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Evaluating Snowfall Detectability of NASA CloudSat with NOAA/NSSL Ground Radar-Based National Multi-sensor Mosaic QPE (NMQ)

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I Abstract

Snowfall is the an important component of precipitation at mid- and high-latitude regions as well as the high-altitude regions(e.g. the Tibetan plateau), and plays an important role in the hydrologic cycle on the earth. Accurate documentation of snowfall around the world will advance our understanding on the energy and energy and water cycle exchanges between the low- and high-latitude areas, and the low- and high altitude areas(e.g. the third pole Tibetan plateau as water tower in Asia). These exchanges drive most hydrologic models and have direct impacts on the planetary circulation of the atmosphere. The advent of satellite remote sensing technology makes feasible the large scale measurement of snowfall on the earth. NASA CloudSat, carrying the first space-borne Cloud Profiling Radar (CPR), is the first satellite that provides scientific communities with global snowfall observations. The CPR works at W-band (94 GHz) and is sensitive to fine particles(liquid/solid hydrometers) of cloud. Therefore, it is used to identify and retrieving the snowfall.

Up-to-date, there is not systematic evaluation of its snowfall detectability at regional and global scale. Validation and evaluation of CPR's capability of snowfall detection is still needed in satellite precipitation communities. The NOAA/NSSL ground radar-based National Mosaic and multi-sensor Quantitative Precipitation Estimates (QPE) (NMQ or Q2) provides the high spatiotemporal resolution (1km/5min) 2-dimensional (2D) multi-suites precipitation products as well as 3-dimensional (3D) products. Such high-resolution QPE products offer an ideal alternate to evaluate satellite-based observations and products. NMQ/Q2 has been refined to the new Multi-Radar Multi-Sensor System (MRMS/Q3) since the summer of 2013

In this study, the CloudSat-CPR's detectability of falling snow is systematically evaluated using NMQ-Q2 snowfall products (i.e., solid snowfall precipitation identification) over the CONUS from January 2009 to December 2011. Spatial and temporal matching is applied to obtain the most matched dataset from both observations considering their differences in spatiotemporal resolution. The evaluation results offer the insights into the performance of CPR in detecting falling snow and also demonstrate its great potential in improving the solid precipitation (snowfall) in the mid-high latitude area and high-altitude area (e.g. the Tibetan plateau). A synthetic approach of incorporating the ground-radar-based NMQ products for evaluating and integrating into spaceborne radar observations will be highly expected with the launch of Global Precipitation Measurement in 2014.

II Study Region and Data

2.1 Study Region

The study region is continental United States (CONUS, Figure1). The data are composed of Q2 precipitation rate, Q2 precipitation type, Q2 precipitation phase, Cloudsat/2B-GEOOPROF, Cloudsat/2c-SNOW-PROFILE. Data time spans from January 1st, 2009 to March 26th 2011. The Q2 observations are considered as reference to assess CPR observation.

