Icing-related hazardous weather revealed by CloudSat and NMQ system: Potential for enhancing the hydrometeor classification in sub-freezing region

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Motivation

Satellite remote sensing offers new and unique insights for the study of cloud and precipitation systems. A contemporary instrument for cloud mapping is the Cloud Profiling Radar (CPR), which is the first spaceborne cloud radar onboard NASA's CloudSat satellite (http://cloudsat.atmos.colostate.edu/). CPR operates at W-band (94 GHz) and provides good sensitivity for measuring the vertical structure of cloud liquid/solid water distribution. On the ground, the Next-Generation Radar (NEXRAD) network has proven its value for nation-wide weather observations. An advanced quantitative precipitation estimation (QPE) system based on NEXRAD is NOAA's National Mosaic and Multisensor QPE system (NMQ, http://nmq.ou.edu). Since June 2006, NMQ (Q2) has been generating high-resolution, national 3-D reflectivity mosaics (31 vertical levels) and a suite of severe weather and QPE products at a 1-km horizontal resolution and 5-min update cycle. The polarimetric NMQ (Q3) will be available in 2013. These products are being merged with CPR observations to yield better depictions of storm structures and microphysical processes.

Mixed-phase clouds account for the majority of convective precipitation and concomitant severe weather over continental regions. The understanding of icing conditions in the mixed-phase clouds is important to estimate and forecast icing hazards with radar observations. This issue is especially critical for aviation and ground transportation. The current study investigates the potential of detection and identification of supercooled liquid drops (SLD)/freezing drizzle (FZ), which are believed to be responsible for hazardous aircraft icing, using observations from spaceborne and ground-based radars. Research products from the CloudSat mission and NMQ, including vertical profiles of reflectivity, liquid water content, characteristic size, temperature, cloud type and phase, are utilized to assist with the discrimination of SLD/FZ from other hydrometeors. The combination of CloudSat and NMQ will provide great potential to enhance the hydrometeor classification in the sub-freezing region.

