Kinematics of Super Tuesday Storms

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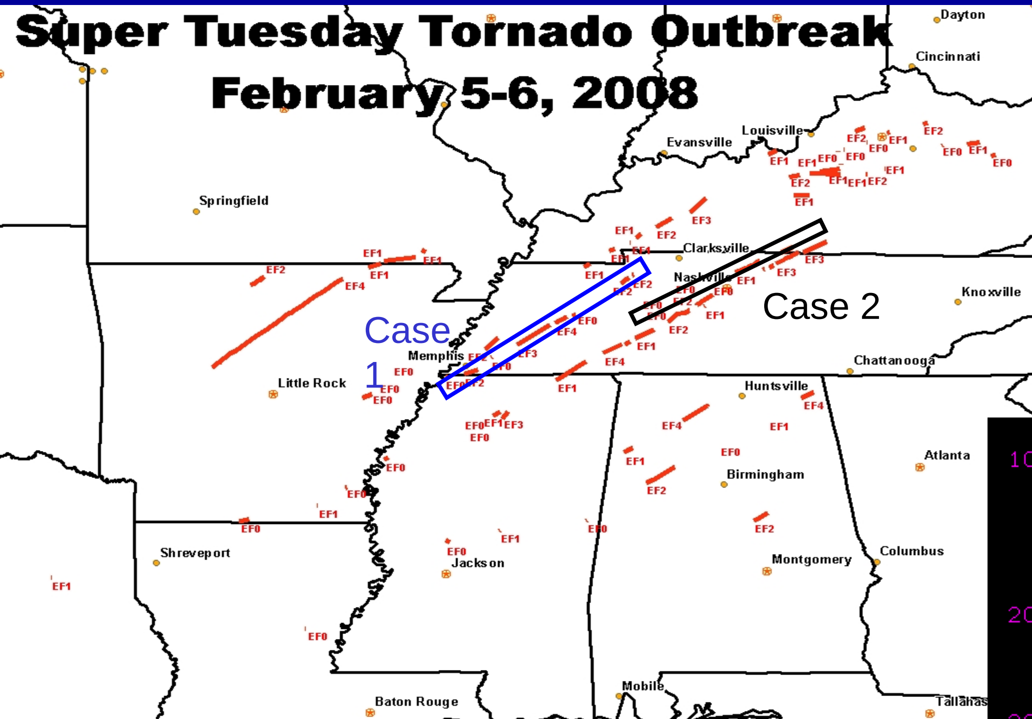
Introduction

- The supercell thunderstorm is one phenomena where research has benefited from multiple-Doppler wind retrievals and various thermodynamic retrieval schemes.
- However, at least two Doppler radars are often not available.
- Peace et al. (1969) was the first to suggest using single Doppler data collected during two time periods to perform wind retrievals – this method has since become known as the synthetic dual-Doppler (SDD) technique.
- Has not been widely used on convective storms due to limitations of the technique.

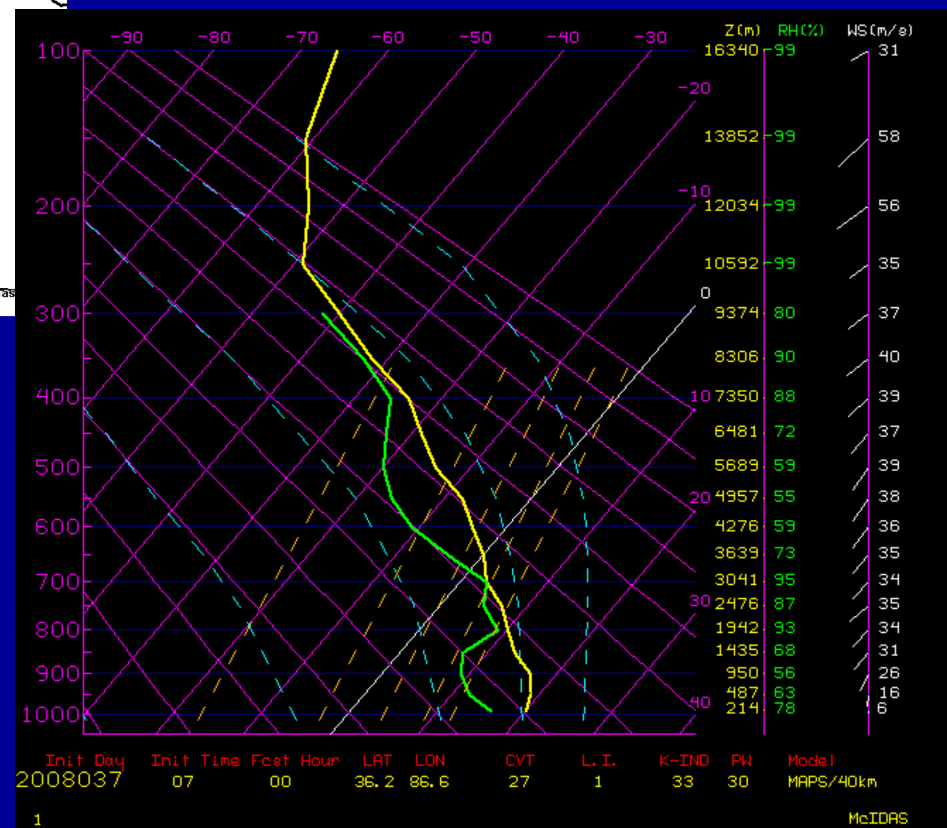
Introduction

- The Super Tuesday outbreak of 5-6 Feb 2008, provided several cases where a SDD analysis might be successfully applied.
- Two cases with differing levels of success will be presented.
- Main Objective:
  - Examine variability on storm structure in an outbreak this large.
  - Thermodynamic retrievals were performed to determine the dominant updraft forcing mechanism.
- Secondary Objective:
  - Explore viability on using the SDD technique on supercell thunderstorms.

