Preparations for Global Precipitation Measurement (GPM) Ground Validation

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Abstract*-The Global Precipitation Measurement (GPM) program is an international partnership led by the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA). GPM will improve climate, weather, and hydro-meteorological forecasts through more frequent and more accurate measurement of precipitation across the globe. This paper describes the concept and the preparations for ground validation within the GPM program. Ground validation (GV) plays a critical role in the program by investigating and quantitatively assessing the errors within the satellite retrievals. These quantitative estimates of retrieval errors will assist the scientific community by bounding the errors within their research products. The two fundamental requirements of the GPM ground validation program are: (1) error characterization of the precipitation retrievals and (2) continual improvement of the satellite retrieval algorithms. These two driving requirements determine the measurements, instrumentation, and location for ground observations. This paper describes GV plans for estimating the systematic and random components of retrieval error and for characterizing the spatial and temporal structure of the error. This paper describes the GPM program for algorithm improvement in which error models are developed and experimentally explored to uncover the physical causes of errors within the retrievals. GPM will ensure that information gained through ground validation is applied to future improvements in the space-borne retrieval algorithms. This paper discusses the potential locations for validation measurement and research, the anticipated contributions of GPM's international partners, and the interaction of ground validation with other GPM program elements.

I. INTRODUCTION: GPM AND GROUND VALIDATION

The Global Precipitation Measurement (GPM) is an international partnership led by the National Aeronautics and Space Administration (NASA) of the United States and the Japanese Aerospace Exploration Agency of Japan (JAXA). The scientific objectives of GPM are to improve predictions of weather and climate and to improve understanding of the Earth's water cycle through accurate, precise, and frequent measurement of precipitation over the globe. These scientific and measurement objectives require microwave remote sensing instrumentation aboard a constellation of spacecraft. At the heart of the constellation is a core spacecraft carrying a Dual-frequency Precipitation Radar (DPR) and a GPM Microwave Imager radiometer (GMI). The core spacecraft will be launched into a 65 degree inclination, 407 km orbit, by a Japanese H-IIA launch vehicle scheduled in 2009. The combined differential frequency radar measurements of the two radars with the high spatial resolution of the multiple GMI passive channels enable the core observations to serve as a transfer standard to the primarily passive sensors of the constellation spacecraft. The unique instrumentation of the core spacecraft will provide the most accurate space-derived precipitation retrievals. The accuracy of the core spacecraft retrievals will be transferred to the observations of the constellation measurements, hence the term, transfer standard. It is anticipated that the constellation will include a European Space Agency GPM (EGPM) spacecraft carrying a high frequency radar and a microwave radiometer suited for the light rain rates and snowfall characteristic of higher latitudes. Another constellation member, the Megha-Tropiques mission, is a joint French/Indian collaboration that will enable excellent sampling of the tropics. Microwave remote sensing instrumentation of the National Polar-orbiting Operational Environmental Satellite System and other international contributions will complete the GPM constellation.

A critical component to GPM's global space-derived objectives is a commensurate, global program of ground validation (GV). GPM is working on a new paradigm for precipitation validation, one in which the validation clients are explicitly recognized and served. As part of the new paradigm, these clients will contribute to the GV system design, its guidance, and its operations. Of particular importance as clients are the precipitation algorithm developers. The GPM precipitation algorithms will be based upon experience from Tropical Rainfall Measuring Mission (TRMM). The TRMM algorithms have evolved through several iterations and are conveniently classified in instrumentation terms: TRMM Microwave Imager (radiometer) algorithm 2A12, Precipitation Radar algorithm 2A25, and Combined instrument algorithm 2B31. For GPM the algorithms will experience new sources of error as the measurements extend beyond the tropics into regions of lighter rain rate and more frequent snowfall. GPM ground validation includes the algorithm developers to enable insight into, and testing of, the sources of retrieval error.

