4th Global Precipitation Measurement (GPM) International Ground Validation (GV) Meeting Summary

Dalia B. Kirschbaum, Earth Systems Science Interdisciplinary Center, University of Maryland, NASA Goddard Space Flight Center, Dalia.B.Kirschbaum@nasa.gov
Jarkko Koskinen, Finish Meteorological Institute, jarkko.koskinen@fmi.fi
Arthur Y. Hou, NASA Goddard Space Flight Center, Arthur.Y.Hou@nasa.gov
Walter Petersen, NASA Marshall Space Flight Center, Walt.Petersen@nasa.gov
Gail Skofronick-Jackson, NASA Goddard Space Flight Center, Gail.S.Jackson@nasa.gov
Ramesh Kakar, NASA Headquarters, ramesh.kakar@nasa.gov

Introduction

The Global Precipitation Measurement (GPM) Mission [*Hou et al.*, 2008] is an international satellite mission designed to use both active and passive microwave remote sensors to unify and advance precipitation measurements by a constellation of satellites. The GPM constellation will consist of a network of satellites provided by a consortium of international and domestic space agencies including NASA, the Japanese Aerospace and Exploration Agency (JAXA), the Centre National d'Etudes Spatiales (CNES), the Indian Space Research Organization (ISRO), the National Oceanic and Atmospheric Administration (NOAA), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). NASA and JAXA will deploy a reference satellite known as the "Core Observatory" carrying a Dual-frequency Precipitation Radar (DPR) and a GPM Microwave Imager (GMI) to be launched in July 2013. NASA will also provide a second GMI to fly on a partner-provided Low-Inclination Observatory (LIO) with a target launch date in late 2014. In support of both pre-launch algorithm development and post-launch product assessment, the GPM Mission has set in motion a variety of dedicated Ground Validation (GV) activities.

The GPM GV activity is designed around three basic approaches that provide verification of products, characterize uncertainties in satellite and ground-based precipitation estimates, and refine the physical assumptions used in the retrieval algorithms. These three approaches include: direct statistical validation of GPM precipitation estimates (e.g., use of large national networks to verify precipitation rates); physical validation of retrieval algorithms (i.e., assessment and testing of algorithm physics and physical assumptions); and integrated hydrologic validation of GPM products (i.e., assessment of product utility in hydrometeorology, water budget studies, and numerical weather prediction as a function of scale and application).

To support the pre-launch phase of international GPM GV activities, the 4th GPM International Ground Validation Workshop was held in Helsinki, Finland, June 21-23, 2010. The meeting, hosted by the Finnish

Photo Credit: John Kwiatkowski [George Mason University, NASA GSFC]

Meteorological Institute (FMI) in coordination with NASA, featured 50 oral presentations and two poster sessions and was attended by 90 participants from 18 countries. Additional information about the workshop and all presentations can be found at: *gpm.fmi.fi.*

This 4th GPM GV Workshop represents the latest in a series of international ground validation meetings. The first three meetings took place in Chilbolton, UK (2003); Taipei, Taiwan (2005); and Buzious, Brazil (2008). Through this series of meetings, GPM has developed a framework for international cooperation and established numerous international GV science projects jointly with the NASA Precipitation Measurement Missions (PMM) Program.

The technical objectives of the 4th Workshop were to:

- Report science results from current GV projects;
- clarify linkages between GV measurements and algorithm needs;
- propose recommended GV practices and uncertainty characterization; and
- discuss innovative methods for integrated hydrological validation and applications.

Discussion and planning of the Light Precipitation Validation Experiment (LPVEx) field campaign, taking place September–October 2010 in Helsinki, illustrated both the scientific progress and significance of GV for the success of the GPM mission and broader scientific community. Current GV activities and specific accomplishments of this workshop are described below.

Connecting GV measurements to algorithm needs

Direct Validation

The workshop participants heard multiple presentations on the continued international efforts to identify significant discrepancies between satellite products and ground-based measurements, with a focus on high-latitude validation.

Chris Kidd [University of Birmingham, UK] introduced the challenges of detecting light rainfall and snowfall in high latitudes (beyond 60° N) given the dearth of surface GV coverage at these latitudes. Kidd emphasized the importance of high-latitude precipitation in the water cycle and the need for better coverage and characterization of precipitation retrievals.

Christian Klepp [Meteorological Institute, Clisap, University of Hamburg] presented on high-latitude precipitation validation over the ocean and **Ralf Bennartz** [University of Wisconsin] discussed validation efforts over land. Both researchers identified existing challenges in accurate microphysical characterization and snowfall retrievals and introduced several current and future projects to improve GV coverage.

Tuomo Lauri [Finnish Meteorological Institute (FMI)] outlined the major error sources of ground-based radar and gauge snowfall measurements, noting that wind drift and wind-induced gauge errors are most significant. He also discussed how to minimize these errors for improved *in situ* snowfall observations.