Event Overview

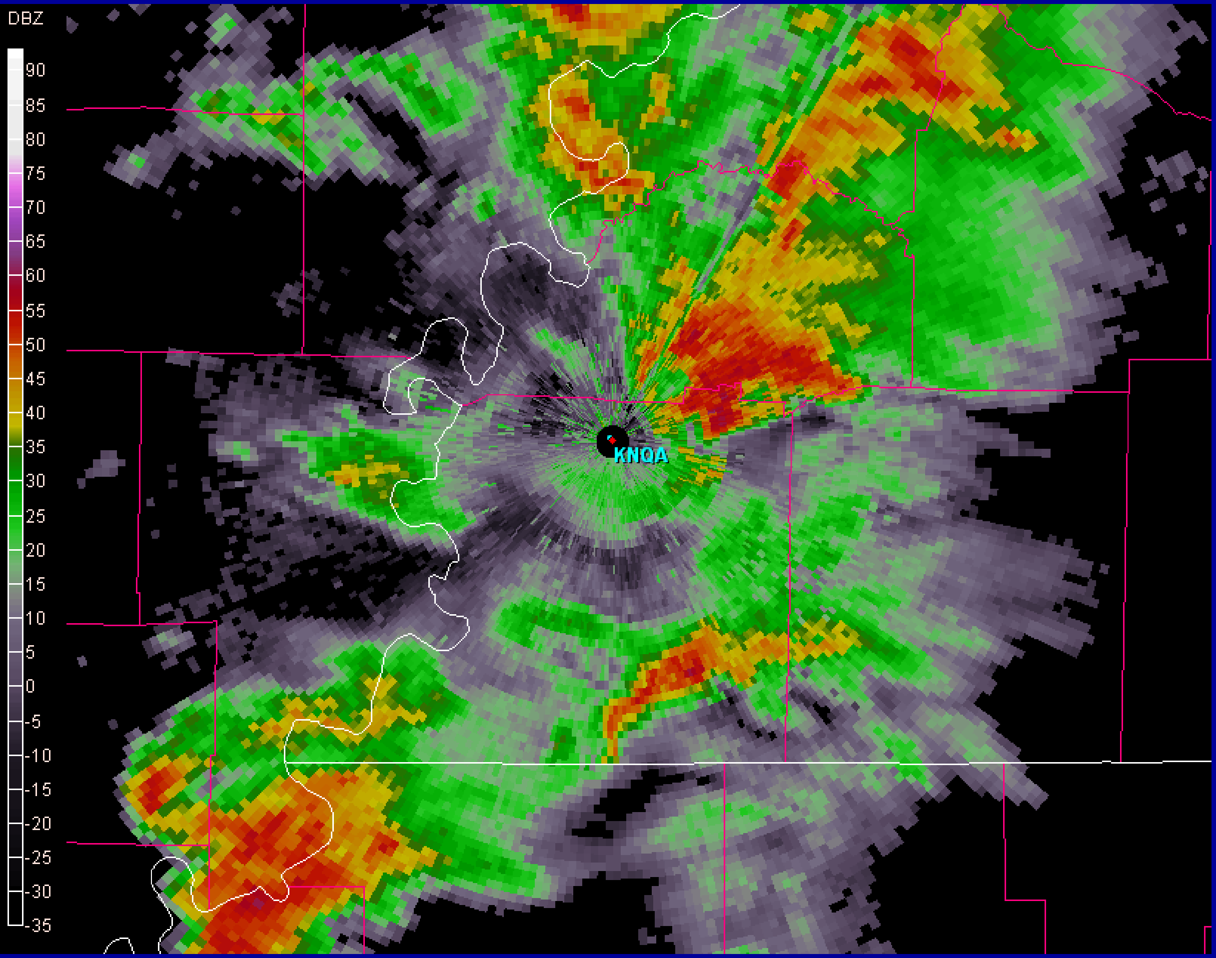


Location of cases relative to the event.



RUC sounding centered on Nashville for 0700 UTC (Case 2).

