A Detailed Analysis of Tornadogenesis in a Simulated Mesovortex

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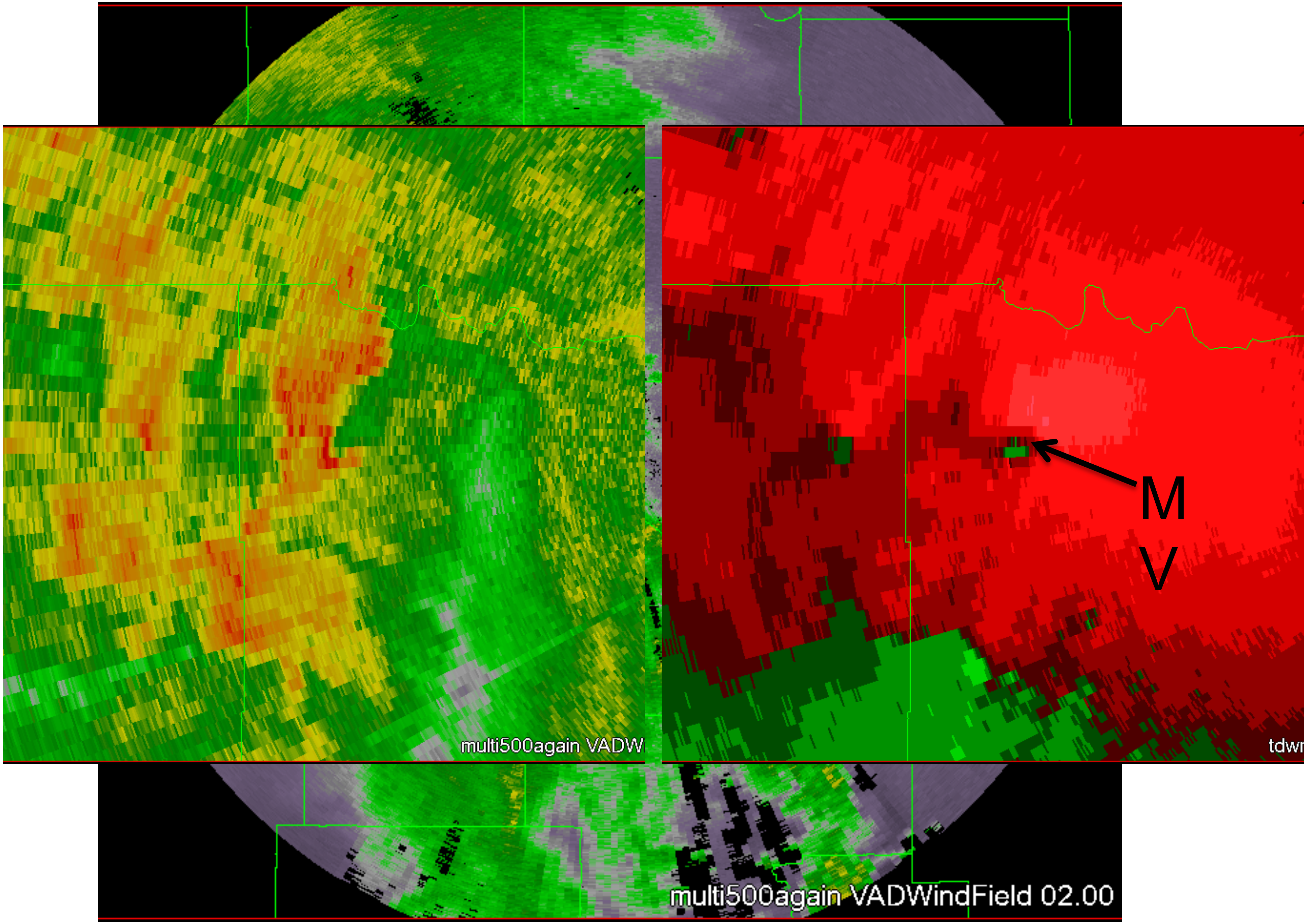
Motivation

- On 8-9 May 2007, an MCS an associated line-end vortex (LEV) moved through southwest and central Oklahoma.
- This system was observed by several WSR-88Ds, the CASA IP-1 network, and the Oklahoma Mesonet.
- The MCS and LEV successfully simulated using the ARPS model and 3DVAR radar data assimilation with 2-km grid spacing (Schenkman et al 2011a).
- Radar indicated MCS contained several mesovortices. Two of these mesovortices were tornadic.
- The first of these mesovortices was successfully ‘forcecasted’ up to 80 min in advance by Schenkman et al (2011b) when CASA radial velocity data were assimilated.

Tornadic Mesovortices

- Tornadic mesovortices are longer-lived and stronger than their non-tornadic counterparts
- Mesovortices are similar to supercell mesocyclones in appearance, but differ in that they are not associated with a deep, persistent rotating updraft. (Weisman and Trapp 2003)
- Mesovortices are also responsible most of the damaging straight-line winds QLCSs.
- This is thought to occur due to a superposition of the mesovortex flow field with a descending rear-inflow jet. (e.g., Wakimoto et al 2006b)
- Little is known about the dynamical relationship between tornadoes and mesovortices.