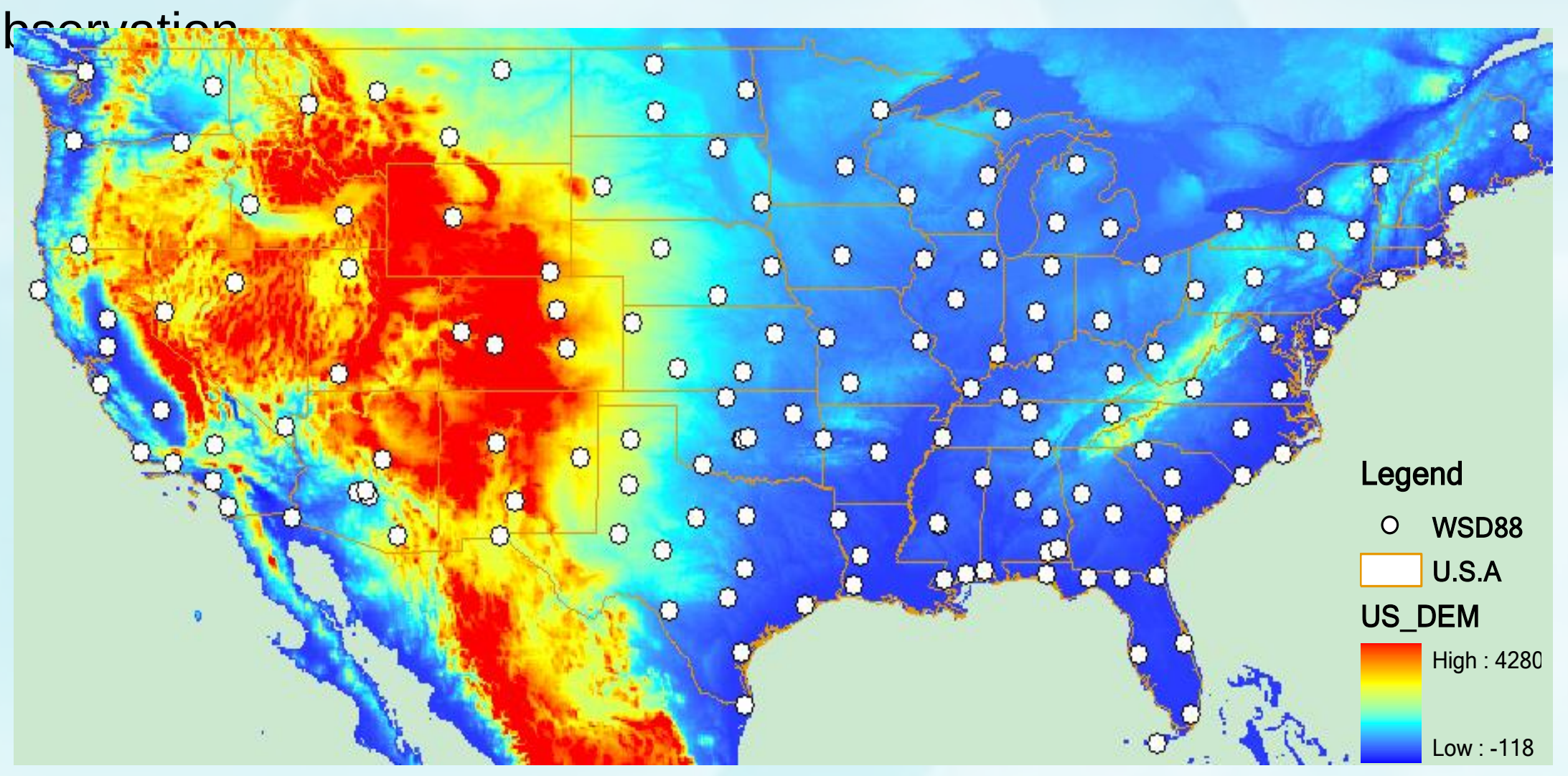


Figure 1 Digital elevation and WSD88 Radar distribution over CONUS.

2.2 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: < -26 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

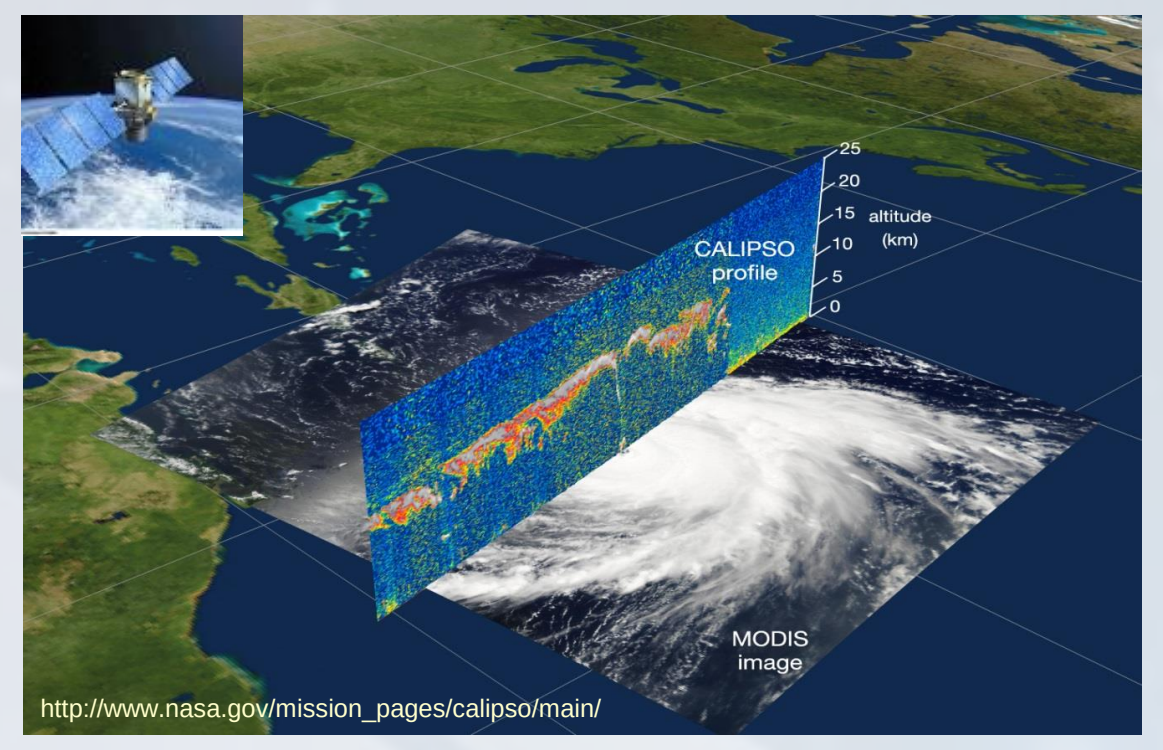


Figure 2 Cloudsat and CPR profile.

