meeting/workshop summaries

Precipitation Measurement Missions Science Team Meeting Summary

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Introduction

The Precipitation Measurement Missions (PMM) Science Team held its annual meeting in Denver, CO, from November 7-10, 2011. The PMM program supports scientific research, algorithm development, and ground-based validation activities for the Tropical Rainfall Measuring Mission (TRMM) and the upcoming Global Precipitation Measurement (GPM) mission.

TRMM, a partnership between NASA and the Japan Aerospace Exploration Agency (JAXA), was launched in 1997 and is currently in its fifteenth year of mission operations. The first-time use of both active and passive microwave instruments and the precessing, low-inclination (35°) orbit have made TRMM the world's foremost satellite for studying precipitation and associated storms and climate processes in the tropics. GPM continues and extends that successful partnership as an international satellite mission to provide next-generation observations of rain and snow—worldwide—every three hours. NASA and JAXA will launch the GPM "Core" Observatory satellite in 2014. It carries an advanced precipitation radar and a microwave radiometer that will set new standards for space-based precipitation measurements. The data they provide will be used to unify the suite of precipitation measurements made by an international network of partner satellites to quantify when, where, and how much it rains or snows globally. NASA and JAXA will launch the GPM Core Observatory satellite in a 65°-inclination, non-sun-synchronous orbit. Additional information about PMM can be found at: *pmm.nasa.gov* and *www.nasa.gov/GPM*.

The PMM meeting agenda comprised:

- Updates on mission status, programmatic news, and other team business;
- scientific and activity reports from principal investigators (PIs) and international partners; and
- coordination of pre-launch algorithm development and ground validation activities for GPM.

The meeting brought together over 150 participants from 10 countries, and included representatives from NASA, JAXA, the National Oceanic and Atmospheric Administration (NOAA), universities, industry, and other international partner agencies. During the first three days of the meeting, participants focused on TRMM/GPM programmatic summaries, international activities, ground validation summaries, and science reports from science team members. In addition to 12 oral presentations, two afternoon poster sessions were held to facilitate discussion of research results in an interactive forum. The final day was devoted to GPM algorithm team meetings. Working groups that focused on hydrology, algorithm development, latent heating, and land-surface characterization met throughout the week.

On November 11, the NASA–JAXA Joint PMM Science Team held a panel discussion to coordinate US-Japan PMM science activities. The panel reviewed the status of GPM sensor algorithms, the reprocessing of TRMM data with Version 7 (V7) algorithms on the Precipitation Processing System (PPS) website, and discussed the procedures for TRMM decommissioning at the end of its mission life.

Programmatic Updates

Ramesh Kakar [NASA Headquarters—*TRMM/GPM Program Scientist*] provided a PMM program status update, outlining upcoming NASA Earth science missions that are currently in formulation and implementation. Kakar reported that the TRMM spacecraft and instruments passed their fourth Senior Review and remain in excellent condition. TRMM's fuel use indicates that its operations will likely overlap with the GPM Core Observatory.

Arthur Hou [NASA's Goddard Space Flight Center (GSFC)—*GPM Project Scientist*] provided an overview of the current status of the GPM constellation. He mentioned that partner satellites—including Suomi NPP and Megha-Tropiques[1] have been successfully launched. He also reported that with the recent cancellation of the GPM Low-Inclination Observatory (LIO), GPM still has 8-10 functioning satellites across the different phases of its anticipated mission lifetime, and that opportunities exist to access radiometer data from Chinese and Russian satellites. Hou discussed accomplishments from the GPM ground validation field campaigns over the past year, and provided the team with an update on joint international science projects, including a collaboration effort under development with the Hydrological Cycle in Mediterranean Experiment (HyMeX) sponsored by the World Climate Research Programme.

Scott Braun [GSFC—*TRMM Project Scientist*] provided an overview of TRMM-related activities, including the availability of fuel remaining onboard that will al-

[1] Megha Tropiques is a joint mission mounted by the Indian Space Research Organization and the French Centre National d'Études Spatiales (CNES).

low for greater overlap with GPM than previously estimated. Braun reported on the release of the TRMM V7 algorithms, which are now in use. The PPS reprocessed the entire TRMM dataset with V7 within one month.