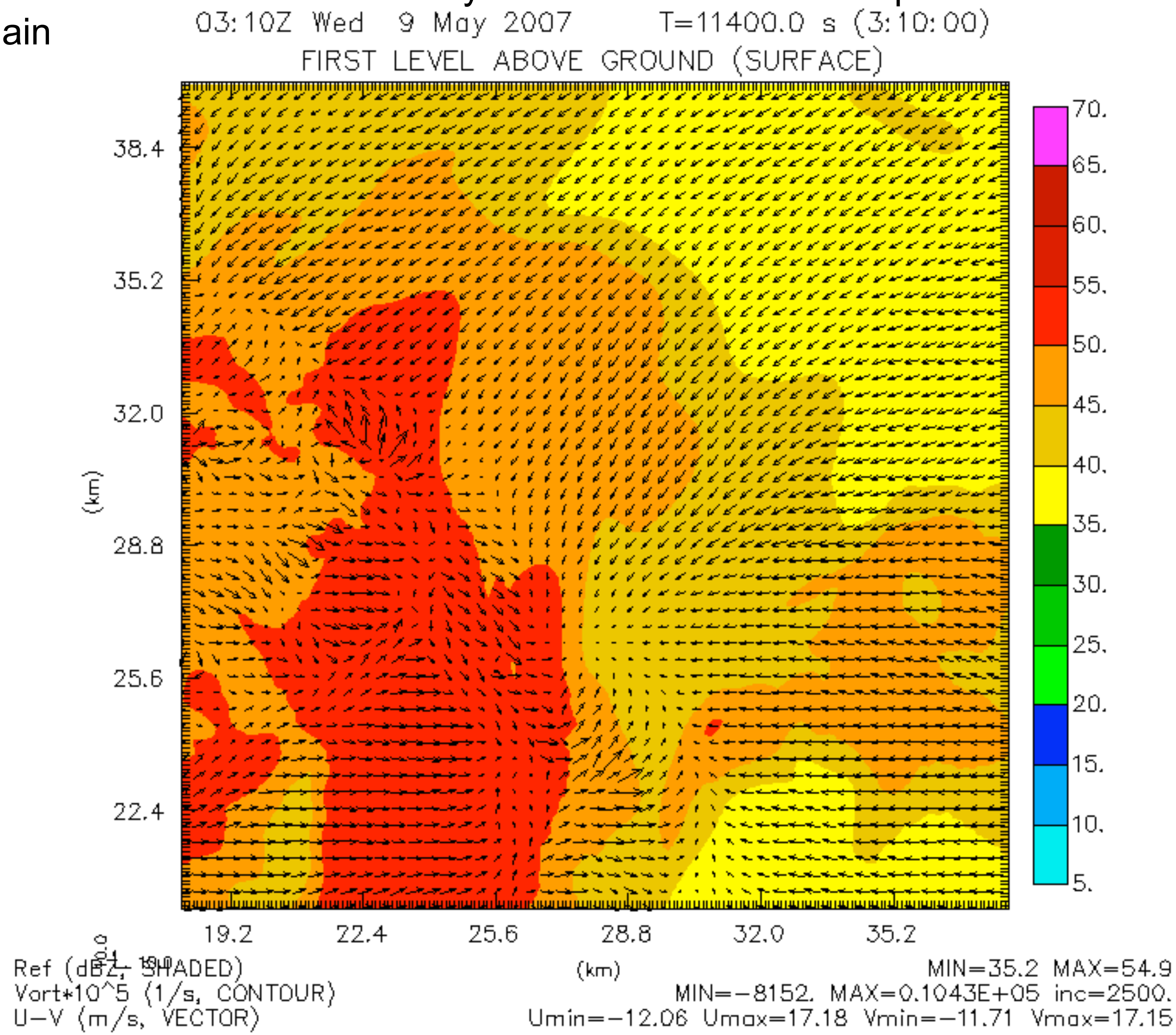
The Case

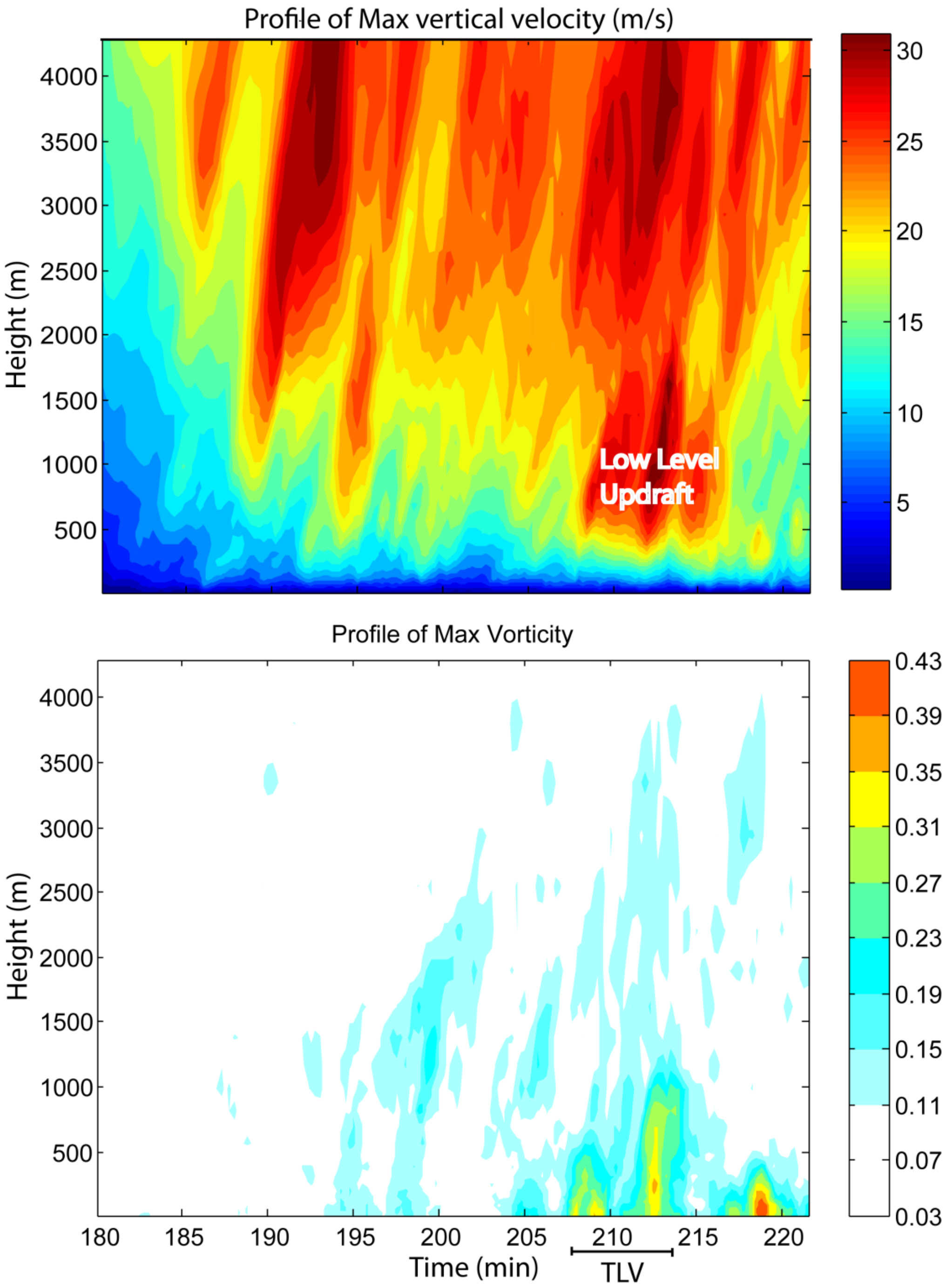

multi500again VADW
tdwr
M
V
multi500again VADWindField 02.00

100-m simulation

- Triple (one-way) nested within the 2-km and 400-m domains.
- I.C. Interpolated from 40-min forecast on the 400-m domain.
- ARPS model, including surface drag.
- Single moment (Lin et al. 1983) microphysics (with $N_{or} = 8x10^5$).

