# 7A.8 EVALUATING UNCERTAINTIES IN GPM OCEANIC PRECIPITATION RETRIEVALS

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## 1. INTRODUCTION

The Global Precipitation Mission (GPM), planned for launch in 2008, will estimate surface rainfall between 65°S and 65°N latitude using a constellation of meteorological research and operational satellites. The GPM mission is an international research initiative led jointly by NASA and NASDA (Japan) in collaboration with several domestic and international partners. The GPM core satellite, built jointly by NASA and NASDA, will contain a multi-frequency passive microwave radiometer and a dual-frequency precipitation radar.

As part of the planned suite of GPM products, error estimates will accompany the satellite precipitation retrievals to provide increased value and credibility.

GPM ground validation (GV) activities will focus on three primary goals (Yuter et al. 2002):

- *Evaluation* to estimate the quality of satellite precipitation products in terms of systematic and random error and their spatial correlation.
- *Diagnosis* to ascertain the causes of errors within satellite products.
- *Improvement* of satellite products by refinement of some of the physical and scaling assumptions within satellite algorithms, the underlying cloud models, and the underlying radiative transfer calculations.

Errors in satellite products can spring from a number of sources. GV will focus on diagnosing sources of error associated with sensor calibration, algorithm assumptions, and algorithm applicability. An important challenge for GPM is to modify precipitation retrievals designed for the tropics as part of the TRMM satellite program to also apply to midlatitude storms.

## 2. ERROR PRODUCT CUSTOMERS

The primary users of GPM error characterization products include three main customer groups:

1. Forecasters interested in a relative confidence level for the GPM products used to prepare < 12-hr forecasts.
2. Data assimilation specialists interested in quantitative information on relative and estimated absolute error covariances to facilitate use of GPM products in model initialization for > 12-hr forecasts.
3. Climate diagnosticians interested in quantitative information on estimated absolute errors in regional precipitation distribution and in global integrated accumulations on > 1 month time scales.

The relative difficulty of the development of error characterization products increases as the requirements become more quantitative and transition from those related to relative error to estimates of absolute error. Given the diverse requirements of each of the customer groups, it is likely that separate tailored products may need to be developed to address their needs.

## 3. OCEAN VS. LAND

The remote sensing of precipitation by passive microwave and active radar differs over ocean as compared to land. The ocean surface presents a cool, diurnally stable, generally slowly varying temperature background against which the passive microwave emission from precipitation can be clearly discerned. In contrast, land surface temperatures vary considerably as a function of time of day and surface type, presenting a complex background against which emission from precipitation is difficult to identify unambiguously. Passive microwave scattering from ice is used as a proxy for rain to estimate surface rainfall over land. Over ocean both emission and scattering channels are used. For active radar precipitation retrieval, precipitation estimation over land is complicated by the absence of a surface reference to constrain attenuation correction. In mountainous regions, complex terrain limits how close to the surface the radar can observe precipitation which impacts rainfall estimation in mountain valleys. Error estimates over land and ocean will be based on different subsets of the physics within each of the satellite retrieval algorithms. Hence error characterization over land and ocean will require different approaches. Given these fundamental differences, parallel sets of global error characterization algorithms are planned associated with the two NASA GPM GV super sites. NASA's tropical ocean super site will be Kwajalein Atoll in the Marshall Islands, and the midlatitude continental site will be colocated with the DOE ARM site in Oklahoma.

## 4. APPROACH

In order to routinely produce error characteristics over the open ocean, the GPM global ocean validation products will utilize continuous input from the GPM core satellite but cannot be dependent on continuous input from the GPM super site at Kwajalein. For a given day, week, or even month, there may not be sufficient rain at the super site location to make a meaningful

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comparison with the satellite overpasses. Additionally, we cannot expect any one oceanic location to be representative of all other oceanic locations. Rather than extrapolating biases from the super site over thousands of km, we will use GPM core satellite radar data from each oceanic region to estimate error characteristics for microwave retrievals for that region. The Kwajalein super site data and data from focused field measurements in other locations will be used to create a rule-base on how to utilize the GPM core satellite data to yield error products. This rule-base will serve as the basis of the algorithm.