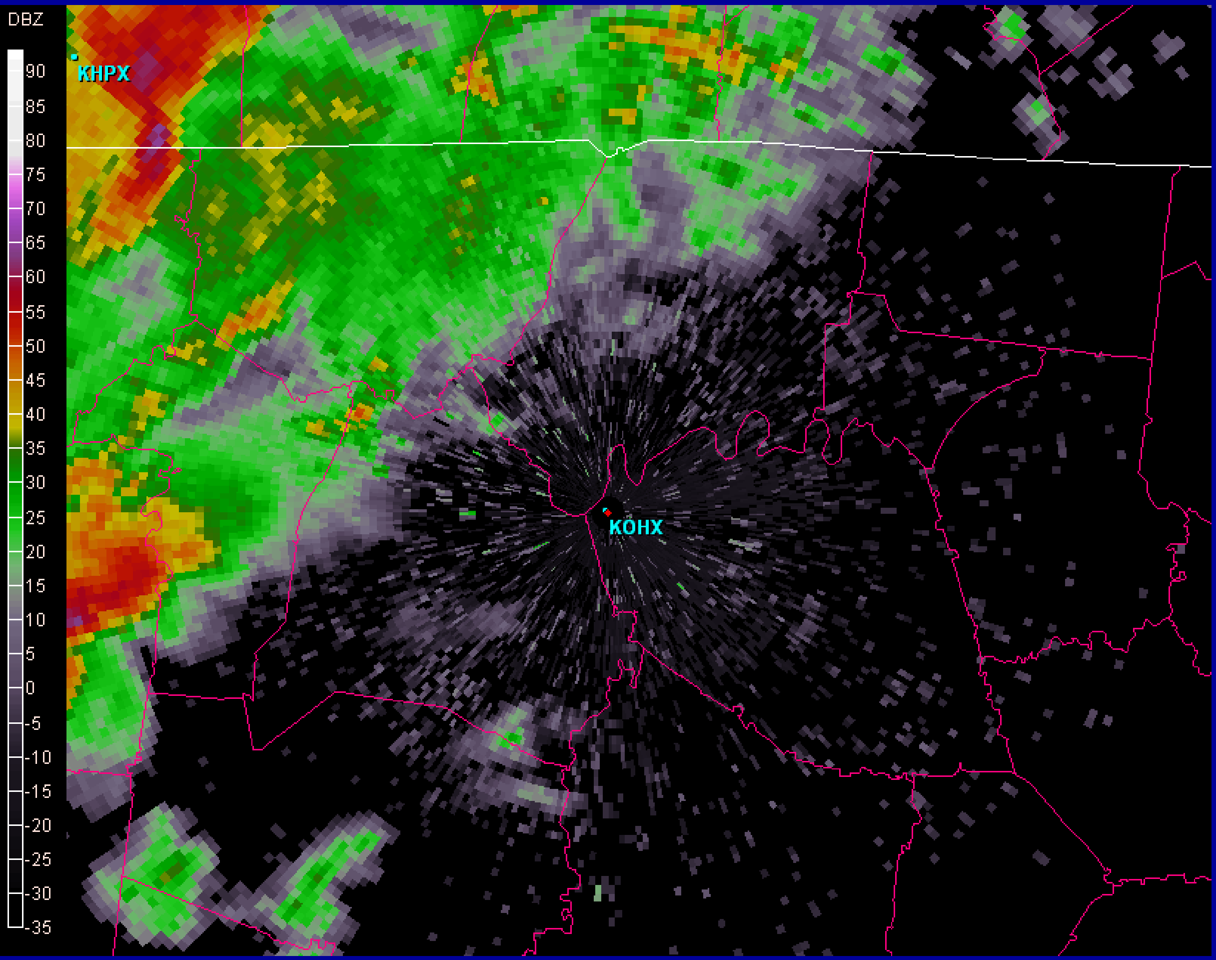
Case 1 - KNQA



Base reflectivity @ 0.9° from 2300 to 0050 UTC

- Developed from a cluster of thunderstorms that initiated in NE Louisiana and SE Arkansas
- Produced an EF2 tornado as it moved into TN, just north of Southaven, MS
- Went on to produce a long track EF3 and the EF4 tornado that devastated Union University near Jackson, TN
- Best SDD analyses came between 2350 and 0020 UTC, when the mesocyclone passed KNQA at a distance of 25-38 km
- Storm motion was from 230° at 26 ms^{-1}

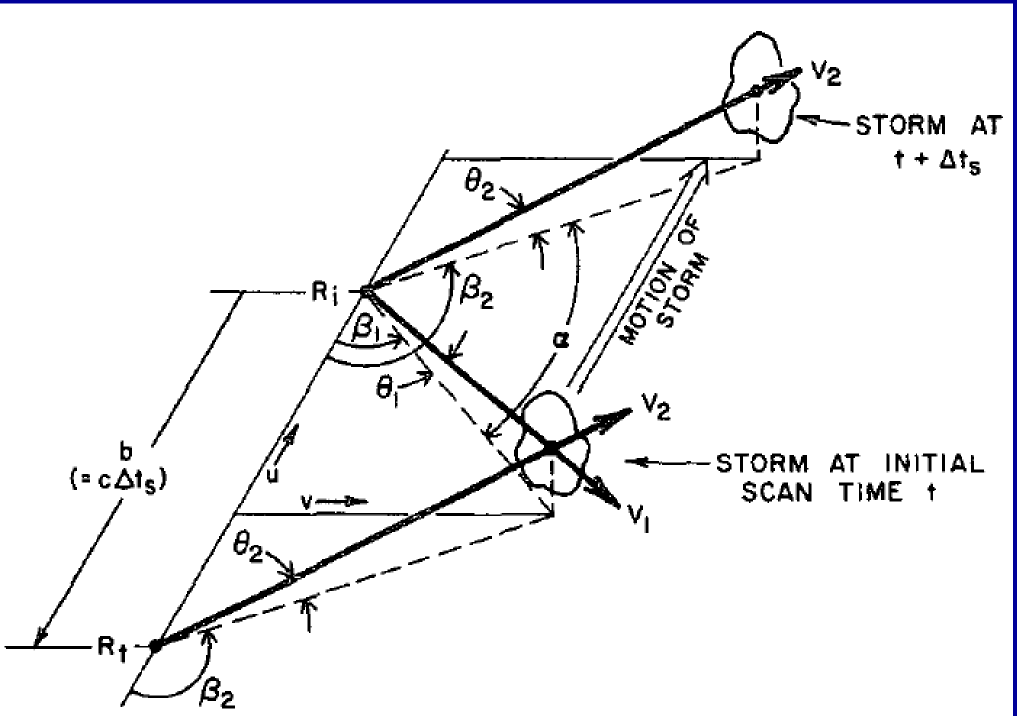
Case 2 - KOHX



Base reflectivity @ 0.9° from 0616 UTC to 0751 UTC

- Developed from a cluster of cells in north Mississippi
- Produced several EF0 tornadoes as it moved to the northeast, towards Nashville
- Best SDD analyses came between 0650 and 0716 UTC, when the mesocyclone passed KOHX at a distance of 16-25 km
- Storm motion was from 242° at 24 ms^{-1}

SDD Wind Retrieval



Geometry of the (synthetic) dual-Doppler technique

- Technique described in detail by Bluestein and Hazen (1989) and Klimowski and Marwitz (1992)
- Follows conventional dual-Doppler geometry (Lhermitte and Miller 1970) and uses the common dual-Doppler software, CEDRIC (Mohr et al. 1986)
- Requirements/Assumptions:
  - Storm-motion must parallel radar site/synthetic baseline at a relatively close distance
  - The storm must move quick enough so that it goes through at least 30° of radar azimuth
  - Velocity fields can not change significantly between volume scans (**quasi-steady-state assumption**)

- Steadiness of supercells first estimated by visually comparing volume scans and further quantified by a correlation analysis of radar variables

- Main source of error is changes in velocity fields between volume scans

- Error can also be introduced through uncertainties in calculating the storm-motion vector, which is used to find the radar baseline through $c\Delta t$ where c is storm speed and Δt_s is time between volume scans (baseline ~ 30 km for both cases)

- Visual comparison of case 1 showed a supercell slightly strengthening between volume scans. Correlation analysis yielded a correlation coefficient (r) of 0.4 - 0.7 below 5 km

- Case 2 – did not change significantly; r value of 0.7 - 0.9 below 6 km

Thermodynamic Retrieval

$$\frac{\partial p'}{\partial x} = -\rho_o \frac{Du}{Dt} + fr_x \equiv F$$

$$\frac{\partial p'}{\partial y} = -\rho_o \frac{Dv}{Dt} + fr_y \equiv G$$

$$\frac{\partial^2 p'}{\partial x^2} + \frac{\partial^2 p'}{\partial y^2} = \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y}$$