Animation of simulated reflectivity and wind vectors over a portion of the 100-m domain





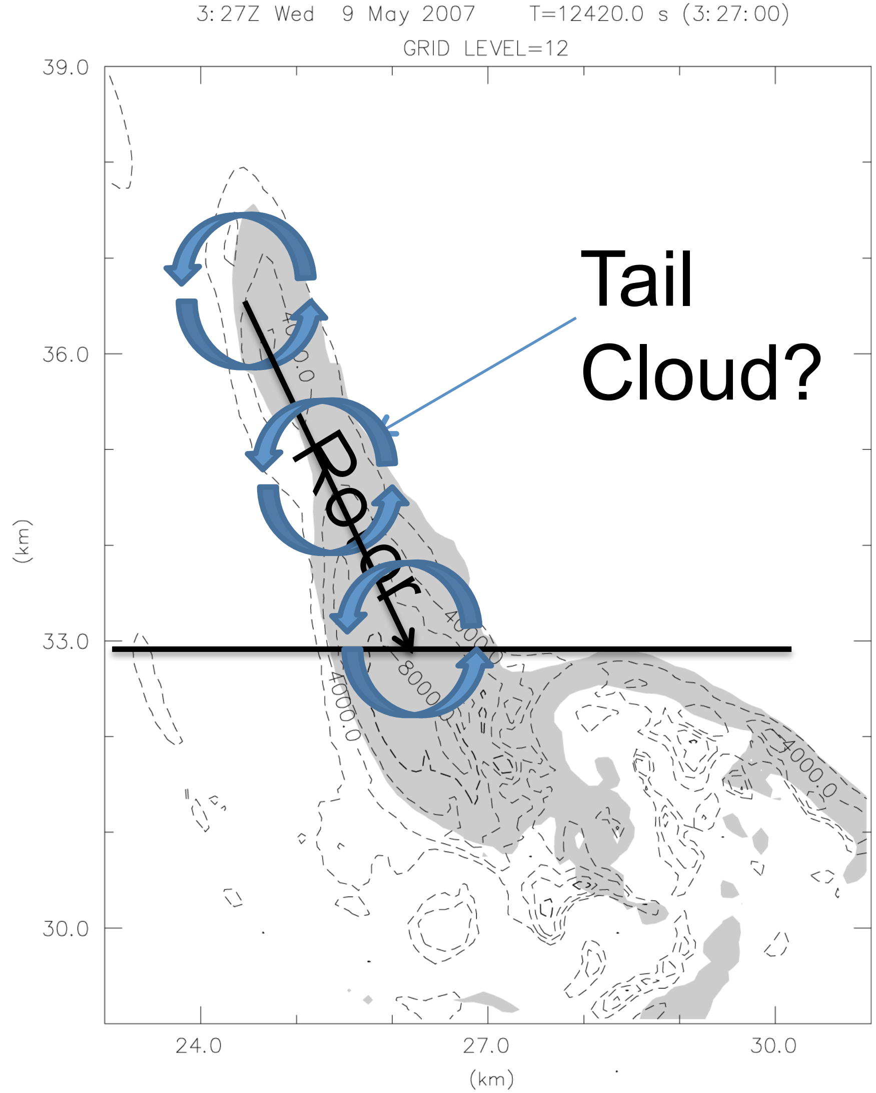
Profile of Max vertical velocity (m/s)
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
30
25
20
15
10
5
Low Level
Updraft
Profile of Max Vorticity
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
0.43
0.39
0.35
0.31
0.27
0.23
0.19
0.15
0.11
0.07
0.03
180
185
190
195
200
205
210
215
220
Time (min)
TLV

Tornado-like vortex (TLV)

