Summary of the Second GPM Applications Workshop

June 9-10th, 2015
University of Maryland Conference Center

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Context for Workshop

In November 2013, a few months prior to the Global Precipitation Measurement (GPM[1]) mission launch, the first GPM Applications Workshop[2] took place. Scientists, Earth observation data users, and *end users* (those who use various decision support systems where Earth science data is used as input) all gathered to learn how data from (at that time) the Tropical Rainfall Measuring Mission (TRMM) were being applied to variety of science and societal issues and what was anticipated from GPM. In order to keep the lines of communication between science teams and the user community, NASA's Applied Science Program intended this to be the first in a series of workshops, and to that end, another workshop was tentatively planned for the spring of 2015.

The GPM Core Observatory, co-led by NASA and the Japan Aerospace Exploration Agency (JAXA), launched successfully in February 2014. The satellite is now well into its second year of operations. The GPM Mission represents a constellation of nine domestic and international satellites that provide estimates of rain and snow worldwide every three hours. The constellation is centered around the GPM Core Observatory satellite, which encompasses the Dual Frequency Radar (DPR) and GPM Microwave Imager (GMI) instruments. Together these instruments are used as a reference standard to unify precipitation data from partner (constellation) satellites. The GPM Core Observatory is a follow-on to the Tropical Rainfall Measuring Mission (TRMM), which ended its mission in April 2015 after providing unprecedented precipitation data for 17 years. While GPM builds on the success of it predecessor, it is also fulfilling its own unique mission that goes far beyond that of TRMM.

With the GPM mission well under way and data products now rolling in both from GPM and from the combined constellation via IMERG[3], the time was right to assemble the community again. The second GPM Applications Workshop took place June 9-10, 2015, at the University of Maryland Conference Center, Hyattsville, MD. In all, there were 108 participants onsite, with up to 30 others participating via *WebEx*. Included among them were representatives of government agencies, academia, the private sector, and international organizations, and others. This meeting was an opportunity to formally introduce the capabilities of GPM to the user community, outline many of the advancements and provide overviews of how TRMM and GPM are being used in a broad range of applications. On June 11 there were two, half-day training sessions to further familiarize people with GPM data products, data access and visualization capabilities. Overall, the workshop provided an excellent opportunity for dialogue between users and scientists/managers about

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[1] GPM is joint endeavor between NASA and the Japan Aerospace Exploration Agency (JAXA).
[2] This meeting was summarized in "Measuring Rain for Society's Gain: GPM Applications Workshop" in the January–February 2014 issue of *The Earth Observer* [**Volume 26**, **Issue** 1, pp. 4-11].
[3] IMERG stands for Integrated MultisatellitE Retrievals for GPM.

how the GPM applications program can grow to better address the user community's needs

This white paper summarizes the presentations at this workshop. Nearly all of the presentations are available for download from pmm.nasa.gov/meetings/2015-gpm-applications-workshop/files. Finally, a high level summary of this workshop will be posted in the Earth Observer.

Opening Plenary Sessions

The meeting began with a plenary session that presented an overview of Applied Sciences and the GPM mission, followed by a session that focused on science advancements from TRMM to GPM.   These were intended to (re)introduce GPM to the user community and present new scientific research that provided initial assessments of GPM data accuracy and performance.

Overview of NASA's Applied Sciences Program and the GPM Mission

Dalia Kirschbaum [NASA's Goddard Space Flight Center (GSFC)—*GPM Deputy Project Scientist for Applications* opened the meeting, welcoming the participants and reviewing the agenda for the next two days. A goal of this gathering was to introduce the precipitation data products—particularly new ones—to existing and potential *users*—many of whom may be sitting in the room. On that note, she said that face-to-face gatherings like this are useful for networking and growing our GPM "user community". She challenged the participants to consider: *Who is it that should be here for this meeting that isn't?* Kirschbaum set the tone for a forward-looking workshop that considers which research topics and/or applications questions should be driving future precipitation measurements—i.e., beyond the GPM mission. Another key element is to gather input for the next Decadal Survey—see *Planning for the 2017 Earth Science Decadal Survey*.