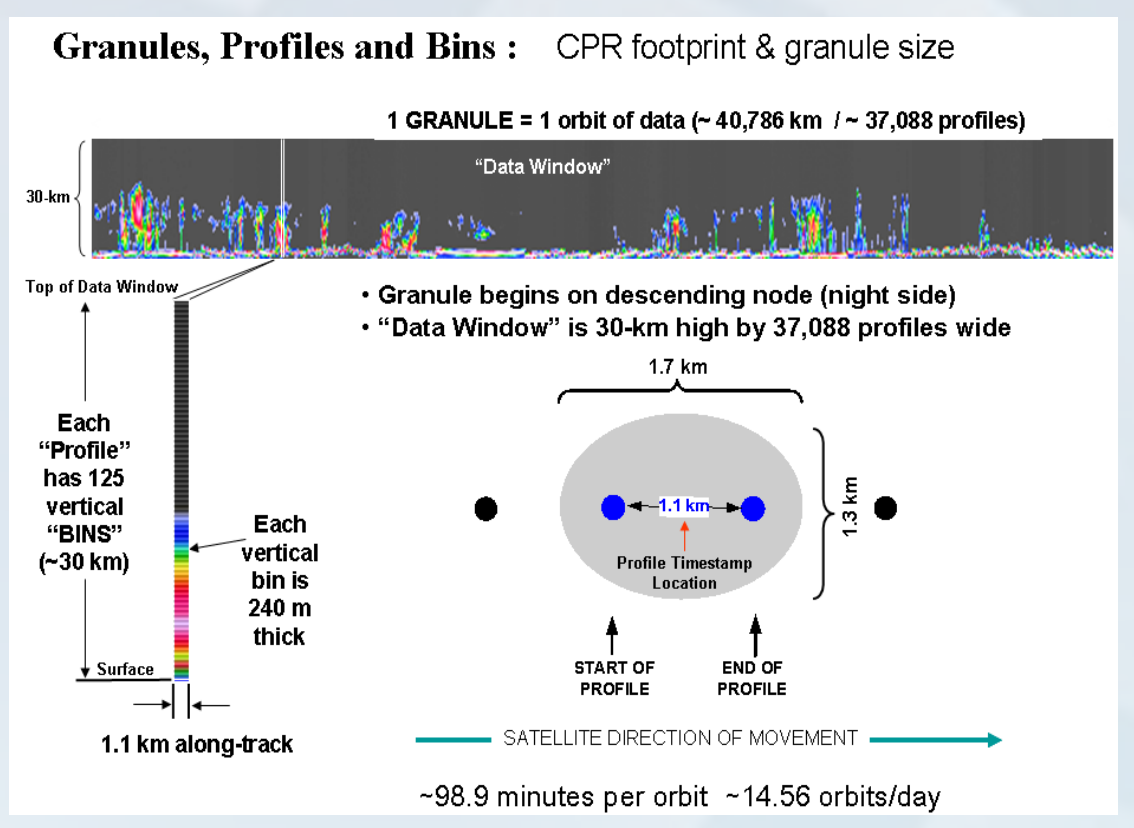


Figure 3 CPR footprint and granuel size.

2.3 MRMS/Q3

MRMS/Q3 is an operational, multi-radar, multi-sensor system built upon the WSR-88D networks with the nationwide dual pol upgrade. It provides real-time, CONUS-wide, high quality (5(2.5) min/1km) radar and precipitation products such as hybrid scan reflectivity, precipitation phase, precipitation type and rate.

