High-resolution radar structure and microphysical processes of cold-season extratropical cyclones

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1. Objectives and observational data

Precipitation substructures (generating cells, precipitation bands) were sampled in the comma head regions of midlatitude cyclones in the central United States during the 2009-10 Profiling Of Winter Storms (PLOWS) field campaign.

Measurements made aboard the National Science Foundation / National Center for Atmospheric Research C-130 aircraft are used here to examine the following questions:

- **What are the physical characteristics of the cyclones and embedded substructures?**
- **What are their microphysical characteristics and how do these vary throughout the cyclones?**

The primary data sets shown here are measurements of equivalent radar reflectivity factor (Z_e) from the University of Wyoming Cloud Radar (WCR) and measurements of hydrometeor size and concentration from Two-Dimensional Cloud and Precipitation Optical Array Probes (2D-C, 2D-P).

2. Overview

Cyclones were sampled by the NSF/NCAR C-130 using vertically stacked profiles and horizontal flight legs, typically oriented across the cyclones' comma head regions. The measurements shown below are typical of the storms sampled during PLOWS. Structural features are shown along a flight leg traversing a cyclone's dry slot and warm-frontal precipitation shield (Figs. 1-2, 30 Jan. 2010) and for a flight leg sampling elevated dry slot convection and deep comma head precipitation (Figs. 3-4, 9 Dec. 2009).

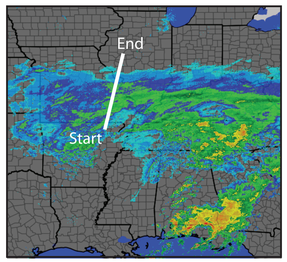


Fig. 1. *WSR-88D radar reflectivity valid 0400 UTC 30 Jan. 2010. NSF/NCAR C-130 flight track indicated by white line.*

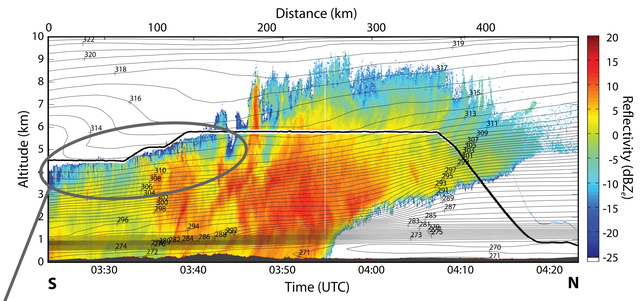


Fig. 2. *Wyoming Cloud Radar reflectivity along the flight leg in Fig. 1. Contours are equivalent potential temperature calculated with respect to ice, derived from the RUC analysis valid 0300 UTC 30 Jan. 2010.*

Convective generating cells atop stratiform precipitation layer

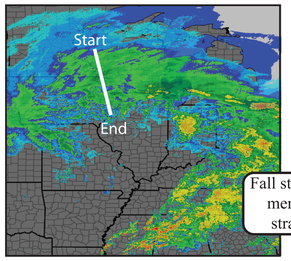


Fig. 3. *As in Fig. 1, but valid 0300 UTC 9 Dec. 2009.*

Deeper elevated convection emerging into dry slot air

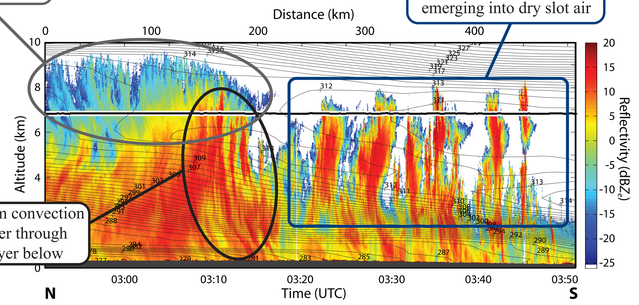


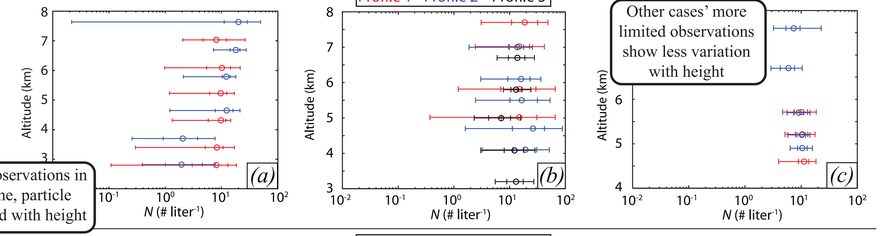
Fig. 4. *As in Fig. 2, but for the flight track in Fig. 3 and for the RUC analysis valid 0300 UTC 9 Dec. 2009.*

Fall streaks from convection merge together through stratiform layer below

Kilometer-scale convective generating cells were consistently observed at cloud top in the cyclones' comma head regions; polarization lidar and in situ icing detector measurements commonly indicated supercooled water's presence in the cells. Fall streaks of ice particles produced by the generating cells were commonly evident merging through the stratiform layer below. The strongest vertical velocities in the comma head region (±1-2 m s^{-1}) were confined to the cloud top convection, with weaker stratiform signatures below. Additional examples and details are described in Rosenow et al. (2013).