David Hudak [Environment Canada] described the challenges associated with making direct or remotely-sensed snowfall measurements from both gauge and radar instruments due to the intrinsically complex scattering of snow caused by variations in their shape, size, and water-phase properties.

Gail Jackson [NASA Goddard Space Flight Center (GSFC)] discussed the current status of satellite-based snowfall retrieval algorithms for the GPM mission, citing the challenge of extracting falling snow signatures from "background" contributions in Brightness Temperature (T_b) values and providing a summary of recommendations for needed GV measurements of snow and precipitation phases.

There were also status reports of direct GV activities from the network of international projects, including representation from:

- ***South Korea,* Mi-Lim Ou** [National Institute of Meteorological Research];
- ***Israel,* Efrat Morin** [Hebrew University of Jerusalem];
- ***Argentina,* Paola Salio** [Centro de Investigaciones del Mar y la ATmosfera (CONICET) UBA];
- ***Ethiopia,* Mekonnen Gebremichael** [University of Connecticut], **Shuji Shimizu** [Japan - JAXA/EORC);
- ***Finland,* Jarkko Koskine**n [FMI]; and
- ***Spain,* Francisco Tapiador** [University of Castilla-La Mancha (UCLM)].

Each presenter described the development and framework of their national observational networks of gauges, radar, and disdrometers in their respective nations and discussed promising results on radar reflectivity and instrument inter-comparison as well as potential GPM application activities.

Physical Validation

The workshop also focused on GV measurements for physical validation, seeking to provide a translation between GV measurements, algorithm inputs, and physical assumptions associated with the use of the inputs. Several meeting participants stressed the importance of accurate modeling and verification of microphysical properties and associated remote-sensing signatures. Specific topics included collaboration in radar/radiometer simulator development and improved characterization and analysis of the multi-dimensional properties of drop and snow size distributions (DSD) and how they may impact retrieval algorithms in different regimes. Discussion topics included assumptions regarding beam-filling corrections, the vertical profile of the rain DSD, appropriate integration times or spatial resolutions for comparison to satellite products, the ability of dual-frequency retrieval algorithms to extract salient features of the snow and rain DSD at DPR pixel, and gate-spacing scales.

Christa Peters–Lidard [GSFC] described an example of innovative physical validation using improved surface emissivity characterization to better estimate satellite retrievals. **Francisco Tapiador** [UCLM] presented new results suggesting that rain DSD variability can be quantified using a high-density network of Parsivel disdrometers.

Chris Kummerow [Colorado State University] and **Walt Petersen** [NASA Marshall Space Flight Center (MSFC)] described a variation of the physical validation approach based on *hypothesis testing*. In this framework, hypothesis testing begins with an *a priori* set of satellite algorithm assumptions that can be systematically adjusted or modified (e.g., the assumed rain rate profile) to attain consistency between measurement constraints (e.g., a given brightness temperature and radar reflectivity used in a combined radar-radiometer retrieval). The job of ground validation in this instance is to then confirm that the algorithm parameter has been or can be modified in a physically consistent fashion based on the results of GV information.

Chris Kummerow further described how hypothesis testing can be less computationally intensive and more efficient in identifying inaccurate assumptions in algorithm parameterizations, including rain DSD, ice retrieval, and cloud water retrievals. **Robert Meneghini** [GSFC] described how hypothesis testing may be used to determine solutions for DSD estimates and identify precipitation phase states given DPR retrievals. The final day of the workshop featured a discussion on hypothesis testing and transforming the framework into guidelines for GV measurements. **V.N. Bringi** [Colorado State University] described a robust bootstrapping methodology for using both disdrometer and C-band polarimetric radar to retrieve characteristic DSD behavior as a function of meteorological regime in both northern Alabama and northern Australia.

Jussi Leinonen [FMI] demonstrated the use of C-band dual-polarimetric radar data in combination with W-band CloudSat information over the Helsinki testbed to regenerate realistic profiles of radar reflectivity at Ka- and Ku-band frequencies. This methodology may be employed for creating a Ka–Ku band reflectivity database for DPR algorithms using future field campaign datasets. **Alessandro Battaglia** [University of Leicester] presented ADvanced MIcrowave RAdiometer for Rain Identification (ADMIRARI) radiometer and micro-rain radar measurements from both Germany and Brazil. These results demonstrated the promise of passive polarimetric radiometer partitioning of cloud from rainwater in light-raining mid-latitude clouds. However, based on recent Pre-CHUVA (Portuguese for 'rain') field campaign results from Brazil, Battaglia also illustrated new challenges for remotely retrieving the cloud and rainwater contents in tropical warm rain situations using ADMIRARI.

Recommended GV practices and characterization of uncertainties

A common theme among the presenters was the identification of error sources associated with ground-based precipitation retrievals and the importance of accurately characterizing the uncertainties and biases of each monitoring system. Several presentations described standard practices for GV such as setting tolerances for radar and radiometer equipment and scanning control for research radar. **V. Chandrasekar** [Colorado State University] is currently working to develop a "best practices" plan for ground radar calibration and suggested several simple calibration activities for research radar such as metal sphere and sun calibration. **Luca Baldini** [National Research Council, Institute of Atmospheric Science and Climate (ISAC)] discussed recommended practices for radar scanning and emphasized the need for "community accepted" standards and protocols to maintain data and metadata quality.