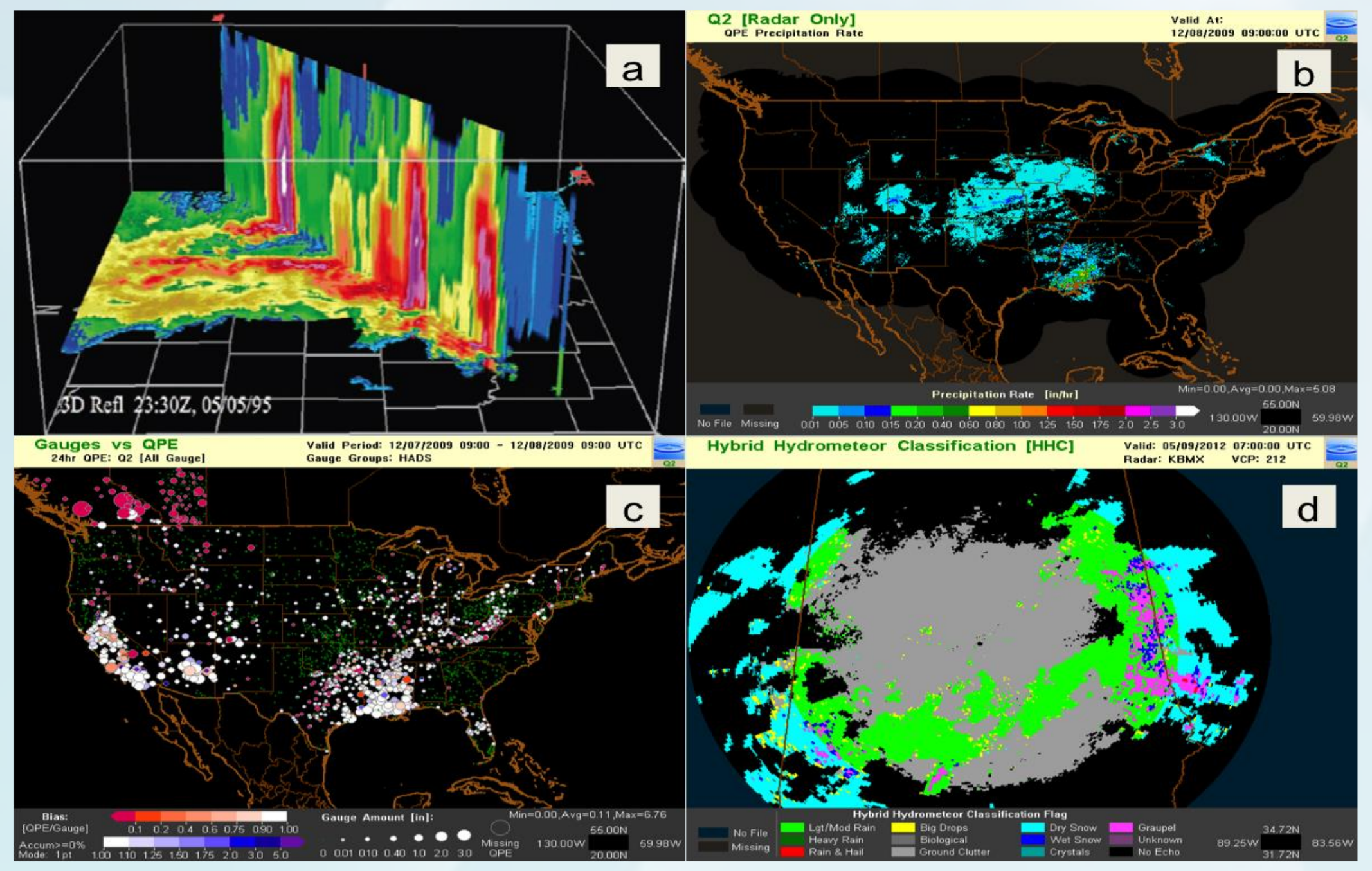
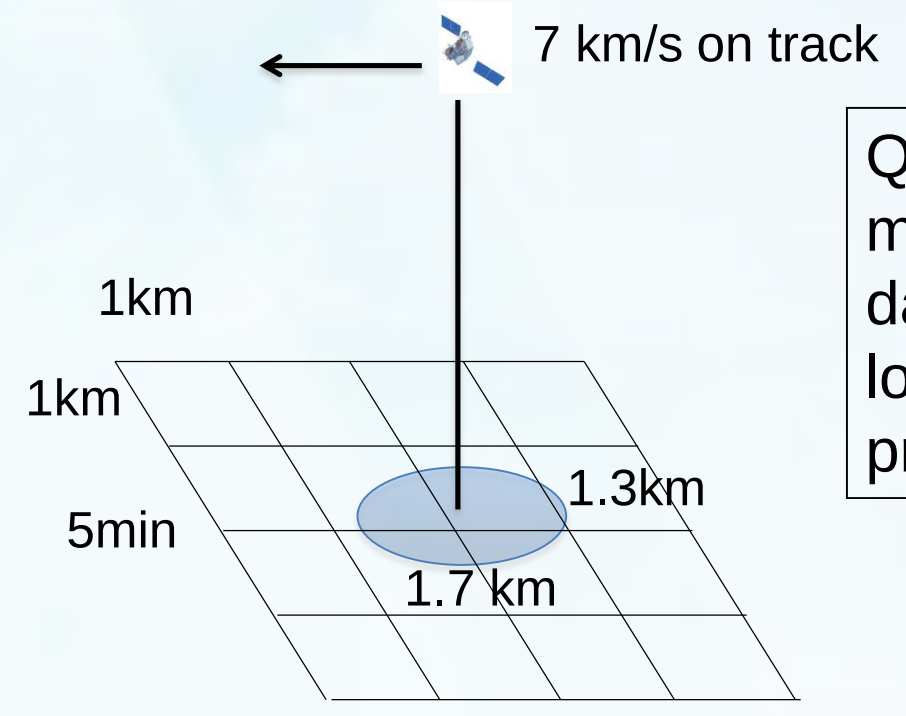


Figure 4 (a) horizontal and vertical cross sections from NMQ-Q2 3D reflectivity mosaic; (b) NMQ-Q2 precipitation rates; (c) spatial bias distribution based on gauge measurements; (d) research product in NMQ-Q3: polarimetric hydrometeor classification.

III Methodology

Time and location matching technology is applied to obtain the instantaneous matching pairs of cloudat vs. Q2 (Figure 5) conditioning on: 1) time difference is less than ±2.5min; 2) The central location of CPR footprints fall in the Q2 grids; 3)both CPR footprints and Q2 have valid records. There is 413202 matching pairs that contains snow information.



Q2 and CloudSat data matching—find the Q2 data with the nearest location and time to each profile of CloudSat.

Figure 5 Matching between Q2 and Cloudsat observation.