Planning for the 2017 Earth Science Decadal Survey

Approximately every 10 years, the National Academy of Sciences assembles a committee to gathers information from the science community on priorities and needs for Earth Science. The last survey was compiled in 2005–06 and the results were published in 2007[*]. Following completion of the 2007 decadal Survey, the National Research Council (NRC) prioritized 15 satellite missions to enable NASA to provide the public with ongoing information about global climate and climate change.

A new survey is now gearing up with an approximate 2017 release planned. The National Research Council (NRC) expects to appoint an *ad hoc* steering committee and a series of discipline and interdisciplinary study panels to carry out the second

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NRC decadal survey in Earth Science and Applications from Space. During the meeting, **Lawrence Friedl** explained that the 2007 decadal survey focused heavily on missions; the 2017 one is expected to be "broader in focus". It will ask us to identify the research questions that should be our priority in the coming decade, to identify the needs for applications, and to propose what the balance between research and applications should be. The last two items in particular suggest that workshops like this can provide valuable input into the next survey.

* – "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", National Academies Press (2007). Available at www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the

Lawrence Friedl [NASA Headquarters (HQ)—*Director of Applied Sciences for NASA's Earth Science Division*] gave an overview of Applied Sciences. NASA defines science as including research, applied research, and applications. Connecting science and scientific research to actionable societal applications is a priority for NASA. New missions are being developed with applications in mind from the very beginning. To emphasize this, he showed a slide listing many applications-related activities (e.g., meetings, workshops, tutorials, publications) that have occurred since the first GPM Applications Workshop in November 2013. Friedl ended by discussing the specific objectives of this workshop from the NASA Applied Sciences perspective, charging the participants to provide feedback about how they are using GPM products, what is inhibiting them from more rapidly adopting such products, and who else should we involve as end user communities as we grow the GPM applications program.

Ramesh Kakar [HQ—*TRMM and GPM Program Scientist*] gave an overview presentation that introduced GPM as well as gave a status update on the TRMM mission, which at the time had been passivated but was just about to reentered Earth's atmosphere. TRMM had established an impressive range of applications and end users. GPM builds on that legacy and expands it by extending the coverage of the mission to 65°N-S and using input from an international constellation to provide greater spatial and temporal coverage than was possible with TRMM. GPM can study precipitation in greater detail—and with greater accuracy—than its predecessor. Kakar proceeded to discuss the two GPM instrument [GPM Microwave Imager (GMI) and Dual Frequency Radar (DPR)] and gave more details about the constellation members. DPR provides a reference standard for GMI, which is then used to "tune" the other radiometers in the constellation—i.e., it improves their accuracy.   He then went on to discuss some of the more interesting results from GPM's first year, introduced the data products, and the wide range of applications for GPM data. (Subsequent presentations describe these areas in more detail.)

Gail Skofronick–Jackson [GSFC—*GPM Project Scientist*] began with an animation showing GPM in action. She used the analogy how the GMI scans the surface, like a x-ray, while the DPR examines rain and snow layer by layer, like a CAT scan. She then discussed some of the GPM enhancements compared to TRMM including

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increased Earth coverage and more advanced instruments. Skofronick–Jackson particularly emphasized the improvements to the radiometer, which she called the "best ever precipitation radar in space today". GMI employs four-point calibration[4] (as opposed to two-point calibration used on the TRMM Microwave Imager), which means that GMI measurements can be used to *unify* constellation (partner) radiometer measurements. She then discussed the differences in GPM precipitation products: GMI (GPROF), DPR, Combined GMI and DPR (CMB), and Multi-satellite (IMERG); she showed a global map of IMERG data from June 1-8, 2015. As was demonstrated with Hurricane Arthur in July 2014, GPM can track hurricanes much further north than TRMM. Also, unlike its predecessor, GPM can observe mid-latitude cyclones, as it did with the snowstorm on March 17, 2014. Skofronick–Jackson described a number of additional applications that use GPM data and summarized GPM ground validation activities, a global effort that includes direct validation sites and field campaigns conducted around the world to validate physical and hydrological retrievals from GPM. She mentioned that the NASA GPM Science Team[5] will be recompeted through ROSES in 2015 and referred participants to a reference article on GPM[6], written by Arthur Hou, the late GPM Project Scientist. Skofronick–Jackson closed by requesting that participants send one-to-two page *Power Point* summaries describing new science and applications using GPM data to herself and/or Dalia Kirschbaum.