Ali Tokay [Joint Center for Earth Systems Technology/NASA] compared the results of several types of disdrometer and rain gauge instruments, concluding that differences exist between the various instruments at small drop sizes but can serve as a valuable network for GPM field campaigns. Within the context of measurement errors and GV, **Witold Krajewski** [University of Iowa] outlined a design for test sites to provide a proof-of-concept demonstration of how retrieval error methodologies can be implemented to characterize uncertainties in gauge, ground radar, and satellite precipitation estimates. Results of the recommended practices discussions will be synthesized and presented at the annual PMM meeting in early November.

Integrated hydrological application and validation

The workshop departed from the discussion of instrument-based GV to discuss how to better understand the space-time scales at which satellite precipitation data are useful for hydrologic applications as well as how these studies may be useful for validation. **Ana Barros** [Duke University] presented a water budget study in the Great Smokey Mountains area, identifying what was known about water budgets in the past and pointing to the level of detail (in the form of good GV) that is needed for accurate hydrological models to model flow and small-scale processes. **Christa Peters-Lidard** described how land-surface models may also be used as a validation tool, employing satellite products in hydrological models to characterize errors and pinpoint uncertainty through forward and backward modeling.

Field campaign design and implementation

Field campaigns related to the GPM Mission are intended to move GV activities forward and better understand precipitation microphysics and variability in the context of satellite retrievals. A planning meeting took place the day following the workshop to discuss the LPVEx field campaign (a collaboration between CloudSat, GPM, the Finnish Meteorological Institute, and Environment Canada), which will occur in the vicinity of Helsinki for six weeks in September and October 2010. The field campaign is intended to characterize the ability of CloudSat (*cloudsat.atmos.colostate.edu*) and other passive microwave (PMW) sensors to characterize the microphysical characteristics of light rainfall and to evaluate their estimates of rainfall intensity in high-latitude land and ocean environments characterized by shallow freezing levels. The experiment also seeks to increase understanding of liquid and ice microphysics along with melting layer microphysics in order to improve GPM pre-launch algorithm development. The field campaign will focus on ground radar, disdrometer and gauge instrumentation networks designed around the Helsinki testbed and will employ detailed *in situ* airborne sampling (U. Wyoming *King Air*) with possible coordination of satellite overpasses. Additional information on the LPVEx field campaign can be found at *lpvex.atmos.colostate.edu*.

The overarching themes of the field campaigns center on five main objectives:

- Coordinating high-altitude and *in situ* airborne sampling;
- performing high resolution sampling of DSD and rain rates;
- creating three-dimensional (3-D) profiles of the solid, liquid, and mixed and melting layer phases of precipitation using radar, profiler, and disdrometer estimates
- accurately sampling land-surface radiance and backscatter from both the air and ground; and
- creating a coupled database of cloud-resolving models, land surface models, and radiative transfer models for testing and validation of satellite retrievals.

As discussed by **Walt Petersen,** there are several future field campaigns to address various aspects of precipitation microphysics, ground retrievals, and latitudinal differences in precipitation sensing. These campaigns include:

NASA-Department of Energy (DOE) MC3E: (April–June 2011). ARM CF N. Oklahoma. Focus: *Mid-latitude continental precipitation retrievals*

NASA-EC-CloudSat Cold Season Experiment: (January–February 2012). EC CARE Facility, Ontario, Canada. Focus: *Snowfall retrieval algorithms*

NOAA–NASA Hydrometeorological Testbed-Southeast: (August–September 2013). Tar/Neuse River Basins, North Carolina. Focus: *Integrated validation* [preliminary discussion phase]

Conclusions

The presentations and discussions at this workshop represented a marked step forward in developing GV practices, outlining existing uncertainties, and drawing a more direct linkage to how GV can help improve algorithm development. The presenters noted that some challenges remain with retrievals, including the issues of light rainfall over oceans, complex terrain, land-surface impacts, and snowfall; however, advancements in DPR and radiometer retrievals may help to fill some of these gaps. The discussion of recommended practices for GV activities as well as the establishment of scattering tables to relate radar and radiometer retrievals may help to decrease errors and improve uncertainty estimates and algorithm functionality. The workshop concluded with a set of action items, which will be developed and presented at the next PMM Science Team Meeting taking place November 1– 4, 2010 in Seattle, WA.

References:

Hou, A. Y., G. Skofronick-Jackson, C. D. Kummerow, and J. M. Shepherd. 2008. Global precipitation measurement. In *Precipitation: Advances in Measurement, Estimation, and Prediction* (Ed. Silas Michaelides), Springer-Verlag, 131-169.