Platforms

1. NMQ-Q3

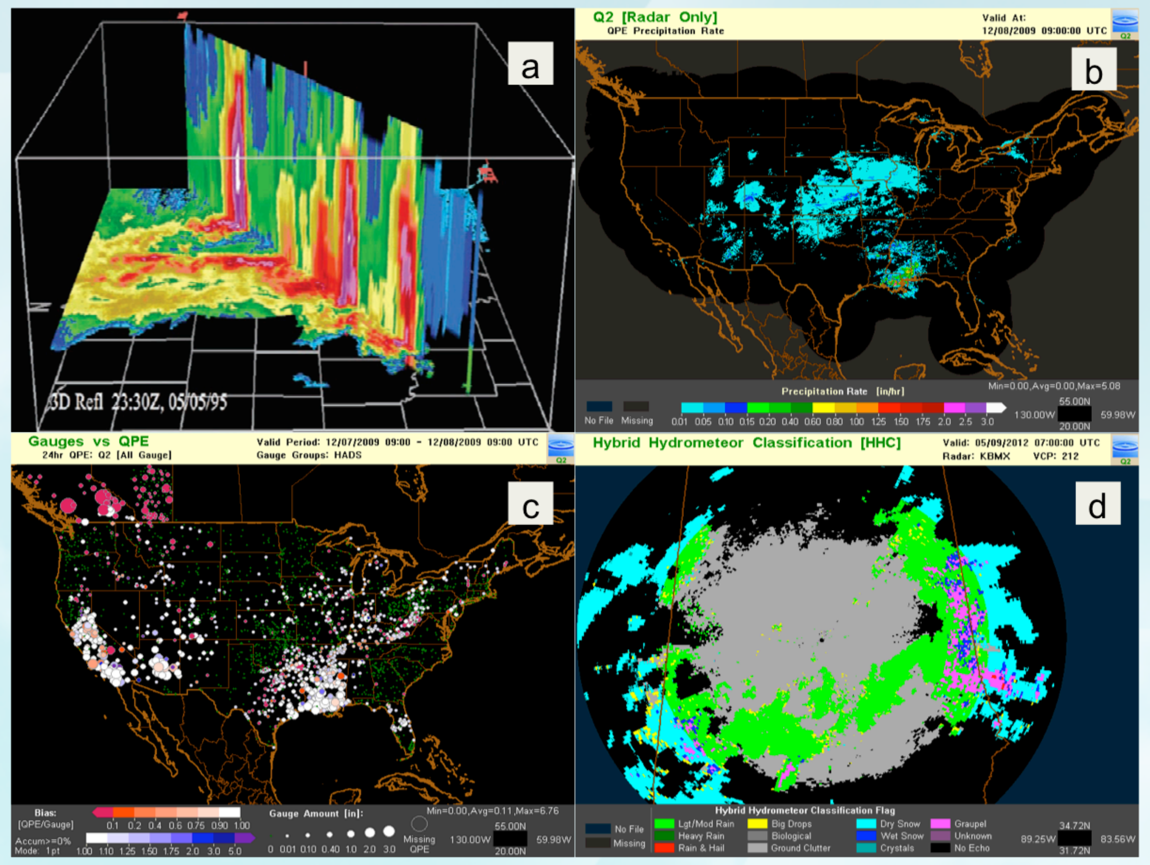
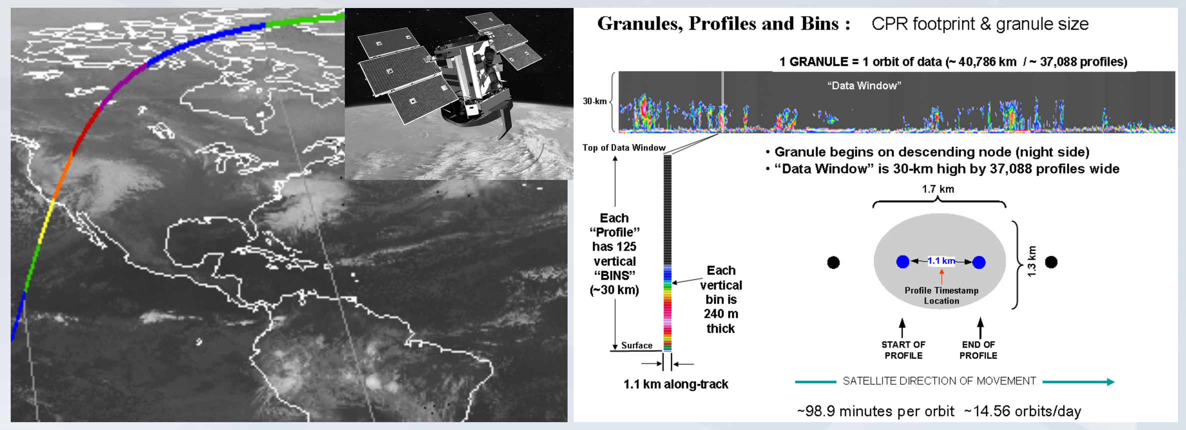


Figure (a) horizontal and vertical cross sections from NMQ-Q2 3D reflectivity mosaic; (b) NMQ-Q2 precipitation rates; (c) spatial bias distribution based on gauge measurements; (d) research product in NMQ-Q3: polarimetric hydrometeor classification.