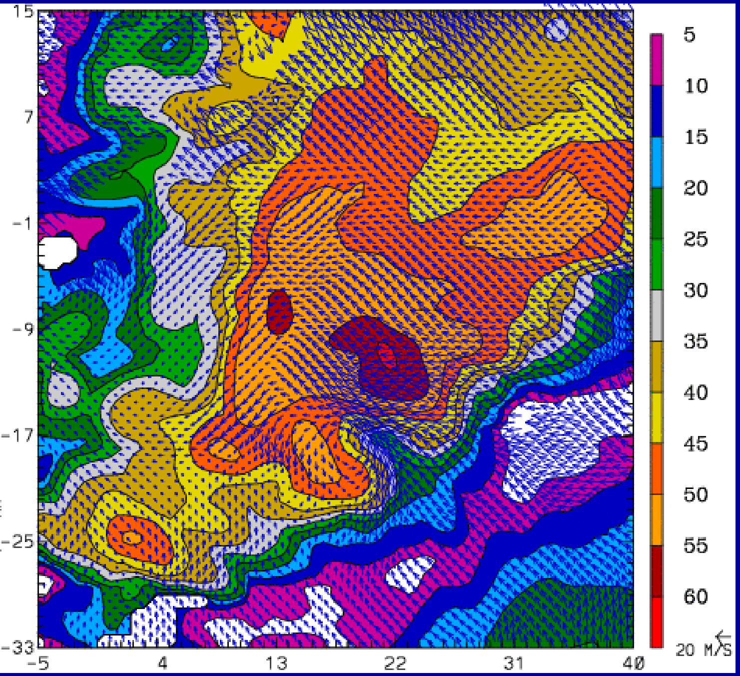
- Method pioneered by Gal-Chen (1978) and modified by others (Hane et al. 1981; Pasken and Lin 1982; Brandes 1984; Hane and Ray 1985)
- Rearrange horizontal momentum equations to solve for pressure where “known” quantities F and G come from the horizontal wind field
- Resulting Poisson equation can only be solved using a least squares solution and is subject to Neumann boundary conditions

$$\begin{aligned} B &= \frac{(\theta - <\theta>)}{\theta} + 0.61(q_v - <q_v>) \\ &= \frac{c_p \theta_v}{g} \frac{\partial(p' - <p'>)}{\partial z} + R - <R> \end{aligned}$$

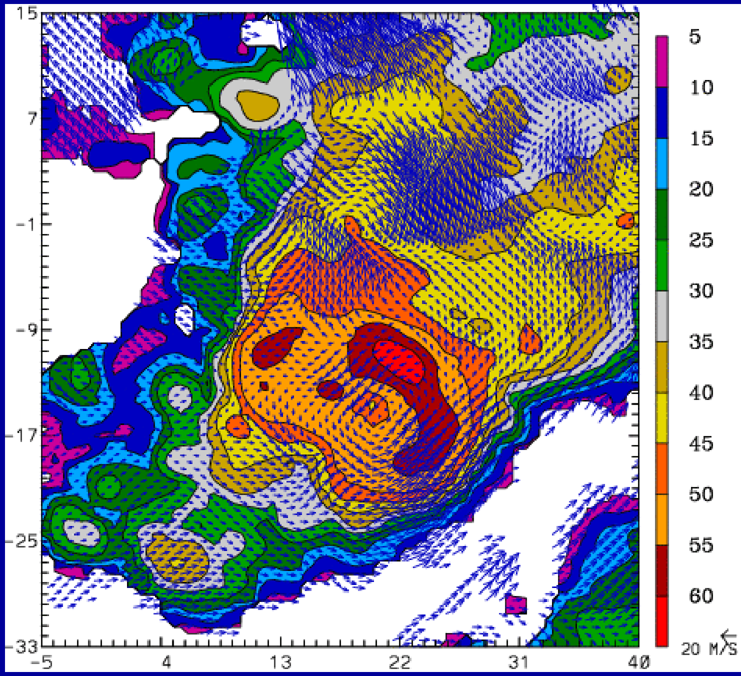
$$R = \frac{1}{g}\frac{Dw}{Dt} + q_c + q_r$$

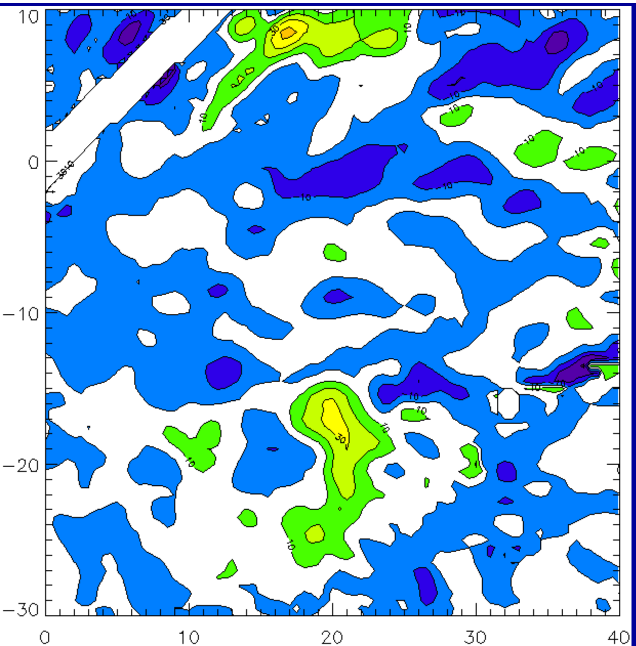
- θ_v, q_c, q_r found using a sounding from each location
- Assumes ice free cloud, so presence of hail introduces error

Results – Case 1



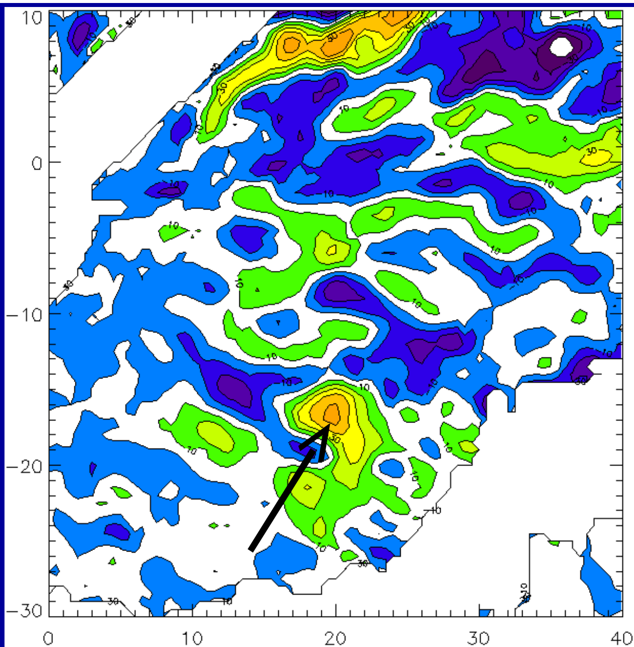
SDD analyses, storm relative flow at 1.5 (left) and 4.0 (right) km

