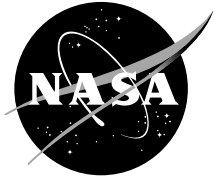# Global Precipitation Measurement - Report 7 Bridging from TRMM to GPM to 3-Hourly Precipitation Estimates

J.M. Shepherd, E.A. Smith
W. J. Adams

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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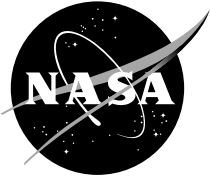
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J. Marshall Shepherd and Eric A. Smith, Lead Authors
Goddard Space Flight Center, Greenbelt, Maryland

Eric A. Smith and W. James Adams, Editors
NASA Goddard Space Flight Center, Greenbelt MD

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1.0 Introduction

Historically, multi-decadal measurements of precipitation from surface-based rain gauges have been available over continents. However, oceans remained largely unobserved prior to the beginning of the satellite era. Only after the launch of the first Defense Meteorological Satellite Program (DMSP) satellite in 1987 carrying a well-calibrated and multi-frequency passive microwave radiometer called Special Sensor Microwave/ Imager (SSM/I), have systematic and accurate precipitation measurements over oceans become available on a regular basis. See Smith et al. (1994, 1998). Recognizing that satellite-based data are a foremost tool for measuring precipitation, NASA initiated a new research program to measure precipitation from space under its Mission to Planet Earth program in the 1990s. As a result, the Tropical Rainfall Measuring Mission (TRMM), a collaborative mission between NASA and NASDA, was launched in 1997 to measure tropical and subtropical rain. See Simpson et al. (1996) and Kummerow et al. (2000). Motivated by the success of TRMM, and recognizing the need for more comprehensive global precipitation measurements, NASA and NASDA have now planned a new mission, i.e., the Global Precipitation Measurement (GPM) mission.

The primary goal of GPM is to extend TRMM's rainfall time series while making substantial improvements in precipitation observations, specifically in terms of measurement accuracy, sampling frequency, Earth coverage, and spatial resolution. This report addresses four fundamental questions related to the transition from current to future global precipitation observations as denoted by the TRMM and GPM eras, respectively.

2.0 Why are 3-Hour Global Precipitation Data Sets Needed?

High-quality estimates of the amount, temporal evolution, and spatial distribution of precipitation are important for a wide range of scientific and applications-related research problems including weather forecasting, flood prediction and control, water resources prediction, hurricane monitoring to name a few. However, unlike measurement of less dynamic and more homogenous meteorological fields such as pressure or even temperature, accurate measurement of precipitation is particularly challenging due to its highly stochastic and rapidly changing nature. It is not uncommon to observe a broad spectrum of precipitation rates within the time frame of 1 to 3 hours at a given location. Furthermore, precipitating systems generally exhibit nonhomogeneous spatial distributions of rain rates over local to regional domains.

For the reasons offered, high temporal and spatial sampling of precipitation is preferred in many research and applications problems. Over land, rain gauges and radars are often appropriate for this purpose but generally lack sufficient coverage. In the case of radar, they suffer from calibration error, topographic blocking, beam broadening, beam overshoot, and non-unique reflectivity-rainrate relationships. Notably, most of the Earth is covered by ocean. This suggests that satellite estimation is required for global coverage. Geosynchronous satellite platforms offer the best temporal coverage but to date have been limited to visible and infrared measuring because of the immense antenna sizes required for microwave measuring. Therefore, microwave radiometers and rain radars flown on low altitude satellites have offered the most accurate retrievals, although they are limited by the intrinsic sampling capabilities intrinsic to low-earth orbits.

By the same token, GPM is striving for a 3-hourly sampling using microwave measurements. But why? The answer lies in the scientific desire to achieve unbiased estimates of rainfall. For example, Morrissey and Janowiak (1996) found that pentad and monthly estimates of rainfall introduces temporal sub-sampling uncertainties that

introduce conditional bias which can cause over-estimation or under-estimation of precipitation depending upon the ambient precipitation intensity. For a 3-hourly sampling scheme, the bias is close to zero but increases markedly for a 12-hour sampling scheme. Li et al. (1996) demonstrated that the start-up time of a sampling scheme is as important as the sampling scheme itself, due to bias introduced by the diurnal cycle of precipitation. For arbitrary start-up times, they found a minimal bias for a 3-hourly sampling scheme relative to a 12-hourly scheme. Soman et al. (1995) found similar results using Darwin radar data. In light of these findings and others, 3-hourly sampling is a reasonable and actually an attainable goal with today's and the near future's mix of satellite assets.

Precipitation and the associated latent heating play vital roles in controlling the Earth's general circulation which leads to the variations in weather systems and climate processes. In addition, atmospheric processes are intricately linked to hydrologic, oceanic, and land surface processes through precipitation fluxes. NASA and other agencies seek to evolve a robust observing system to determine the Earth system's variability, forcing, responses, change consequences, and likelihood of predictability. So the measurement of precipitation at temporal and spatial scales concomitant with the actual scales of rain production, sorting, distribution, and fallout becomes essential. By establishing measuring requirements that adhere closer and closer to the cloud macrophysical and microphysical scales at which rain is produced is sure to lead to a better understanding of the 4-dimensional life cycles of precipitating systems. In each area, improved understanding translates to improved climate predictions, weather predictions, and hydrometeorological predictions, which helps serves a broad spectrum of societal applications including agriculture, water resources, health, and public communications.

