Observations of Low Level Mesocyclone Evolution

Using A New Trajectory Mapping Technique

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Tornadic Supercell on 29 May 2004 Geary, OK USA

Radar Overview

SMART-Radars

(Shared Mobile Atmospheric Research and Teaching)

- **2 mobile C-band for all studies**
- **Volume scanes 2.5 ~ 3 min**
- **Gate spacing 67m**
- **Beamwidth: ~ 1.5°**

Dual-Doppler Analysis

- **Used SOLOII for editing**
- **Natural neighbor interpolation to Cartesian grid**
- **750 x 750m x 500m grid**
- **Used CEDRIC's variational, double boundary condition scheme for retrieving W. W=0 @ ground.**
- **Actual dual-Doppler analyses every ~2.5 minutes**

Time-interpolated radial velocities and created pseudo-dual-Doppler analysis every ~45 seconds

- Storm motion based on least-squares minimization of time interpolated vertical vorticity.
- limits advection of vertical motion
- more dynamically consistent flow

Trajectory Methodology

- **Trajectories initialized every 250 m and every 60 seconds**
  - computed backward in time 10~15 minutes (500~1000 seconds)
  - used 4th order Runge-Kutta for time integration with time step of 5 seconds.
- **Between the raw radar sweeps and the individual trajectories 4 levels of filtering exist**
- **Goal: Represent storm-scale Lagrangian evolution**
  - In strong three-dimensional flows, static Eularian analyses can be misleading, especially when U,V >> W (lowest ~3 km). Advection and deformation on one scale, shapes the flow characteristics at smaller scales.
- **Different types of trajectory maps:**
  - Information at a single point in time, e.g. altitude, u,v,w, vorticity, reflectivity etc… or
  - Information integrated over time, e.g. vorticity tendency terms, divergence tendency terms, cloud physics
  - Ultimate goal is to recognize different flow regimes through derived variables

$$\frac{d\omega_H}{dt} = \omega \cdot \nabla v_H + \nabla \times (B\hat{k}) + \frac{1}{\rho^2}(\nabla\rho \times \nabla P)_H$$

Derived Trajectory Mapped Variables

- **Color filled plot:**
  - **Height of trajectory at the end of the backward calculation, referred to as "Initial Altitude" or Z_0**

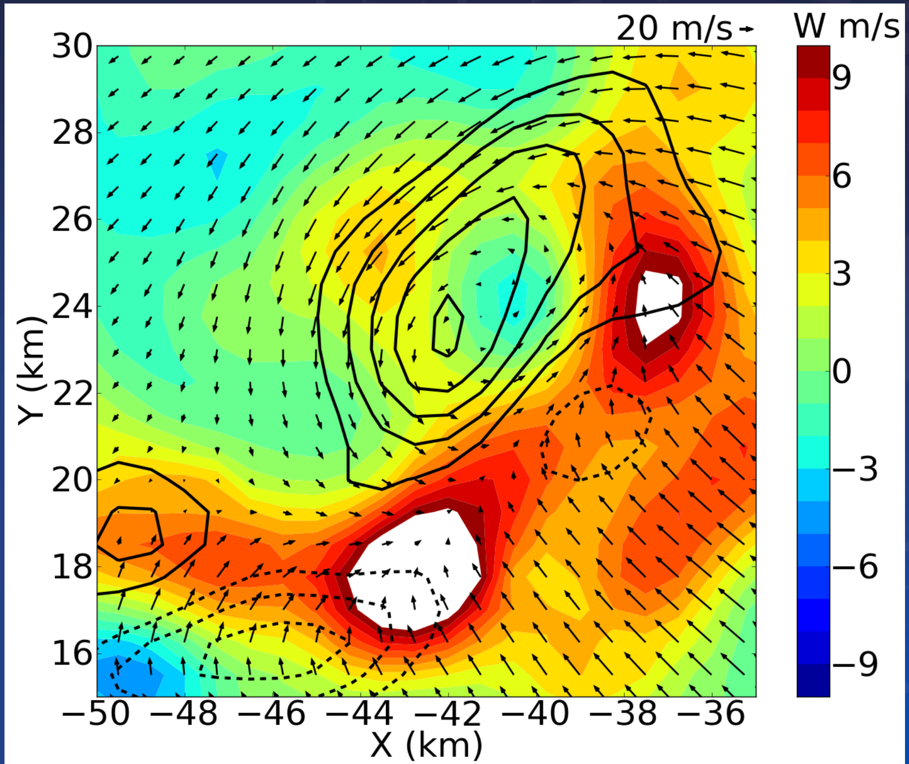
- **Contour plot:**
  - **Derived vertical vorticity : initial vertical vorticity plus the integration in time of the stretching and tilting terms in the vertical vorticity tendency equation:**

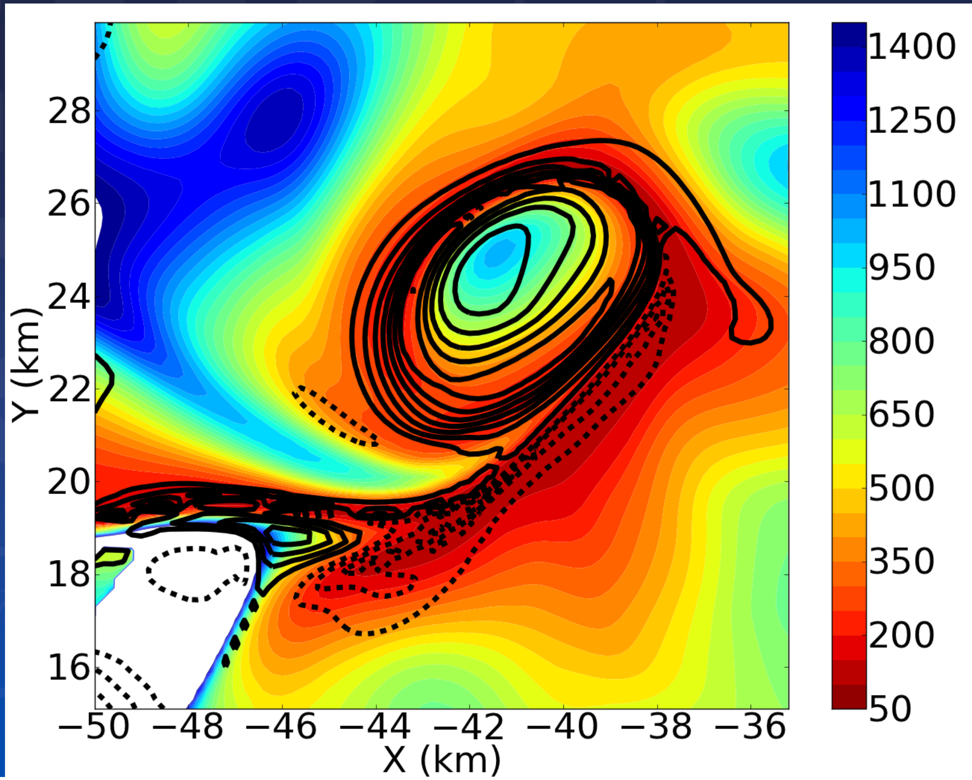
$$\zeta_F = \zeta_I + \int \left(\omega_H \cdot \nabla w + \varsigma \frac{\partial w}{\partial z}\right) dt$$

Dual-Doppler and Trajectory map
0017:45 UTC, Z = 700m

- Vertical Velocity (color filled) and Vertical Vorticity (contoured every 5×10^{-3} s^{-1})
- Split updraft/downdraft mesocyclone structure indicates mature phase/

- Z_0 (m) (color filled) and derived vertical vorticity (contoured every 5×10^{-3} s^{-1}) (~300s)
- Trajectory map reveals annular pattern in initial altitude and derived vertical vorticity (lower plot).

