Airborne Radar Observations of Severe Hailstorms: Implications for Future Spaceborne Radar

ATS 741 In-Class Presentation
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Motivation

• Introduce a new dual-frequency nadir-point airborne Doppler radar (HIWRAP)
• Understand the behavior of the HIWRAP in terms of measuring thunderstorms
• Find implications for future design and development of spaceborne radars
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

Fig. 1. HIWRAP Concept

Photo Credit: Heymsfield et al. (2007), NASA Website

Photo Credit: http://www.remotesensingsolutions.com/instruments/HIWRAP.php
Flight Tracks

3. Overview of the hailstorms
Conditions were highly favorable for severe weather during 23–24 May 2011 in the Oklahoma–Kansas region. There were two ER-2 flights and several severe thunderstorm overpasses during this period; the first flight was from 2133 UTC 23 May to 0131 UTC 24 May, and the second flight was between 1920 and 2240 UTC on 24 May. In the following, we will give a general description of the environmental conditions and time evolution of the storm. Two cases of intense convective storms are presented in this paper. Case 1 (C1) during the first flight was located northwest of the S-band polarimetric radar located at Norman, Oklahoma (KOUN). Case 2 (C2) during the second flight was located near the Kansas–Oklahoma border within range of the Weather Surveillance Radar-1988 Doppler (WSR-88D) S-band polarimetric radar located at Vance Air Force Base in Oklahoma (KVNX). Figure 1 shows the general locations of the two flight lines, S-band radars, soundings, and storms of interest superimposed on a 3-km AGL reflectivity map. All heights in this paper are above ground level, with the exception of upper-air sounding heights, which are above mean sea level.

a. Upper-air soundings
The upper-air soundings at Norman (OUN) and Lamont (LMN), Oklahoma, provide general environmental conditions for C1 and C2, respectively. The 0000 UTC OUN sounding (Fig. 2) was closest to C1 and showed a pseudo-adiabatic convective available potential energy (CAPE) of \( \frac{3600}{2} \) J kg\(^{-1}\), but special soundings launched as part of MC3E at Purcell, Oklahoma, showed even larger instability, with CAPE of 3800–4200 J kg\(^{-1}\) between 1732 and 2030 UTC. The 1800 UTC LMN sounding (Fig. 3) was closest to C2 and showed a CAPE of \( \frac{4400}{2} \) J kg\(^{-1}\); the 2100 UTC LMN sounding had a slightly lower CAPE of 3600 J kg\(^{-1}\). The freezing level is at \( \frac{4.3}{2} \)-km altitude in both soundings. The extreme instability in these soundings provides a ballpark estimate of over 80 m s\(^{-1}\) using \( \frac{w_{\text{max}}}{2} \frac{(2 \text{CAPE})^{1/2}}{} \), which indicates the maximum vertical motion at the equilibrium level calculated from the positive area in CAPE. The equilibrium level is \( \frac{175}{2} \) hPa (\( \frac{13}{2} \) km MSL) for the above soundings. The CAPE-derived updraft will never be realized because of precipitation loading and other factors, but it suggests the likelihood of very intense updrafts. The bulk Richardson number was 41 m s\(^{-2}\) at \( \frac{1}{2} \).

Storm #1: 0121-0126 UTC

Storm #2: 2145-2148 UTC
Storm Overview:
Storm #1: 0121-0126 UTC
AGL. The reflectivities at Ku and Ka bands are completely attenuated below 3 and 5 km AGL, respectively. The ZDR does not have a distinctive hail signature (Fig. 12c) at lower levels during the overpass time. A strong positive Doppler velocity is noted in the storm's core that is associated with the updraft (Figs. 12f), although these Doppler velocities are weaker than those in Fig. 9. The profiles in Fig. 13 also indicate that this storm is weaker than the C1 storm. The S-band reflectivity (Fig. 13a) barely reaches 55 dBZ, the Ku-band reflectivity peaks at 47 dBZ, and the Ka band peaks at 37 dBZ at 12-km altitude. The lower S-band reflectivity relative to Ku above 11 km is mainly due to the differences in volume-scan and overpass times and spatial resolutions between HIWRAP and KVNX. Doppler velocities are also somewhat different from C1, where peak upward motions (without fall speed added) of 25 m s⁻¹ occur at a lower altitude between 4 and 8 km. Several regions of downward Doppler velocities (0 m s⁻¹), indicative of downdrafts or large fall speeds, are present at higher altitudes surrounding the main updraft region of C2. These were higher than for C1, with a minimum just lower than 230 m s⁻¹ at 10.5 km AGL and 22-km distance. Similar to what was observed in C1, the Ka-band Doppler (Fig. 12f) showed downdraft features that are similar to those of the Ku-band Doppler (Fig. 12e), and therefore NUBF Doppler biases do not appear to be responsible for this feature.

5. Interpretations from the observations

a. Summary of observations

The analysis of MC3E hailstorms with HIWRAP and polarimetric measurements has shown several prominent features: 1) strong updrafts are suggested by the Doppler velocities, with 39 m s⁻¹ at 10.7 km (250 hPa) and 30 m s⁻¹ at 13.7 km (160 hPa) in storm C1, 2) large attenuation is observed in C1 and C2, 3) a tall ZDR column up to 7.5 km is accompanied by a depression of r_h, 4) S-band reflectivities exceed 70 dBZ, with 60 dBZ extending up to 10.5-km altitude, and 5) the Ku- and...
Updraft Velocity:
Storm #1: 0121-0126 UTC

\[ \mathbf{v}_T = A' \mathbf{Z}_e^b \]

Ulbrich (1977)
Scattering and Attenuation: Storm #1: 0121-0126 UTC

Properties of DFR:
- Independent of number concentration
- Indicator for hailstone scattering
Summary

• The reflectivities at Ku and Ka bands suffer from Mie-scattering, high attenuation, and likely multiple scattering in the storm cores.
• DFR may be used to differentiate a 50-dBZ storm from a 70-dBZ storm.
• The retrieval precision of updraft velocity is likely to be affected by the footprint size.