3.0 Why are 3-Hour Rain Estimation Techniques from TRMM Insufficient?

Adler et al. (2000) are currently using a combination of TRMM and geosynchronous Infrared IR (geo-IR) data to provide 3-hourly estimates of precipitation over 50°N-50°S using an approach based on TRMM post-realtime multi-satellite algorithm 3B42. This product initially uses a combination of TRMM estimates and TRMM-calibrated SSM/I estimates. However, because the low Earth orbit sampling properties of TRMM and DMSP satellites leave spatial gaps at the 3-hour time resolution, microwave-calibrated geo-IR estimates are used to fill the gaps. The merged 3-hour product is typically available with a 3-hour data latency (i.e., delay after realtime). These current TRMM-calibrated 3-hour estimates are now being tested by the TRMM Science and Data Information System (TSDIS), while the associated computer codes are being modified to implement future microwave data streams emanating from Advanced Microwave Sounding Unit (AMSU) and Advanced Microwave Sounding Radiometer (AMSR) instruments.

Clearly, the evolving era of merged multiple-satellite rain estimates underpinned by a reliable calibrating source such as TRMM represents a valuable testbed for developing the GPM constellation mission's data processing system. Yet, problems still loom. For example, TRMM is projected to provide data only through the 2003-2004 time frame. Also, the EOS era constellation will not achieve consistent global coverage or 3-hour time resolution at a sufficient frequency. Moreover, there are genuine scientific concerns with the current techniques used to estimate precipitation from geo-IR data streams in order to achieve high temporal resolution.

4.0 What are Drawbacks of IR-Based Rain Estimation Techniques?

The current TRMM approach to achieve high temporal precipitation sampling, i.e., to estimate 3-hourly rainfall maps, employs geo-IR measurements to fill temporal gaps not sampled by the TRMM satellite. While the robust temporal coverage provided by geosynchronous infrared data has been an unchallenged asset of the world's geostationary satellite network, geo-IR retrieval algorithms have been problematic since the first attempts to use them began in the mid 1970s. The major shortcoming is that they suffer from underlying weak statistical relationships between IR radiances at cloud top (generally represented as equivalent black body temperatures or (EBBTs)) and rainfall at the surface. In the recent reviews of Bellerby et al. (2000) and Ba and Gruber (2001) concerning several well-established geo-IR techniques used in the operational community, these problems are underscored.

The standard assumption behind all such techniques is that cold cloud tops (e.g., cloud EBBTs below some threshold) are directly associated with precipitating cumulonimbus clouds. This is why geo-IR techniques largely perform as convective precipitation algorithms, albeit several attempts have been made with marginal success to classify cold clouds into convective or stratiform categories according to EBBT texture signatures. Nonetheless, high-level cirrus and other non-precipitating clouds often exhibit cloud-top temperatures below the screening threshold, which then creates false precipitation areas. This results in inherent overestimation of rainfall when cirrus and other cold cloud tops are present. If the estimates are later bias-adjusted according to a microwave algorithm, the procedure which the TRMM algorithm incorporates, the average rain rates applied to the true raining areas must be underestimated to compensate for assigning positive rain rates to the false areas.

Geo-IR techniques are also generally found to underestimate rainfall from stratocumulus clouds, which are ubiquitous in mid-latitude coastal regions, because much of the drizzle regions of the stratocumulus decks have cloud top temperatures warmer than the precipitation cutoff. In the case of altostratus and multi-layered cloud systems, geo-IR-techniques exhibit variable performance according to the ambient thermal conditions. Further difficulties are introduced by the inability of these techniques to sense any direct information on rainfall occurring below the cloud bases of precipitating clouds as Bellerby et al. (2000) has discussed. In addition, geo-IR techniques must apply significant downscale averaging to achieve any meaningful accuracy.

For these reasons and other more subtle problems, 3-hourly estimates using geo-IR calibration and merging techniques are susceptible to significant uncertainties. In general, such techniques possess bias and precision uncertainties for 3-hour estimates exceeding 20 percent and 50 percent, respectively, with little room to improve because there are no meaningful physics tools to exploit in making the estimates. This is the foremost reason why a microwave constellation system is so appealing to precipitation users, and why the GPM mission offers such a compelling research program to scientific disciplines affected by the global water cycle.