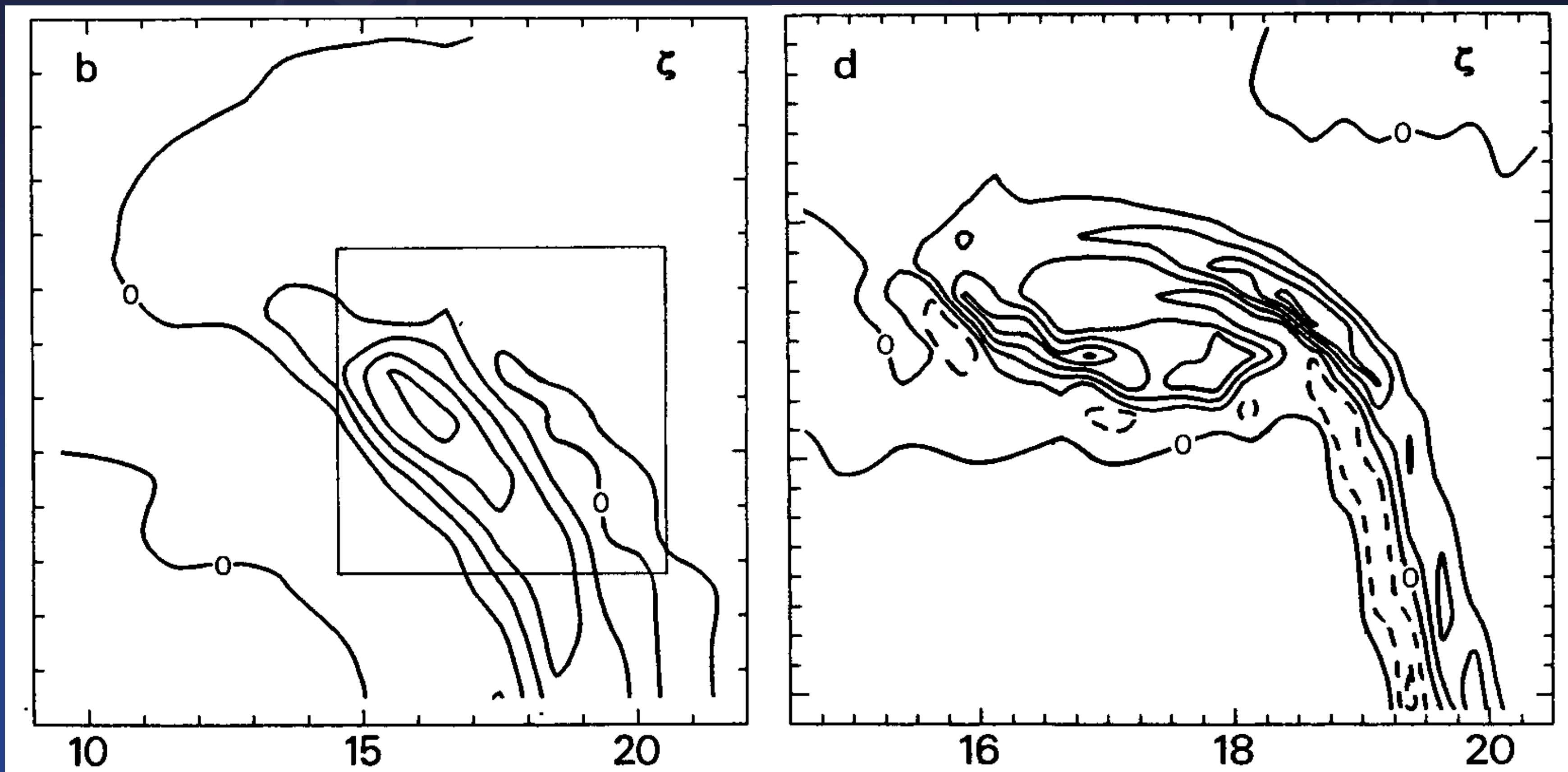




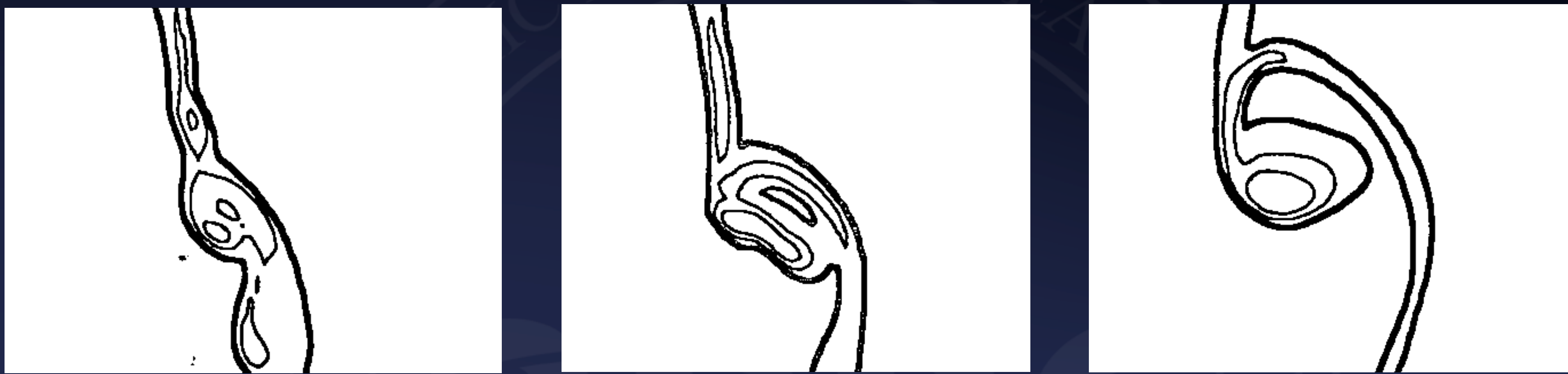
Example of Annular Structure at Higher Resolution

Klemp and Rotunno (1983) Vertical Vorticity (every 5×10^{-3})

