# PERFORMANCE OF THE FALLING SNOW RETRIEVAL ALGORITHMS FOR 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.

*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 and estimate falling snow.

The cornerstone, or anchor, of the GPM mission is the GPM Core Observatory in a unique 65° non-Sunsynchronous 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 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 5hour latency with temporal resolution of 30 minutes and spatial resolution of  $0.1^{\circ} \times 0.1^{\circ}$  (~10km x 10km) grid box [Fig. 1]. Some products have a 1-hour latency for societal applications such as floods, landslides, hurricanes, blizzards, and typhoons and all have latelatency high-quality science products.



Figure 1: The multi-satellite merged product called IMERG on 01/01/2016 at 00UTC. Note the snow estimates in blue to purple colors.

## 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.

Herein we focus on the GPM Microwave Imager (GMI) retrievals of falling snow. The 166V, 166H,  $183\pm3$ , and  $183\pm7$  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.

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 will be 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.

Furthermore, much retrieval algorithm work has been done to improve GPM retrievals over land. The Bayesian framework for GMI retrievals is dependent on the a priori database used in the algorithm and how profiles are selected from that database. Thus, a land classification sorts land surfaces into ~15 different categories for surface-specific databases (radiometer brightness temperatures are quite dependent on surface characteristics). In addition, our work has shown that 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.

#### **3. VALIDATION EFFORTS AND ACHIEVEMENTS**

Within 3 weeks after launch, GPM's GMI was able to detect and measure falling snow (Fig. 2 left). When compared to ground data (Fig. 2 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 2: 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].

Validation efforts compare GPM satellite data to similar measurements from the national network (Fig. 4) of operational weather radars [11]. The goal of this Validation Network (VN) is to identify and resolve significant discrepancies between the US national network of ground radar observations and satellite observations. In addition, NOAA's Multiple Radar Multiple Sensor (MRMS) system [10] combines data streams from multiple radars, satellites, surface observations, upper air observations, lightning reports, rain gauges and numerical weather prediction models to produce a suite of products every two minutes at a resolution of 1km and with 31 vertical levels. Both the VN and MRMS data include shortfalls, errors and uncertainties (as listed above), especially for falling snow.

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 the CloudSat spacecraft [13].

# 4. RESULTS

Falling snow validation efforts are underway as reprocessed and improved algorithms are being released in early 2016. Prior to this new retrieval algorithm, the falling snow estimates were unreliable. The validation focus will be on snow in the US where 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. Falling snow estimates are in the process of being improved and validated as reported in the IGARSS 2016 presentation. Our presented work will examine both the detectability of falling snow and the accuracy of falling snow rates for GPM.

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