2. CloudSat-CPR

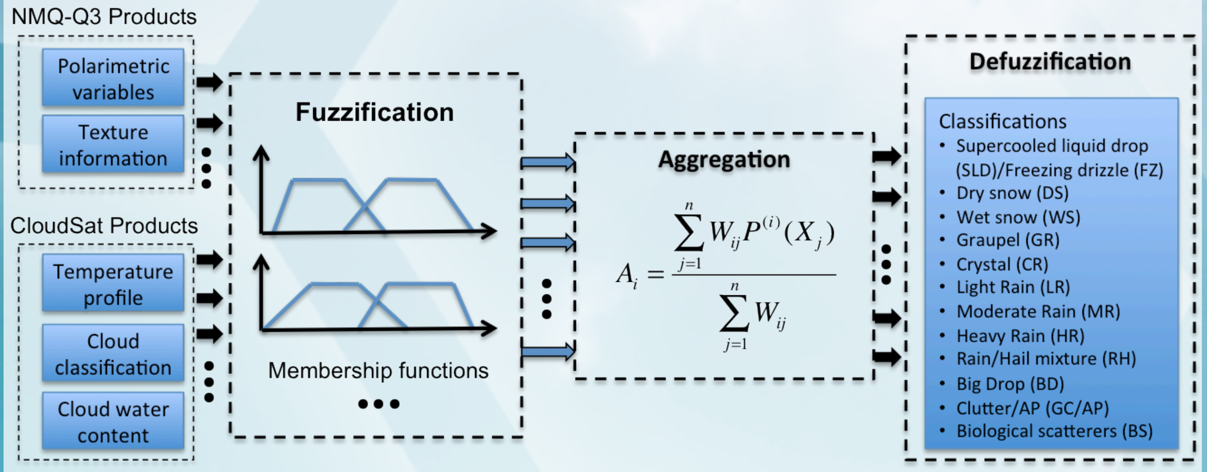


- CPR is more than 1,000 times more sensitive than existing weather radar.
- CPR can "see" inside clouds to determine how much water and/or ice is inside.
- CPR provides vertical structure of clouds and rain from space
- CPR produces new meteorological data types including cloud-layer thickness, cloud top and base altitudes, and cloud water and ice content.

- *Nominal Frequency:* ***94 GHz***
- *Minimum Detectable Z: < -29 dBZ*
- *Pulse Width 3.3 μsec*
- *Data Window: 0-25 km*
- *Antenna Size: 1.85 m*
- *Integration Time: 0.16 sec*
- *Nadir Angle (since 15 Aug 2006): 0.16°*
- *Vertical Resolution:* ***500 m***
- *Cross-track Resolution:* ***1.3 km***
- *Along-track Resolution:* ***1.7 km***
- *Sample Rate: 0.16 sec/profile*
- *Along-track Velocity: 7 km/sec*

3. Methodology

- **Fuzzy-logic Enhanced Hydrometeor Classification Algorithm (EHCA)**



The well-known hydrometeor classification algorithm (HCA) was developed by NSSL specifically for the polarimetric WSR-88D (Park et al. 2009). However, HCA can not discriminate SLD/FZ due to the similarity of S-band radar signals between small, spherical drizzle hydrometeors and light snow.

The proposed EHCA integrates CloudSat products, which provide great potential to improve hydrometeor classification, especially for the region above the freezing level. Liquid drops and ice particles have distinct scattering characteristics at S- and W-band frequencies. In addition, small cloud/precipitation particles can be well detected by CloudSat. Therefore, the use of CloudSat (and combined CALIOP) data will help to identify species (e.g., SLD and FZ) that S-band radar cannot detect. We propose to develop EHCA using CloudSat and NMQ-Q3 datasets.

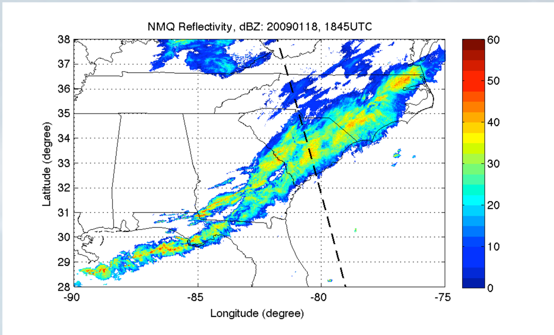
The inputs applied by EHCA include polarimetric variables (Z_H, Z_{DR}, ρ_{HV}, K_{dp}), texture information (SD[Z_H], SD[Φ_{dp}]), profile of temperature, humidity, cloud classification, ice/liquid phase, and ice/liquid water content and distribution. EHCA is expected to produce new category SLD/FZ. Moreover, DS, WS, GR, CR, and LR will be improved compared to original HCA.

The development and/or modification of membership functions for corresponding categories will be key works for the proposed EHCA. In addition, the validation of EHCA results will be another important issue.