Another important client of ground validation are the researchers assimilating observational precipitation data into their forecasts. The needs of data assimilation are addressed with a GPM ground validation product providing spatial and temporal covariance information on the retrieval errors. Currently, this is a research objective. GPM recognizes the research and planning necessary to bring the covariance product into productive use by the data assimilation community. The ultimate test of improved precipitation data assimilation and ground validation's role will be improved numerical weather forecasting.

II. GPM GROUND VALIDATION OBJECTIVES AND IMPLEMENTATION

A. Ground Validation Objectives

The objectives of the GV program are fourfold: (1) to quantitatively assess the error in space-borne precipitation retrievals, (2) to diagnose the sources of space-borne retrieval error, (3) to suggest modifications to the space-borne algorithms to reduce retrieval error, and (4) quantitative evaluation and improvement of the techniques and algorithms of GV. In the following, the section 'Error Characterization' addresses the first objective, 'Algorithm Improvement' addresses the second two objectives and 'Ground Validation Self-Assessment' addresses the fourth objective.

Error Characterization

The operational activities call for routine delivery of error estimates from validation sites. These error estimates will be derived from comparisons of satellite retrievals and ground based observation and retrievals obtained during spacecraft over-flight events of the site. The delivery of the error estimates will be on a monthly basis and will involve estimates of systematic errors (bias), its uncertainty, and random errors (precision). One method of calculating these estimates is based on a composite retrieval derived from a mean of time and space-coincident satellite and validation products. This composite answer would serve as a proxy for the truth. Variance and bias statistics on the difference from the composite values, representing multiple overpass events, will be calculated and delivered monthly to the Precipitation Processing System (PPS). See Fig. 1 for an illustration of the monthly error report creation and delivery. Significant over-flight discrepancies between the algorithms will be emphasized in the reports along with a pointer to the relevant local measurement data that may help explain the discrepancy.

Inter-comparison statistics from a single validation site are insufficient to provide a measure of precision and bias for extension over the globe. Fixed validation sites are subject to locally applicable bias and variance statistics. The international partnerships within GPM will alleviate site-specific errors by providing a composite of sites with a variety of climatology and geography.

Global error estimation for the satellite retrievals, beyond the immediate vicinity of the validation site, is an area of ongoing research within the GPM GV program. One of the more promising methods is illustrated in Fig. 1 with the actions associated with the 'protocol' deliverable of the GV supersite ('supersite' is defined in a later section of this paper). It is envisioned that each GV supersite will develop a protocol and deliver it to the PPS. The protocol is a means of generating error estimates, including spatial and temporal covariances, anywhere on the globe subject to GPM precipitation retrievals. The method illustrated in Fig. 1 is one based upon regime classification [1] [2] whereby features of the precipitation or atmospheric state define a vector. Precipitation events within a common vector will exhibit similar error characteristics. Through identification of the proper vector and its corresponding error database, error information on the satellite retrieval will be accessed and delivered to the validation client. The protocol flow in Fig. 1 is depicted with a dashed line since its development and refinement will be on a version basis, similar to the space-borne algorithms. Delivery to a validation client is illustrated with a dashed line since the error covariance information will be delivered only upon request. Note that the PPS role is primarily that of executing the protocol and that the protocol will be an autonomous numerical procedure of uniting retrieval data with the error database. Validation clients for the covariance information are researchers involved with climate and weather forecasting. These researchers are interested in assimilating observational precipitation data within their forecasts. Proper assimilation of precipitation data requires a weighting with respect to model errors. Error covariance data as provided by the regime-based protocol method is one way this can be accomplished.

