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Relationship of Graupel Shape to Differential Reflectivity: Theory and Observations

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1. Introduction

Graupel are the most important ice phase radar targets in cumulonimbus clouds, but are seldom observed at the ground, melting before they get to the surface in summer conditions. Identifying graupel is important because of the indirect indication of the presence of supercooled water.

Conical graupel may produce a negative Zdr, depending on the geometry and fall modes, a condition easily identified since most hydrometeors, both liquid and solid, have positive Zdr.

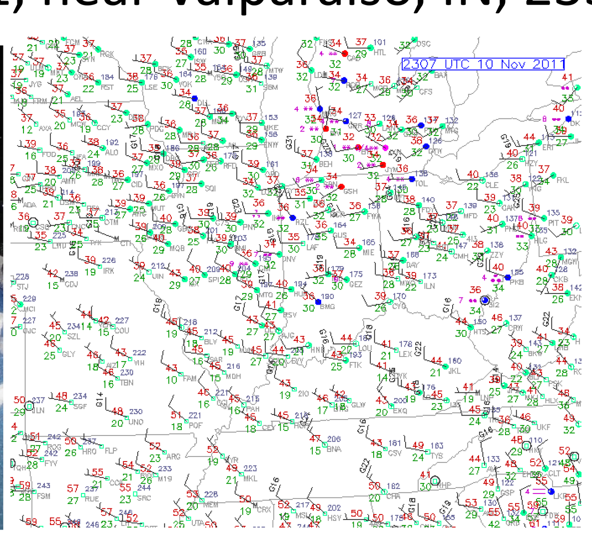
In situ growth conditions play an important role in the geometric shape of the conical graupel, with the cone axis stably aligned with gravity. In particular, the apex angle of the cone (α), depends on the temperature, droplet sizes and updraft vs fall velocity strength (Cober and List, 1993).

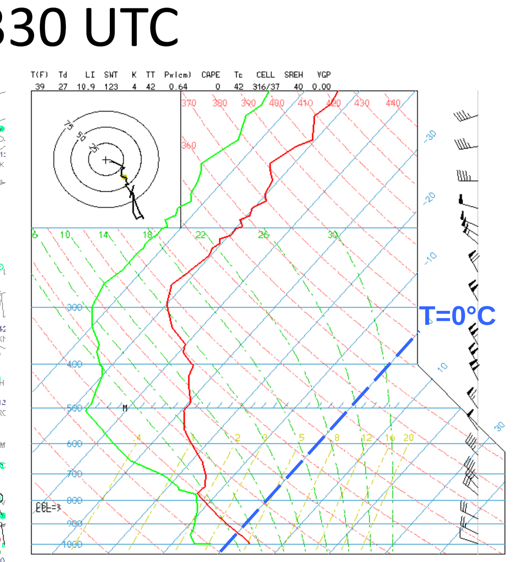
Large areas of slight negative Z_{dr} above the melting layer might indicate that graupel is more prevalent than previously believed in non-winter conditions.

The aim of this project is to understand how we can derive the environmental conditions favorable for the growth of conical graupel and/or characterize the supercooled liquid water from dual polarization radar observations.