Many previous studies have revealed structural differences in oceanic precipitation among different regions. Two recent studies taking very different approaches are Nesbitt et al. (2000) and Trenberth et al. (2000). Nesbitt et al. (2000) used TRMM satellite data to characterize structural differences in terms of low-level radar reflectivity, 85 GHz ice scattering, and lightning. They found that rainfall over oceanic regions was distributed among mesoscale convective systems ($\geq 2000$ km$^2$) with ice scattering and smaller precipitation features with and without detectable ice scattering. Trenberth et al. (2000) used global model output to describe structural differences in terms of the heights of lower-troposphere convergence and upper-troposphere divergence associated with large-scale overturning. They found two dominant modes, the first associated with Hadley, Pacific-Walker, and Atlantic-Walker circulations, and the second associated with relatively shallower but rigorous overturning associated with the tropical eastern Pacific and Atlantic ITCZs. A key question is how structural differences in precipitation from region to region map into differences in error characteristics. The regional differences in typical spatial scales of the precipitation in *x-y* and *x-z* and the GPM precipitation algorithm applicability are some of the factors that can influence regional error characteristics.

### *4.1. Error decomposition*

Automated, objective comparison of spatial patterns within 2-D fields is an emerging discipline. Meteorological applications include numerical model verification, data assimilation, and comparisons among products derived from remote-sensing observations.

Hoffman et al. (1995) decompose the differences between two 2-D fields where one is labeled “estimate” and one “truth” into those related to displacement error, amplitude error, and residual error. Displacement error is represented like a velocity field and is a measure of how much the difference between the patterns can be accounted for by shifting the estimate in space to best fit the truth. Amplitude error is represented similar to a geopotential field and is a measure of how much of the difference between the patterns can be accounted for by changing the amplitude of the displaced estimate field. Both displacement error and amplitude error are required to vary slowly and smoothly with position. Small-scale variability superimposed on the large-scale features falls under residual error in this methodology. Hoffman et al.’s 3-part decomposition is well suited to describe differences in 2-D patterns associated with large-scale meteorological features that evolve slowly in time such as pressure highs and lows, the jet stream, and fronts. An additional benefit of this methodology is that the decomposition of errors can aid in diagnosis of deficiencies in the creation of the “estimate” field. Different types of errors in physical assumptions can preferentially be associated with displacement versus amplitude errors. For example, in numerical models, errors in initial conditions at synoptic scales can lead to both displacement and amplitude errors but are more commonly associated with displacement errors (Hoffman et al. 1995).

Comparisons among model output fields (such as forecast versus initialization) are simplified by their common spatial and time scales. Comparisons among model output and observations or between observation types often involve rescaling one field to match the spatial scale of another. The variability and estimation uncertainty of precipitation-related fields has scale dependencies (Joss and Gori 1978; Zepeda-Arce and Foufoula-Georgiou 2000; Harris et al. 2001; Liu et al. 2002). Tustison et al. (2001) define representativeness (i.e., rescaling) error as the error associated with representing model output or observations at a scale other than their inherent or native scale (e.g., the spatial resolution of the model computations or the field of view or resolution volume of the sensor). This source of error is independent of those associated with the observation and model fields at their native scales. Tustison et al. (2001) compared 2-km hourly rainfall accumulations to accumulations at spatial scales of 4, 8, 16, and 32 km for samples of WSR-88D data from four sites. They found that normalized rescaling error is non-trivial and decreased from ~60% at 4 km to ~50% at 32 km. Based on a multi-year comparison of daily rain gauge accumulations versus radar-derived accumulations for 1 km$^2$ areas in Switzerland, (J. Joss, personal communication, 2001) estimated a representativeness error for an individual rain gauge of ~100%.

When fields do not have the same native scale and are not properly rescaled to a common grid, the difference between the “truth” and “estimate” fields is the sum of errors associated with the rescaling error and the estimation (or modeling) error. These multiple sources of error are often attributed solely to estimation error, which can lead to poor inferences about the nature and sources of errors. Given the scale dependence of many precipitation characteristics, it may often be the case that the rescaling errors are larger in magnitude than either estimation or observation errors.