Kinji Furukawa [JAXA—*Acting JAXA GPM Project Manager*] began by asking us to remember three acronyms from his presentation: JAXA, DPR, and GSMaP[7]. JAXA has partnered with NASA on both TRMM and GPM, and has provided instruments for other Earth Observing System missions. JAXA's slogan is: *Explore to realize*; they seek to realize safe and affluent society using space and the sky. The JAXA slogan for GPM is: *Measure rain and snow for the benefit of all.* Furukawa shared more details about DPR, the JAXA instrument on GPM. As its name implies the radar measures at two microwave frequencies: Ka and Ku and can produce three-dimensional profiles of precipitation (analogous to a CAT scan); it also provides a reference standard for GMI, which in turn is used to calibrate the constellation radiometers. He showed an example where DPR observed Typhoon Halong in August 2014. He then proceeded to discuss GSMaP, which is a multi-satellite precipitation product produced by JAXA, providing hourly global rainfall maps in near real time. (For additional details, see Misacho Kachi's additional presentation in the next section.) Furukawa concluded with a brief discussion of how to retrieve GPM data from JAXA.

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[4] Unlike other microwave imagers, the GMI uses a secondary calibration system with noise diodes on the lower frequency channels. The noise diodes provide four calibration points, rather than just two. The dual calibration system enables on-board trending of non-linearity, as well independent cross-checking of each calibration element for stability and anomalous behavior.

[5] This is a Team of teams that includes 56 NASA Principal Investigator (PI)-led teams and 23 no-cost international PI-led teams.

[6] Hou, A. Y., R. K. Kakar, S. Neeck, A. a. Azarbarzin, C. D. Kummerow, M. Kojima, R. Oki, K. Nakamura, and T. Iguchi (2014), The Global Precipitation Measurement Mission, Bull. Am. Meteorol. Soc., 95(5), 701–722, doi:10.1175/BAMS-D-13-00164.1.

[7] GSMAP stands for Global Satellite Mapping of Precipitation.

George Huffman [GSFC—*GPM Deputy Project Scientist, Chair of Multi-satellite Mission Team*] began his presentation discussing the evolution of precipitation data products. TRMM was originally designed for 5˚ x 5˚ degree monthly data for the tropics, but the mission expanded to have a much stronger applications focus, which necessitated finer scale data. TRMM experimented with a Constellation concept; GPM built on TRMM's success and the International Constellation is now an integral part of the mission. GPM is not just TRMM-plus, however. New algorithms need time to be "tuned" to the system. Huffman showed the diverse, changing, uncoordinated set of precipitation-relevant input data that are part of the Constellation. Current passive microwave coverage of the globe is dense; it meets the criteria of covering the Earth within three-hour about 90% of the time. However, there are still gaps, and many applications require finer time intervals. In order to achieve a higher resolution product, the Integrated Multi-satellitE Retrievals for GPM (IMERG) product uses *morphing*, which means it interpolates between microwave overpasses from constellation sensors. The IMERG algorithm combines the TRMM Multi-Satellite Precipitation Analysis (TMPA), CMORPH[8], and PERSIANN algorithms to create a 0.1ºx0.1º, 30 minute product. Huffman showed a slide of how TRMM data products mapped into GPM data products, then proceeded to describe how one accesses data. He showed the IMERG access page as an example, then listed systems that provide the data and discussed latency for near real time products. Participants had an opportunity to learn more about IMERG during a "Meet the Developer" brownbag, that took place during lunch, and there was also a poster related to IMERG as part of the afternoon poster session.

Q&A/Discussion
There were several specific questions about data products for Huffman and the other speakers. Several raised questions about transitioning from TRMM (TMPA) to GPM (IMERG). Huffman and Skofronick–Jackson asserted that the plan was to continue processing TMPA through 2017.

Science Advancements: TRMM to GPM Era

Dave Randel [Colorado State University] began by commenting that while the GPM Constellation concept looks nice on a graphic, in practice there is lots of work that must be done to make it work. He then described how the GPM algorithm process works to incorporate measurements from DPR and GMI for Level 1 and Level 2 products utilizing the Goddard Profiling Algorithm (GPROF). Randel describe the development of the latest version of GPROF 2014, which is a *Bayesian algorithm*, meaning it is based on empirical data and relies heavily on the data that has been collected to date to "match" the signals that the satellite obtains to what we experience as precipitation on the ground. Randel showed comparisons of GPROF 2014 and the previous version GPROF 2010 (which was based on *Version 7* of the TRMM algorithm). He also mentioned challenges that still need to be overcome.