4. Informative Datasets

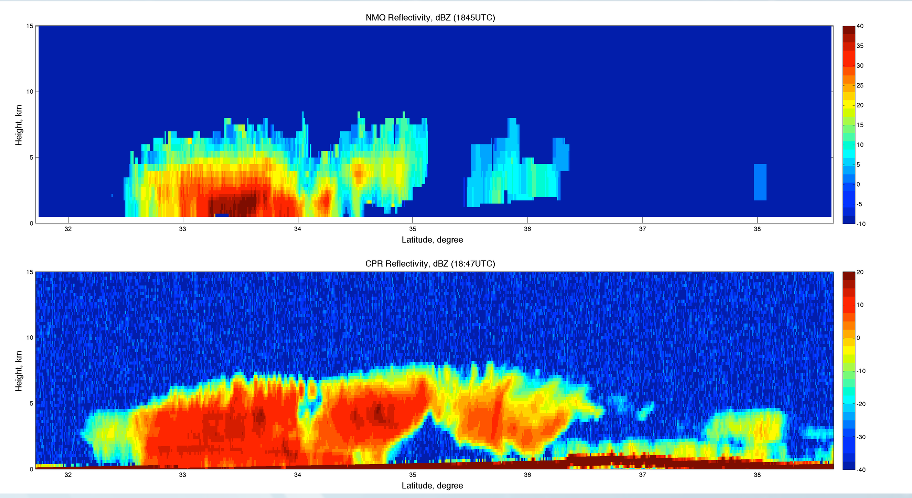
CloudSat science team has generated products which help the analysis of cloud/precipitation processes. Currently the NMQ (Q2) only provides the products based on single-pol data. The polarimetric-radar-based products will be available in NMQ-Q3 system, which will be constructed after the upgrade of NEXRAD.

The right figure shows NMQ hybrid scan reflectivity overlapped with CloudSat track (dashed line) for event 18 January 2009, ~1845 UTC. The following figures show the vertical profile of products from NMQ and CloudSat along the dashed line.