$\Delta x = 1000$ m $\Delta x = 250$ m

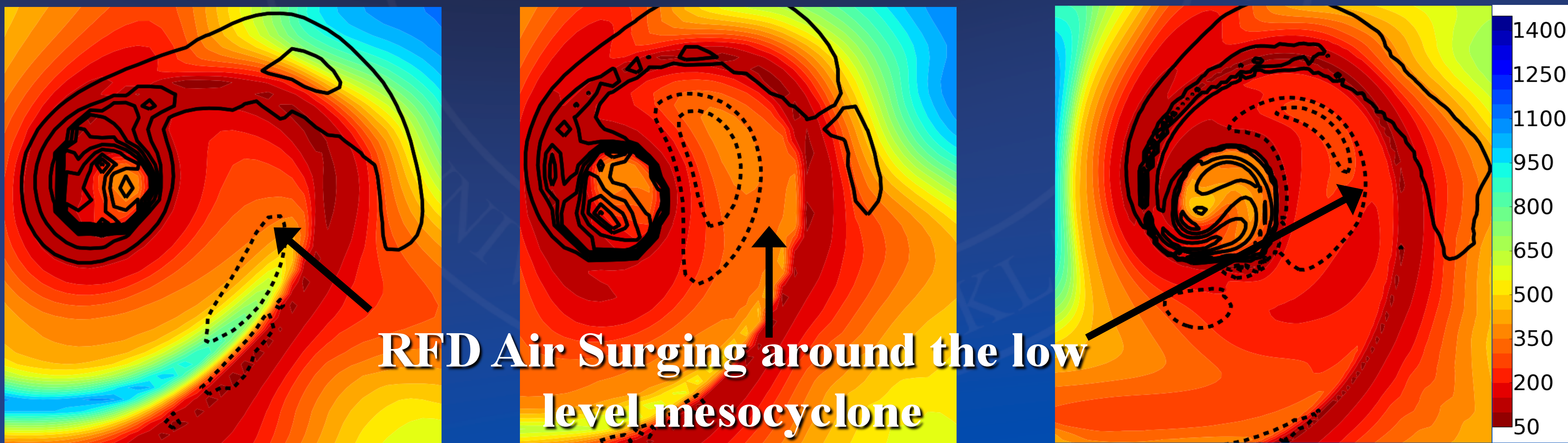


Vertical Vorticity for first tornado in Wicker and Wilhelmson 1995



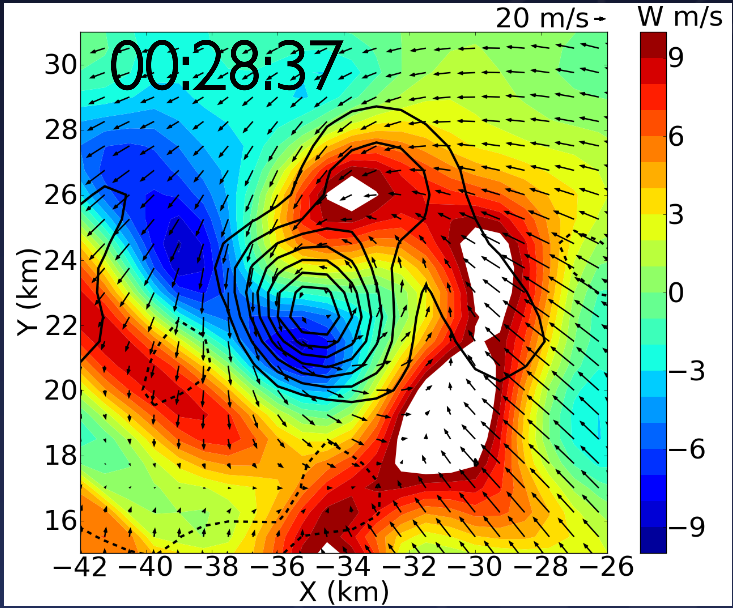
Advection of Derived Vertical Vorticity (~750s) air 0024-0028

0024 0026 0028



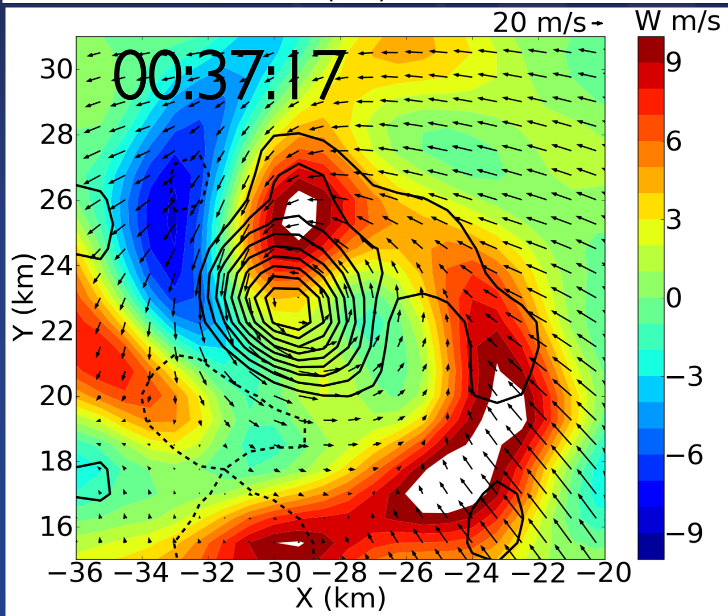
Dual-Doppler Analysis 0039-0045 UTC

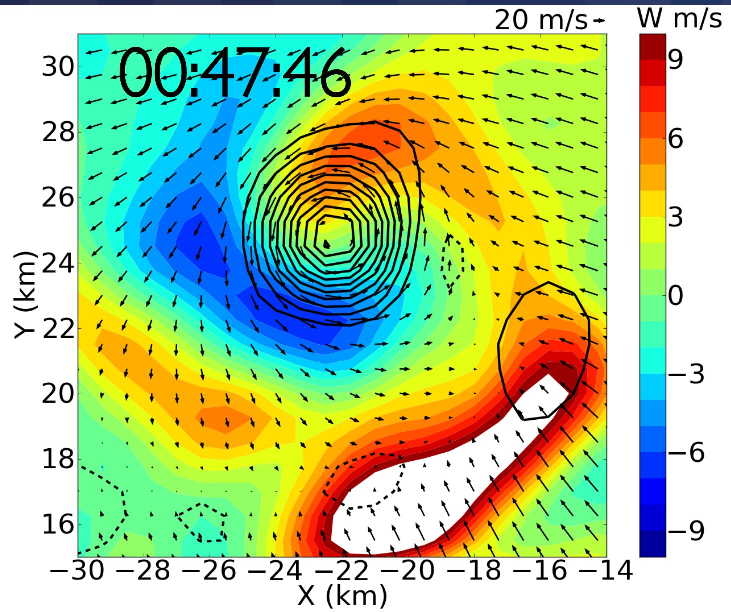
Vertical Velocity (color filled) and Vertical Vorticity (contoured every $5x10^{-3}$ s^{-1})



- No occlusion, as the mesocyclone moves back into predominantly updraft.
- The mesocyclone has intensified due to increased stretching as the circulation becomes nearly collocated with the secondary updraft.
- After intensification, the RFD strengthens again, finally leading to the occlusion of the low level mesocyclone.
- Downdraft appears to have formed at a further radius than previous downdraft