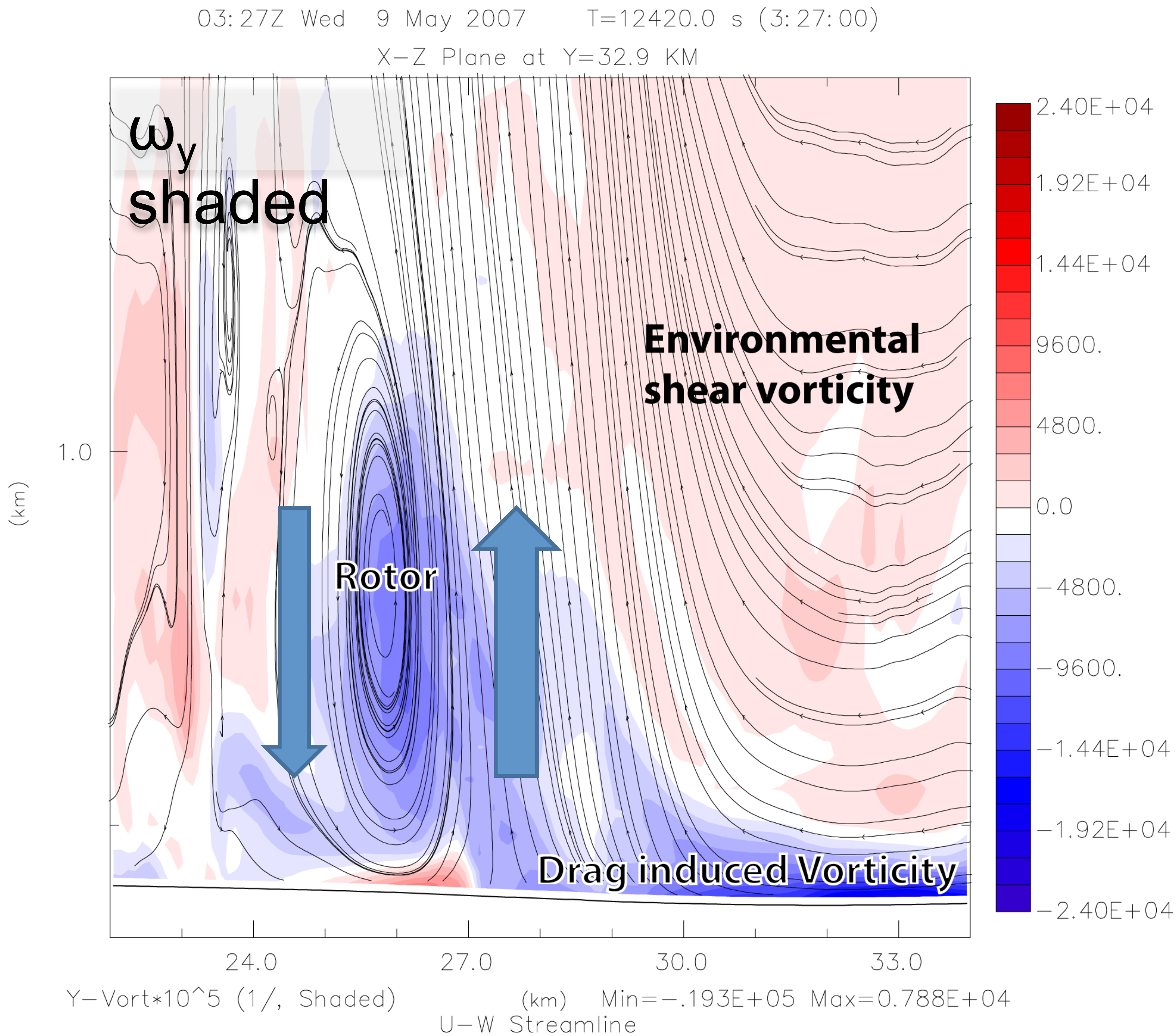
- Backward trajectory analysis indicate that an important source of tornadic vorticity is strong low-level stretching.
- The strong stretching occurs as the parcel encounters the strong low-level updraft.
- What is the cause of the low-level updraft?

Rotor

~600 magl, $q_c > 0.03$ shaded,y-comp vort contoured.



- The strong low-level updraft is associated with a horizontal rotor on the northwest side of the developing TLV.
- The low-level updraft forms in strong low-level convergence on the eastern side of the rotor.
- Rotor develops before and persists through the lifetime of the TLV.
- All parcels in the rotor originate near the ground in the storm inflow, suggesting surface friction may be the source of vorticity in the rotor.