Art Azarbarzin [GSFC—*GPM Project Manager*] provided an update on the development of the GPM Core Observatory, reporting that integration and testing of the spacecraft is proceeding well. The High-Gain Antenna Subsystem is the next component scheduled for integration onto the Observatory. Azarbarzin also reported that the GPM Microwave Imager (GMI) is in thermal vacuum testing at Ball Aerospace and Technologies Corporation, and will be delivered to GSFC in February 2012. The Dual-frequency Precipitation Radar (DPR), built by JAXA and Japan's National Institute of Information and Communications Technology (NICT), recovered well from the March 2011 earthquake; its new delivery date is March 2012. The mission operations review is scheduled for August 2012.

Erich Stocker [GSFC] gave an update on GSFC's PPS website, which is now providing an enhanced search interface for accessing TRMM V7 data via *storm-pps.gsfc.nasa.gov/storm/html/Storm.html*. Features originally scheduled for implementation during the GPM mission phase have been completed early. Users may now create custom standing or special orders based on parameter subsetting of TRMM V7 products as well as geographical subsetting.

Partner Activities

Riki Oki [JAXA] provided the team with an update describing JAXA's related precipitation measuring missions, including the Global Change Observation Mission 1st-Water (GCOM-W1), which will launch in 2012 to join the GPM constellation. Algorithm development for the DPR and Combined DPR/GMI Level-2 (L2) products continues, as does algorithm development for improvements to the Global Satellite Mapping of Precipitation project, which is now available by cell phone from the Japanese Weather Association. Oki also discussed the K_a-band radar, which is now undergoing ground validation testing.

Kenji Nakamura [Nagoya University, JAXA/GPM] elaborated on the details of the recent rainfall validation efforts for the K_a-band radar in Okinawa and Tsukuba, with results to be incorporated into DPR algorithms.

Toshio Iguchi [NICT], leader of the DPR algorithm team, reported that development of L2 products is closely in line with its original schedule. The baseline code is ready to submit; the at-launch code will be developed by next fall. Iguchi shared the results of testing several algorithm methods [Hitschfeld-Bordan (HB) and HB-Dual-frequency Retrieval (DFR)] and of synthetic data retrievals for error analysis.

Yukari Takayubu [University of Tokyo—*JAXA/TRMM Project Scientist*] summarized the evaluation of changes present in the TRMM V7 algorithms that are now being used to process TRMM data, including new rain-type classifications, adjustments to rain-rate reporting over land and oceans, and adjustments due to the non-spherical raindrop model. She also discussed TRMM data continuity, and reported that no problems have appeared due to the satellite's orbital boost in 2001 or from switching from original electrical components in the radar that failed in 2009 to backup components, which are currently performing well.

Remy Roca [(CNES—*Megha-Tropiques Project Scientist*] gave an update on the successful launch of the Megha-Tropiques satellite, which will be a member of the GPM Constellation on October 12, 2011. The satellite is in sun-synchronous orbit at a 20° inclination, with three-to-five passes per day for studying water and energy cycles in the tropics. Its microwave imager—Microwave Analysis and Detection of Rain and Atmospheric Structures (MADRAS)—and humidity sounder—Sounder for Probing Vertical Profiles of Humidity (SAPHIR)—will contribute to the GPM global dataset. Roca reported that data have been received, and that the algorithms are currently being calibrated and validated.

Alan Geer [European Center for Medium-range Weather Forecasts (ECMWF)] discussed ECMWF efforts to incorporate cloud- and precipitation-related satellite observations into numerical weather prediction models. He noted the need for better satellite coverage as well as better cloud and microphysics models. Geer also discussed current work on bias reduction in microwave sounder data.

Ralph Ferraro [NOAA/National Environmental Satellite, Data, and Information Service] discussed NOAA's satellite program, which will contribute to the GPM constellation. This includes the successful launch of Suomi NPP—a joint mission with NASA—on October 28, 2011. Ferraro also provided an overview of NOAA-led projects that focus on precipitation retrievals. One of those projects is the Hydrometeorology Testbed-Southeast pilot project, planned for implementation in 2013 in Western North Carolina. The project's focus is quantitative precipitation estimation, to complement GPM ground validation.

