FALLING SNOW ESTIMATES FROM THE GLOBAL PRECIPITATION MEASUREMENT (GPM) MISSION

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ABSTRACT

Retrievals of falling snow from space represent an important data set for understanding the Earth's atmospheric, hydrological, and energy cycles, especially during climate change. Estimates of falling snow must be captured to obtain the true global precipitation water cycle, snowfall accumulations are required for hydrological studies, and without knowledge of the frozen particles in clouds one cannot adequately understand the energy and radiation budgets. While satellite-based remote sensing provides global coverage of falling snow events, the science is relatively new and retrievals are still undergoing development with challenges remaining (e.g., [1], [2], [3]). This work reports on the development and testing of retrieval algorithms for the Global Precipitation Measurement (GPM) mission Core Satellite [4-5], launched February 2014, with a specific focus on meeting GPM Mission requirements for falling snow.

Index Terms— Precipitation, snow, microwave, satellite, validation

1. INTRODUCTION

The GPM Core Observatory was launched 27 February 2014 from Tanagashima Island, Japan. The prime mission lifetime (instrument design life) is 3 years (to May 2017) but fuel is projected to last well beyond that, with the GPM Core Observatory lasting potentially 20+ years if the instruments do not fail. One of GPM's requirements is to measure rain rates from 0.2 to 110 mm/hr and to detect the presence of falling snow.

The cornerstone, or anchor, of the GPM mission is the GPM Core Observatory in a unique 65^{o} non-Sun-synchronous orbit at an altitude of 407 km serving as a physics observatory and a calibration reference to improve precipitation measurements by a constellation of 8 or more dedicated and operational, U.S. and international passive microwave sensors. This orbit allows for highly sophisticated observations of precipitation in the mid-latitudes where a majority of the population lives. GPM's constellation concept sets the GPM Core Observatory spacecraft's orbit to allow for coincident measurements with partner precipitation satellite sensors (as listed in [5]). These coincident measurements help to remove biases in the passive microwave brightness temperatures (and hence the resultant precipitation retrievals) among the various sensors using GMI as the calibrator. This allows for next-generation unified precipitation estimates globally but with fine temporal and spatial scales.

GPM has several retrieval product levels ranging from raw instrument data to instantaneous swath precipitation estimates to gridded and accumulated products and finally to multi-satellite merged products. The latter merged product, called IMERG, is available with a 5-hour latency with temporal resolution of 30 minutes and spatial resolution of 0.1^{o} x 0.1^{o} (~10km x 10km) grid box. Some products have a 1-hour latency for societal applications such as floods, landslides, hurricanes, blizzards, and typhoons and all have late-latency high-quality science products.

2. FALLING SNOW ESTIMATES FROM GPM

Estimates of falling snow from ground and space based sensors have been difficult due to the physical characteristics of snowflakes including their complex shapes, sizes, fall patterns, melting fractions, and densities; and their radiative characteristics including weak falling snow signatures with respect to background (surface, water vapor) signatures for passive sensors over land surfaces [6], differences in near surface snowfall and total column snow amounts, and any polarization effects due to oriented ice particles in clouds [7]. While these challenges are slowly being resolved, knowledge of their impact on expected retrieval results is an important key for understanding falling snow retrieval estimations.

Because of these challenges and because of the early timeline of the development of mission requirements, GPM's documents only require the "detection" of falling snow. Nevertheless, falling snow rates are routinely produced for GPM data. Several processes for the detection of falling snow will be discussed in the IGARSS presentation (herein only one process will be described).

The error bars associated with the snowfall rates have many uncertainties from both the satellite retrievals and from the ground based observations. These will also be described during the presentation and herein this manuscript.

We focus on the GPM Level 2 instantaneous swath retrievals of precipitation from data from both the GPM Microwave Imager (GMI), from the Dual-frequency Precipitation Radar (DPR), and the combined DPR-GMI algorithms. The 166V, 166H, 183±3, and 183±7 GHz channels on the GMI were added to TRMM's 9 channels from 10-89 GHz and designed to observe the smaller precipitation particles associated with light rain and falling snow found in the mid-latitudes. The Ka-band (36 GHz) channel on the DPR is also useful for light rain and falling snow and is sensitive to different particle size distributions.

GMI retrievals are based on a Bayesian framework [8]. The at-launch a priori Bayesian database is generated using proxy satellite data merged with surface measurements (instead of models). In March 2016, the Bayesian database was replaced with the more realistic observational data from the GPM spacecraft radar retrievals and GMI data. It is expected that the observational database will be much more accurate for falling snow detection [9] and retrievals because that database will take full advantage of the 166 and 183 GHz snow-sensitive channels. In March 2017, the algorithms will be further improved when Version 05 is implemented.

Our work has shown that for GMI retrievals knowing if the land surface is snow-covered, or not, can improve the performance of the algorithm. Improvements were made to the algorithm that allow for daily inputs of ancillary snow cover values and also updated Bayesian channel weights for various surface types.