IV Results

4.1 Potential deficiency of Cloudsat

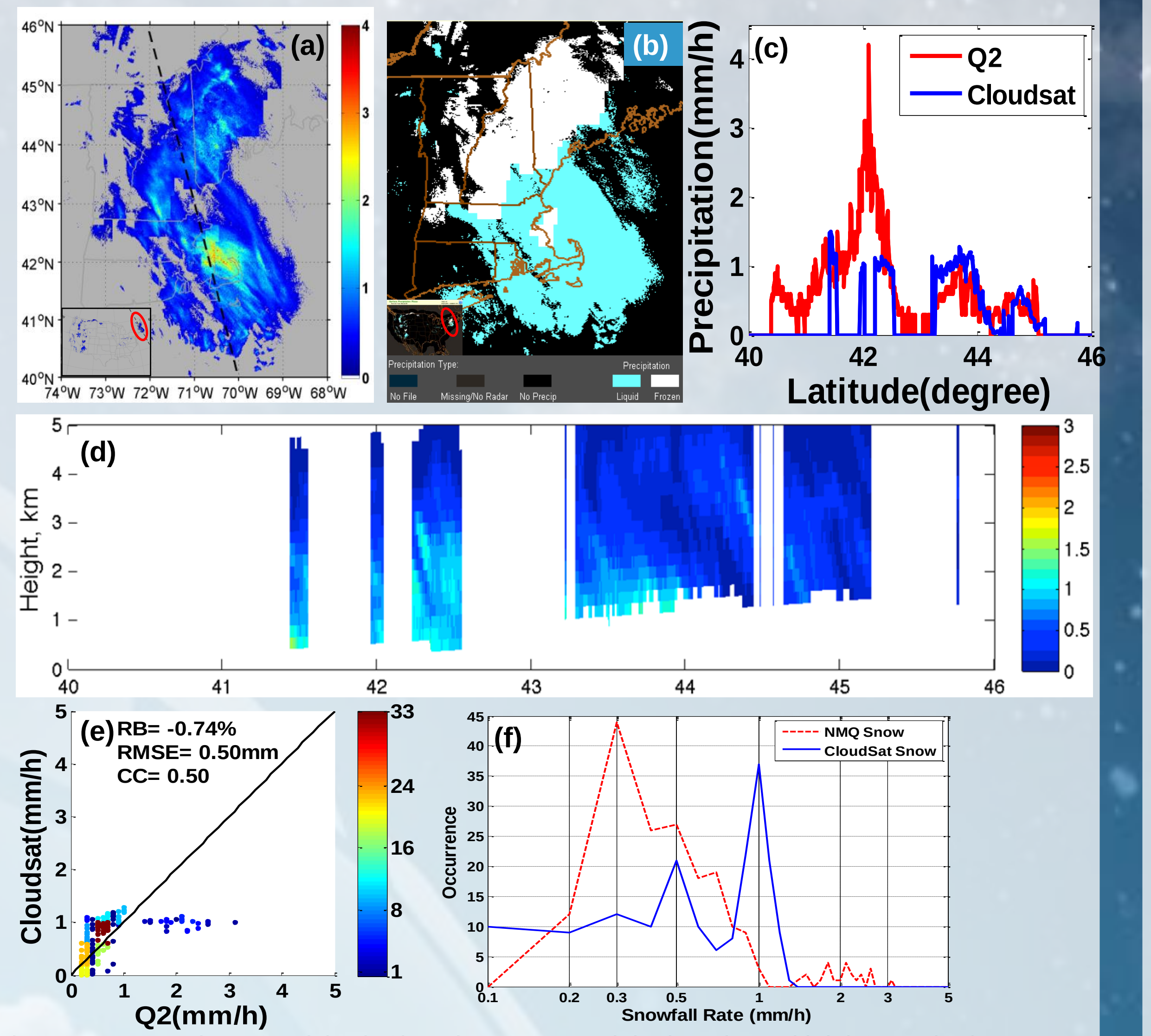


Figure 6 NMQ radar reflectivity (left) and surface precipitation phase (right) for 03/21/2011 snow storm. The reflectivity (~15 dBZ) and classification result clearly show the heavy snowfall region.

The CloudSat snowfall suffered severe attenuation when the snowfall is heavy. In addition, the snowfall detection/retrieval by Cloudsat might be degraded by (1) the limitation in near-surface surveillance and (2) the insufficient correction of precipitation attenuation. Figure 6 shows an 03/21/2011 snow storm in the northeastern CONUS. This case shows the effect of attenuation from heavy snowfall on CloudSat snowfall detection and retrieval. In addition, it is noted that Cloudsat well caught the temporal variation of snowfall as measured by NEXRAD radar although their snowfall retrievals tend to be underestimation. The reason is likely due to the fact that NEXRAD radars have a better capability in low-level atmosphere surveillance at the near radar range (e.g., <50km) while CloudSat may observe the upper level atmosphere than NEXRAD radars. The precipitation attenuation also contributes to the snowfall underestimation.