Algorithm Improvement

The second broad objective of ground validation is to improve the accuracy of the retrievals, i.e. algorithm improvement. Algorithm improvement is a continuous activity of GV and necessitates the direct involvement of the algorithm developers in the GV process. The algorithm developers are noted graphically in Fig. 1 where they have responsibility within the data processing and analysis facility of the supersite. In this operational concept, algorithm developers will provide a ground validation version of the spacecraft retrieval algorithms. The GV version of the algorithms will have a capability for substitution of measured physical values in lieu of physical assumptions within the algorithm and model methodology. Algorithm retrieval assumptions are considered to be a significant contributor to the overall retrieval error. Understanding and quantifying the error sources due to model assumptions is a specific objective of the ground validation program.

Since algorithm developers are best aware of the physical assumptions found within their models and algorithms, they are responsible for the creation of a GV version of the retrieval algorithms. The GV algorithm will be a 'transparent version' of the spacecraft retrieval algorithm enabling a comprehension of internal algorithm flow and decision; the GV algorithm is the converse of a 'black box' algorithm.

Some of the prime sources of retrieval error, handled within the algorithms as assumptions, are: (1) beam filling or horizontal variations of precipitation within the remotely sensed spatial resolution, (2) assumptions regarding

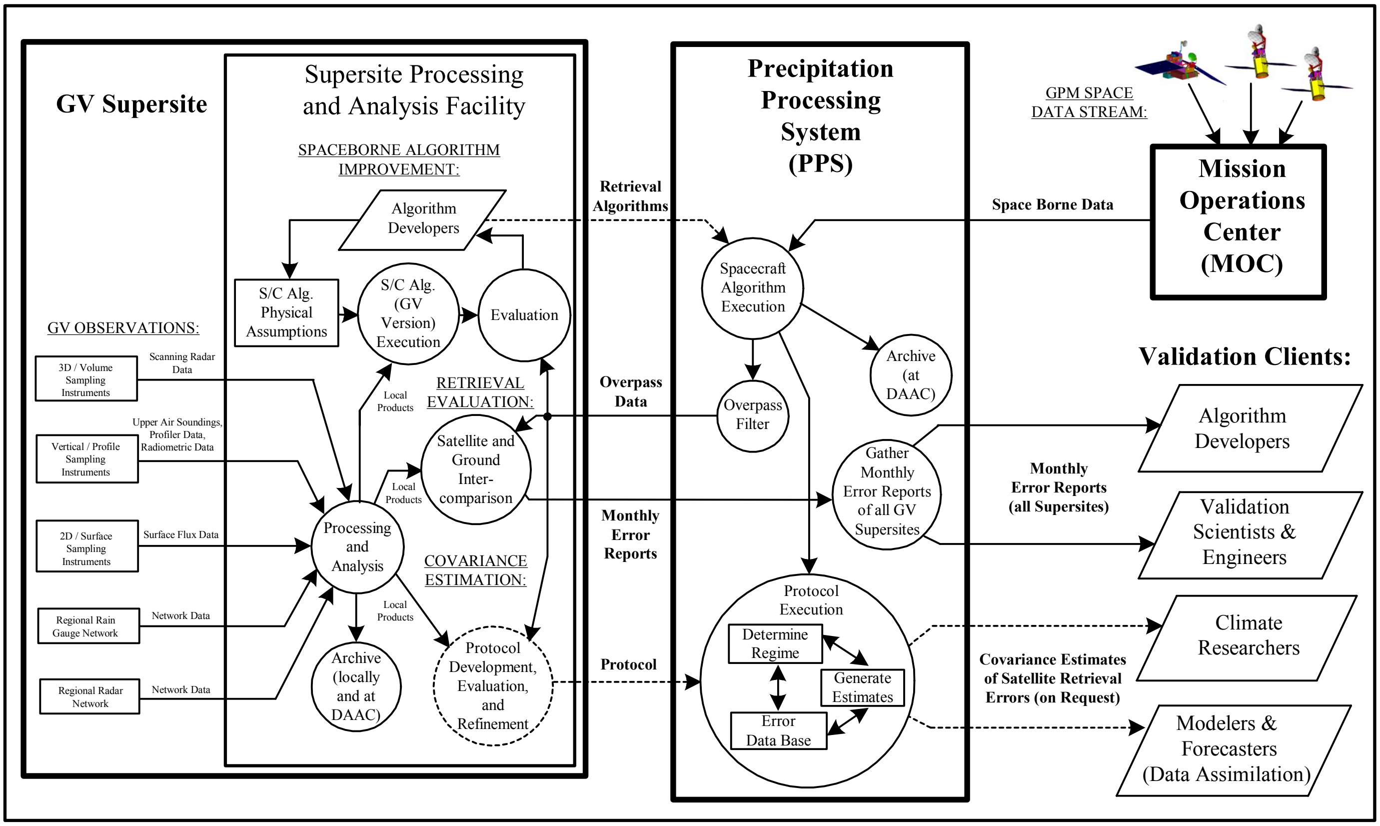

Figure 1. Measurement, data processing, data analysis, and information flow between the ground validation system supersite and other GPM functional elements.

parameters of the rain drop size distribution, (3) assumptions on the vertical extent of ice and liquid water regions of the atmosphere, and (4) assumptions regarding radar attenuation due to clouds and water vapor (important for the DPR Ka-band radar).

Ground Validation Self-Assessment

The GV instrumentation and techniques are subject to calibration and retrieval errors as are the space-borne measurements. The GV system, in providing quantitative estimates of satellite retrieval error, will at the same time, provide estimates of its own retrieval error.

Similarly, GPM will plan for research at the supersites that improves the GV instrumentation, techniques, and retrievals over the mission lifetime.

B. Supersite Concept