The presentations from other international partners gave updates on ground validation projects to characterize precipitation regimes in the speakers' respective countries. These included talks by **Mi-Lim Ou** [Korean Meteorology Administration], **Efrat Morin** [He-

brew University of Jerusalem], and **Francisco Tapiador** [Universidad de Castilla La Mancha]. In the course of their ground validation measurements, **Alexis Berne's** [École Polytechnique Fédérale de Lausanne] group in Switzerland produced the first high-resolution precipitation dataset for alpine regions. **Luiz Machado** [Centro de Previsão de Tempo e Estudos Climáticos/Instituto Nacional de Pesquisas Espaciais /(CPTEC/INPE)] discussed the cloud processes in the main precipitation systems in Brazil: A contribution to cloud resolving modeling and the Global Precipitation Measurement (CHUVA) project, a field campaign across seven precipitation regimes in Brazil, to characterize cloud types and processes, test different precipitation estimation algorithms, and examine boundary layer and cloud microphysical modeling. Machado also presented the results from the Belem campaign in June 2011. **Guy Delrieu** [CNES/University of Grenoble] reported on the Hydrological Cycle in Mediterranean Experiment (HyMeX), which is currently taking place across Southern Europe and the Mediterranean, to improve understanding of the Mediterranean water cycle, with an emphasis on the predictability and evolution of intense events. In 2012 and 2013, the focus will be on the Western Mediterranean. One of the goals of HyMeX is to understand rainfall in complex terrain.

TRMM Science

The year 2011 marked the completion of the fourteenth year of TRMM operations, so many presentations centered on topics that TRMM's 14-year record could begin to address. **Marshall Shepherd** [University of Georgia] presented an overview of the effects of urban centers on local and regional precipitation patterns. **Edward Zipser** [University of Utah] talked about using the record for improved regional analysis of precipitation—in particular, for Southeast Asia, North American monsoons, and Argentina. **Bill Lau** [GSFC] discussed long-term rainfall trends and the physical factors that contribute to them. Specifically, Lau shared results on rain type and its relationship with sea-surface temperature, which showed that an increase in sea-surface temperatures results in a higher number of heavy rainstorms. **Bob Adler** [University of Maryland, College Park] talked about his group's work to answer the question of how TRMM estimates can be combined to develop the "best" rainfall product. They are building a TRMM Composite Climatology map of surface rainfall that uses multiple TRMM rainfall estimates over 13 years of its record to make a rainfall climatology map product. These maps are currently available on the PPS website.

With the release of the V7 algorithms in July 2011, **Daniel Cecil** [University of Alabama, Huntsville] described how changes between the V6 and V7 algorithms affect TRMM retrievals in intense convective systems. **Wesley Berg** [Colorado State University (CSU)] presented results from TRMM V7 products, Special Sensor Microwave/Imager, and CloudSat to compare how each product characterizes rainfall distributions and to identify where improvements need to be made. They found that TRMM V7 has improved upon light-rain detection but that regional biases remain. **Tiruvalam Krishnamurti** [Florida State University (FSU)] described the vertical distribution of heating in mesoscale models over the Asian monsoon region. His group compared TRMM Precipitation Radar (PR) estimates to model results to evaluate model forecasting potential. **Timothy Liu** [NASA/Jet Propulsion Laboratory] presented work aimed at resolving the air–sea movement of water via evaporation, and the influence of the ocean on the land-water balance. **Richard Johnson** [CSU] evaluated TRMM latent heating algorithms. **Tony Del Genio** [NASA Goddard Institute for Space Studies (GISS)] reported on work that used both TRMM PR data and CloudSat/Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) data to look at the relationship between column water vapor and cloud height during the development stage of the South Asian monsoon. A group at GISS used their results to improve regional modeling for areas that have been difficult to resolve in global climate models.

Algorithm Activities

Algorithm improvements continue for the DPR and GMI instruments for the GPM Core Observatory. **Robert Meneghini** [GSFC] talked about how scattering tables can be used to improve assumptions about microphysical particles and the surface reference technique, which may ultimately be applied to correct for reducing attenuation of the radar signal. **Chris Kummerow** [CSU] discussed radiometer algorithm development. The *Bayesian* method uses a database of globally representative GMI observations that are matched with DPR rain rates and structures. **Bill Olson** [University of Maryland, Baltimore County, Joint Center for Earth Systems Technology] provided an update on the combined DPR/GMI algorithm whose *beta* version was distributed to the science team in September 2011.