Z=700m

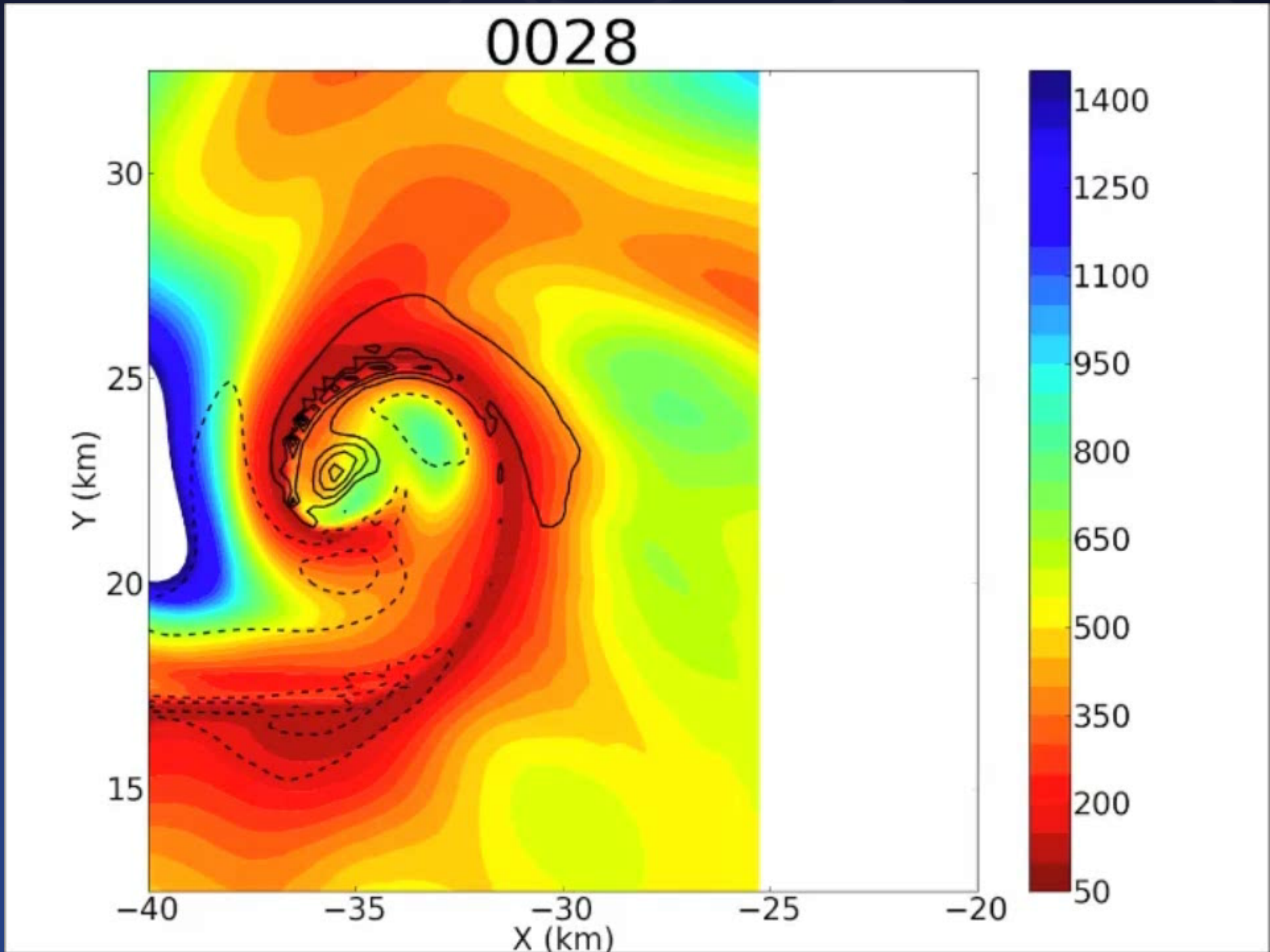




Trajectory maps 0028-0045 UTC:

Inflow Air is being concentrated by outflow from the RFD

- 500s Z_0(m) (color filled) and Derived Vertical Vorticity (contoured every 5×10^{-3} s^{-1})



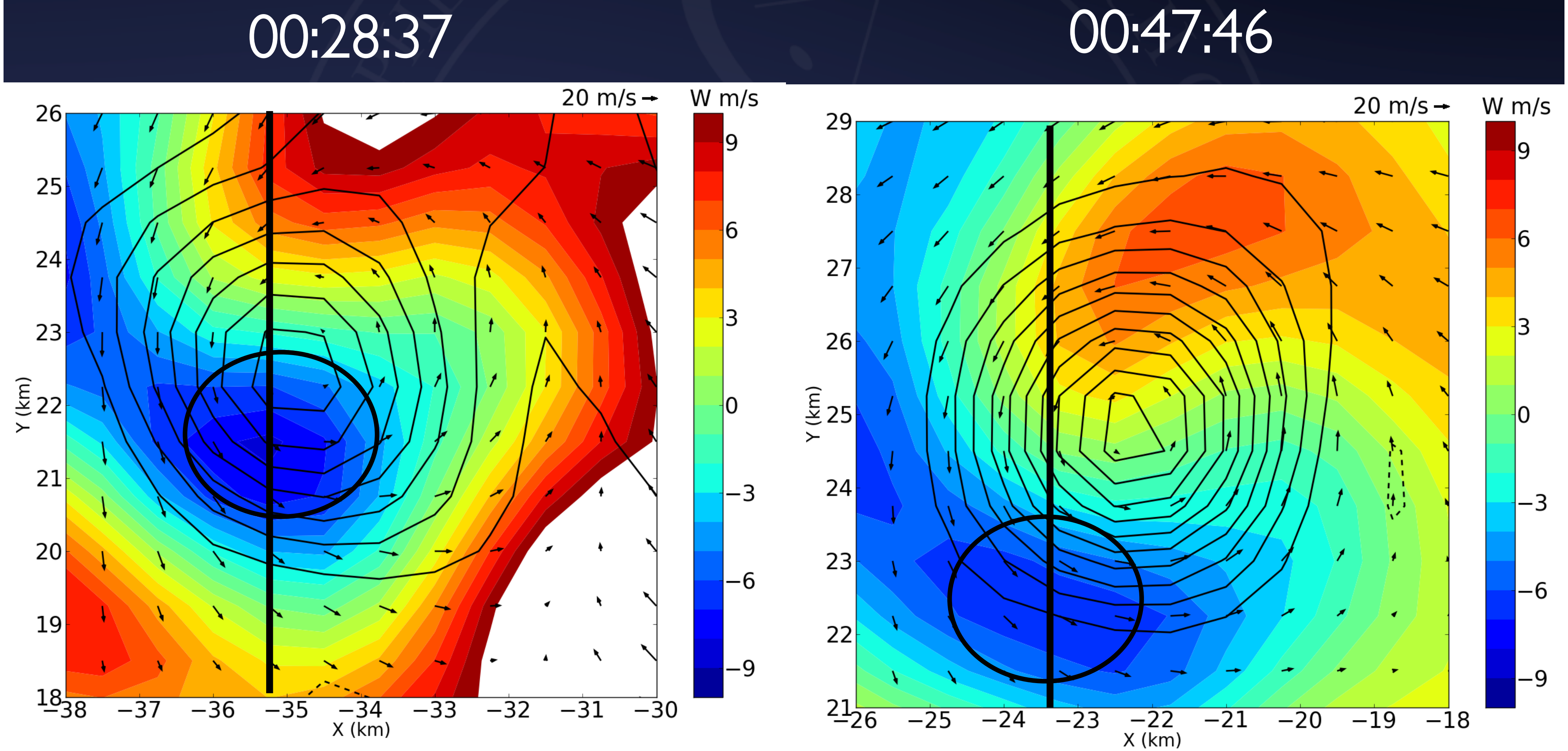
- Initially, downdraft air is being advected into the circulation.

- Then, low level air wrapped around the circulation after the center of the circulation became co-located with the secondary updraft.

- Finally, as the last RFD surge developed, air that had passed through a strong downdraft (cooler colors) wrapped around the circulation, coinciding with contraction.