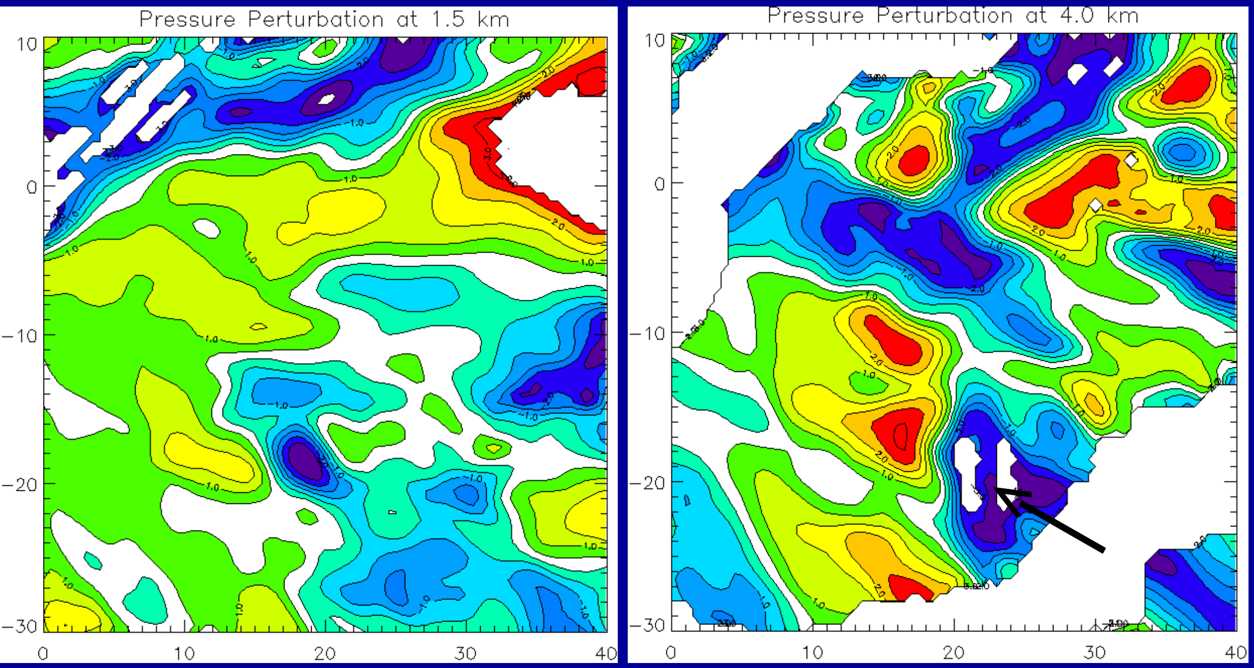




Vertical motion at 1.5 (left) and 4.0 (right) km. Warm colors > 0 ms^{-1}; cool colors < 0 ms^{-1}; contour interval 10 ms^{-1}

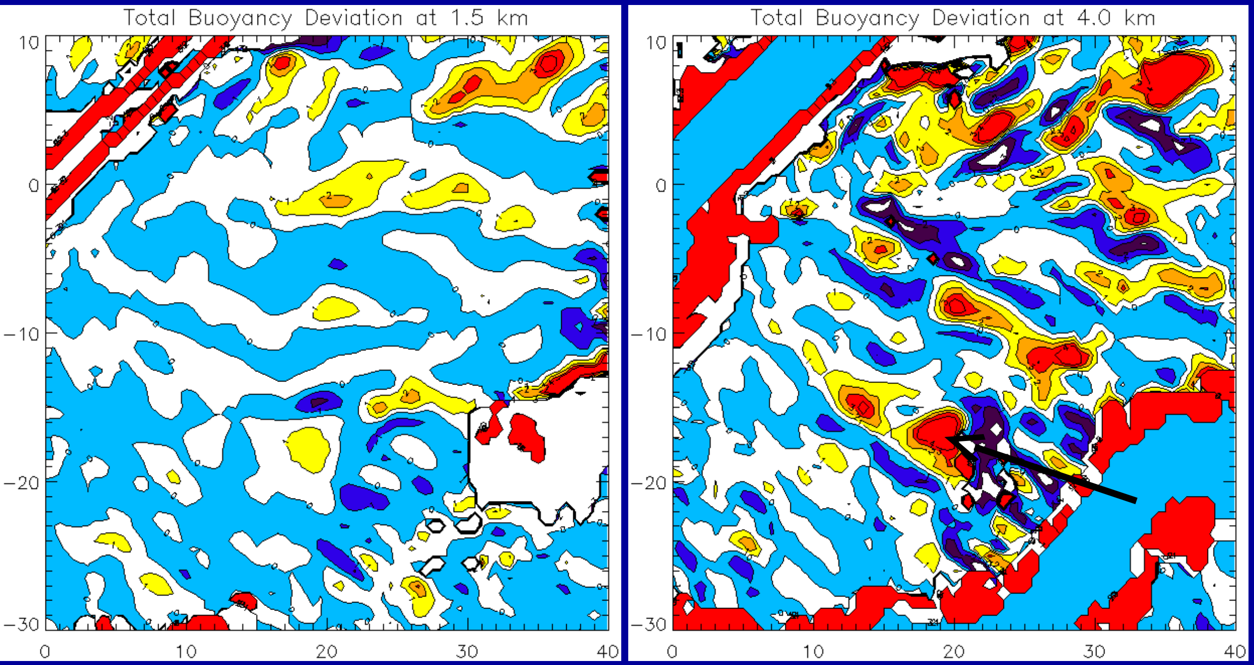
Peaks at 50 ms^{-1} at 4.0 km





Pressure perturbation at 1.5 (left) and 4.0 (right) km. Warm colors > 0 hPa; cool colors < 0 hPa; contour interval 0.5 hPa.