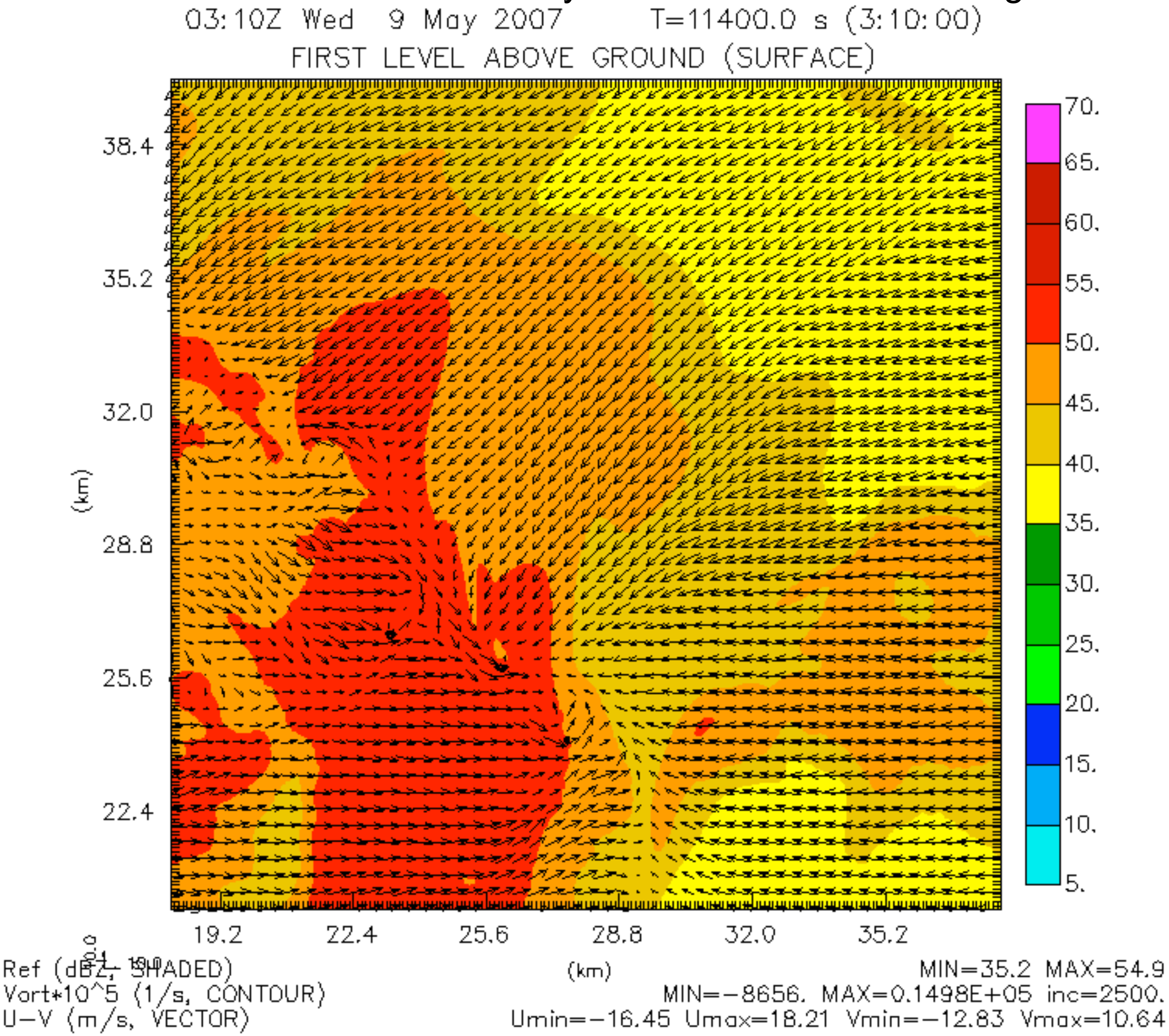


03:27Z Wed 9 May 2007 T=12420.0 s (3:27:00)
X-Z Plane at Y=32.9 KM
ωy
shaded
Environmental
shear vorticity
Rotor
Drag induced Vorticity
1.0
(km)
24.0
27.0
30.0
33.0
2.40E+04
1.92E+04
1.44E+04
9600.
4800.
0.0
-4800.
-9600.
-1.44E+04
-1.92E+04
-2.40E+04
Y-Vort*10^5 (1/, Shaded)
(km)
Min=-.193E+05 Max=0.788E+04
U-W Streamline

Surface Drag

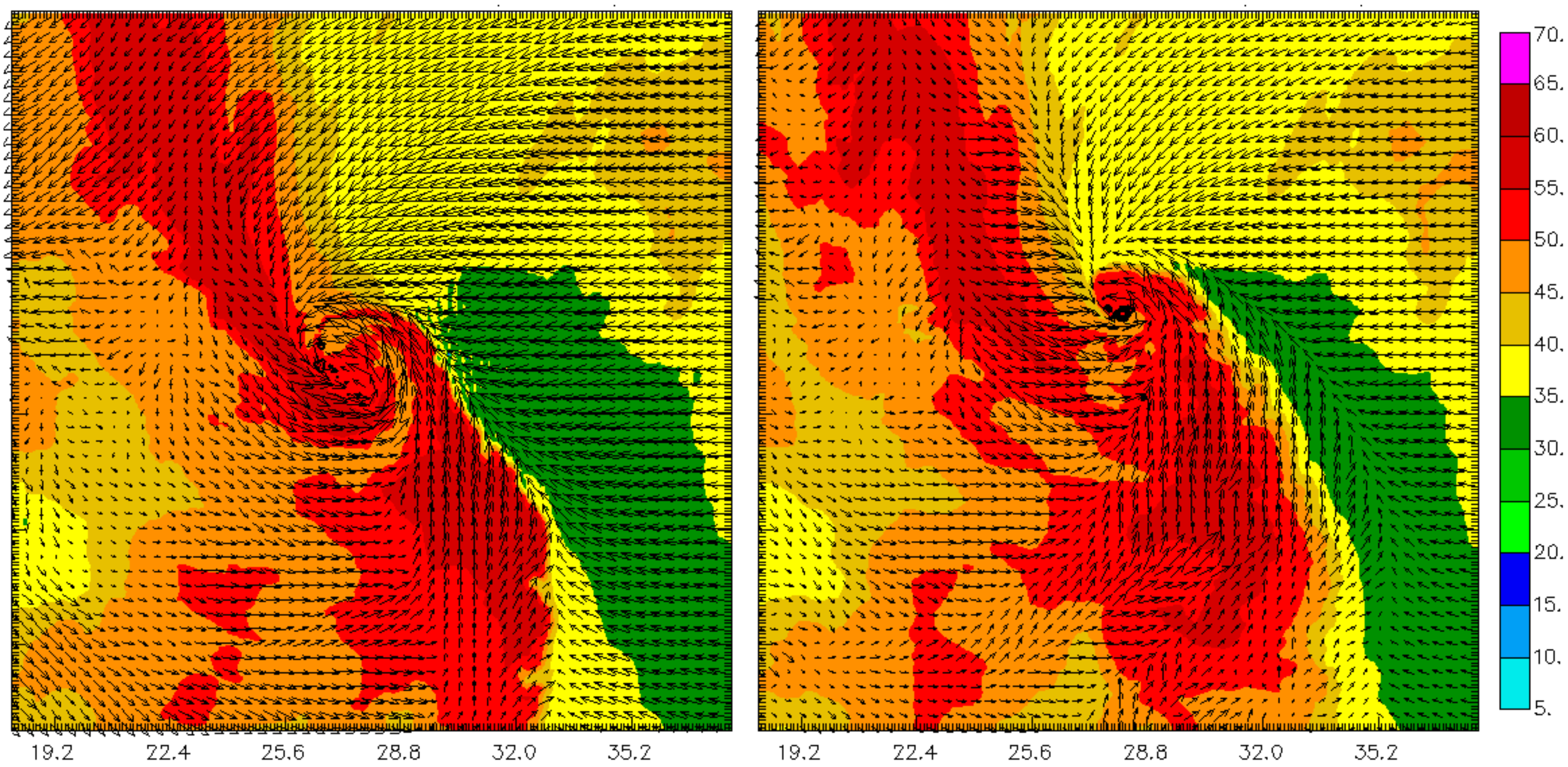
- To verify the surface drag is the cause of the rotor/low-level updraft we run the inner domain again with surface drag turned off.
  - Caveat: Outer domain still has friction on. However, this should not be important as the low-level vorticity (jet) generally develops within the 100-m domain as the convective storm strengthens.
  - Also, storm is near the middle of the domain, reducing boundary effects.