Downdraft Comparison:
Horizontal cross-section

Vortex-relative winds (vectors), vertical velocity (color filled), and vertical vorticity (contoured every $5x10^{-3}$)

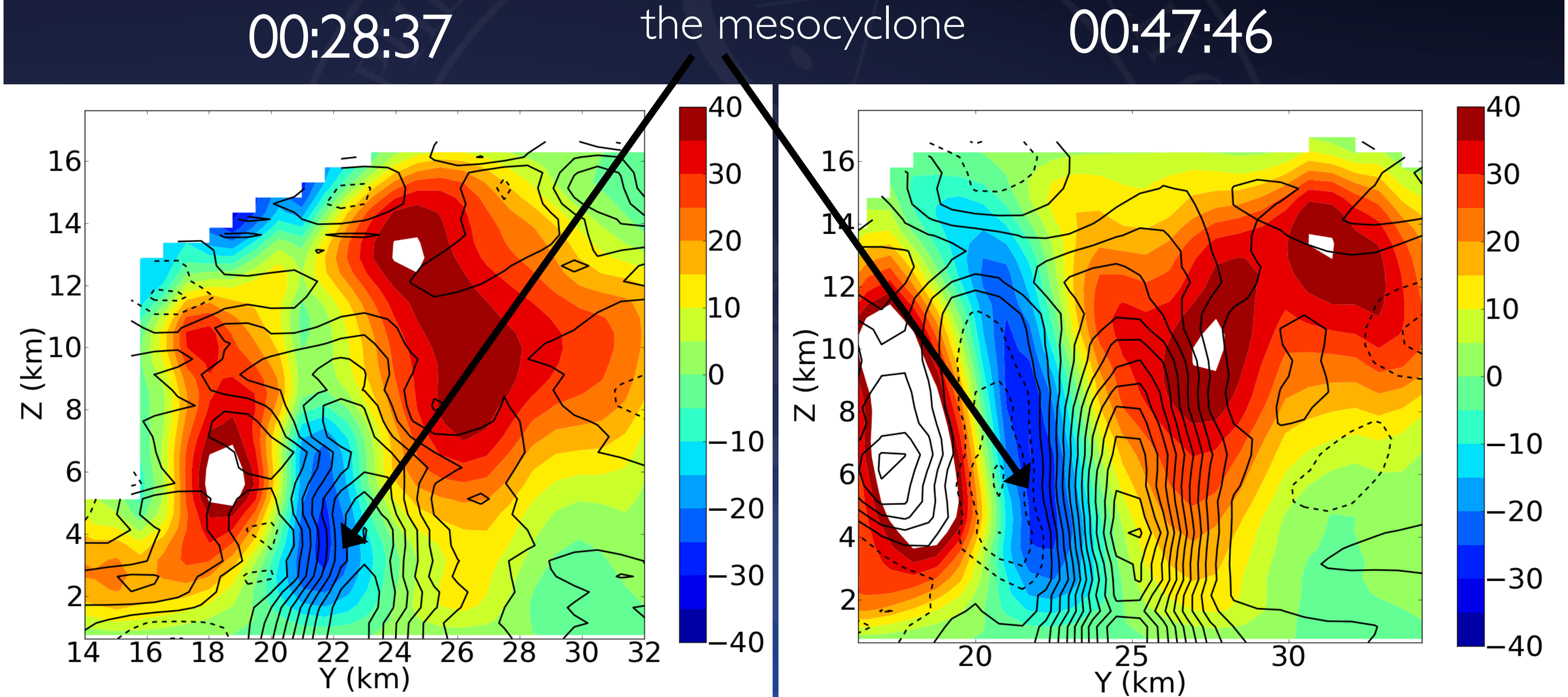


Downdraft Comparison:

Vertical cross-section

Vertical velocity (color filled), and vertical vorticity (contoured every $5x10^{-3}$)

Second downdraft is further displaced from the center of the mesocyclone



$$\frac{d\omega_H}{dt} = \omega \cdot \nabla v_H + \nabla \times (B\hat{k}) + \frac{1}{\rho^2}(\nabla \rho \times \nabla P)_H$$

Derived Trajectory Mapped Variables

- **Color filled plot:**
  - **Integration in time of precipitation loading induced baroclinic generation of streamwise horizontal vorticity (PLBG) (Wakimoto and Cai 2000), used only qualitatively:**

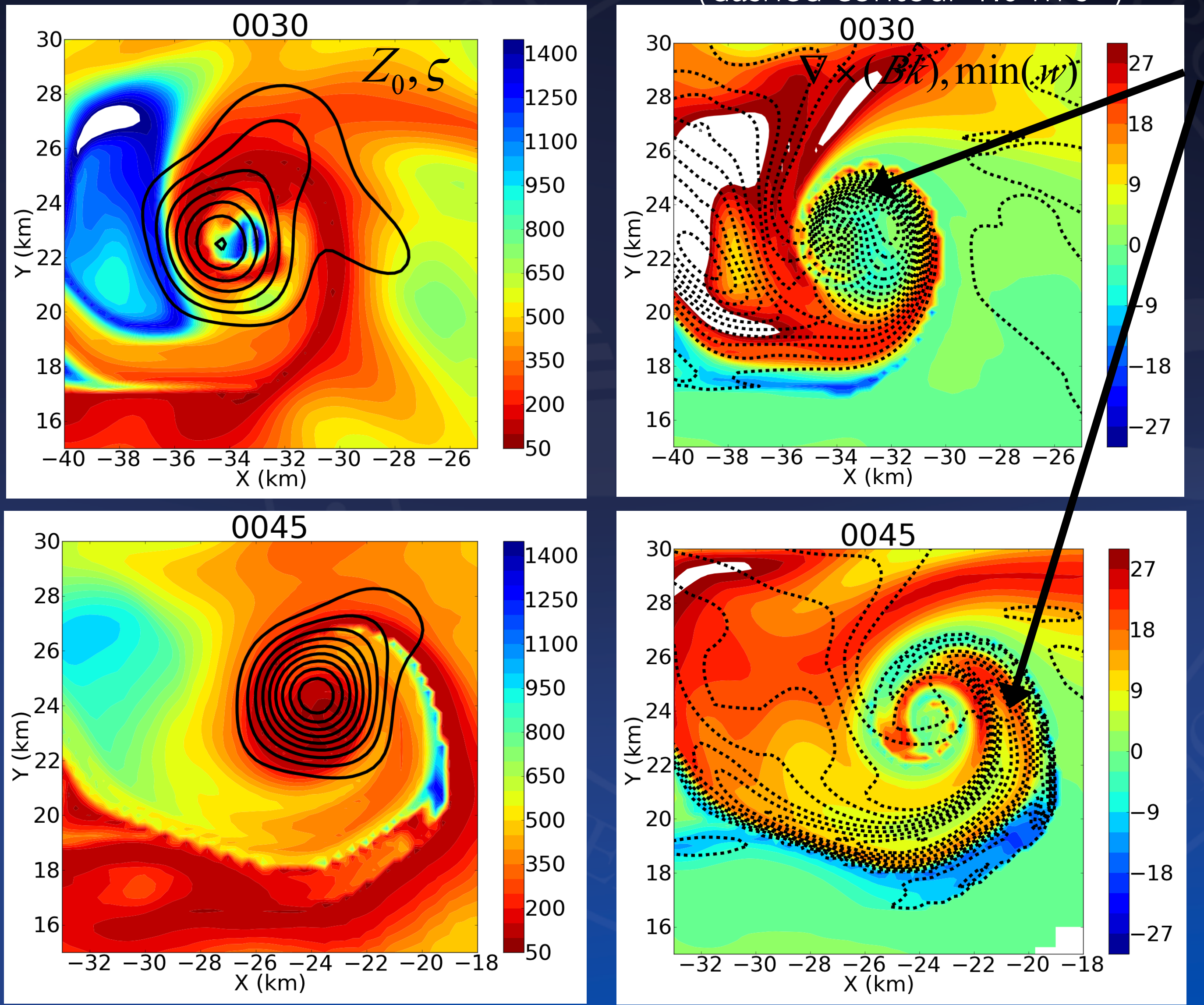
$$\frac{d\omega_H}{dt} = \omega \cdot \nabla v_H + \boxed{\nabla \times (B\hat{k})}$$

- **Contour plot:**
  - **Maximum downdraft along the backward trajectory**

Trajectory Maps 0030 vs 0045 UTC (~1000 sec)