GMI retrievals rely on the 2 meter air temperature (from model data) to determine if frozen snow or liquid rain [15]. DPR retrievals rely on the temperature at the lowest range gate detectable to distinguish between rain versus snow. Note that because of surface clutter issues and the cross track scanning nature of DPR, it cannot sense all the way to the Earth's surface and typically sees only 500 to 2000 m above the surface.

3. DETECTION EFFORTS AND ACHIEVEMENTS

Within 3 weeks after launch, GPM's GMI was able to detect and measure falling snow (Fig. 1 left). When compared to ground data (Fig. 1 right) clearly there are inconsistencies in the patterns and amounts/intensity of the estimated falling snow. Now both the satellite estimates and the ground data will have errors and uncertainties, and so it is a matter of reducing these errors and uncertainties in both the satellite products and the ground radar datasets.

Some of these errors and uncertainties are due to unknowns and variability in the Z-S relationships for the ground based radars, some are due to complications with near surface falling snow (blowing snow, melting, density estimates), some are due to surface temperature estimates or models not able to match the actual surface (or near surface air) temperatures, and some are due to the non-linear and under-constrained relationships between the observations (whether they be satellite or ground-based) and the physical properties of the falling snow.

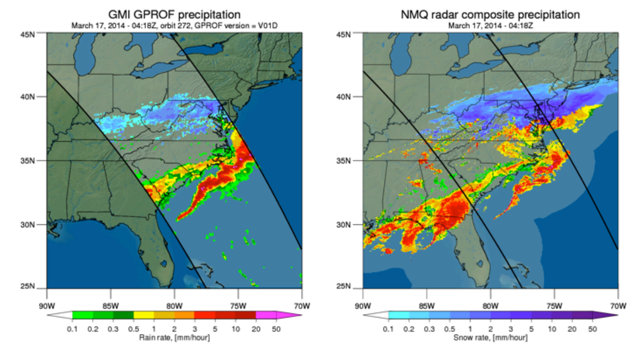

Figure 1: This snow event occurred March 17, 2014 and deposited more than 7" of snow in the Washington, DC metro area. *Left:* GMI retrievals of liquid rain and falling snow. *Right*: Ground measurements from NOAA's National Mosaic & Multi-Sensor QPE (CONUS 3D radar mosaic at 1km resolution) [10].

One major area of validation is proving that we can detect falling snow. Prior publications show that, theoretically, GPM should be able to detect falling snow at rates of > 0.5-1.0 mm/hr (melted rate) or about 1 cm/hr or higher (fluffy rate) [9], [12]. Thus GPM is only expected to be able to estimate moderate and high snow rates due to the instrument capabilities on the GPM Core Observatory. For lighter snow rates, one must turn to CloudSat [13].

One study was to use data from surface observations to validate falling snow events as detected by GPM's Dual-Frequency Precipitation Radar (DPR). Specifically, ground observations (ASOS/AWOS) from Iowa Environment Mesonet database were compared to DPR estimates (Fig. 2). Cases where DPR reported 0 mm h^{-1} whiel the ASOS/AWOS reported non-zero snow rate can be explained by a few factors. The first reason is that there could be missing data at a specific point. Another possible reason is that DPR cannot pick up shallow events as observed in lake effect snow events. It is also possible that there is error in the ground observation. For example, what a human observer sees as light snow could actually just be blowing snow.

The main goal of ASOS/AWOS investigation was achieved: GPM can correctly classify precipitation as snow as shown in Figure 2. It should be noted that GPM does well classifying precipitation when the satellite actually detects it: as a majority of light snow cases and all of moderate snow cases correctly classified. However, this was too small of sample size to make conclusions about heavy snow. This work showed GPM can detect liquid equivalent snowfall rates 0.2 mm h^{-1}. Other detection process studies will be reported during the IGARSS presentation.

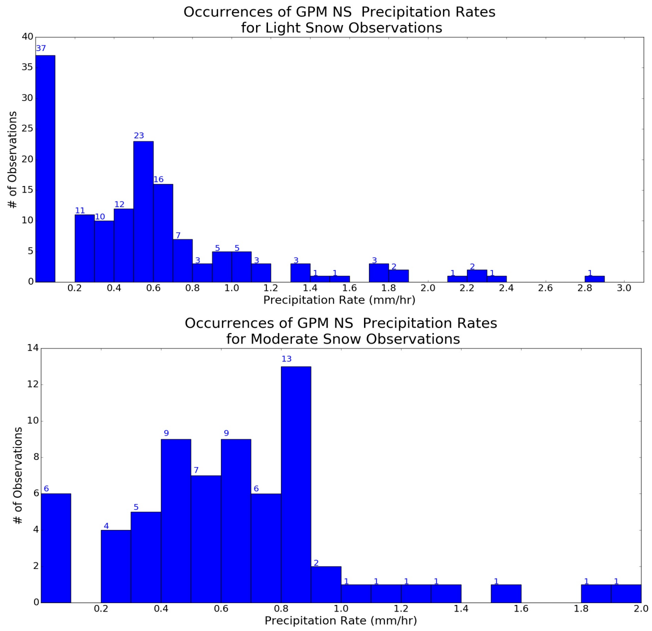

Figure 2: Light and moderate snowfall observations depend on observed visibility. Snowfall intensity increases with increasing precipitation rates. Majority of light snow events around 0.5 mm h^{-1} whereas majority of moderate snow events closer to 0.8 mm h^{-1}. Note that an observation with a precipitation rate greater than 8 mm h^{-1} is not shown on the moderate snow plot.