2. Graupel events

2.1. 10 November 2011, near Valparaiso, IN, 2330 UTC



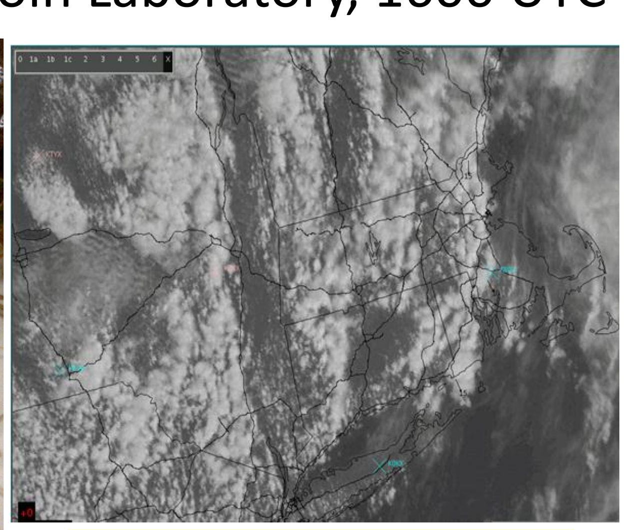


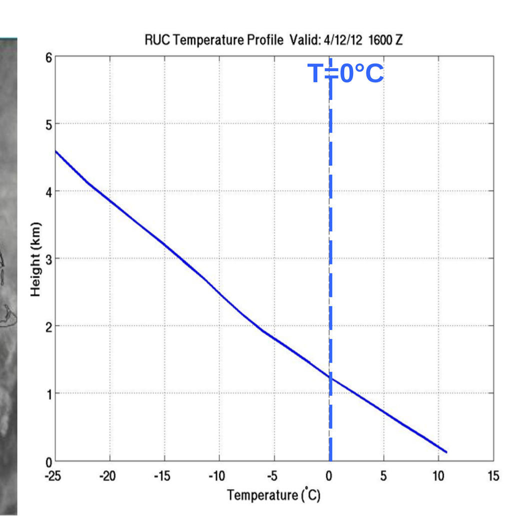
Measured apex angles (α):
- 1x 40 deg
- 2x 50 deg
- 1x 52 deg
- 1x 56 deg
- 1x 60 deg
- 1x 70 deg

Surface analysis at 23 UTC. Surface temperature was very close to freezing with snow reported at the ground in the region.

Freezing level right above the surface, very little or no melting occurring before the ground.

2.2. 12 April 2012, Lincoln Laboratory, 1600 UTC





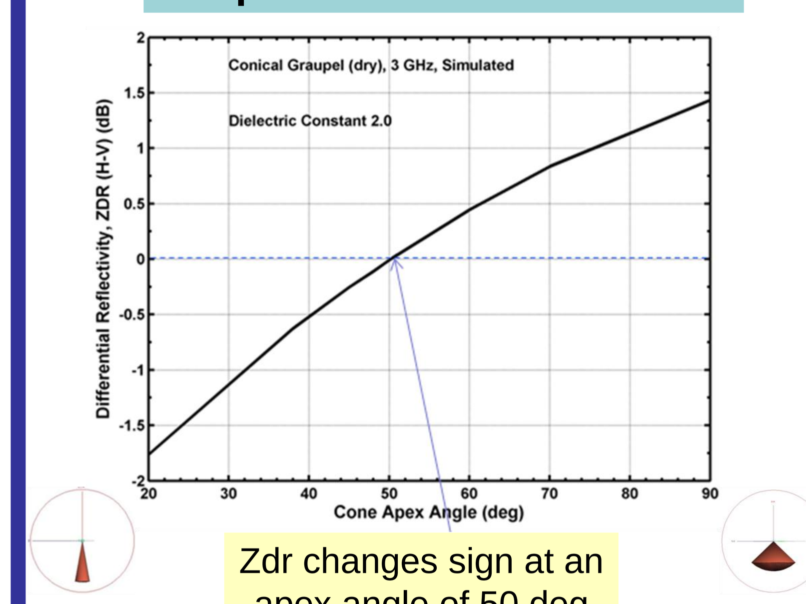
Nominal 8 mm long dimension

Cold core, cut-off low pressure system triggers low-topped convective cells

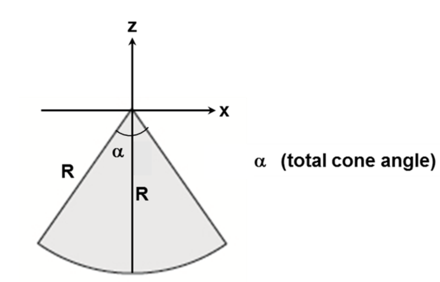
Freezing level about 1.2 km above the surface yet graupel survive to the ground.