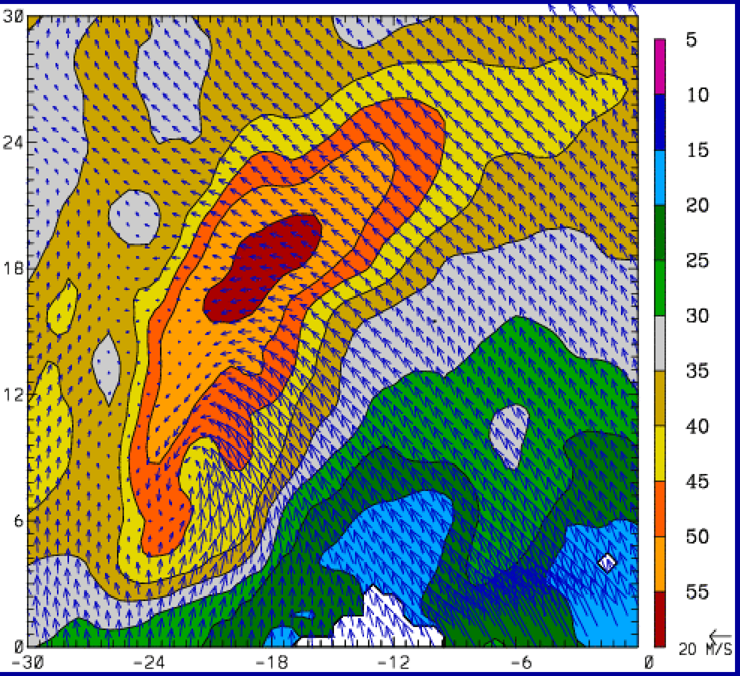
Attains local minima of -3.0 hPa at 4.0 km.



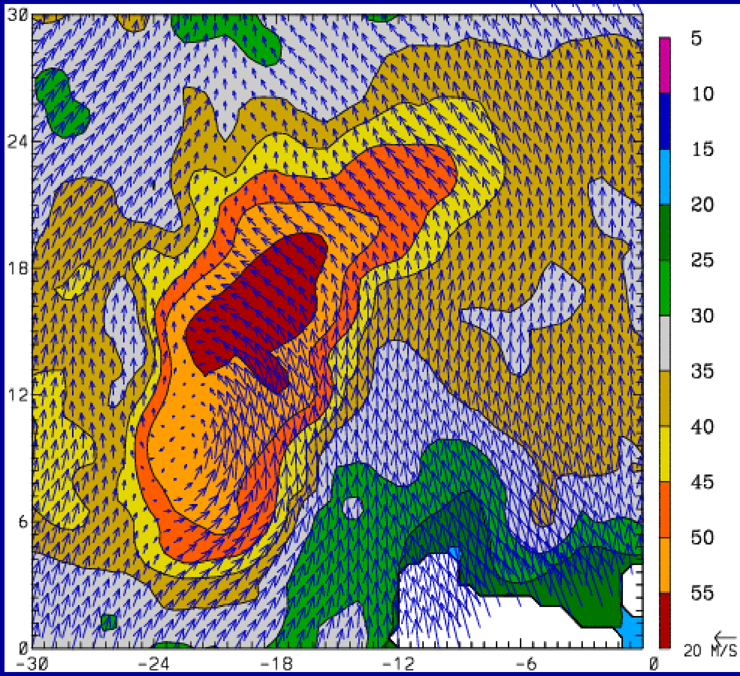
Buoyancy deviation at 1.5 (left) and 4.0 (right) km. Warm colors > 0°; cool colors < 0°; contour interval 1°.

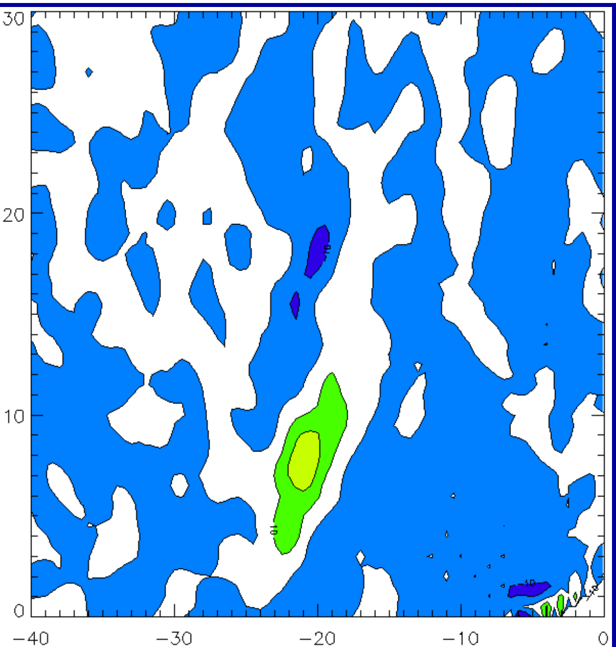
Local maximum greater than 4° reached at 4.0 km.

Results – Case 2



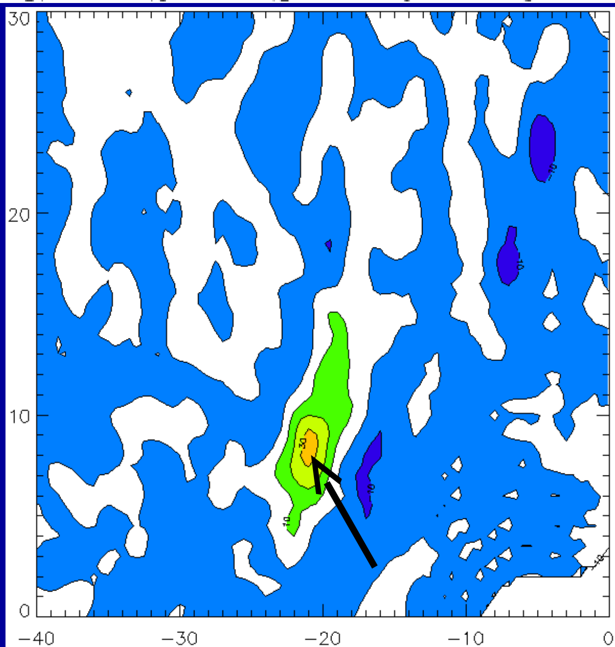
SDD analyses, storm relative flow at 1.5 (left) and 3.0 (right) km