4. FALLING SNOW RATE RETRIEVALS

Falling snow rate retrievals over North America can be compared as shown in Figure 3 for the GMI and DPR estimates (the Combined DPR+GMI estimates are similar to the DPR estimates but with slightly lower snow rate magnitudes. One can easily see that the GMI estimates much less snow over the Bay of Alaska (and ocean overall) than the DPR or combined. This is likely due to the differences in the retrieval processes. DPR is likely classifying the precipitation as snow higher in the atmosphere (500-2000m) where DPR detects the presence of precipitation whereas GMI uses the 2 m air temperature (which as one can imagine, may be warmer than freezing above the warmer ocean surface.

To test the theory that the problem lies in the differences in the algorithm processes between DPR and GMI, the DPR retrievals were re-run using the 2 m air temperature algorithm [15] to indicate liquid rain versus falling snow. The results of that test are shown in Figure 4. Clearly, these DPR falling snow retrievals are much closer to the GMI results. This does not necessarily mean that the GMI approach is better than the DPR approach since there are instrumentation and algorithm limitations and advantages for both DPR and GMI. The truth lies between the two approaches.

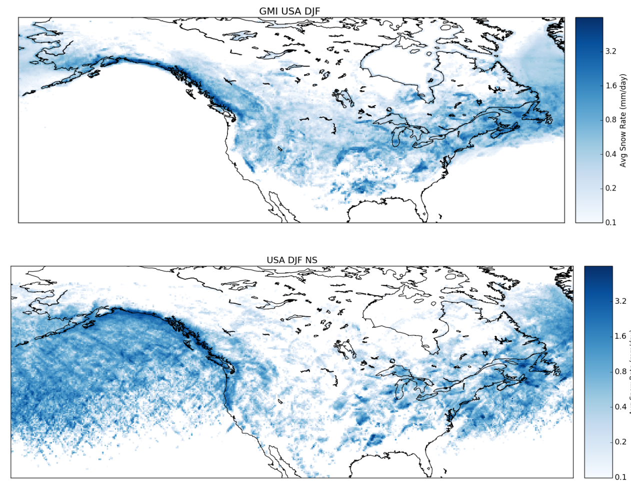

Figure 3: Average snow rates for two years of GMI (top) and DPR (bottom) data. March 2014-February 2016.

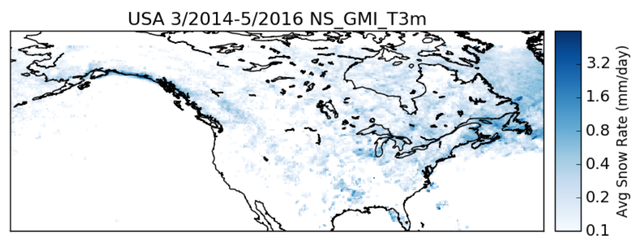

Figure 4: Average snow rates for two years of DPR data using the GMI approach to indicate frozen precipitation versus liquid precipitation. March 2014-February 2016.

5. RESULTS

Falling snow validation efforts are underway as reprocessed and improved algorithms were released in early 2016 and Version 05 will be released in sprig 2017. Prior to this new retrieval algorithm, the falling snow estimates were unreliable. The validation focus was on snow in the US where relatively robust ground data exists. In addition, data from pre-launch GPM falling snow field campaigns [14] will be used if possible. Validation comparisons will be made for falling snow patterns, extent, intensity (or more likely the amount in the near surface levels since intensity is very much dependent on snowflake density and fall rate which are not easily available to the satellite (and for limited for ground based sites).

Accumulated snow amounts will also be used as part of the validation. It is likely that, for now, mountainous terrain or areas where melting snow might occur, that validation will be rather uncertain. Indeed, falling snow estimates and validation are about

50 years behind (and 10 times more complex) than falling liquid rain estimates.

5. CONCLUSIONS

The GPM mission is well on its way to providing essential data on precipitation (rain and snow) from micro to local to global scales via providing precipitation particle size distributions internal to the cloud, 5-15 km estimates of regional precipitation and merged global precipitation. Once TRMM data is recalibrated to the high quality standards of GPM (and as GPM continues to operate), TRMM and GPM together, with partner data) can provide a 25-30+ year record of global precipitation. Scientists and hazard decision makers all over the world value GPM's data.

6. REFERENCES

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