Our plan for both the diagnosis products and the error characterization products will be to decompose the sources of error into the four categories described above: displacement error, amplitude error, rescaling error, and the remaining residual error.

### *4.2 Evaluation of intermediate and final products*

Satellite precipitation validation has historically involved comparison of surface rain rates, the final derived product in the chain of satellite data processing (Ebert et al. 1996; Smith et al. 1998; Adler et al. 2001). Surface-based in situ sensors such as rain gauges and disdrometers can measure rainfall at the surface over small areas < 1 $m^2$ that are essentially point measurements in comparison to the instrument field of views (IFOVs) of the satellite sensors. We currently have no satellite or ground-based remote sensor that can directly measure areal surface rainfall (i.e., areal rainfall within 10 m of the surface). Passive microwave instruments measure the integrated emission and scattering of the column of hydrometeors. Radars obtain volumetric measurements of the column of hydrometeors but earth curvature, refraction by the atmosphere, and sensor characteristics limit their ability to make measurements very close to the surface. In passive microwave retrievals, the integrated column information is combined with physical assumptions about the vertical column of hydrometeors as input to a transformation to surface rain rate. In radar retrievals, the basic concept is similar except that usually the lowest altitude radar measurement is used as input to a transformation rather than a column-integrated value.

A complementary validation approach is to examine and evaluate intermediate products in the chain of satellite data processing. In order to diagnose potential sources of error, the numerous physical assumptions in the satellite retrieval need to be partitioned such that the intermediate products examined incorporate some, but not all of the assumptions associated with the final products. Vertically integrated parameters are clear choices as intermediate products for evaluation.

Column-integrated liquid water content (LWC) has particular utility as an intermediate product over the ocean. The absorption of microwave radiation is a function of the depth of the rain layer and the volume absorption coefficient, which is in turn a function of the mixing ratios of rain, cloud droplets, and water vapor. Over the ocean, the emission of absorbed radiation by liquid water can be detected by the lower frequency passive microwave emission channels < 22 GHz. Volumetric liquid water content is a common output of numerical models and can also be derived from radar reflectivity data though there is more uncertainty in the *Z-LWC* translation than the *Z-R* translation (Hagen and Yuter 2002; Heymsfield et al. 2002). The mean volume diameter of rain drops ($D_o$), proposed as a volumetric product for the portion of the GPM core satellite swath with dual-frequency radar coverage, is another parameter that can be used to estimate LWC. Additionally, for comparisons with surface-based polarimetric radars, LWC can be estimated from differential propagation phase polarization parameters (Bringi and Chandrasekar 2001). Volumetric LWC from models and radars would need to be appropriately scaled (see Section 4.1) and column integrated to compare to the passive microwave estimates. Column-integrated intermediate products would provide a basis of evaluation and diagnosis that focuses on the brightness temperature inputs and physical assumptions within radiative transfer calculations related to surface reflection and emission (Smith et al. 2002), beam-filling (Kummerow et al. 1998), and microphysics (Tesmer and Wilheit 1998).

## 5. DATA FLOW AND PROTOTYPE ERROR CHARACTERIZATION PRODUCT

The top-level data flow for the GPM global and local site ocean validation product algorithms is shown in Figure 1. The bottom left of the figure shows the Kwajalein super site and focused measurement (FM) activities. For TRMM, the data flow has consisted of satellite overpass products and observations from Kwajalein coming in, and a variety of GV-site products including rain maps, convective-stratiform maps, and CFADs coming out for archival in the NASA Goddard DAAC. For GPM, production of the TRMM-like GV local site products will continue and be augmented by other GV-site products associated with the new dual-polarization capabilities of the Kwajalein S-band radar and new instruments such as multiple frequency radiometers and dual-frequency radars deployed on Kwajalein Atoll. A change in validation strategy for GPM compared to TRMM is that the super sites are not only responsible for site products characterizing the local region but also for global validation products characterizing error characteristics for their precipitation regime - tropical open ocean in the case of Kwajalein.

