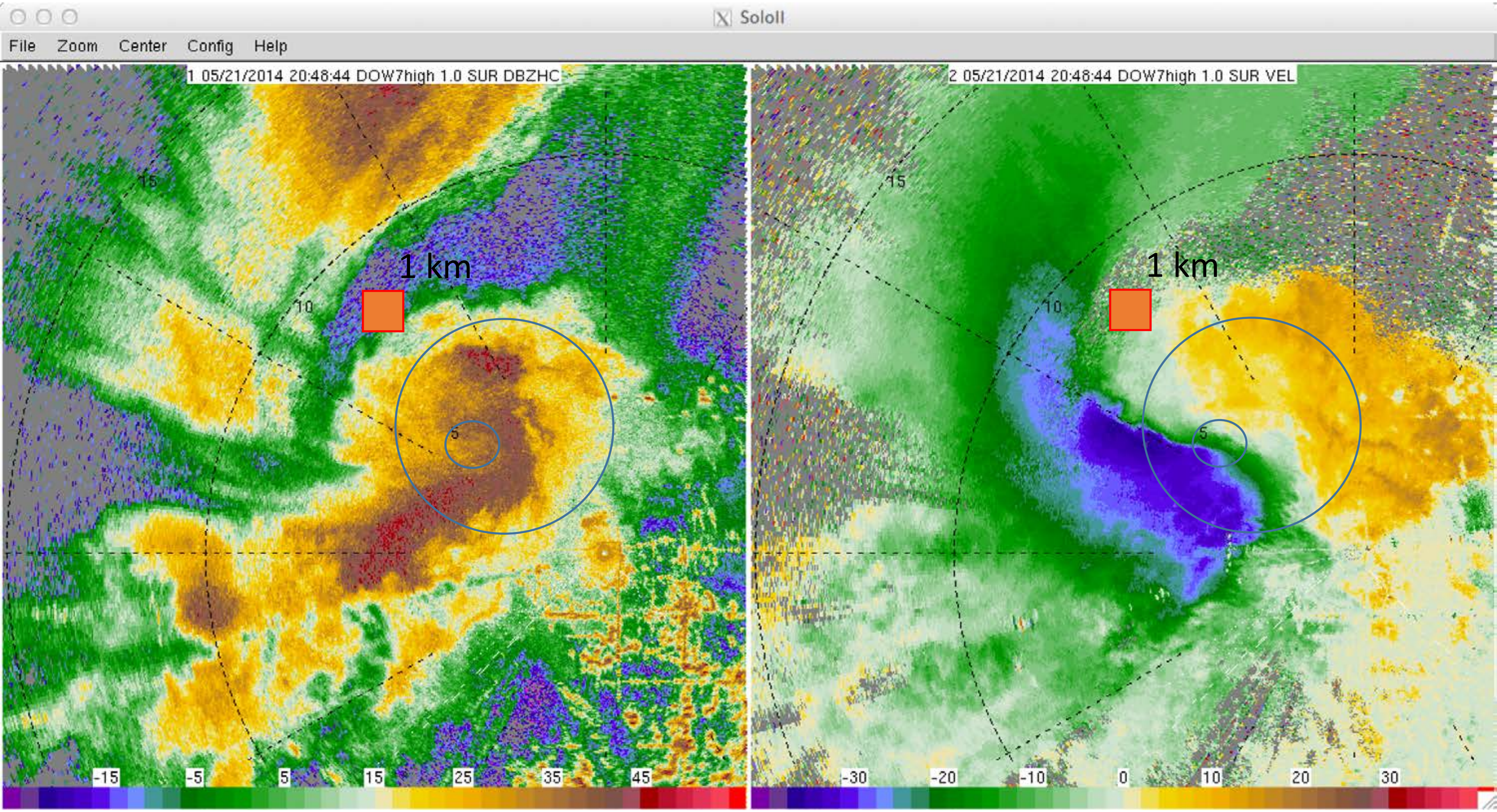


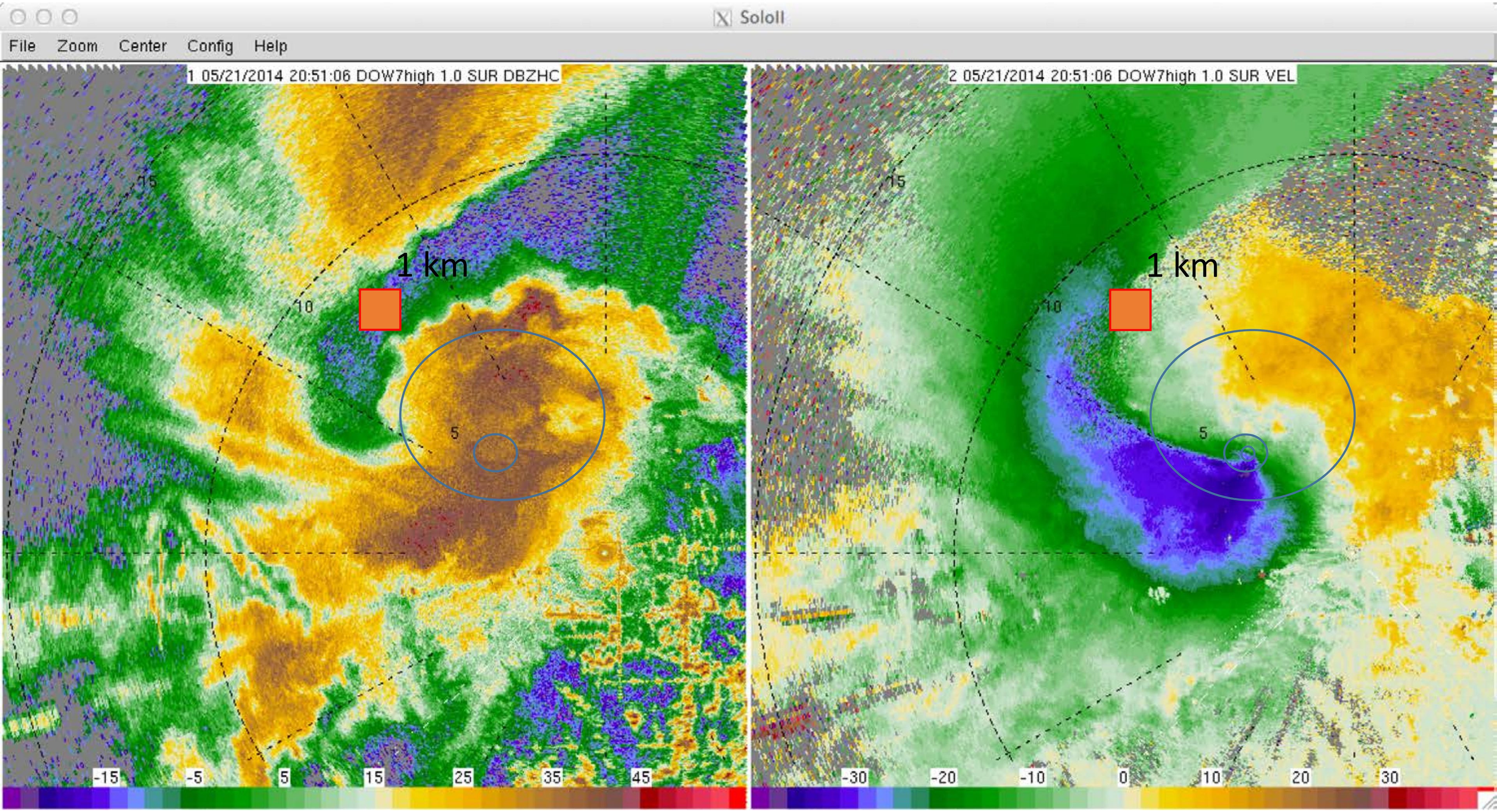
Expected "turbulent" spectrum of tornado sizes

But, tornadoes have a preferred size: Diameter = 200 m



A couple images of "marginal tornadoes" observed by a DOW near DEN on 5/21/2014




SoloII
File
Zoom
Center
Config
Help
1 05/21/2014 20:51:06 DOW7high 1.0 SUR DBZHC
2 05/21/2014 20:51:06 DOW7high 1.0 SUR VEL
1 km
1 km
15
10
5
15
10
5
-15 -5 5 15 25 35 45
-30 -20 -10 0 10 20 30

Issues related to tornado risk

- Type of tornado: Supercell or non supercell
- Peak winds in core flow of median supercell tornado ~60-70 m/s (130-150 mph) might lift wings
- Median diameter of core flow region ~250 m, but in strong tornadoes, damaging winds will occur outside maximum wind region
- Supercell tornadoes capable of EF-4 to EF-5 damage comprise ~25% of cases
- Tower and other 'hard' structures likely resistant to all but the worst supercell tornadoes at DEN
- Multiple tornadoes and other complex structures are not rare
- Tornado forward speed usually 5-15 m/s (10 – 30 mph) = few to several minutes to avoid.
- Avoidance (i.e. moving aircraft/vehicles out of path) could be done intelligently … if expert tracking/predicting tornado motion used WSR-88D data. (Otherwise, moving might increase risk.)