Hydrometeor Classification of Snow using a Fuzzy Logic Method

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Objective

The objectives are to identify hydrometeor classification equation sets that work for specific radar wavelengths and to verify those solutions using in situ measurements of snow particles during a regional snow event. Hydrometeor classification helps in identifying heavy snow bands that can drastically affect road surface

Introduction

The 20-21 November 2010 snow event near Grand Forks, North Dakota is studied using observations from two polarimetric radars and the University of North Dakota Citation Research Aircraft. The 20-21 November 2010 observations were obtained during a field project called Students Nowcasting & Observations with the DOW at UND: Education through Research (SNOwD UNDER). Bulk snowflake types were identified using a hydrometeor classification algorithm (HCA) that uses polarimetric radar variables as input. The HCA results are compared with in situ ("truth") images of particles collected using a Two Dimensional Cloud Imaging Probe (2DC). Attention is focused on times when the aircraft is passing between two HCA-identified crystal type regions.

Background

Meteorological Definitions of Snow and Ice

- Dendrites (a type of ice crystal) are one single snowflake
- Aggregates are multiple dendrites and other crystals clumped together

Polarimetric Radar

- Polarimetric radars send out pulses in both horizontal and vertical orientations
- Can be used to determine average precipitation particle shape
- Two polarimetric wavelengths used (3 cm for DOW/CSWR; 5 cm for UND)

Polarimetric Variables

Here is a table of the common polarimetric variables. Each one tells something different about the hydrometeors that are present. These values for snow and ice are from reference [2]

Polarimetric Variable	Definition	Values for snow and ice
Zh (horizontal reflectivity)	Related to the fraction of backscattered power from hydrometeors	-20 to 40 dBz
ZDR (differential reflectivity)	Ratio between the horizontal and vertical reflectivity. Major player in the HCA. ZDR>0 ZDR= 0 ZDR<0	Dry aggregated snow: 0.1 to 0.3 dB Horizontally-oriented ice: 4 to 5 dB Ice: -2 to 0 dB
KDP (specific differential phase)	The difference in differential phase between two point at different ranges	For snow and ice: -2 to +7 deg/km (usually zero)
RhoHV (Correlation Coefficient)	Degree of self-similarity of hydrometeors size, shape, and phase	Non-meteorological <.8 Hail/Melting snow (mix) .8 to .97 Rain or snow (self-similar) >.97

Polarimetric Variables Plots

- Reflectivity higher inside than outside the banded regions (both radars)
- Reflectivity maxima slightly higher in CSWR
- Reflectivity minima similar (both radars)