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[8] CMORPH stands for the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center's Morphing Technique.

Orographic precipitation and land/water areas are still difficult to represent. He also noted that a Bayesian algorithm is ultimately insufficient to handle extreme precipitation events. Improved classification of land and phase discrimination of precipitation is needed to move toward a physical model for precipitation.

Joe Turk [NASA/Jet Propulsion Laboratory] described "big picture" improvements of GPM over its predecessor—particularly focusing on land surface. He started with a chronology of precipitation measurement techniques (which have progressed toward increasingly complex representations of precipitation physics) and also of precipitation-sensitive satellite observation, which were originally completely research-oriented, but have moved toward having an increasingly operational focus. Turk then explained the crucial role that the GPM radiometer plays in assessing the condition of the surface. The radiometer essentially "stares" at the Earth's highly variable surface and can measure emissivity whenever it is not raining. Emissivity varies the most over oceans but scientists understand the physics over the ocean pretty well; land surfaces, transition areas (coasts), and inland bodies of water are areas of active research. The emissivity values from the radar are useful because they allow for improved surface classification, which feeds into the GPROF algorithm and improves the accuracy of GMI measurements. Turk showed results from a comparison of CloudSat radar[9] and GMI over Northern Canada, Chilean Coast, off the East Coast of Finland, and Seattle, WA. GMI only looks at precipitation while CloudSat looks at the whole cloud, nevertheless the results seem similar from both instruments. He explained that in the future there will be increased use of physical models for land emissivity; more realistic forward modeling of clouds/precipitation; and more efficient methods to couple land info to the retrieval techniques. Turk said we are moving, "toward an integrated hydrological observing system", which **Christa Peters-Lidard** described further in her presentation.

Misako Kachi [JAXA, EORC] covered GSMaP and GPM applications, which include: weather forecasting/monitoring, flood warning/prediction, agriculture/industry/education, and public health. GSMaP has its own algorithm, taking rainfall data from multiple sources and creating a merged rainfall product. Kachi proceeded to present some GSMaP user analysis (by region and purpose) then she went into more detail on some of the specific applications: flood mapping and agricultural insurance. She also described GPM synergies with other satellites [TRMM, Himawari-8 (a Japanese Weather Satellite)/AHI, GCOM-W1/AMSR2]. She mentioned that a GSMaP NOWCAST product—with 0.5 hour latency—will be available soon covering the East Asia region. She ended by describing two GMI research products for sea surface temperature and sea ice concentration.

Christa Peters–Lidard [GSFC—*Deputy Director of Hydrospheric and Biospheric Sciences*] said that there are "unprecedented opportunities to understand hydrology more comprehensively than ever before." She showed the fleet of Earth observing

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[9] Another satellite-based radar system intended for studying clouds, http://www.nasa.gov/mission_pages/cloudsat/.

satellites and noted how many have hydrological applications. She discussed the idea of integrated hydrologic validation, which involves assessing the performance of satellite precipitation products in hydrological and water resources applications and characterization of model and observation errors. She discussed the Precipitation Measurement Mission (PMM) Hydrology Working Group, of which she is a member. The working group focuses its activities around two questions: H*ow can we improve current and future PMM products? How useful are current and future PMM products for hydrologic science and applications?* For the remainder of the presentation she focused on synergy between GPM and the Soil Moisture Active Passive (SMAP) mission[10] in areas such as product evaluation, improving precipitation products, improving retrievals, joint retrievals, and coupled physics. She concluded by introducing several future missions that should add to the hydrological information that is available such as the GRACE-Follow-on, ICESat-2, and SWOT, which should produce monthly water budgets, surface water and snow products, and surface water/discharge products, respectively.