Z_0 (m) and Vertical Vorticity every 5×10^{-3} s^{-1}

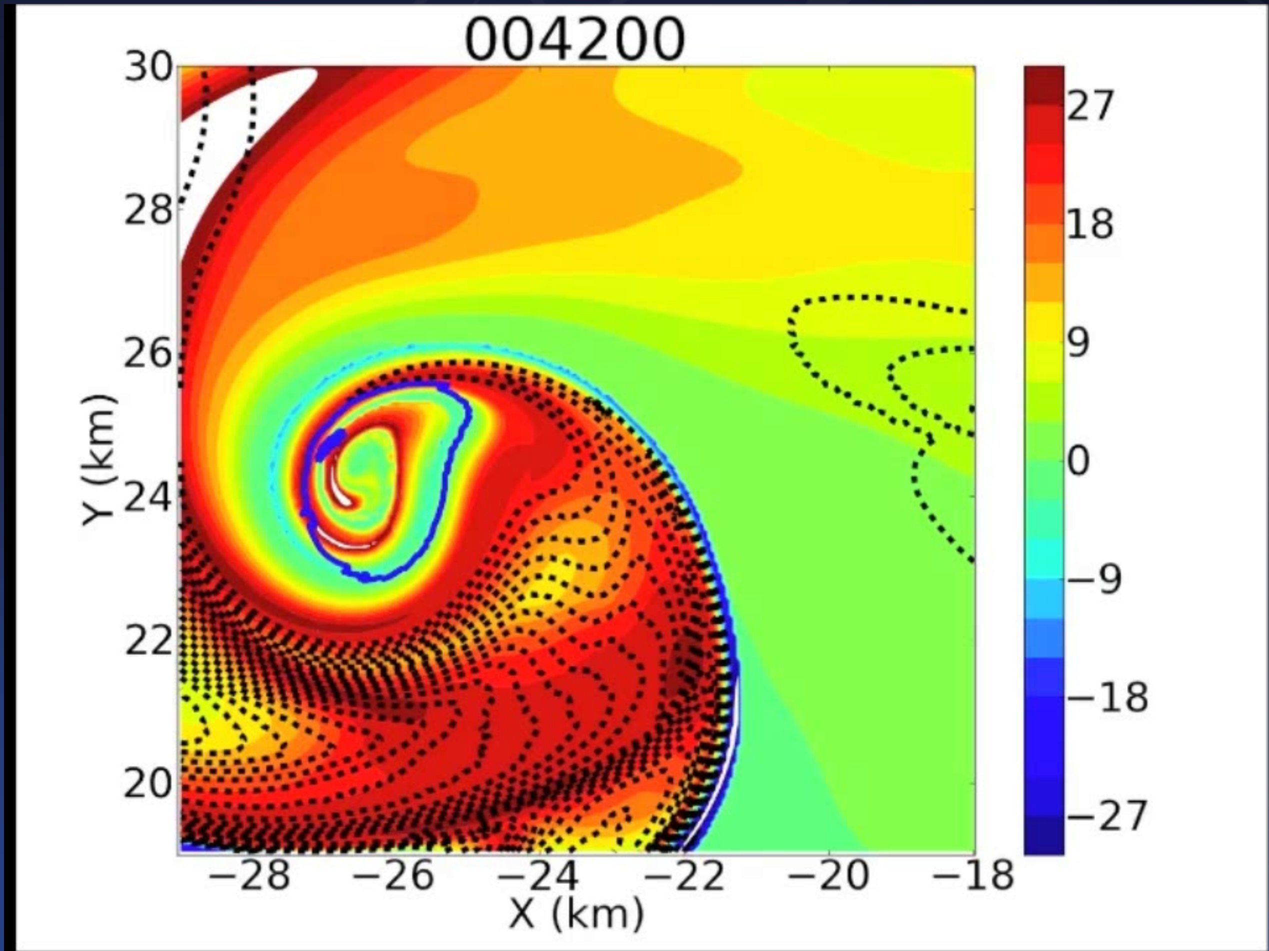
PLBG (10^{-3} s^{-1}) (color filled) and Minimum W (m s^{-1}) (dashed contour 1.0 m s^{-1})



- Compared to previous analysis, forward flank air is wrapping around the low level mesocyclone unimpeded.
- The air flowing out of the downdraft is focused into the circulation at the earlier time and into the gust front at the later time.

Evolution of Air Regimes in Low-Level Mesocyclone

- PLBG (10^{-3} s^{-1}) (color filled) and Minimum W (m s^{-1}) (dashed contour 0.5 m s^{-1}) (~1500 sec) and Derived Vertical Vorticity contour (30×10^{-3} s^{-1} blue)



- Low-Level (~100-200m) Inflow Air (purple) and forward flank air (red) are rotating around a contracting radius

- Positively tilted forward flank air (~400m) (blue) is rotating around an outer radius. Timing coincides with contraction of the circulation

Evolution of Air Regimes in Low-Level Mesocyclone

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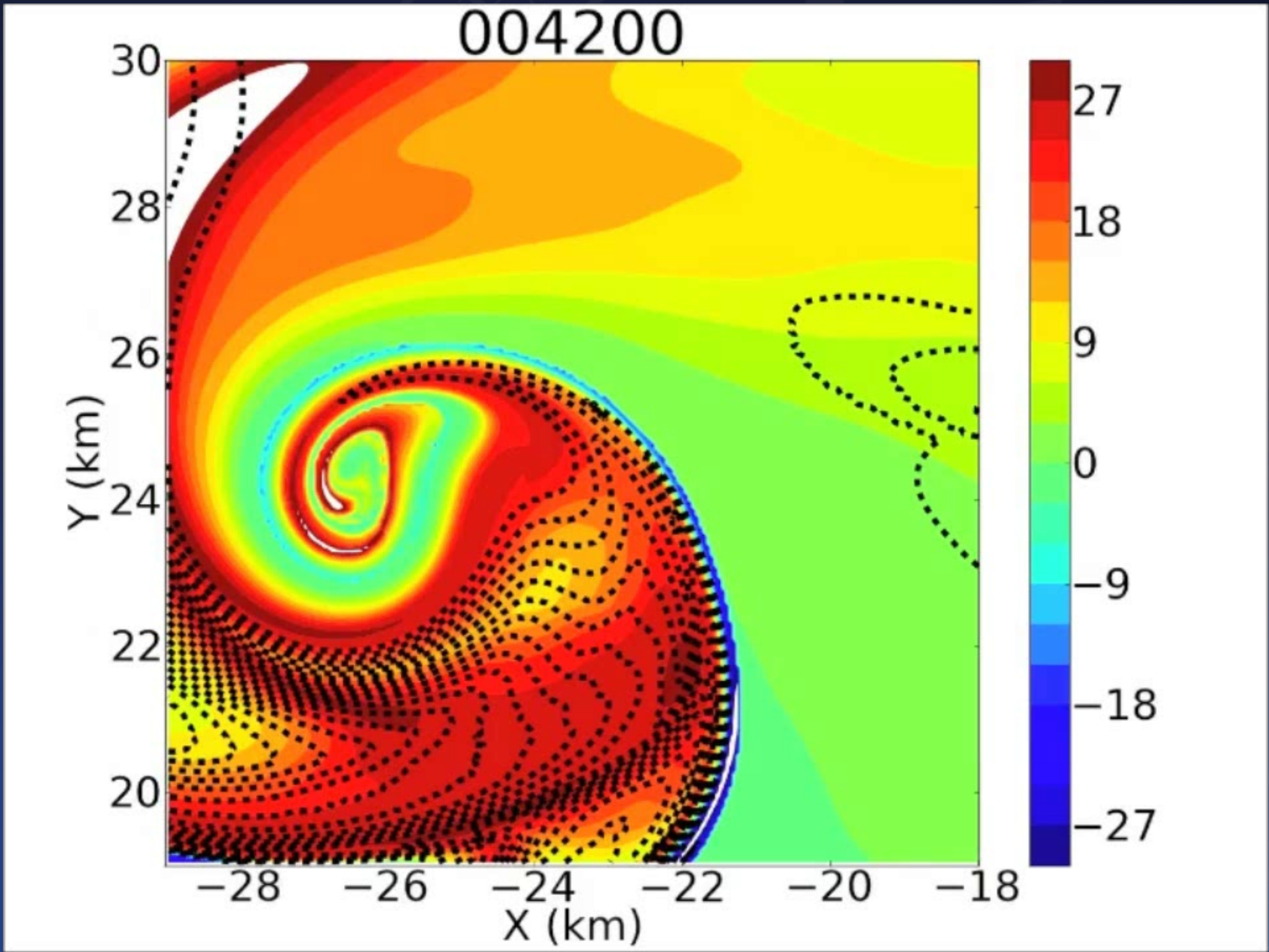