Animation of simulated reflectivity and wind vectors- No drag simulation

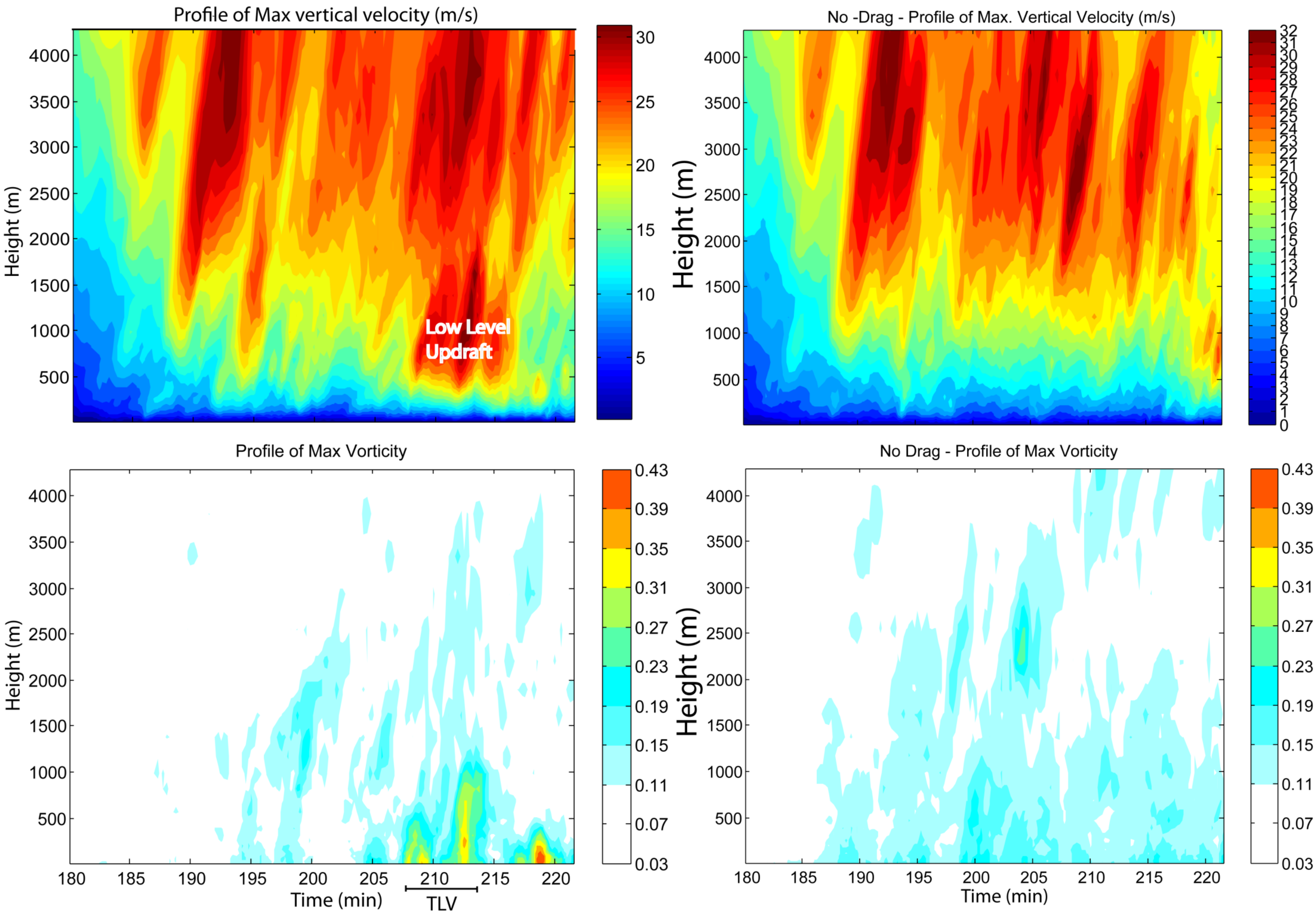


No Drag

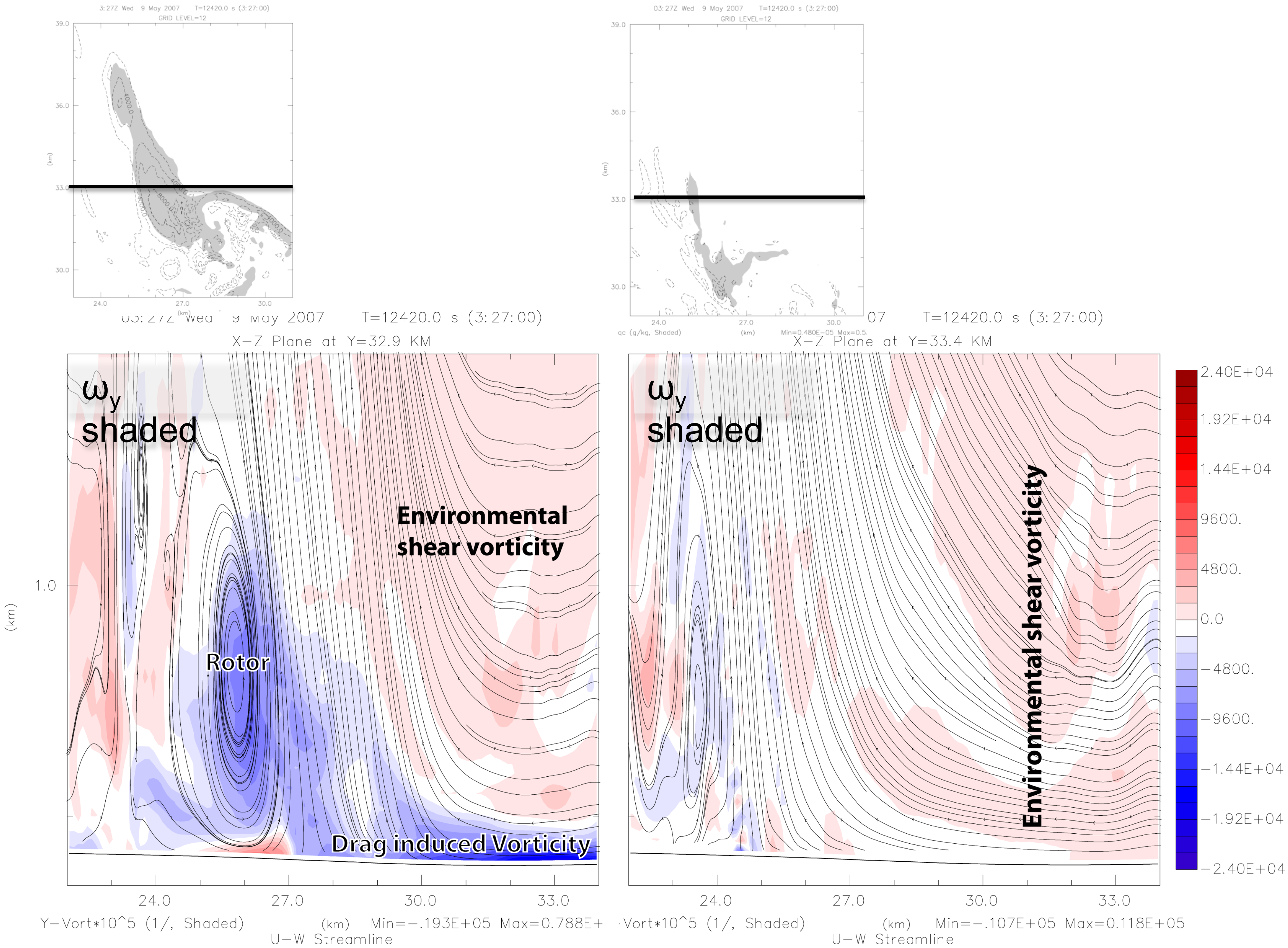
Drag



19.2
22.4
25.6
28.8
32.0
35.2
19.2
22.4
25.6
28.8
32.0
35.2
70.
65.
60.
55.
50.
45.
40.
35.
30.
25.
20.
15.
10.
5.