Panel Plenary Sessions

With the general background on Applied Sciences and the GPM mission in place, the remainder of the meeting concentrated on the details of the applications.   There were five panel plenary sessions that were set up to align with elements of the Applied Sciences program. These were:

- Weather Forecasting;
- Weather Communication;
- Water Resources, Food Security, and Agriculture;
- Public Health and Ecological Forecasting; and
- Disasters

The format was very similar to that which was used at the first workshop. With the exception of Weather Communication, each session began with a keynote address, followed by three presentations on related topics. Afterward the speakers reconvened on stage for a panel plenary discussion (with the keynote speaker serving as chair), during which the panel also addressed questions from the audience. In the case of Weather Communication, there was no keynote address. The three presentations, one of which was remote, took place just as with the other sessions, but there was no formal panel discussion at the end.

Weather Forecasting

Benjamin Ruston [Naval Research Laboratory, Ocean and Atmospheric Science and Technology Directorate] began with some background on NRL, which is comprised

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[10] **EDITORS NOTE**: The SMAP radar halted transmissions on July 6, 2015, and is not operational at this time. The radiometer, however, continues to collect science data.

of six divisions performing scientific and technical research. His focus was on numerical weather prediction at NRL. Ruston explained that *ensemble modeling methods*, where input from more than one model is synthesized to produce a forecast, are essential to really "get [weather forecasting] right". He pointed out that ensemble methods help "remember" the precipitation input better than relying on a single model. Having multiple inputs also helps to produce a more accurate portrayal of the actual atmosphere.

Ruskin described the current version of NAVGEM[11] (*Version 1.2.1*) which is replacing the older NOGAPS[12] model, and showed the impressive list of instruments whose data is already assimilated, with more planned for the future. He also talked about future versions of NAVGEM. NAVGEM *Version 1.3* is scheduled for operational promotion this month (June 2015). After summarizing the improvements both to data assimilation and the forecast model itself, Ruston focused on the improved cloud fractions over the current version. Most noteworthy is the improvement in the ability to detect high clouds, particularly in tropical convective regions, and significant improvement in solar radiation budget. Quick on the heels of that release, *Version 1.3.1* is planned for October 2015 and Ruston summarized the improvements and then focused on one in particular, namely Geostationary Clear Sky Radiance. In this context, he spent time focusing on the work they have done to assimilate data from the Crosstrack Infrared Sounder (CrIS) onboard Suomi NPP into their model.

In 2016, NAVGEM *Version 1.4* is scheduled. Updates in this version are primarily related to data assimilation. A noteworthy addition will be the incorporation of global four-dimensional data assimilation (4DVAR). Also, as NOGAPS continues to transition to NAVGEM, there is an emphasis on better parameterization of upper level (i.e., stratospheric) radiances to reduce upper level temperature biases, thereby improving the model's accuracy. As an example, Ruston described the new parameterized water photochemistry planed for Version 1.4 and beyond. Upgrades keep on coming! NAVGEM Version 2.0 is also planned for 2016, with even more improvements. He closed by discussing several new research activities at NRL including: CalWater2, which focuses on atmospheric rivers; High Impact Weather Prediction Project (HIWPP) which is a collaboration with the National Oceanic and Atmospheric Administration's (NOAA's) Earth System Research Laboratory (ESRL); Next Generation Global Prediction System (NGGPS), a NOAA National Weather Service (NWS) research-to-operations initiative to expand and accelerate critical weather forecasting research to improve accuracy of weather forecasts; and a project aimed at optimizing global and regional Earth prediction.

Kevin Garrett [NOAA's National Environmental Satellite Data and Information Service (NESDIS), Joint Center for Satellite Data Assimilation (JCSDA)] described efforts to prepare to assimilate GPM data at NOAA. They have been preparing pre-assimilation tools for data quality assessment, i.e., comparing GMI observations to GMI simulations. JCSDA has also been preparing preprocessing algorithms for data

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[11] NAVGEM stands for Navy Global Environmental Model.
[12] NOGAPS stands for Naval Operational Global Atmospheric Prediction System.