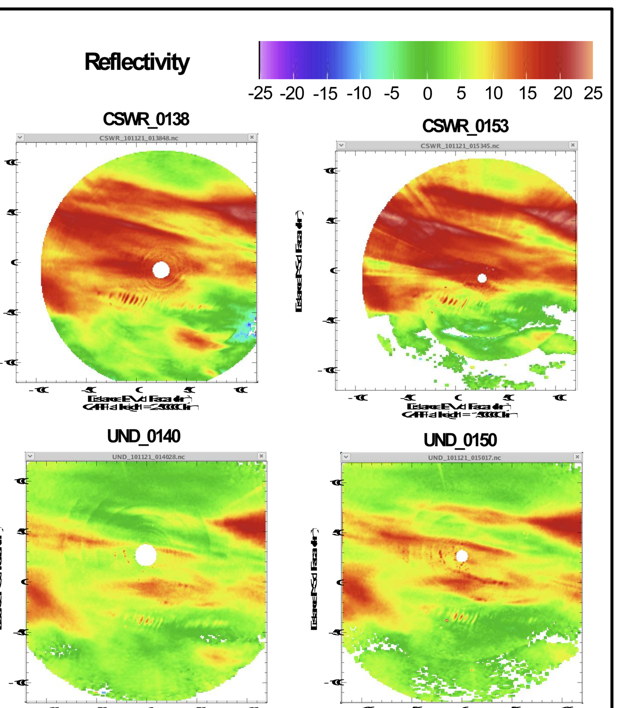

Figure 1:Reflectivity

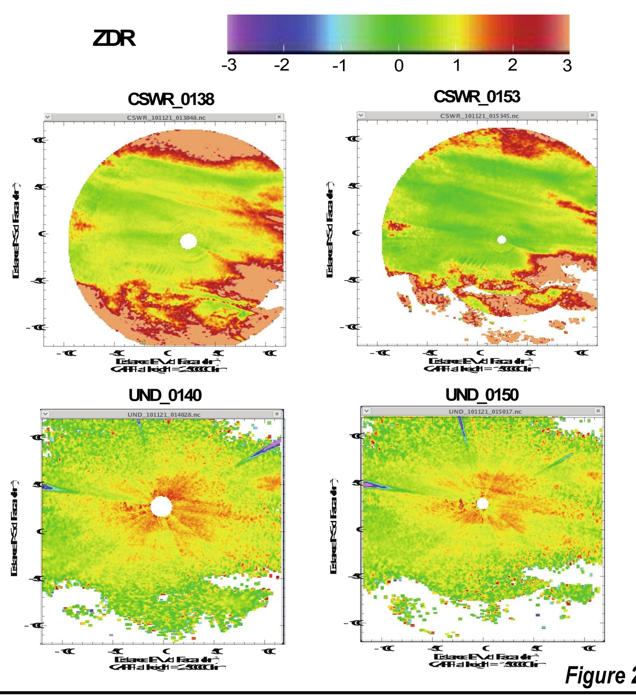

Figure 2: ZDR

ZDR values are near:
- zero within the band for the CSWR radar (large aggregates)
- one outside the banded regions for the CSWR radar (ice crystals)

UND ZDR plots are much noisier than CSWR
- CSWR radar was more sensitive then the UND radar

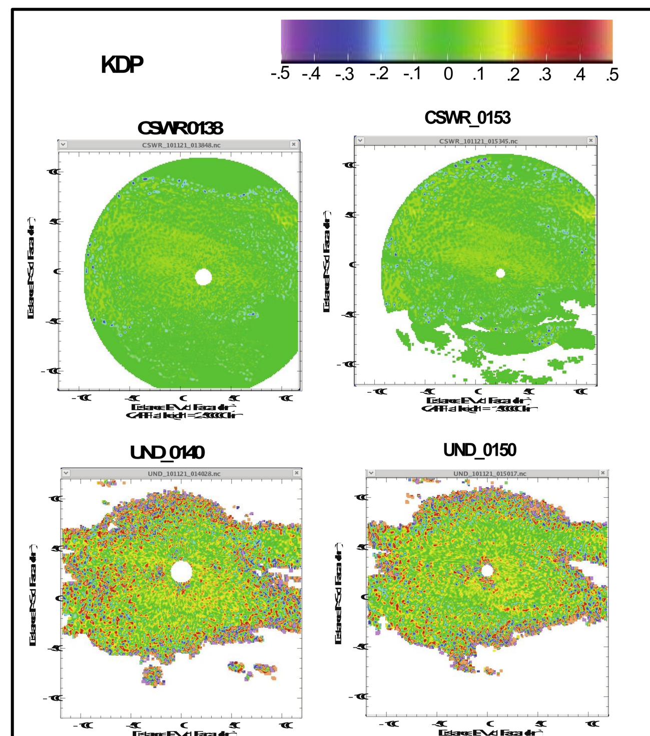

Figure 3:KDP

KDP values are near
- .1 inside bands (CSWR)
- 0 outside of bands (CSWR)
- Used mostly to discriminate between rain and ice hydrometeors in the 5 cm HCA[1]

UND KDP plots are much noisier than CSWR
- CSWR radar was more sensitive than the UND radar