Those ground validation sites with established, routine communications with the Precipitation Processing System as illustrated in Fig. 1 are termed supersites. In particular, the creation of monthly error reports detailing the statistics on bias, its uncertainty, and retrieval precision from the supersite and its delivery to the PPS is a primary supersite deliverable. Data from direct comparison between ground observations and satellite retrievals over the supersite will constitute the basis of the monthly report. This is shown in Fig. 1 with the overflight subset of data presented by the PPS to the GV supersite. Information on significant space borne retrieval and GV retrieval discrepancies, together with details on the corresponding meteorology and atmospheric physics, are described within the reports. These monthly reports will be of value to ground validation researchers and algorithm developers.

NASA Contributed Supersites

NASA will contribute two supersites to the global validation system. These two sites were selected on the basis of several factors: geographic and climatological significance, level of physical infrastructure, and synergy with other organizations and research programs. One supersite is planned for Kwajalein Atoll in the Republic of the Marshall Islands (8° 44'N, 167° 44E) in the tropical western Pacific Ocean. Kwajalein is presently a TRMM validation site and was deemed the best choice from a comprehensive evaluation of potential tropical oceanic locations[3]. In addition to its oceanic and tropical location, Kwajalein has excellent infrastructure and meteorological research capabilities shared with a U.S. military facility. Among the meteorological instruments is an S-band polarimetric weather radar and rain gauge locations distributed on several islands of the atoll.

The second NASA contributed supersite is planned for co-location with the Central Facility of the Department of Energy's (DoE) Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) site. This site has excellent infrastructure, adequate precipitation, and a continental climate. The study area extends over an area of approximately 143,000 square kilometers in north-central Oklahoma centered near Lamont (36° 37'N, 97° 30'W). One of the most compelling rationales for choosing the ARM SGP site for GPM validation is the complementary nature of the long-term cloud, radiation, and atmospheric research conducted at this site. It is anticipated that the cloud research of the ARM SGP site will assist the precipitation research of GPM for a more complete picture of precipitation in the water cycle.

In addition to the two supersites, NASA will contribute a regional rain gauge network in central Florida as a collaborative effort between Kennedy Space Center and the several state water management districts of central Florida. Data from the gauges will complement data from the WSR-88D National Weather Service radar in Melbourne, Florida maintaining and building upon the TRMM validation work from this locale.