3. Vertical profiles

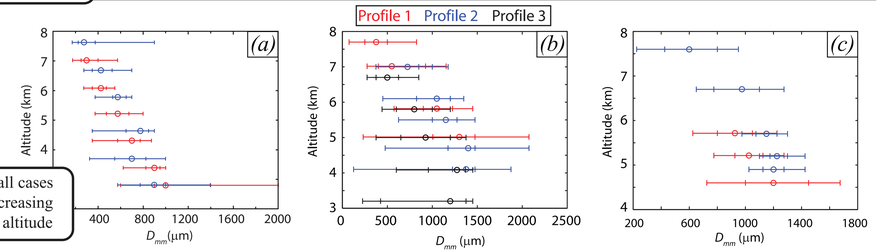
Fig. 5. Particle concentration (N) statistics by flight leg for vertical profiles in comma head precipitation, for (a) 15 Feb. 2010, (b) 2-3 Dec. 2009, and (c) 21-22 Feb. 2010 cyclones. Circles indicate median values, vertical tick marks indicate 5th-25th-75th-95th percentiles.



Most comprehensive observations in 15 Feb. case; over time, particle concentrations increased with height

Other cases' more limited observations show less variation with height

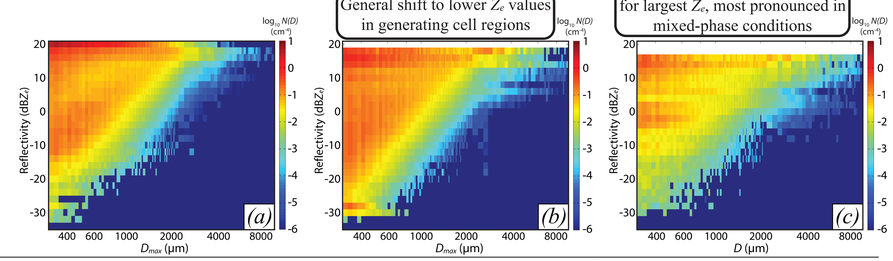
Fig. 6. Flight leg statistics as in Fig. 3, except for median particle diameter with respect to mass (D_{mm}).



With few exceptions, all cases consistently feature decreasing particle diameter with altitude

4. Cumulative characteristics

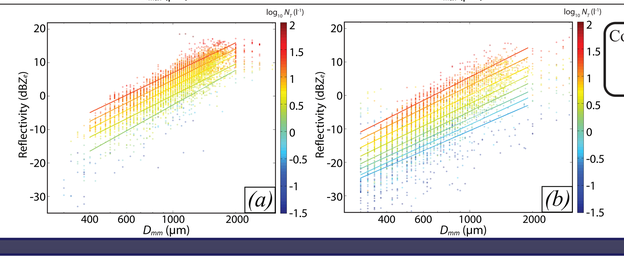
Fig. 7. WCR Z_e interpolated to the C-130's location vs. N(D) from 2D-C and 2D-P for all PLOWS cyclones, for (a) stratiform precipitation regions, (b) ice-phase generating cell regions, and (c) mixed-phase generating cell regions.



General shift to lower Z_e values in generating cell regions

$N(D)$ broadens in generating cells for largest Z_e, most pronounced in mixed-phase conditions

Fig. 8. Scatterplot and power-law fits of WCR Z_e vs. median mass diameter (D_{mm}) by particle concentration (N_T, color shading) for all PLOWS cyclones, for (a) stratiform precipitation regions, and (b) generating cell regions.



Consistent increase in D_{mm} with Z_e in all cases; N more broadly distributed with respect to Z_e

Scatterplots show generating cell measurements much more broadly distributed and shifted lower with respect to Z_e

5. Conclusions

- Kilometer-scale generating cells consistently observed near cloud top throughout comma head of cyclones
- The convection produces fall streaks of ice particles that merge through a stratiform layer below
- Supercooled water often present at cloud top in generating cells
- In situ measurements broadly consistent with large scale seeder-feeder process
  - Particle generation in convection aloft, growth by deposition and aggregation through stratiform layer below
  - Particle concentration characteristics most apparent in 15 Feb. case, but similar trends in particle diameter in all cases
- Cumulatively, median mass diameter relates well to reflectivity, with number concentration more broadly distributed with respect to reflectivity
- Measurements in generating cell regions are collectively biased to lower reflectivity compared to stratiform regions
- Most broad size spectra apparent with largest reflectivity in generating cell regions
  - Most apparent in mixed-phase conditions, suggesting a subset of generating cells produce large particles

6. Acknowledgments

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7. References

Rosenow, A. A., D. M. Plummer, R. M. Rauber, G. M. McFarquhar, B. F. Jewett, and D. C. Leon, 2013: Vertical velocity and physical structure of generating cells and convection in the comma head region of continental winter cyclones. *J. Atmos. Sci.*, in press.