Figures 1-3 have been filtered with the following parameters: RhoHV <.60 filtered and Reflectivity>26 filtered

Hydrometeor Classification Algorithm (Marzano et al.) [1]

- Determines probability of particular hydrometeor species given the polarimetric observables (zhh, zdr, kdp) and air temperature (T) profile
- Three species relevant to this study: ice crystals, dry snow, & graupel
- There are three main stages-
  1. fuzzification-specific equation setting happens for each hydrometeor
  2. inference-weighting occurs for each individual hydrometeor class
  3. defuzzification-hydrometeor with the largest value (from 0 to 1) is assigned to each location in space
- HCA "trained" with 1000 independent simulations for each hydrometeor class[1]

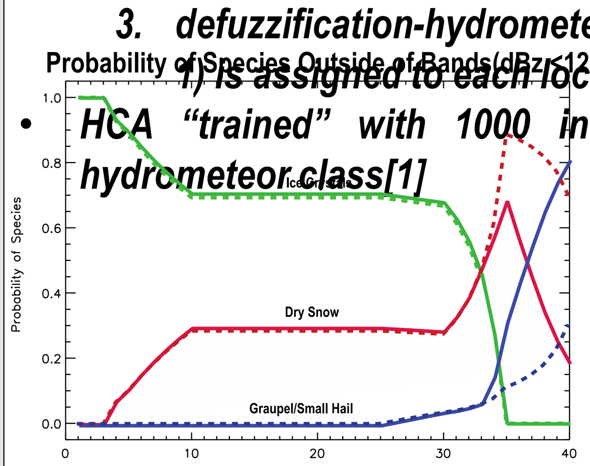

Figure 4: Probabilities of species outside the bands with varying dBz.

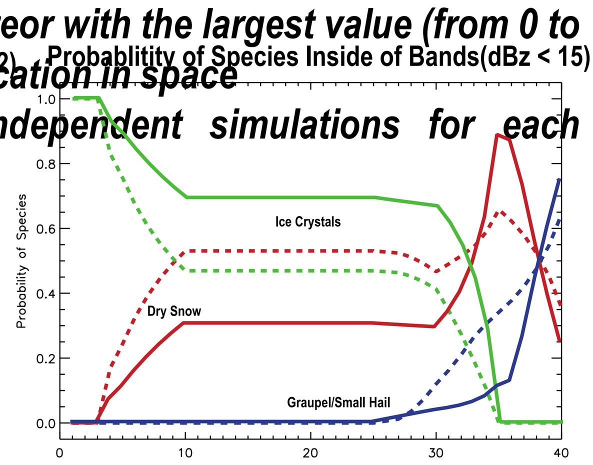

Figure 5: Probabilities of species inside the bands with varying dBz.

About Figure 4 and 5

Outside bands:
- Both radars similar results (ice crystals) until around 33 dBz

Inside Bands:
- Probabilities close for ice crystals and dry snow between 8 dBz and 30 dBz
  - This is why bands showed up on the horizontal plots

Methodology

Processing Radar Data

- RSL library - converts radar files between UF format & sweep format
- SOLOii - removes ground clutter and rotate radar orientation
- Reorder - interpolate spherical coordinate data to Cartesian
- HCA – classifies the dominant hydrometeor type at each location

Processing Aircraft Data

- Used CPLOT software to
  - Visualize precip particles
  - Plot sizes versus concentration
  - Plot aircraft tracks

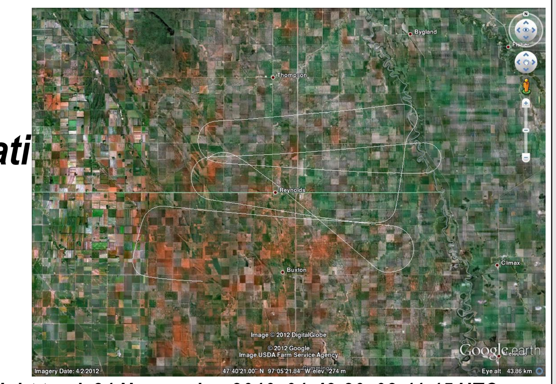

Figure 6:The descending flight track 21 Novemeber 2010 01:43:20- 02:11:15 UTC.