International Partnerships

Commensurate with a global mission is the need for international validation sites. JAXA and the National Institute of Information and Communications Technology (NICT) will operate two validation sites in Japan, one in the semi-tropical climate on the southern island of Okinawa and another in a cool temperate climate, with snowfall, at Wakkanai in northern Hokkaido. JAXA will emphasize Dual-frequency Precipitation Radar calibration, including absolute pointing calibration from their GV sites. JAXA will use active radar calibration instruments on the ground as an expansion of the technique currently used for the TRMM Precipitation Radar. Of particular interest is minimizing relative pointing errors between the two radars since spatial sampling misalignment between the two radars will adversely affect retrievals of drop size distribution and rainfall rate.

Europe will contribute to GV through a multitude of observational sites across the breadth of Europe[4]. The totality of sites is referred to as a distributed or virtual supersite. Some individual locations such as Catalunya in Spain are expected to have supersite capabilities. Europe will develop validation activities suited to its meteorology (including snow) and topography (including mountainous terrain) and commensurate with the measurement capabilities of its EGPM satellite.

Many additional international partner sites are anticipated and their description is beyond the scope of this paper. For a comprehensive description of global GV capabilities and interests the reader is referred to [4].

III. Ground Validation Status

Recent significant events in the GPM ground validation program include: (1) defined the top-level requirements in a systems engineering and program management framework, (2) held the First International Workshop on GPM ground validation, and (3) conducted the GPM Front Range Pilot Project experiment.

A. Requirements Definition

Ground validation requirements development is a focus of the project team at NASA and is a necessary step in the GPM systems engineering and project management approach. In this process, well-defined, science-community-vetted requirements will precede the design work. In March 2004 the project conducted a peer review of the top-level GV requirements. The recommendations of the review team's scientists and systems engineers represent an important step in vetting and formalizing the requirements.

B. First International Workshop on GPM Ground Validation

The First International Workshop on GPM Ground Validation was held in Abingdon, UK from November 4-7, 2003. Participants from 20 nations representing scientific, engineering, and management disciplines provided information on their research capabilities and interests and participated in working group sessions. A report summarizing the activities and providing recommendations for GPM validation from the working groups is to be released as a GPM Report[4]. The workshop provided a productive forum for developing and guiding a global strategy to precipitation validation. From the workshop participation, it is anticipated that a number of international GPM validation site partnerships will develop.

C. GPM Front Range Pilot Project

The GPM Front Range Pilot Project is an experimental research initiative requested by the GPM project and conducted by Colorado State University, the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory and the NOAA Aeronomy Laboratory. Experimental activities were conducted in May and June 2004 and involve instrumentation at several sites between Denver and Fort Collins east of the Front Range. The objectives of the Pilot Project include evaluating the complementary sensitivities of X-band and S-band polarimetric radars over a wide range of rainfall intensities, evaluating an optimal choice of frequencies for radar wind and drop size profilers, and developmental work on the regime classification technique for the continental supersite in Oklahoma.

References

[1] W.A. Petersen, et al., "TRMM Observations of Intraseasonal Variability in Convective Regimes over the Amazon," J. Climate, Vol. 15, No. 11, pp. 1278-1294, 2002.

[2] S.W. Nesbitt, E.J. Zipser, C.D. Kummerow, "An Examination of Version 5 Rainfall Estimates from the TRMM Microwave Imager, Precipitation Radar, and Rain Gauges on Global, Regional, and Storm Scales, J. Appl. Meteor., in press.

[3] W. Adkins, S. Yuter, E.A. Smith, and W.J. Adams, "Global Precipitation Measurement - Report 5, Potential Tropical Open Ocean Precipitation Validation Sites," NASA/TM-2002-210010, April 2002.

[4] E.A. Smith, et al., "Report of 1st International GPM GV Requirements Workshop," GPM, November 4-7, 2003; Abingdon, U.K. Global Precipitation Measurement Report, in press.