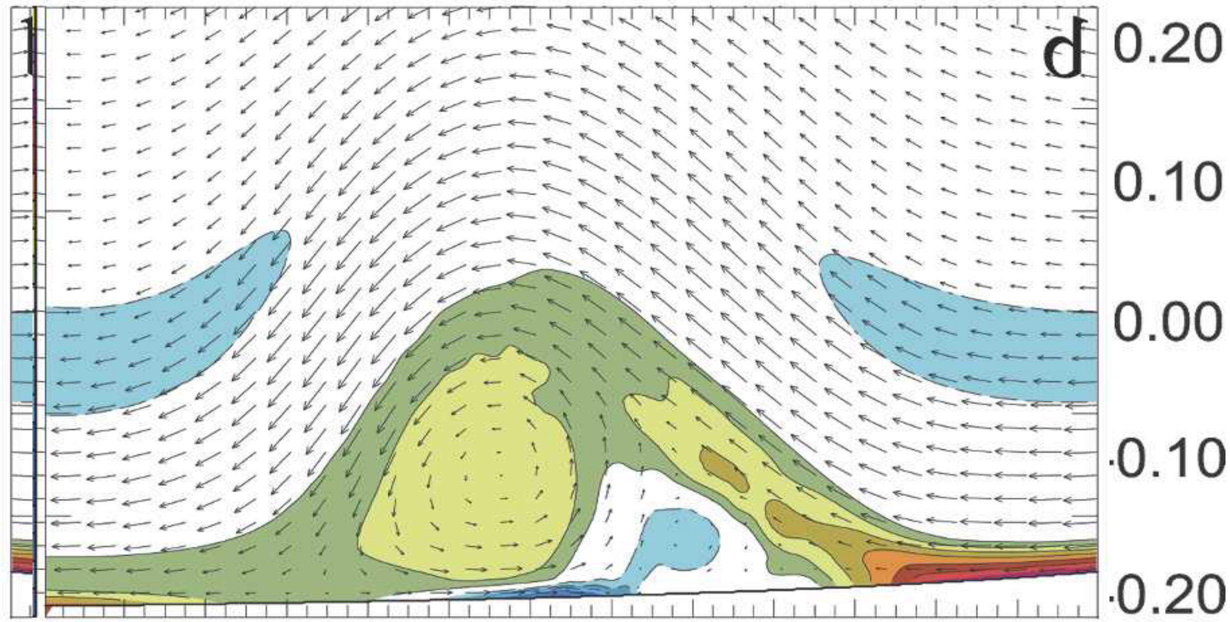
vortex in no drag run

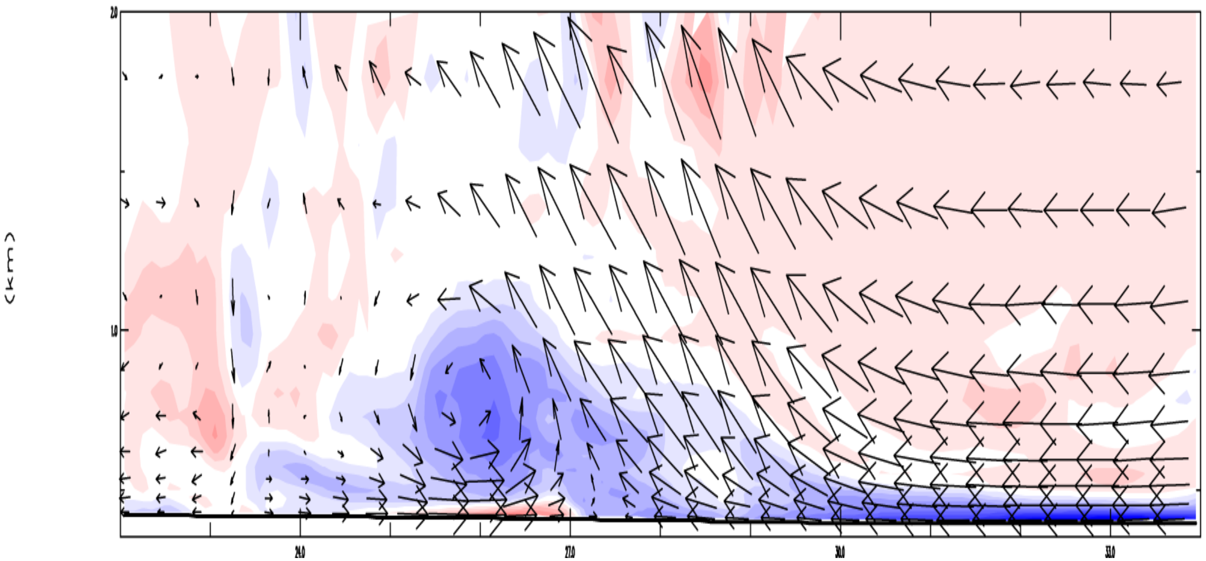


3:27Z Wed 9 May 2007 T=12420.0 s (3:27:00)
GRID LEVEL=12
03:27Z Wed 9 May 2007 T=12420.0 s (3:27:00)
X-Z Plane at Y=32.9 KM
X-Z Plane at Y=33.4 KM
qc (g/kg, Shaded)
Min=0.480E-05 Max=0.5
ω_y shaded
ω_y shaded
Environmental shear vorticity
Rotor
Drag induced Vorticity
Environmental shear vorticity
Y-Vort*10^5 (1/, Shaded) (km) Min=-.193E+05 Max=0.788E+
Vort*10^5 (1/, Shaded) (km) Min=-.107E+05 Max=0.118E+05
U-W Streamline
U-W Streamline
2.40E+04
1.92E+04
1.44E+04
9600.
4800.
0.0
-4800.
-9600.
-1.44E+04
-1.92E+04
-2.40E+04

How does surface drag lead to rotor formation?

- Seems to be analogous to the rotor that forms in lee of a mountain when flow with a thin vortex sheet near the ground generated by surface drag passes over a mountain and breaks up into lee-waves.
- Doyle and Durran (2002) found that rotor forms in 2-D simulations (with surface drag) owing to boundary layer separation caused by an adverse pressure gradient associated with lee waves.
- In our case:
  - The adverse pressure gradient is the caused by the gust front instead of a lee-wave.
  - The low-level wind maximum is created by flow accelerating into the intensifying storm, rather than by flow coming down a mountain