3. Z_{dr} Calculations for idealized shapes

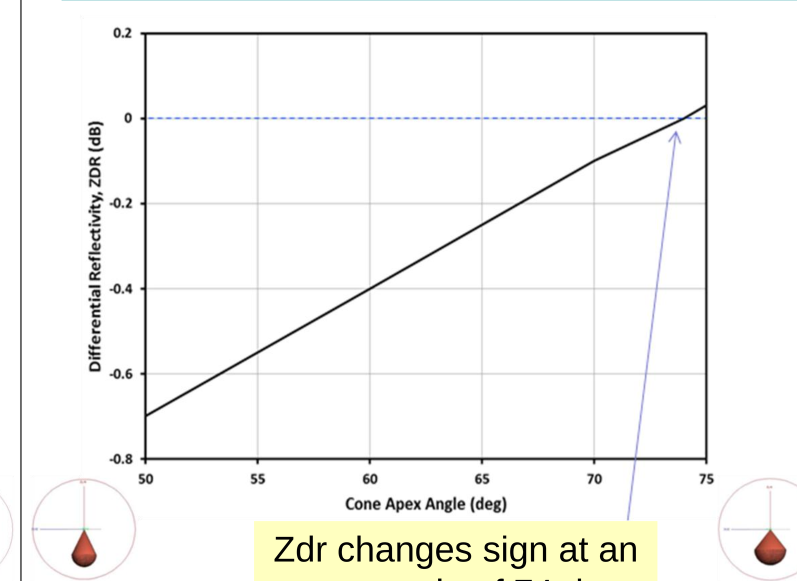
Shape Model 1: Curved base



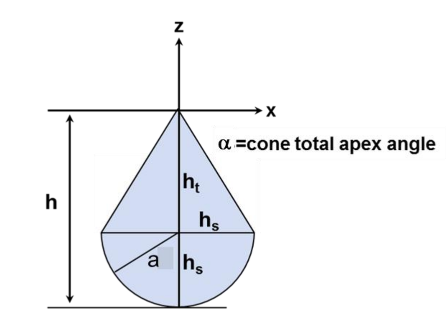
Zdr changes sign at an apex angle of 50 deg



Shape Model 2: Hemispherical base



Zdr changes sign at an apex angle of 74 deg



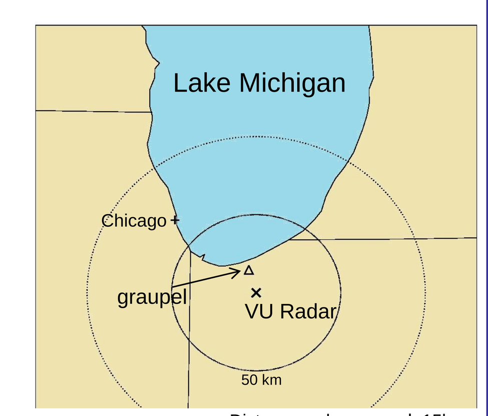
These simulations show how Z_{dr} varies with the apex angle for two different graupel geometries. For both model shapes, negative Z_{dr} occurs at low apex angles, model 1 lower than 50 deg, model 2 lower than 74 deg. These calculations were made with the FEKO electromagnetic simulation software tool (http://www.feko.info/).

4. Observed Z_h and Z_{dr}

4.1. Event 10 November 2011, 2331 UTC, elv = 1.5°

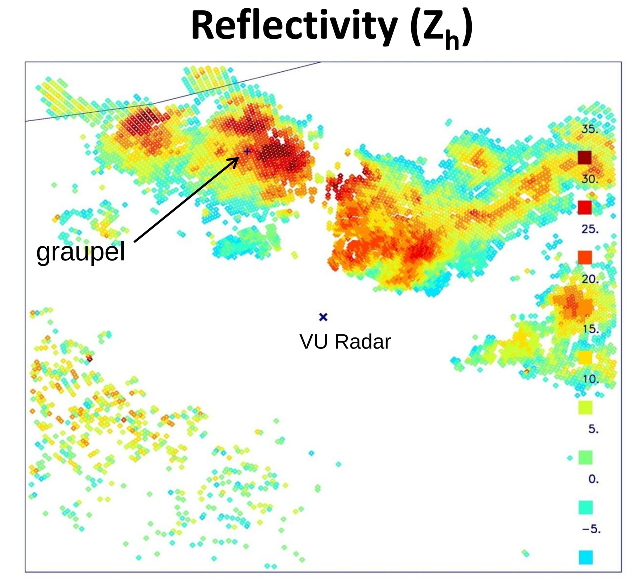
Reflectivity shows scattered convection. At the location where the graupel was observed Z_h values are between 20 and 30 dBZ, consistent with the presence of graupel.

Negative Z_{dr} (between -1 and 0 dB) were seen around the same location.