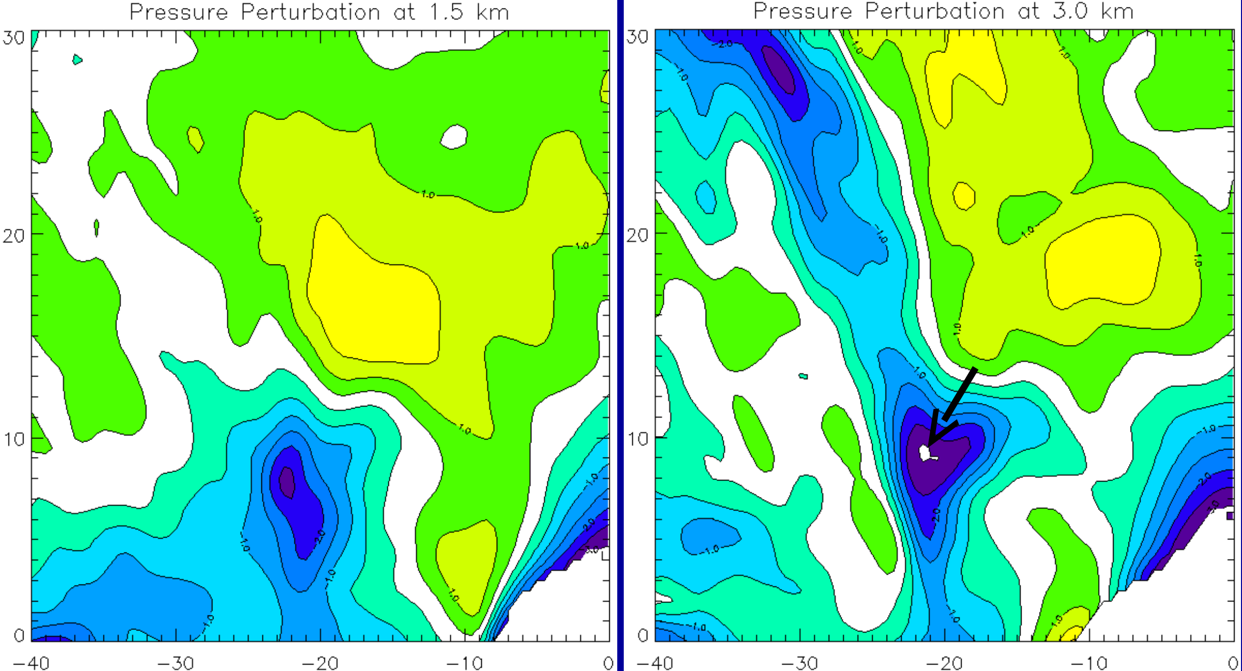




Vertical motion at 1.5 (left) and 3.0 (right) km. Warm colors > 0 ms^{-1}; cool colors < 0 ms^{-1}; contour interval 10 ms^{-1}

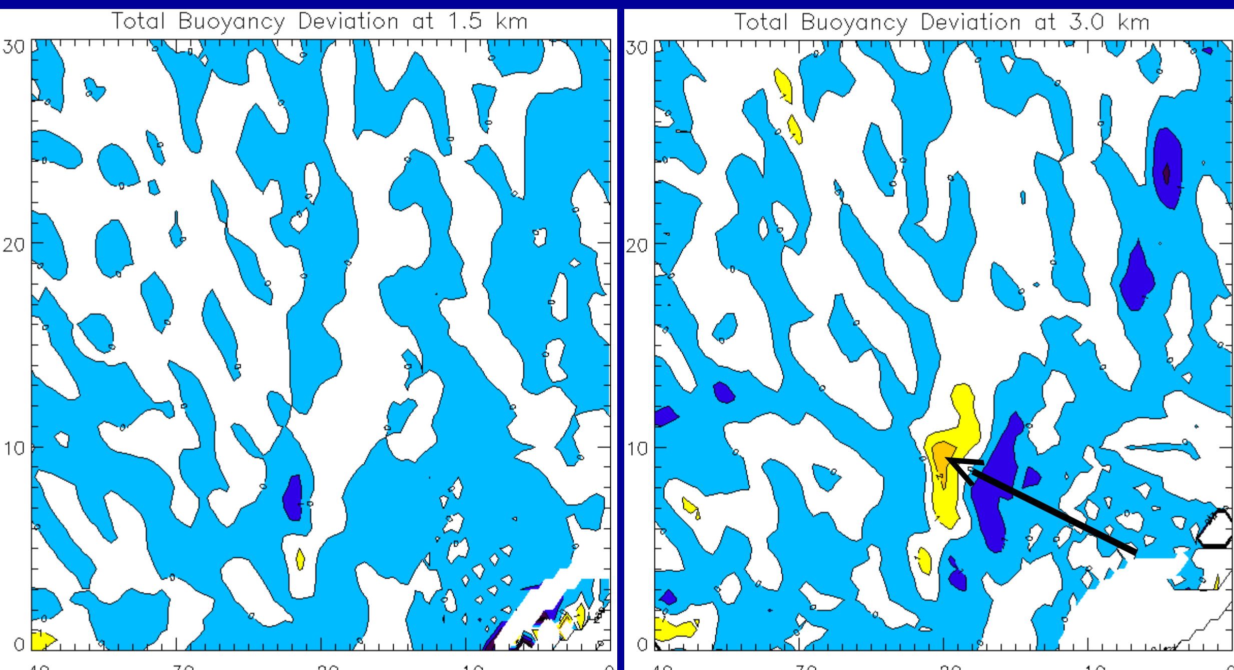
Peaks at 34.5 ms^{-1} at 3.0 km





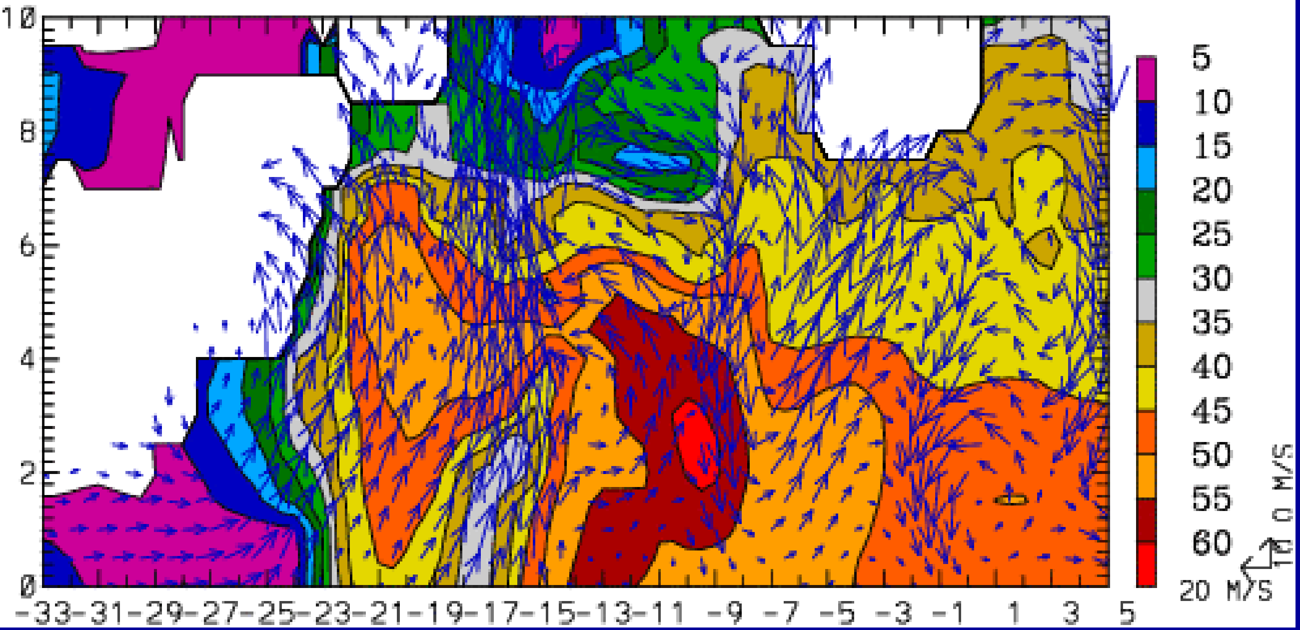
Pressure perturbation at 1.5 (left) and 3.0 (right) km. Warm colors > 0 hPa; cool colors < 0 hPa; contour interval 0.5 hPa