  - Three dimensionality means the vorticity is stretched in the rotor-parallel direction by flow accelerations into the developing mesovortex.





Top Figure adapted from Doyle and Durran (2007)

Conclusions

- The low-level updraft/rotor appears to be *critical* for tornadogenesis in this case.
- Horizontal vorticity in rotor is generated by surface drag which creates an inflow jet. As this jet encounters the storms (forward flank) gust front, a rotor forms immediately behind the GF.
- Experiments without drag do not produce a rotor, strong low-level updraft, or tornado-like vortices (broader mesovortex instead).

Ongoing Work

- How common is this feature? Tail-cloud?
- Did earlier modeling studies of supercells, which found large baroclinic vorticity generation in the same region of the storm as the rotor, get it right for the wrong reason?
- Relative importance of tilting of rotor vorticity vs. stretching in the low-level updraft.
- RFD vorticity vs rotor vorticity.

- Dowell and Bluestein (1997) found intense low-level shear in the inflow region of a supercell. Is this from surface drag?

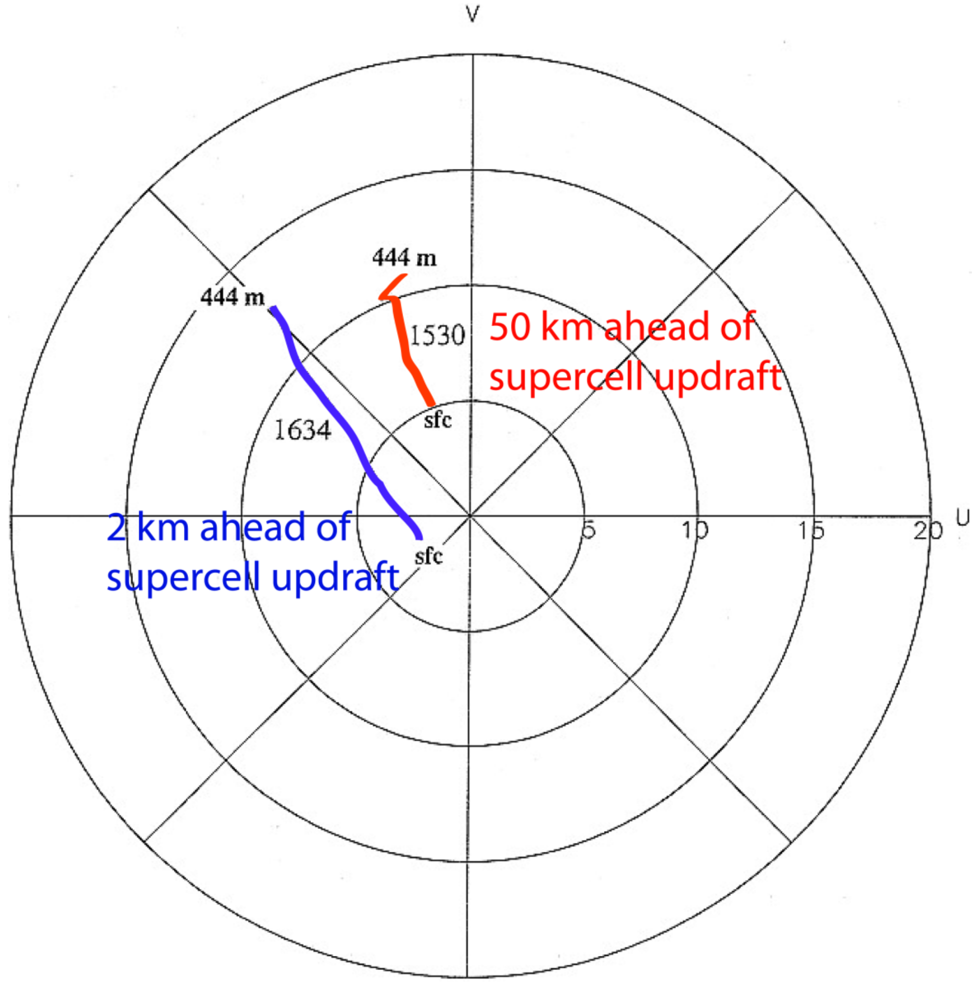


Figure adapted from Dowell and Bluestein (1997)