4.2 Snow detectability by Cloudsat

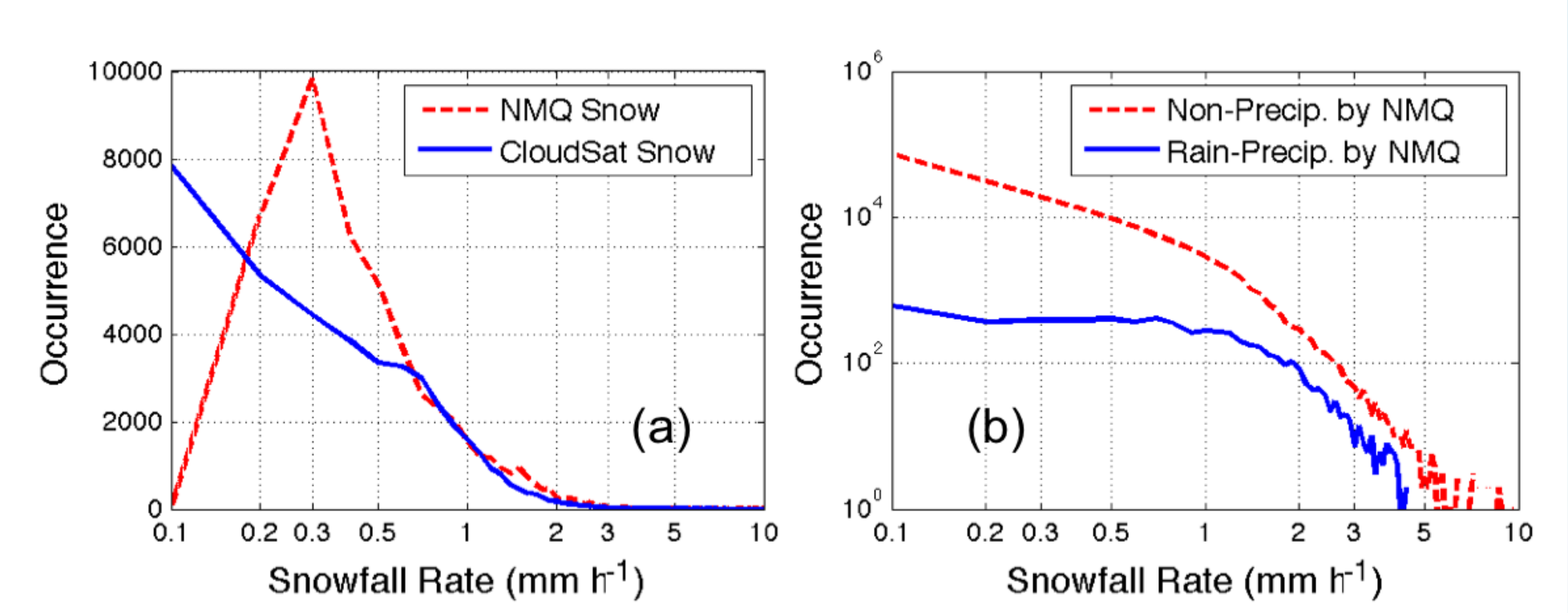


Figure 7 (a) Occurrence of snowfall identified by both NMQ and CloudSat; (b) Occurrence of snowfall identified by CloudSat but classified by NMQ as non-precipitation or rainfall.

The snowfall in the data pairs is mostly light snow. Light, moderate, and heavy snow data account for 85.8% (81.5%), 13.3% (17.3%), and 0.9% (1.6%) for CloudSat (or NMQ), respectively. Figure 7a shows that NMQ has a much fewer occurrence frequency for very light snowfall (e.g., 0.1 mm/h). Figure 7b shows that NMQ outputs non-precipitation while CloudSat detects snowfall. In this scenario, 96.6% (or 89.2%) CloudSat data indicate the light snow less than 1 mm/h (or 0.5 mm/h). There are still small percentages of data for moderate snow (3.2%) and heavy snow (0.19%) that have not been detected by NEXRAD radars.