Grant Petty [University of Wisconsin, Madison] discussed a methodology to exploit information content of the channels within the Bayesian framework to retrieve data from the GMI. The method uses a database of globally representative GMI observations that are matched with DPR rain rates and structures. Petty also shared results of algorithm improvements using available TMI data. **Guosheng Liu** [FSU] discussed additional improvements to the radiometer algorithm, including the complex process of snowfall detection over land. He described how liquid water present in a snow cloud causes uncertainty in the satellite retrievals, noting that progress is being made to better resolve this issue using an empirical orthogonal function-based

detection method. Liu's group is also developing a database for making snowfall retrievals over the ocean, which is currently limited by subpixel variability.

Filipe Aires [Estrellus] talked about work on developing emissivity databases in the GPM era to better represent the background state of the surface for more accurate satellite retrievals. **Christa Peters-Lidard** [GSFC] presented modeling work that incorporates soil moisture and vegetation emissivity to reproduce the dynamics of land-surface emissivity. **Chandra Chandrasekar** [CSU] described the classification module of the DPR L2 algorithm that sorts retrieval profiles into different rain types and then determines microphysical properties. They tested the algorithm in three ground validation experiments to further differentiate between stratiform and convective rain.

Several presentations discussed integrating radiometer data from different instruments. **Tom Wilheit** [Texas A&M University] described the GPM intersatellite calibration (X-CAL) project, which seeks to make radiances from constellation radiometers physically consistent. **Pete Robertson** [GSFC] discussed his group's evaluation of the Microwave Integrated Retrieval System (MIRS), a product that combines data from polar-orbiting microwave sounders such as the Advanced Microwave Sounding Unit (AMSU). This work examines how to integrate all the constellation sensors to yield a unified precipitation product. In the coming year, they will be adding the Advanced Technology Microwave Sounder (ATMS) on Suomi NPP and Sondeur Atmospherique du Profil d'Humidité Intertropicale par Radiometrie (SAPHIR) on Megha-Tropiques. **George Huffman** [GSFC/Science Systems and Applications, Inc.] discussed the Integrated Multi-satellite Retrievals for GPM (IMERG) project that will take data provided by GPM and its constellation and integrate it into global precipitation datasets at three different latencies.

Ground Validation

Light Precipitation Validation Experiment

Chandra Chandrasekar [CSU] gave an update on the Light Precipitation Validation Experiment (LPVEx) that took place in Helsinki, Finland in coordination with representatives from CloudSat, the GPM Ground Validation program, the Finnish Meteorological Institute, Environment Canada (EC), the United Kingdom National Environmental Research Council, Vaisala Inc., and the University of Helsinki. The ground validation activities occurred in two segments; in September and October 2010 the campaign focused on widespread rainfall; from October 2010 to January 2011 it focused on dry and melting snow. Since GPM will measure light rain and falling snow, this ground validation effort contributes to the database of liquid and ice microphysics at high latitudes. The LPVEx Data Analysis Working group, which met from October 13-14, 2011, is still analyzing the data. The current consensus is that the LPVEx datasets can impact both the *a priori* model databases and associated scattering tables that underpin the CloudSat and GPM precipitation algorithms.

Midlatitude Continental Convective Clouds Experiment

Walt Petersen [GSFC/NASA's Wallops Flight Facility] gave an overview of the Midlatitude Continental Convection Clouds Experiment (MC3E) campaign that took place in the spring of 2011 in Oklahoma. The campaign was very successful and the team was able to make observations of a "dream scenario" convective storm[2] on May 20 and a tornado-generating storm on May 24. Data analysis is ongoing and was the subject of many subsequent talks. **Steven Rutledge** [CSU] presented on the successful NASA Polarimetric (NPOL) radar operation during MC3E. The radar was in operation from April 22–June 2, 2011, and captured a wide range of data on numerous mesoscale convective storms and a tornadic supercell. **Wei-Kuo Tao** [GSFC] summarized model forecasting during the MC3E campaign. He described how they used models to make real-time predictions and then compared the results immediately to observations in the field. The model performed well, but simulations were sensitive to initial and boundary conditions. After MC3E, the group ran simulations to validate the microphysical assumptions in their models against the MC3E data. This allowed for improved simulated data for the algorithm developers.

Pablo Garfias [University of Bonn] and **Alessandro Battaglia** [University of Leicester] showed results of partitioning of the liquid water path (LWP) into cloud and rain components in different precipitation regimes using the ground-based Advanced Microwave Radiometer for Rain Identification (ADMIRARI). The ADMIRARI was deployed at the pre-CHUVA, LPVEx, and MC3E ground validation campaigns to improve precipitation estimates at high latitudes.