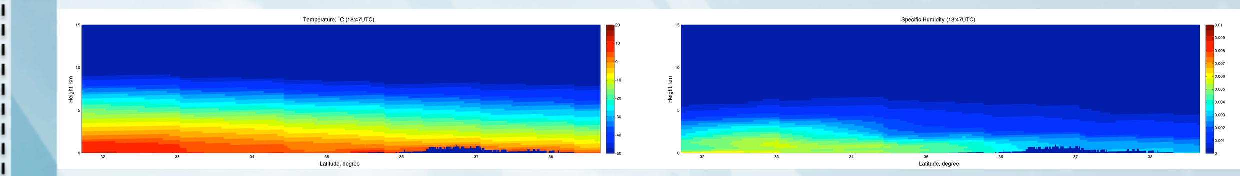


Profile of NMQ reflectivity

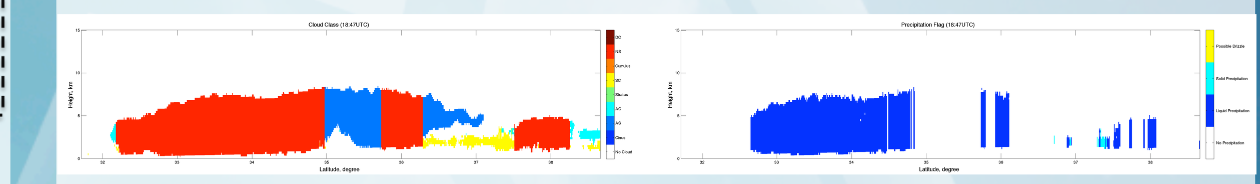
Profile of CPR reflectivity



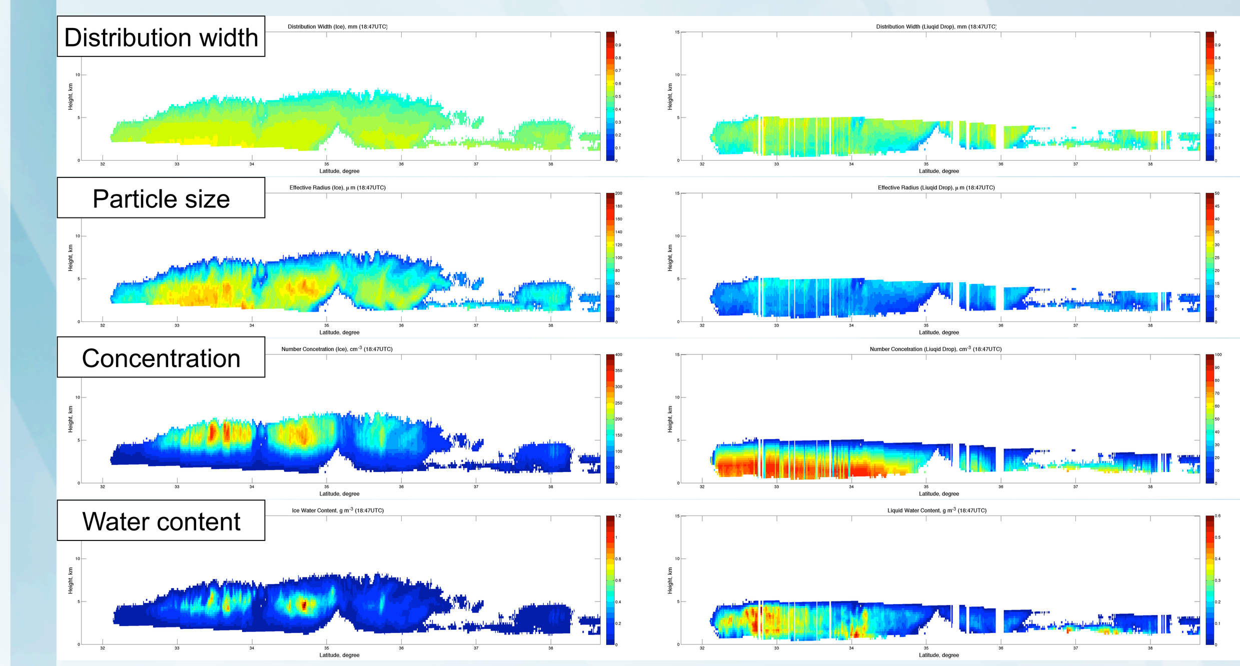
Profile of temperature and humidity



Cloud class and precipitation phase

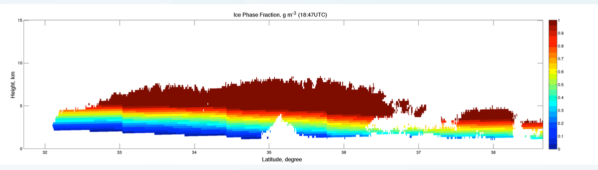


Cloud/precipitation microphysical information



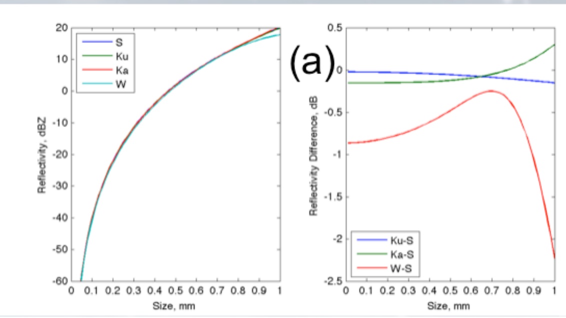
Left column: Ice particles Right column: liquid drops