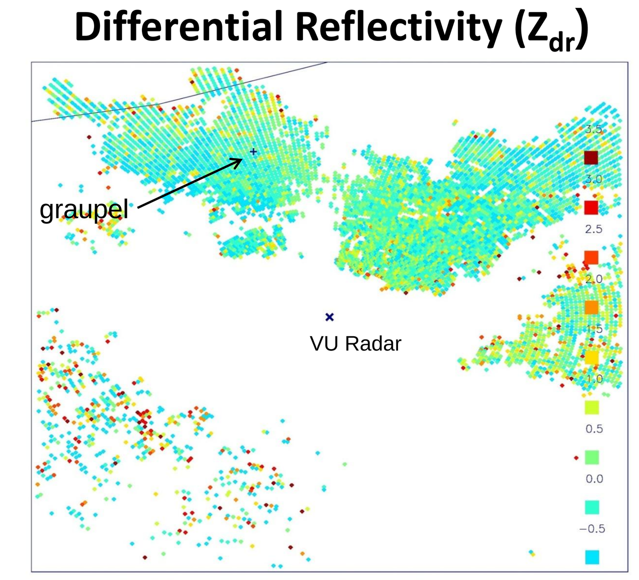


Distance radar-graupel=15km

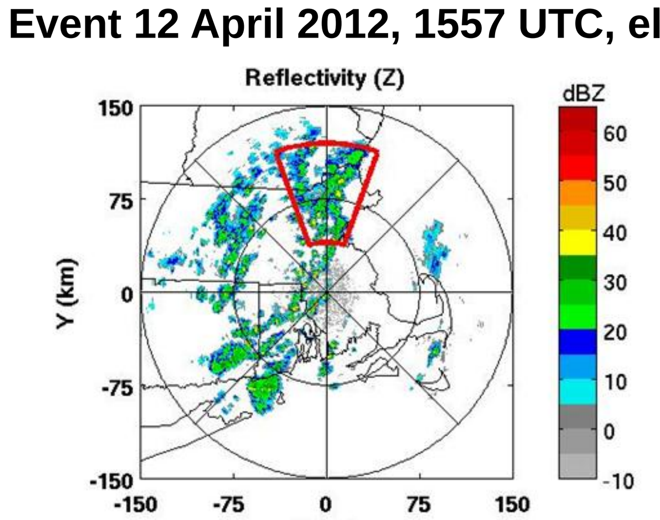
Reflectivity (Z_h)

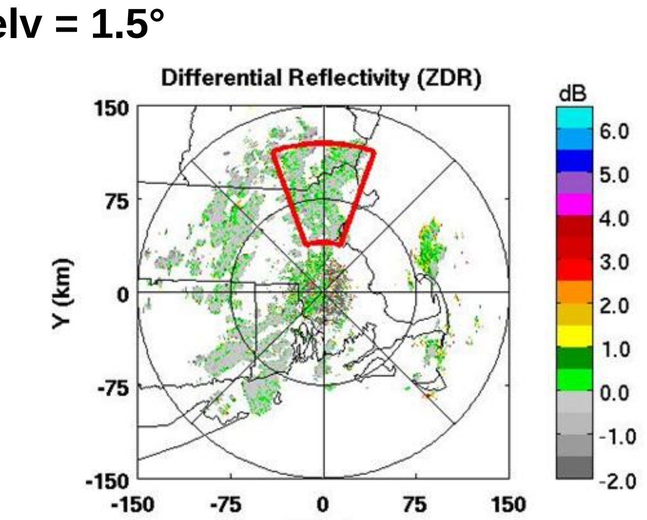


Differential Reflectivity (Z_{dr})