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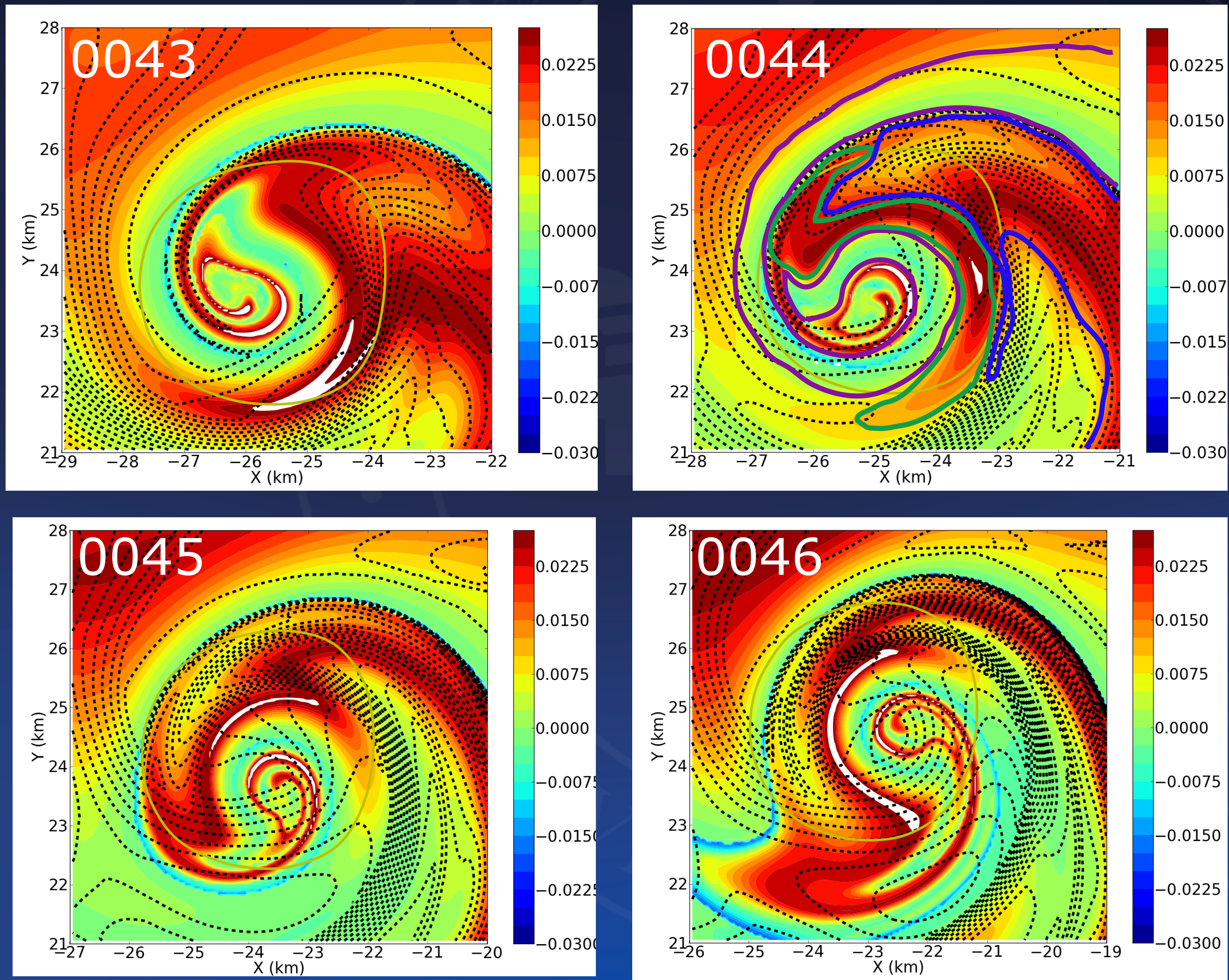
Conclusions

- The mapping of trajectories is a useful tool to visualize the time dependent effects of advection
- The evolution of the derived vertical vorticity resembles the evolution of vertical vorticity in high resolution numerical simulations.
- The transition of the supercell from the mature stage into the dissipating stage coincided with a large intensification and deepening of the mesocyclone. The intensification coincided with a shift in the radius at which the occlusion downdraft forms.
- The location of the rear-flank downdraft (RFD) relative to the center of the circulation had a major impact on the deformation and advection of air into the circulation. At small radii, the RFD was associated with circulation broadening and at larger radii, the RFD was associated with occlusion.
- During the occlusion stage, three different flow regimes were identified: rising inflow air, rising forward flank air, and forward flank air that rose in the updraft before sinking in the RFD and surrounded the circulation.
- Any questions?

Evolution of Air Regimes in Low-Level Meso

- PLBG (10^{-1} s^{-1}) (color filled) and Minimum W (m s^{-1}) (dashed contour .25 m s^{-1}) (~1500 sec)