Results

Comparison of UND and CSWR radar with 5cm algorithm

- constant altitude cross sections of HCA output
  - show the most likely hydrometeor type at each location
  - Reflectivity and ZDR bands (Figs. 1 and 2) are seen in CSWR radar and so the HCA detects bands of dry snow aggregates
  - Reflectivity bands are seen for UND (Fig. 1) but ZDR for UND is noisy. Noisy ZDR is probably why HCA does not pick up the snow bands in HCA output.

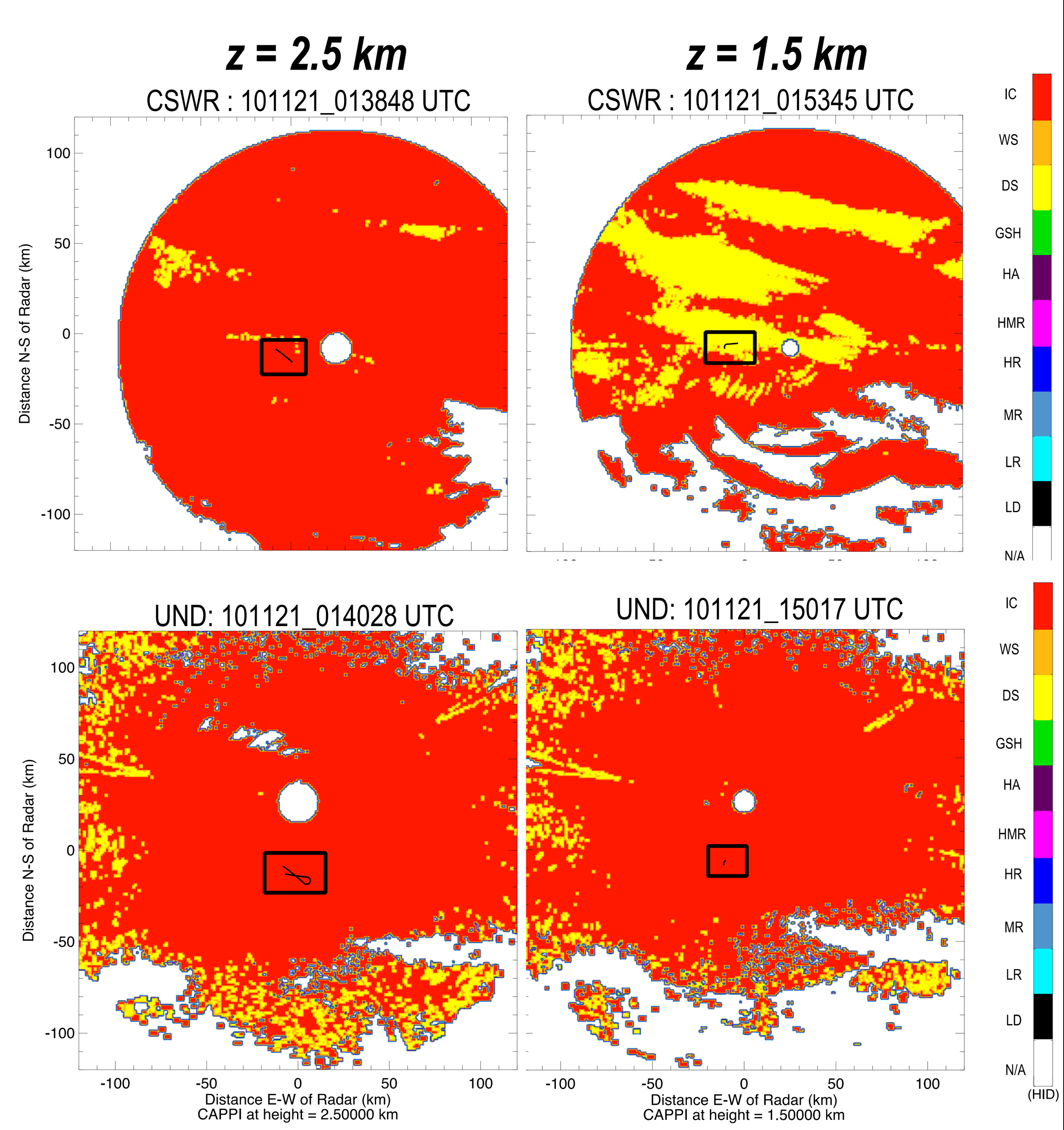

Figure 7: The boxes indicate where the aircraft was flying at the times and altitudes indicated (z=2.5 km left; z=1.5km right). HCA-identified ice crystals(red) and dry snow (yellow).

Results

Images of the hydrometeors in and around the snow bands are available from the 2DC probe. Smaller particles which are considered ice crystals are found both outside and inside the bands. However, inside the bands there are some very large particles that are not present outside the bands.