GPM Cold Season Precipitation Experiment

Walt Petersen provided the team with an update on the preparations for the GPM Cold Season Precipitation Experiment (GCPEx) ground validation campaign in Canada, January 17–February 29, 2012, which is underway as of this writing. **David Hudak** [EC] summarized Canadian activities, including a detailed plan for the GCPEx campaign. GCPEx, like MC3E, consists of airborne and ground-based observations that will collect radar, radiometer, and rain-gauge measurements,

[2] To learn more about the MC3E dream scenario, see *The NASA-GPM and DOE-ARM Midlatitude Continental Convective Clouds Experiment (MC3E)* in the January-February 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 1**, pp. 12-18].

among others, to characterize light rain and snow for satellite retrievals. To learn more about GCPEx, please visit: *pmm.nasa.gov/GCPEx*.

Other Ground Validation Activities

As part of integrated hydrologic modeling activities, **Ana Barros** [Duke University] presented ground validation results in complex topography in the southern Appalachian Mountains, where her group looked at storm systems produced in response to hurricanes near the coast. **Christopher Williams** [Cooperative Institute for Research in Environmental Studies, University of Colorado, Boulder] reported on the work of the drop size distribution (DSD) working group that is trying to understand the relationships and correlations between DSD parameters. They use the data collected during the ground validation field campaigns, with the goal of improving algorithm development process.

Luca Baldini [Istituto di Scienze dell'Atmosfera e del Clima (CNR)] discussed radar calibration procedures and scanning strategies for ground validation. These procedures build community standards for calibrating instruments of different makes, models, and agencies. **Witold Krajewski** [University of Iowa] discussed error propagation through ground validation networks.

Closing

At two well-attended poster sessions, the science team further discussed applications of precipitation data including, among other topics, flood prediction, health applications, algorithm development, evaluation of TRMM V7 data, and other ground validation efforts being done by PIs. **Dalia Kirschbaum** [GFSC] outlined the education and public outreach efforts for GPM, and **Jacob Reed** [GFSC] gave a demonstration of the PMM website launched last summer at *pmm.nasa.gov.*

Finally, **Arthur Hou** [GSFC] spoke of upcoming milestones for the mission, including integration and testing of the GMI and the DPR, both of which will be shipped to GSFC in Spring 2012.

The 2011 PMM Science Team Meeting closed with a summary of progress made during the working groups for hydrology, algorithm development, latent heating, and land surface characterization, which highlighted both the successes and challenges that remain as the PMM team heads into the last two years before the GPM Core Observatory is launched. ■

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Hampton University] and **Larrabee Strow** [University of Maryland, Baltimore County] showed new climate-focused retrieval strategies for IR spectra. The concept is to optimize retrievals for decadal climate change using the CLARREO time- and space-averaged spectra instead of weather applications at small spatiotemporal scales. Their studies showed that existing retrieval algorithms—e.g., those used for AIRS—have difficulty extracting climate trends. They suggested new methods for all-sky retrievals (Smith) and probability-density-function-sorted retrievals (Strow). Both methods greatly reduce the cloud-generated nonlinearity effects. These methods are in the early stages of development, but look very encouraging. **Stephen Leroy** [Harvard University] showed that global RO sampling has sharp spikes at a few latitudes that are systematic for any RO observations for climate-change-related phenomena. He described advanced Bayesian sampling methods that can greatly reduce these biases from zonal-mean climate observations.

Mission Studies

Paul Speth [LaRC] summarized engineering studies performed to examine alternate options for the CLARREO mission. These studies showed that the ISS could achieve about two-thirds of the baseline CLARREO mission and at greatly reduced cost. Three of the Earth Venture-2 proposal concepts related to CLARREO science were summarized during the meeting; summaries were also provided for the ISS (IR spectrometer and RS spectrometer) and a free-flyer mission (IR spectrometer). While none of these currently meet all of the minimum mission requirements for CLARREO, they provided significant advances in climate science closely related to the CLARREO concept.

David Young and **Bruce Wielicki** [LaRC] delivered a final wrap-up, and the team discussed plans for publication of the science results and future collaborations among the team. The next meeting will be held in Hampton, VA, in April 2012. ■