assimilation and preparing data assimilation systems for GMI use in NWP using Observing System Experiments (OSE). Garrett described work on data gap mitigation, developing the capability to assimilate GMI brightness temperatures into NCEP GDAS[13]. JCSDA is coordinating with NESDIS, NCEP, and NASA to achieve near real-time ingesting and processing of GMI data. He showed an example of how the forecast track of Hurricane Julio, which tracked across the Eastern/Central Pacific August 4-8, 2014, is improved when GMI data is assimilated versus when no satellite data is used.
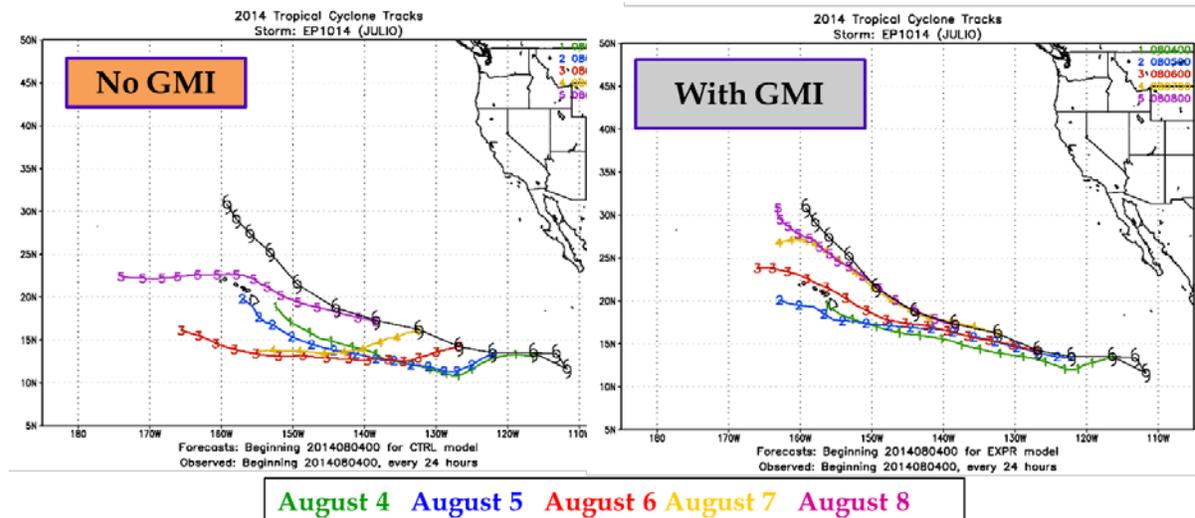

Figure X: Forecast tracks for Hurricane Julio (2014), which occurred off the coast of Mexico from 4-8 August. The track lines indicate the forecast for each of the days the storm occurred. The left plot shows track forecasts made without assimilating GMI data, the right shows track forecasts with GMI data assimilated. The results indicate that the forecasts better match the "true" forecast shown in the black track when GMI data is included in the modeling.

Brad Zavodsky [NASA's Marshall Space Flight Center (MSFC) Short-term Predication Research and Transition (SPoRT) Center] began with an overview of the center[14]. SPoRT works to transition unique NASA and NOAA observations and research capabilities to the operational weather forecasting community to improve short-term weather forecasts on a regional and local scale. Zavodsky described how SPoRT works with users to identify problems/challenges throughout the process and develop solutions. He then focused in on SPoRT's work as a GPM Early Adopter. In this role, SPoRT has worked to transition Level-1 GMI data to forecasters at the National Hurricane Center and Weather Prediction Center. Forecasters can use this information to supplement radar data in data-void regions over water and parts of western U.S. SPoRT obtains real-time Level-2 rain rate data from the GPM Precipitation Processing System, formats it for AWIPS II and disseminates to forecasters. Zavodsky then spoke about work to integrate GPM Level-3 IMERG data

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[13] NCEP GDAS stands for the National Center for Environmental Prediction's (NCEP) Global Data Assimilation System (GDAS).

[13] http://weather.msfc.nasa.gov/sport/

to forecasters. He showed an example with Hurricane Blanca from June 4, 2015, noting that such data is likely more useful for hydrological applications to pinpoint areas of heaviest rainfall—due to latency. SPoRT has also completed work to integrate real-time high-resolution version of NASA Land Info System (LIS) used, for example, by SERVIR partners in East Africa for soil moisture diagnostics and local NWP model initialization. IMERG is replacing the TRMM TMPA product as the precipitation forcing dataset outside the continental U.S. and will also be used to validate regional model forecasts of precipitation.