2DC Images of Ice Crystals and Dry Snow

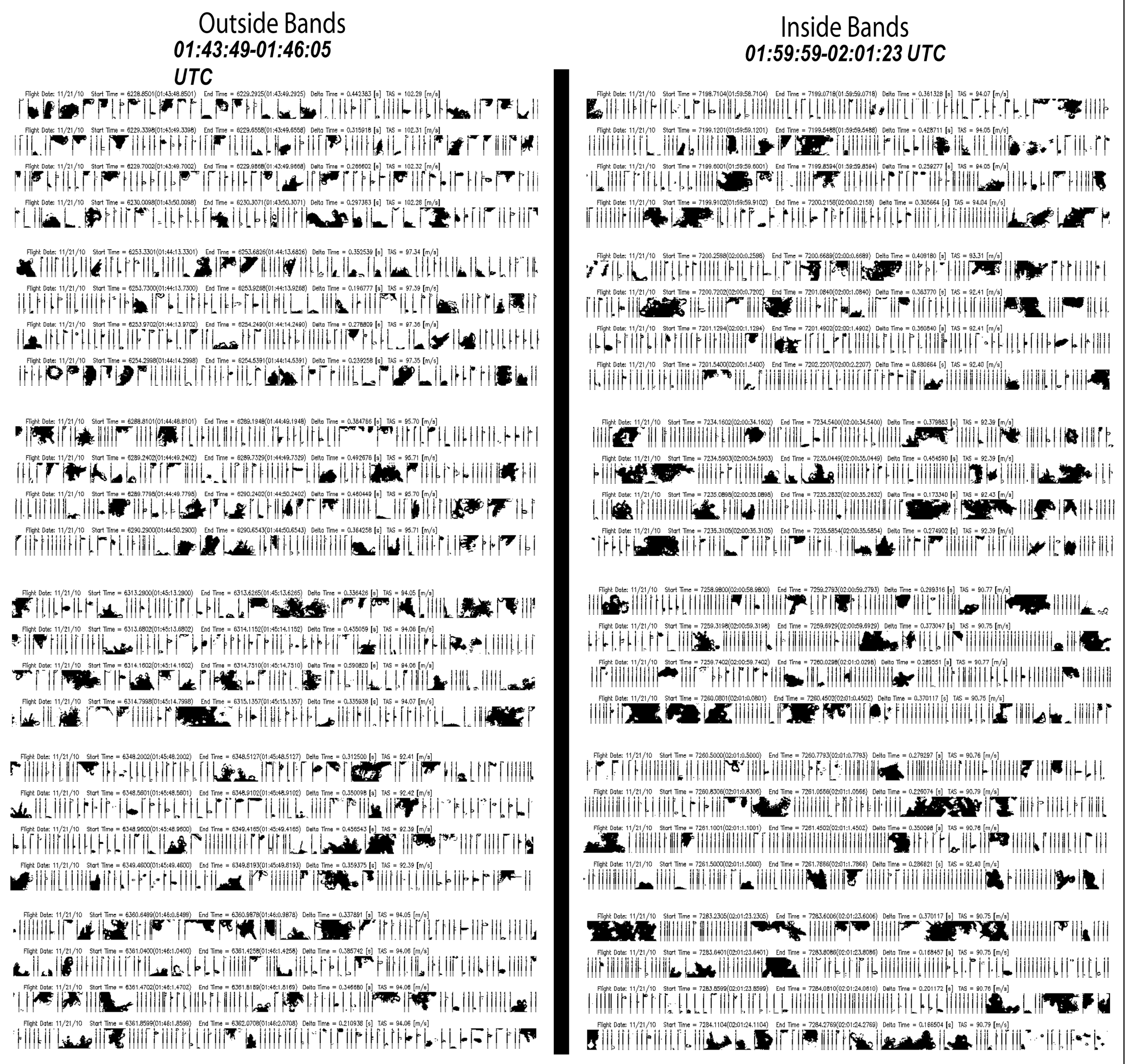

Figure 8: 2DC images from the 21 November 2010 aircraft flight.

The size distribution which corresponds to the 2DC image given above show that the greater concentration of large (2.25 and 3.0 mm) hydrometeers are inside the snow band. The larger hydrometeors result in lower ZDR values (on average, spherical shape) which are seen in Figure 2.

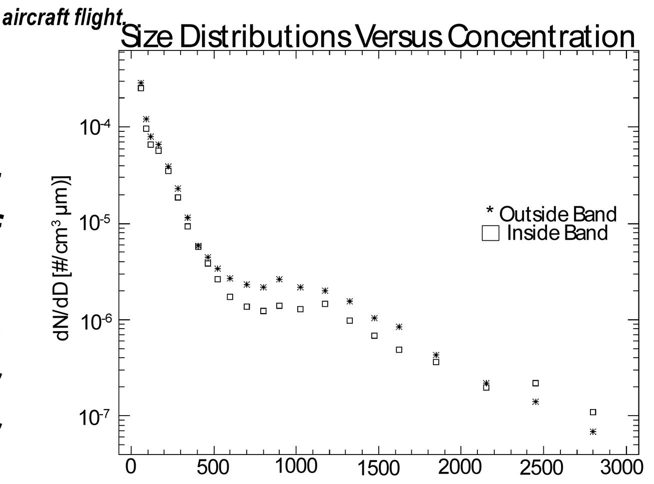

Figure 9: Size distribution of hydrometeors obtained on the 21 November 2010 aircraft flight for samples outside (01:43:49-01:46 :05 UTC) and inside (01:59:59-02:01:23 UTC) the snow bands.

Conclusion

The hydrometeor algorithm designed for 5 cm radars also appears to work for a 3 cm radar. The larger particles inside the snow bands are apparently on-average spherical in shape enabling detection of "snow aggregates" via near zero ZDR and larger reflectivity.

Future Work

- Look at the other three SNOwDUNDER case studies that occurred on different days to check consistency between the aircraft observations and HCA output.
- Use the algorithm on a different UND radar case that has better ZDR output

Acknowledgements

This research was funded by a ND EPSCOR (AURA) grant for Summer and Fall 2012.

References

[1] Marzano F.S.Univ of Rome "La Sapienza,Rome, D.Scaranari, and G.Vulpiani,2007:Supervised Fuzzy-Logic Classification of Hydrometeors Using C- Band Weather Radars.IEEE Trans. on GeoScience and Remote Sensing.45, 3784 - 3799

[2] National Oceanic & Atmospheric Administration,cited 2012:Dual-Polarization Radar Training. [http://www.wdtb.noaa.gov/courses/dualpol/]