Ice Phase Fraction

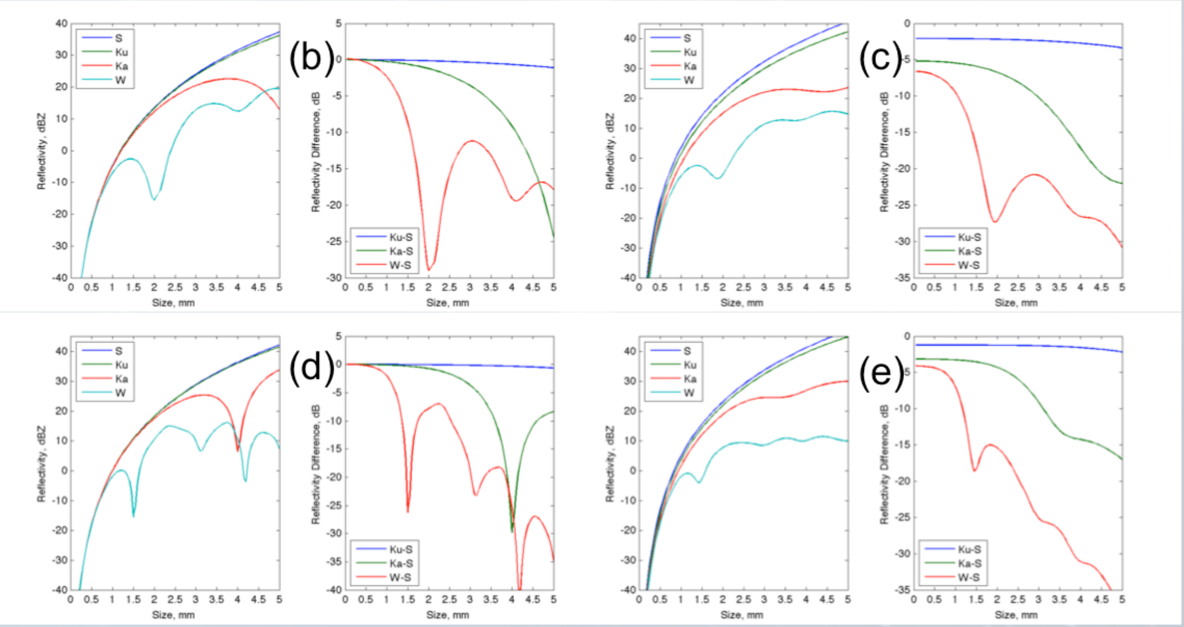


5. Research Plan

5.1. Investigate scattering characteristics



(a) supercooled water drops (temperature -5 °C)
(b) dry graupel or snow aggregate (density 0.5 g m^{-3})
(c) wet graupel or snow aggregate (density=0.5 g m^{-3}, melting ratio=10%)
(d) dry ice aggregate or hail (density 0.917 g m^{-3})
(e) wet ice aggregate or hail (density 0.917 g m^{-3}, melting ratio=10%)



This work involves the simulation based on the scattering theory. The scattering characteristics will give a guide for evaluating radar reflectivity for different hydrometeors.

5.2. Study multi-frequency and polarimetric signatures in the sub-freezing region.

This work will statistically analyze CloudSat and NMQ data with co-locations. Radar reflectivity, liquid water content, characteristic size and other quantities are quantified/linked together for various scenarios (frequency, hydrometeor type, and PSD). Corresponding empirical relations and/or physical constraints will be derived if they are available. Statistics of these quantities are also done for various categories. Emphasis will be put on small water drops (supercooled, size <1 mm), ice crystals (plate and column), and dry/wet graupel/aggregate/hail.

5.3. Construct/modify membership functions.

Based on the study of microphysical signatures and statistics of state variables, determine the critical range of membership functions for various classification categories. Necessary adjustments will be made through the diagnosis of the phase of hydrometeors, which can be pursued through a quantitative comparison of multi-frequency radar observations given a classified hydrometeor type.

5.4. Validate EHCA using multi-source observations.

There are two approaches for the validation of EHCA although challenging. The primary one is the cross-verification with multi-system data/products. Quantitative comparison of multi-frequency reflectivity as well as microphysical quantities, such as ice/liquid liquid water content, characteristic size, number concentration, and effective radius, will assess the classification result for the given hydrometeor type. On the other hand, all the available sources of direct verification, which are supported by NASA, NOAA, NWC, FAA or other agencies, will be considered. For example, we will take advantage of field experiments collecting in-site hydrometeor data within clouds (e.g., NASA's filed campaigns; weather balloons launched by NSSL, FAA icing condition report). We will also utilize surface station reports from the NWS.

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