5.0 How will GPM Improve Frequent Global Rain Estimates?

GPM represents the next generation of space-based precipitation estimation and builds upon valuable knowledge and experience gained during the TRMM era. In the GPM era, up to nine constellation satellites will provide more accurate and physically-based microwave precipitation estimates on a global basis with ~5 percent bias and ~20 percent precision uncertainty for 3-hourly products. Such direct measurements of precipitation and hydrometeor structure mitigate errors introduced by non-precipitating clouds, diverse

macro cloud physics, and varying precipitation types. GPM's novel Dual Frequency Precipitation Radar (DPR) and its up to nine passive microwave radiometers (PMRs) on the constellation fleet provide an excellent means to cross-calibrate similar precipitation-measuring instruments in space and on the ground (e.g., from carefully-instrumented ground validation sites). Thus, GPM will enable improved measurements of light rain, warm rain, snow, and other modes of frozen precipitation. The DPR will better detect explicit precipitation microphysics than was possible from the single frequency TRMM Precipitation Radar (PR), thereby leading to improvements in latent heating algorithms and mass spectra properties associated with the highly varying drop size distribution (DSD). See Figure 1.

GPM is also important because from an end-user perspective it will almost seamlessly advance a rainfall product line from the TRMM era in which acquiring the first complete and accurate tropical climatology of rainfall was the major objective, to an era where high frequency sampling, complete global coverage, microphysical variability, and thorough error quantification will become a reality. All of these new capabilities are needed for a significant improvement in our understanding of the global water and energy cycle and in detecting actual accelerations or decelerations in the water cycle that are associated with changes in the Earth's climate system, particularly in terms of global temperatures. Furthermore, a broad sector of the applications community will be provided with critical new datasets needed for improving weather forecasting, flood prediction, freshwater resources prediction, agricultural planning, health monitoring and other important applications with bearing on people's lives and livelihoods. Finally, GPM will engage multiple international partnerships consistent with the United Nation's designation of the GPM mission as a centerpiece for peaceful uses of outer space.
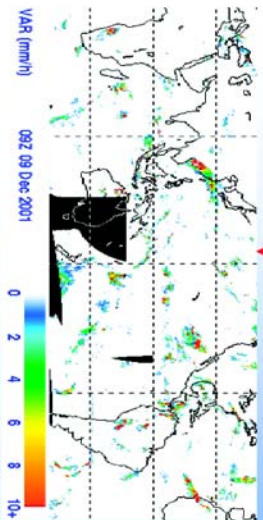
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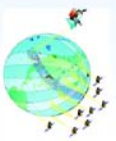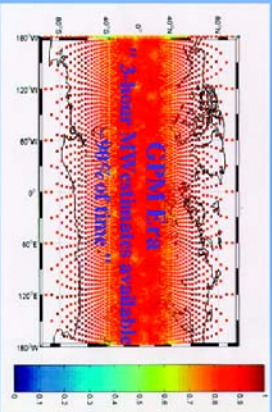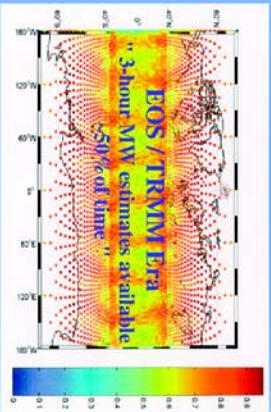
Current Capabilities:
Year 2002-TRMM + 2 SSM/I

HQ (mm/h)

09Z 09 Dec 2001

0 2 4 6 8 10+

VAR (mm/h)

09Z 09 Dec 2001

0 2 4 6 8 10+
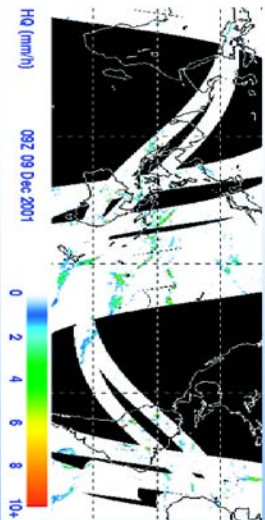
Gap-filling & high time resolution achieved by calibrating & merging lessor-quality infrared (IR) data. IR estimates must be implemented to obtain 3-hourly products -- but known IR problems with non-precipitating cumulus, stratus, & cirrus lead to bias & precision uncertainties in 3-hour estimates exceeding 20% & 50%, respectively.

Years 2002-2007 TRMM +
EOS Era Satellites
Enables Pre-GPM
Constellation Testbed

EOS /TRMM Era
" 3-hour MW estimates available
<50% of time "

GPM Era
" 3-hour MW estimates available
>90% of time "

Year 2007: How GPM Advances
Current Capabilities?

- Provides more accurate & physically-based global full-microwave rain estimates.

- Generates user-friendly gridded precipitation products (with quantitative error quantification) driven by need of stakeholders -- e.g., climate scientists, weather/hydrometeorological model forecasters, & algorithm developers.

- Enables near global coverage of high quality rain measurements (i.e., ~5% bias & ~20% precision uncertainties for 3-hour products).

- Improves measurement of frozen precipitation & snow, as well as light & warm rain.

- Detects explicit precipitation microphysics using first dual-frequency space Radar.

- Allows seamless extension from TRMM of precipitation climatologies for assessing global water cycle variations & climate changes.

- Includes pre-launch assessment of needs of broad applications communities including those of freshwater resources, agriculture, health, emergency management, & public communications.

- Engages multiple international partnerships consistent with recent U.N. designation of GPM mission for peaceful uses of space.

Figure 1: Schematic of how bridging process from TRMM to GPM missions will improve in 3-hour rain products.

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