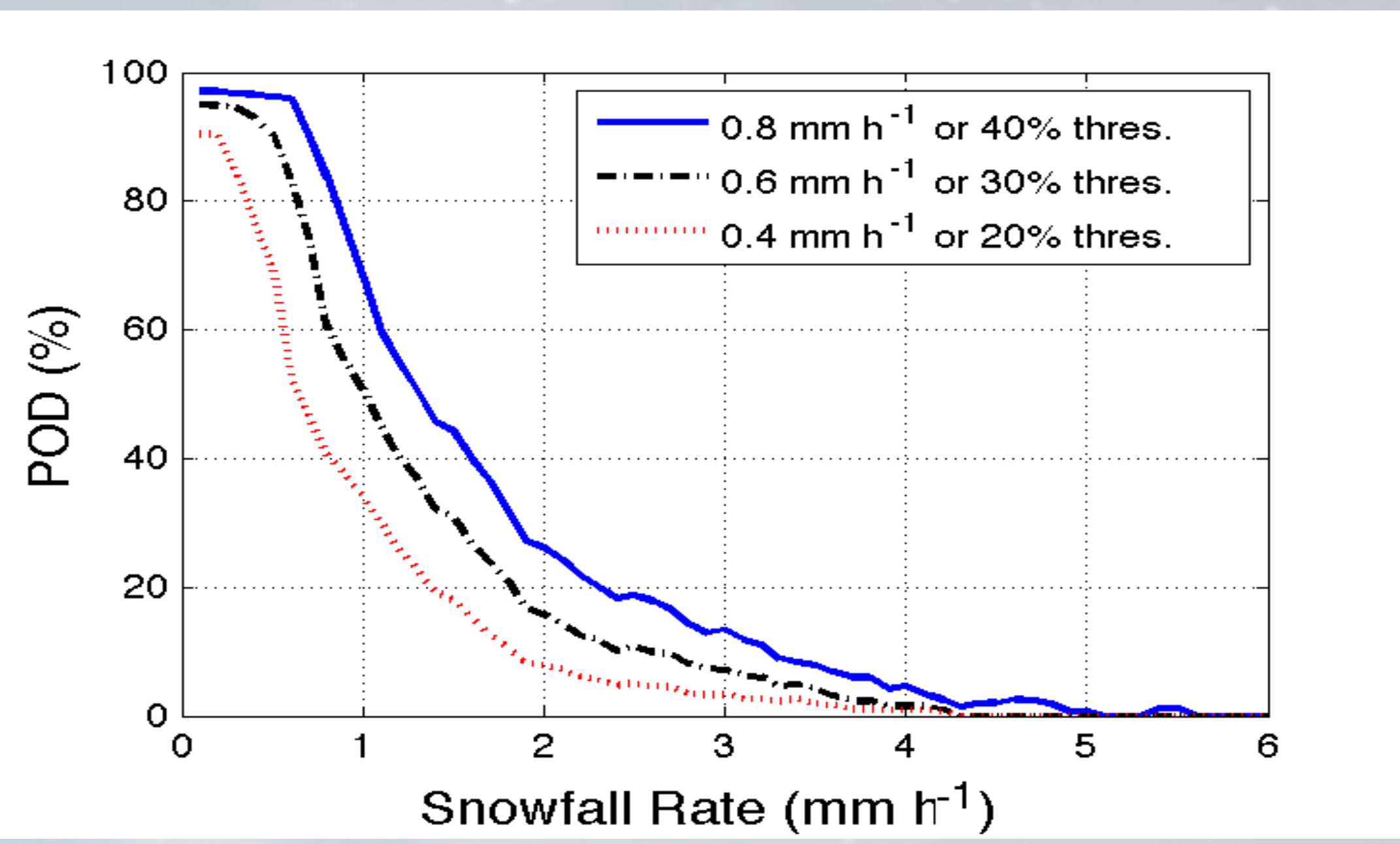


Figure 8 The probability of detection (POD) of snowfall by Cloudsat in terms of snowfall rate. Cloudsat has a successful snowfall detection only when its' snowfall estimation falls into the given ranges of snowfall rate determined by NMQ.

As shown in Figure 8, the probability of detection (POD) of snowfall for CloudSat is quantitatively assessed with the data pairs containing the snowfall identified by NMQ. This indicates that the snowfall attenuation has a major impact on the snowfall detectability of CloudSat. The POD for heavy snow remains very low. The snowfall detectability of CloudSat is generally good for light snow, especially for snowfall rate less than 0.4 mm/h, for which the POD is higher than 95% with less strict thresholds. With the strict threshold indicated by the dotted line, the POD remains more than 80%.

4.3 Attenuation

Fig. 9 shows the estimation difference between CloudSat and NMQ for heavy snow (i.e., rate greater than 2.5mm/h). The data points ("cross" mark) apparently show a linear relation represented by the solid line as Y=-0.952X+0.929. This relation indicates that the attenuation may cause a 55.3% underestimate for snowfall of 2.5 mm/h. The underestimation increases with the snowfall intensity and can reach 90% when snowfall is over 20 mm/h..

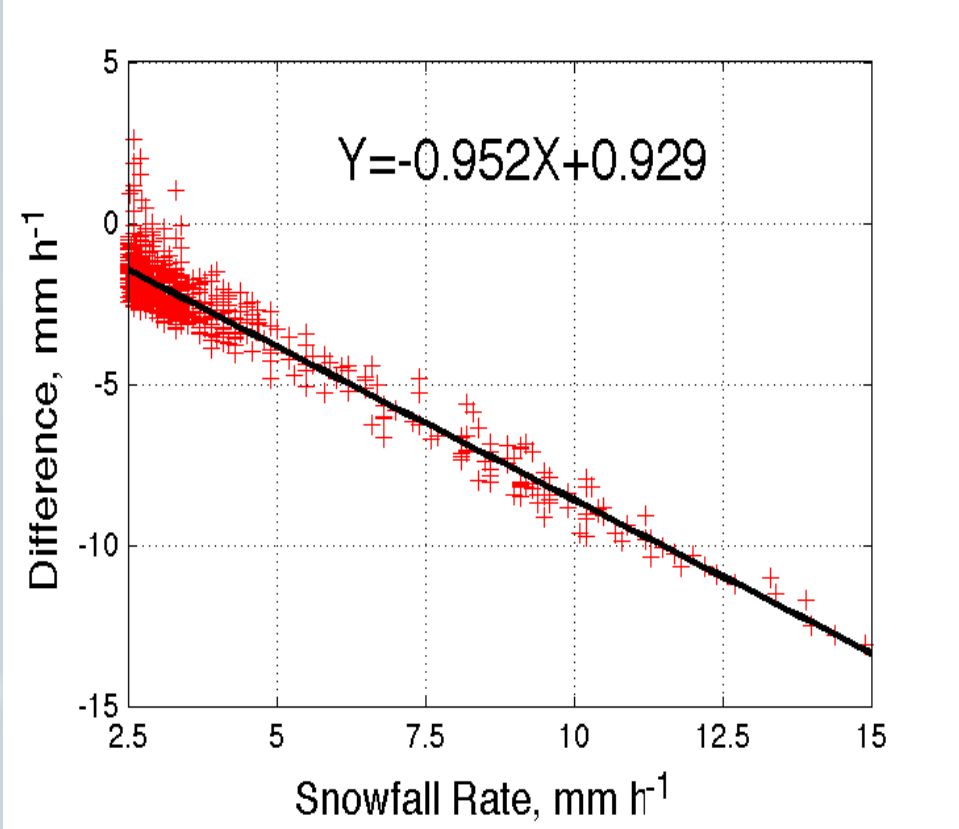


Figure 9 Linear regression of Q2 and Cloudsat observation.