Attains local minima of -3.0 hPa at 3.0 km.



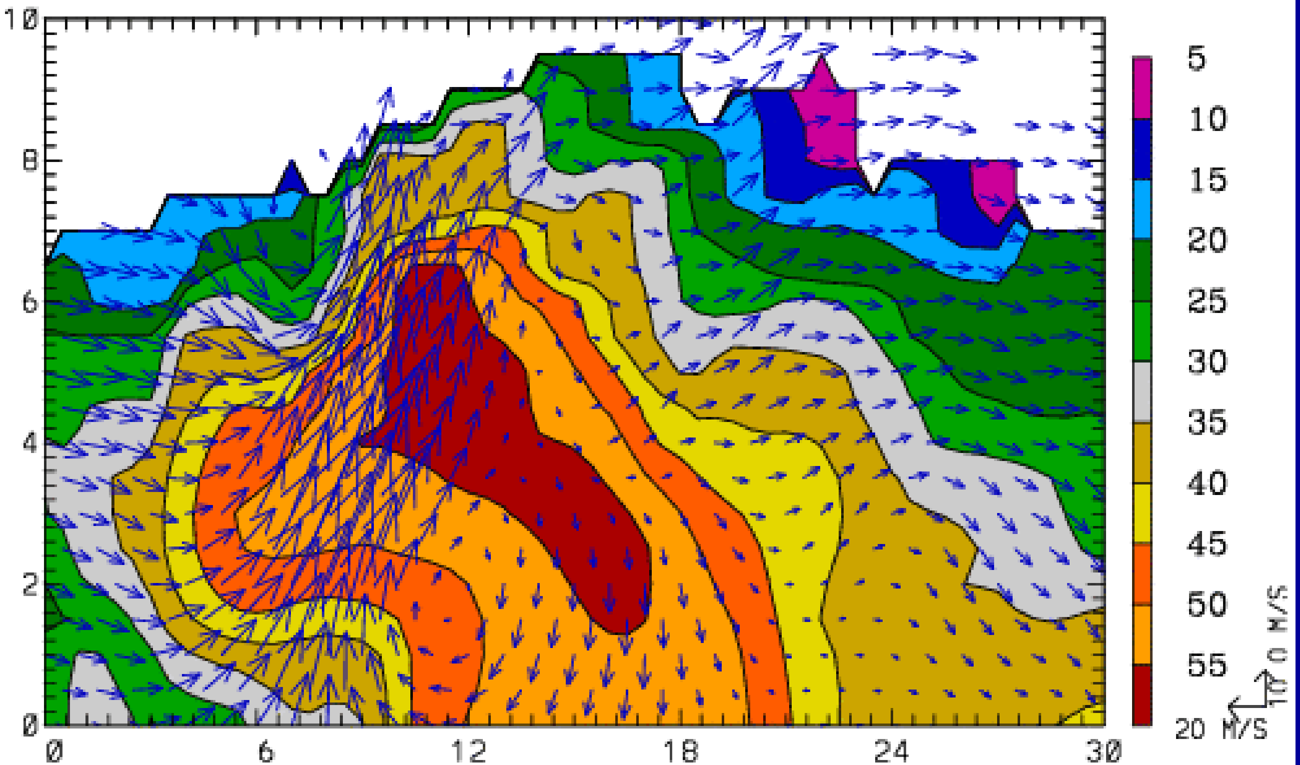
Buoyancy deviation at 1.5 (left) and 3.0 (right) km. Warm colors > 0°; cool colors < 0°; contour interval 1°

Local maximum near 2.5° reached at 3.0 km.



Case 1 vertical cross section taken at x = 19.5 km

Strong updraft on southern storm flank, but erroneous flows in northern part of storm



Case 2 vertical cross section taken at x = -21 km

Strong updraft on southern storm flank

Conclusions

- Given the visual comparison of volume scans, correlation analysis, and actual results from the SDD analyses, case 2 appears to contain less error.
- If a subjective quality score had to be given, case 2 would rank 4/5 whereas case 1 would be 2/5.
- SDD technique captured the mesocyclone of case 1 fairly well, however, due to the evolving nature of this supercell, errors are unavoidable.
- Case 2 demonstrates how well the SDD technique can work IF the requirements are met:
  - quasi-steady-state
  - move through at least 30° of radar azimuth
  - propagate parallel to the radar site at a relatively close distance
- Often difficult for supercells to meet just one of these requirements – uniqueness of case 2.

Conclusions

- Consider case 1 reliable enough for comparison.
- Case 2 was smaller and not as strong (updraft of 34.5 ms^{-1} @ 3.0 km vs. 50 ms^{-1} at 4.0 km).
- Case 2 was in a high shear-low(er) cape environment compared to the first.
- Implications of such a low-level updraft maximum on low-level vorticity stretching.
- Buoyancy deviations of case 1 were greater (more than 4°), possibly leading to greater buoyancy forcing.
- Magnitude of pressure perturbations within the mesocyclones (-3.0 hPa) were similar, but different structures
- Environmental differences played a significant role in their development.

Future Work

- Examine other storms from a single Doppler viewpoint to put these in perspective.
- More SDD analyses.
- VAD analyses will be used to reveal changes in SRH during storm passage and details of outflow.
- More robust thermodynamic retrievals.
- Eventually, a high resolution numerical simulation will be used for further comparisons of SDD analyses and thermodynamic retrievals.