4.2. Event 12 April 2012, 1557 UTC, elv = 1.5°

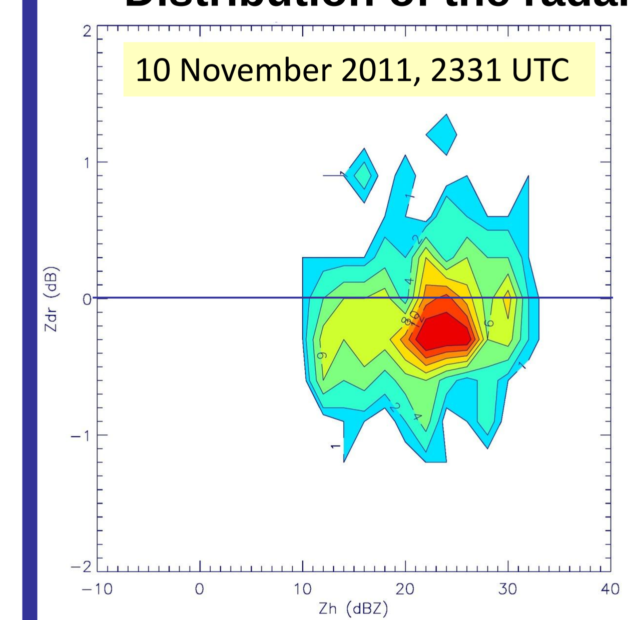


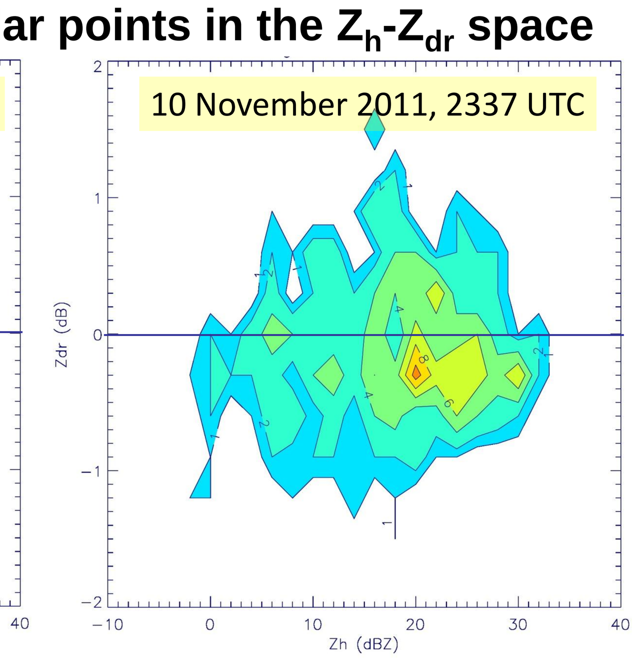


NEXRAD KBOX

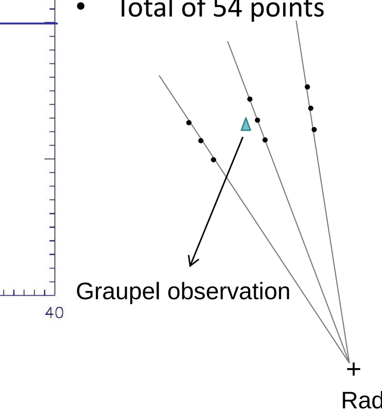
4. Observed Z_h and Z_{dr} (cont.)

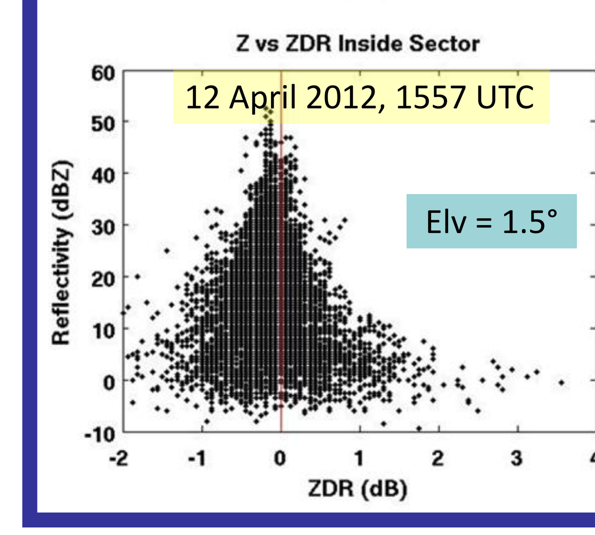
Distribution of the radar points in the Z_h-Z_{dr} space





Points used in the histograms:
- 3 gates adjacent to the observation
- 3 azimuths adjacent to the observation
- First 6 tilts
- Total of 54 points





Both images for 10 November 2011 clearly show the negative Z_{dr} around the region where graupel was observed at the ground.

The 12 April 2012 scatter plot for the red sector also shows a substantial amount of negative Z_{dr} points, evidence of the presence of conical graupel.

5. Discussion

Radar observations show a clear negative Z_{dr}, indicating small apex angles, in agreement with the observations at the ground.

In general, the only hydrometeor types that produce a negative Z_{dr} are either conical graupel with small apex angles, or vertically aligned ice crystals (example: Dolan and Rutledge, 2009), the latter only occurring under the influence of an electric field. These two particle types are easily separated with other radar variables or environmental conditions.

Because graupel is by definition a rimed particle, the region where graupel grows is a region where there is supercooled water and thus prone to icing. The ultimate goal is to get information on icing severity from the information provided by Z_{dr}. Cober and List, (1993) have made experiments in wind tunnels and observed that the apex angle in conical graupel increases with increasing airflow velocity and droplet median volume diameter (all other conditions held fixed), and decreases as the in situ temperature increases. Therefore, negative Z_{dr} due to the presence of conical graupel should give an indirect assessment of icing conditions.

In order to obtain a degree of icing severity from the shape of the conical graupel, more research is needed, and more cases analyzed along with PIREP reports.

References:
- Cober, Stewart G., List, Roland,1993: Measurements of the Heat and Mass Transfer Parameters Characterizing Conical Graupel Growth. *Journal of Atmospheric Sciences*, 50, 1591-1609.
- Dolan, Brenda, Steven A. Rutledge, 2009: A Theory-Based Hydrometeor Identification Algorithm for X-Band Polarimetric Radars. *J. Atmos. Oceanic Technol.*, 26, 2071–2088.

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