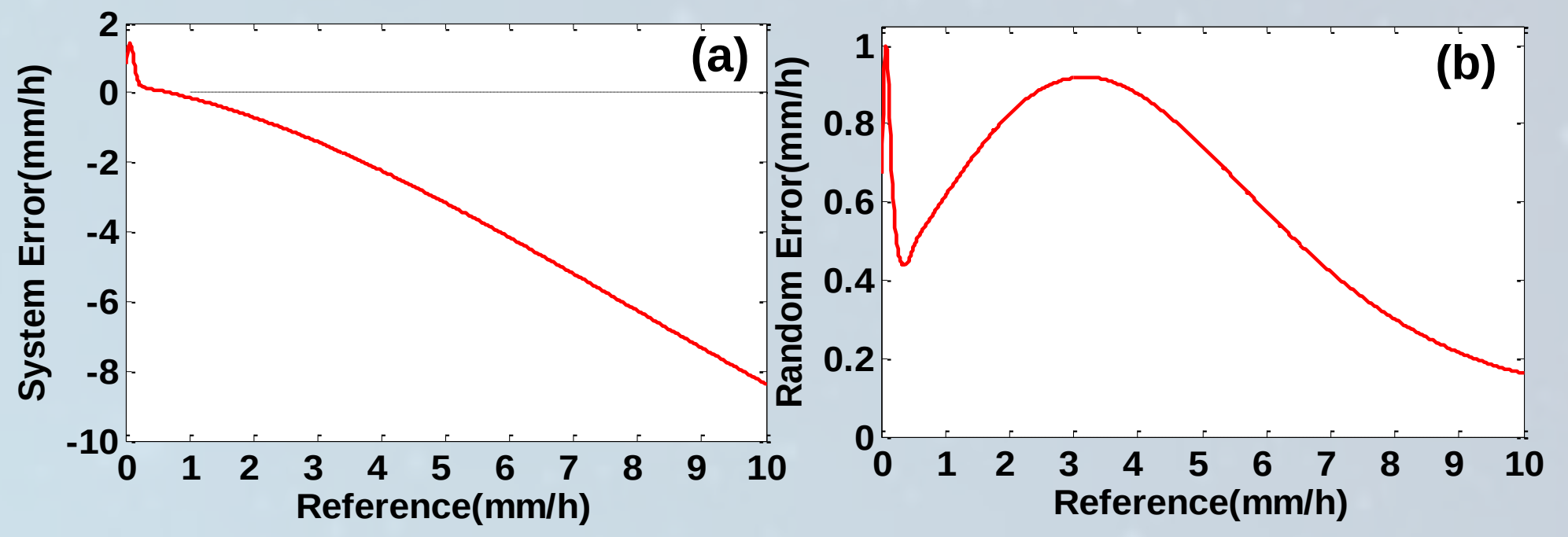


Figure 10 System and random error modeling as a function of the snowfall intensity.

As shown in Figure 10, Cloudsat has positive system error when snowfall rate less than 0.2mm/h and has negative system error when snowfall rate greater than 0.2mm/h. Cloudsat has great uncertainty in light snowfall (<0.2mm/h) and heavy snowfall(2-6mm/h).

V Conclusions

- Cloudsat suffers from severe attenuation in heavy snowfall event.
- The POD of falling snow is generally high (e.g., ~90%) for light snow and decreases with the growth of snowfall intensity
- Cloudsat has high POD for light snowfall(<0.2mm/h)(Figure 7)
- Cloudsat has positive system error when snowfall rate less than 0.2mm/h and has negative system error when snowfall rate greater than 0.2mm/h(Figure 10a).
- Cloudsat has great uncertainty for light snowfall (<0.2mm/h) and heavy snowfall(2-6mm/h) (Figure 10b).

Reference:
1. Qing Cao, Yang Hong, Sheng Chen, Jonathan J. Gourley, Jian Zhang, and P. E. Kirstetter, 2013: Snowfall Detectability Of NASA's CloudSat: The First Cross-Investigation Of Its 2C-SNOW-PROFILE Product and National Multi-sensor Mosaic QPE (NMQ) Snowfall Data. Geophysical Research Letters(Submitted)
2. Sheng Chen, Yang Hong, Qing Cao, Jonathan J. Gourley, P.E. Kirstetter, Jian Zhang and Junjun Hu, 2013: Comprehensive evaluation of Precipitation Estimated from Cloudsat Cloud Profile Radar with an Error Model over Continental Unites States. Journal of Hydrometeorology(submitted)

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