The global ocean validation product algorithms will be run at Goddard Space Flight Center as part of the GPM satellite data processing. Sensor data from the core satellite is input to the satellite retrieval algorithms to yield a wide array of GPM-internal products and public products. For simplicity, these are described generically as precipitation products showing surface rain rate, passive-microwave-derived vertical profiles of hydrometeors, estimates of $D_o$ in rain drop spectra for GPM dual-frequency radar coverage area, attenuation corrected profiles of reflectivity for the GPM single-frequency radar coverage area, and corrected brightness temperatures for the passive microwave swath. These data are input to the global ocean validation product algorithms. The outputs of the global ocean validation product algorithms are GPM-internal diagnostic products and public error characteristics products.

TRMM measurements over the tropics indicate that on average only 4% of the area between 35°S and 35°N contains precipitation at any given time (J. Kwiatkowski, personal communication 2002). Given the practical constraints of limited daily precipitation upon which to base the error estimates, and the expected regional and seasonal patterns in error characteristics, a temporally and spatially coarse reference map is suggested as a prototype GPM error characterization product. This error characteristic map would be a daily product based on running statistics of data obtained over the last 30 days for areas of ~20° x 20°. The prototype product would initially use TRMM data as a proxy for the GPM core satellite data and is aimed at customer groups 1) and 2) which require error estimates for use in interpreting the current day's set of precipitation retrieval products.

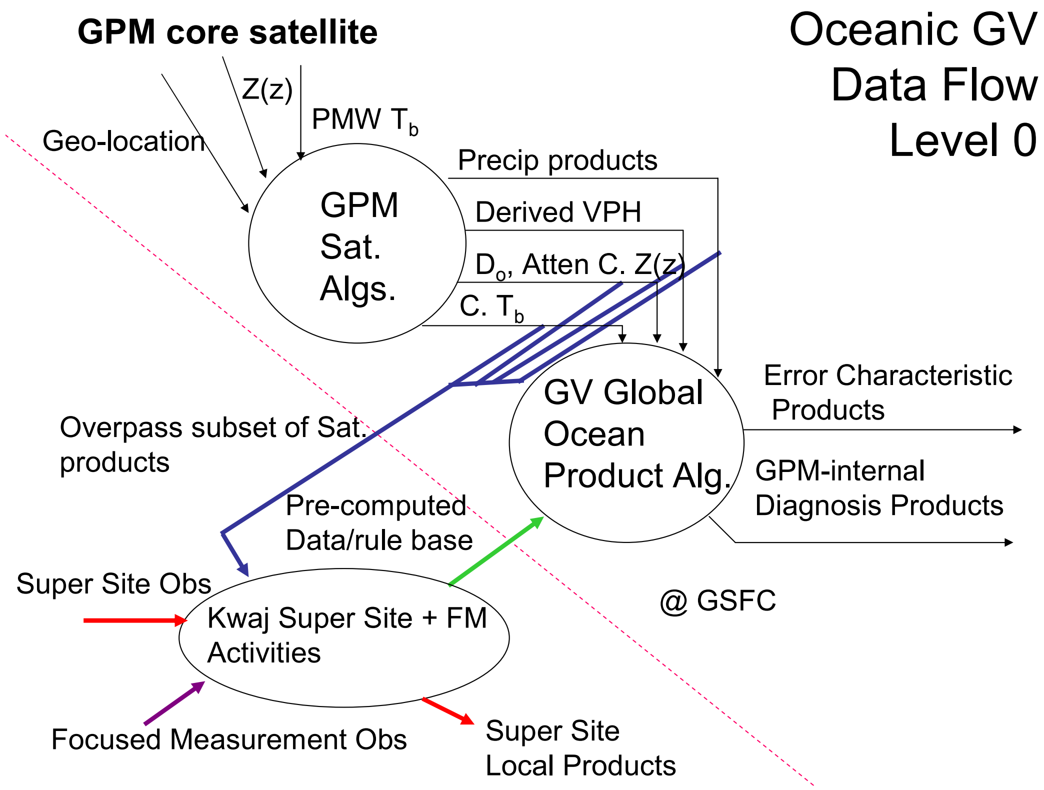

*Figure 1. Top level data flow showing relationships among satellite retrieval algorithms, global ocean validation products, and the Kwajalein super site and focused measurement data streams.*

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