Kinematics of Super Tuesday Storms

Todd Murphy and Kevin Knupp
University of Alabama in Huntsville
Outline

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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.
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.
Super Tuesday Tornado Outbreak
February 5-6, 2008

Location of cases relative to the event.

RUC sounding centered on Nashville for 0700 UTC (Case 2).
Case 1 - KNQA

- 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\(^{-1}\)

*Base reflectivity @ 0.9° from 2300 to 0050 UTC*
Case 2 - KOHX

- 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

*Base reflectivity @ 0.9° from 0616 UTC to 0751 UTC*
SDD Wind Retrieval

• 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 $\Delta t_s$ 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

\[ \frac{\partial p'}{\partial x} = -\rho_0 \frac{Du}{Dt} + fr_x \equiv F \]
\[ \frac{\partial p'}{\partial y} = -\rho_0 \frac{Dv}{Dt} + fr_y \equiv G \]

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

- 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

- \( \theta_v, q_c, q_r \) 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.