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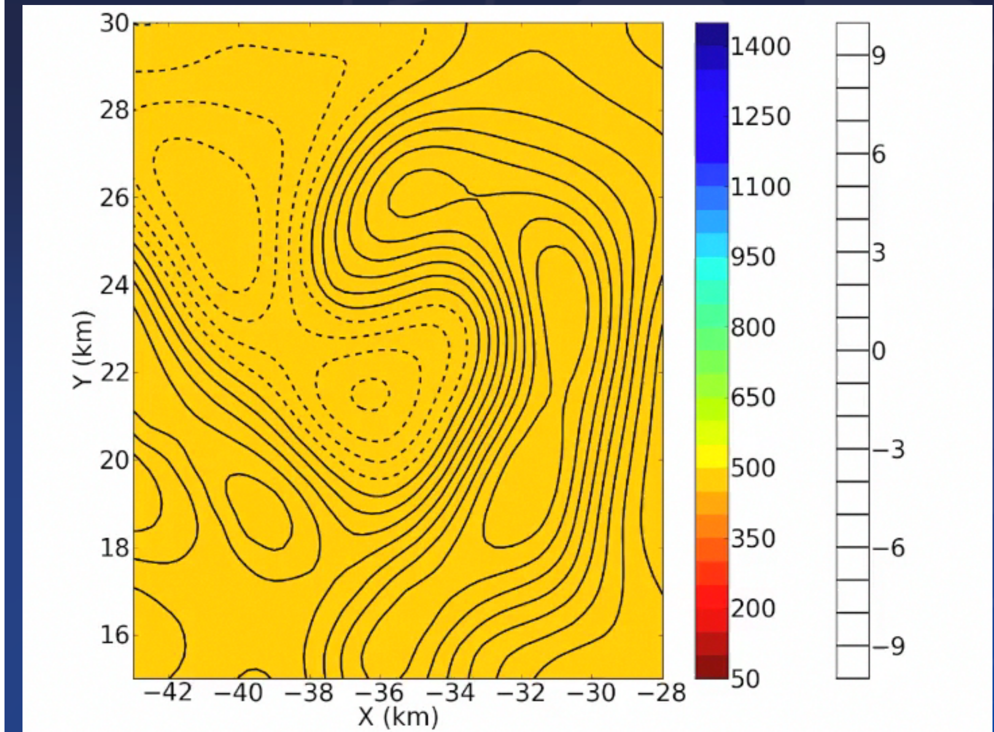
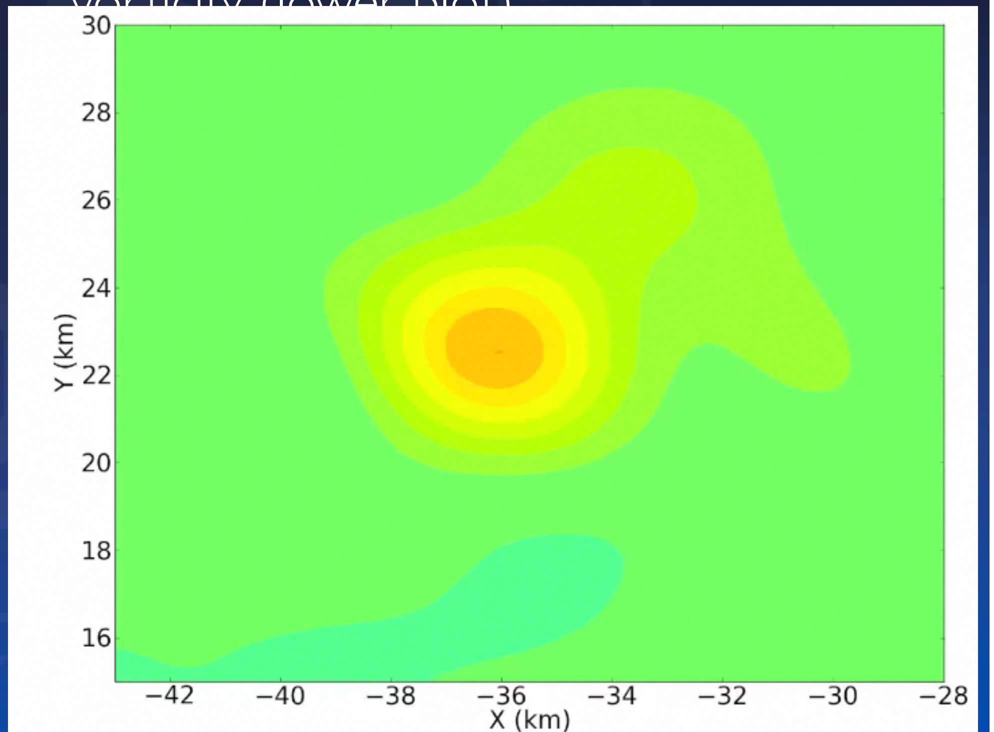
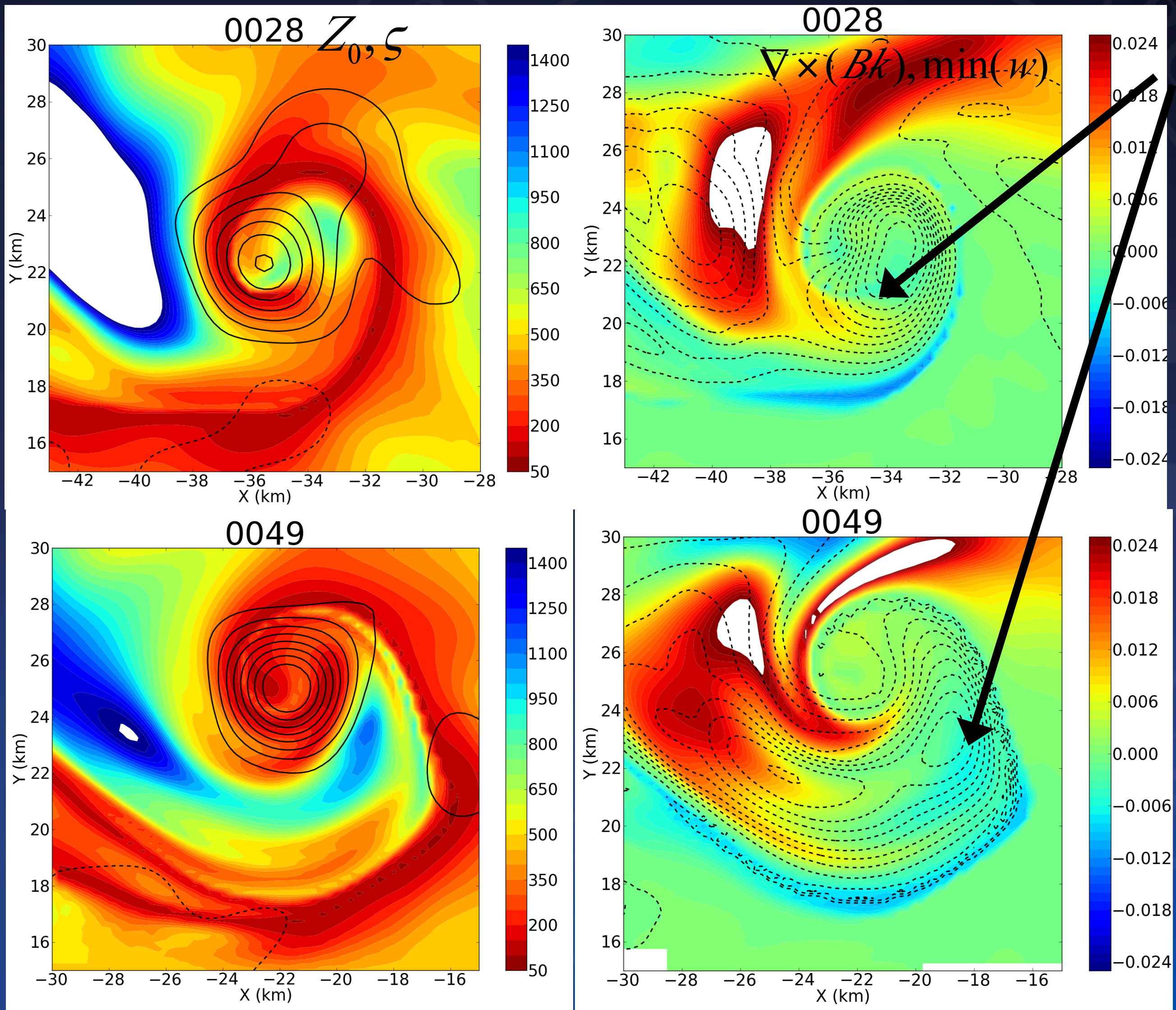




Trajectory Maps 0028 vs 0049 UTC (~500sec)



- Compared to previous analysis, forward flank air is wrapping around the low level mesocyclone unimpeded.
- The air flowing out of the downdraft is focused into the circulation at the earlier time and into the gust front at the later time.
- The advection patterns due to the location of the downdraft also affect the pattern of the derived vertical vorticity.