Yasushi Suzuki [Japan Weather Association (JWA)] discussed satellite applications of weather services in Japan (*tenki.jp*). JWA is a private company, one of **62** private weather companies in Japan. Through the Meteorological Service Act, the Japan Meteorological Agency authorizes "the weather business." Approximately 30 Billion Yen is spent on weather forecasting with 9300 certified forecasters. JWA offers value-added products the fill in for the lack of public weather information. Suzuki showed *tenki.jp* website and discussed some of JWA's activity. JAXA's GSMaP products are used on the website. He described the Train Weather Channel for the Narita Express (NEX), which connects Narita airport and Tokyo. Passengers can find out about their weather both before departure and after they arrive. He then showed an image from the website that showed the GSMaP rainfall distribution over the Pacific as two tropical cyclones were approaching Japan. He also discussed providing information from GSMaP on mobile phones. His next slide showed the history of microwave radiometer data; the amount of data has increased by about five times since 2003. He then focused on a GMI case study of a heavy precipitation event in Japan. Results show that incorporating GMI data has improved precipitation forecasts from the JMA mesoscale NWP system.

Panel Discussion
After responding to a couple of questions specific to technical details of their presentations, the panelists fielded questions on how observations from satellite sensors are integrated into numerical weather prediction (NWP) models. Specifically, all panelists responded to a question from Dalia Kirschbaum on the extent to which advanced GPM measurements improve NWP when assimilated. The panelists agreed that there are challenges to assimilating Level 1 and Level 2 data as well as incorporating DPR data something that most NWP models have not yet figured out how to do. The panelists stressed that there are efforts to make adjustments to microphysics in the NWP models using observational guidance, such as work that is being done at the University of Alabama. However, there is still no straightforward way to assimilate this detailed information. The panelists also explained that the integration of such data is model dependent (e.g. global model cloud vs. radiative transfer clouds), citing that parameters must mesh with the selected model. Overall, the panelists seemed optimistic on how GPM Level 1 and Level 2 data could ultimately improve the forecasts. They also emphasized that validating forecasts using near real-time products such as IMERG enables you to

quickly determine bad versus good observations faster than the typical lag-time of 24 to 48 hours for most data sources would allow.

Weather Communication

Todd Hutchinson [The Weather Company (TWC)] discussed the use of GPM/IMERG data at one of the world's largest private weather companies that provides services to a wide variety of consumers and broad spectrum of business—www.theweathercompany.com. (*The Weather Channel* is part of TWC.) They offer services both directly and indirectly to consumers, business-to-business connections, and services to governments and agencies. Hutchinson described how TWC collects data from government and partners to input into their own global forecasts, which can be augmented by human forecasters as needed, to produce compelling and useful products. Satellite data drives TWC content through: forecasting situational awareness, indirect forecasting applications, and "storytelling". Use of data from polar orbiting satellites is increasing for mapping the global state of precipitation, graphical animations of global precipitation, and NWP initialization. He proceeded to describe some recent analysis comparing IMERG data to NOWRad observations. He showed how NOWRad compares to the IMERG Early Run (which currently has a latency of six hours after observation, with the goal of 4 hours) and Late Run (which has a latency of 16 hours after observation, with the goal of 12 hours). The overall agreement between the two is good but there are areas for improvement. IMERG seems to have too much heavy precipitation and not enough light precipitation; both capture the same amount of "no precipitation"—which is good! Reducing the latency of the Early Run to four hours would improve the agreement even further, as would increased microwave instrument coverage, smoother transitions from MW to IR data, and improved depiction of light precipitation.

Marshall Shepherd [University of Georgia—*via WebEx*] is the host of *WxGeeks* (www.weather.com/tv/shows/wx-geeks) on The Weather Channel, the first "Sunday morning talk show" dedicated to science, technology, and math (STEM)—with emphasis on weather and climate. Shepherd focused his presentation on the role the program plays as a communications tool for the science community. It is intended to provide a forum for important conversations within the larger weather community. He then outlined why such conversations are crucial, showing a guest commentary[15] that he wrote for The Washington Post's *Capital Weather Gang* (discussed in the next summary) entitled "Cutting NASA's earth science budget is short-sighted and a threat". He suggested that the mere fact he has to write a column defending investment in NASA's Earth Science Program shows why science communication and outreach is essential. There is a gap between the opinions of scientists and the general public. To reinforce this, he showed a slide that showed

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[15] http://www.washingtonpost.com/blogs/capital-weather-gang/wp/2015/05/01/cutting-nasas-earth-science-budget-is-short-sighted-and-a-threat/

the significant difference in the opinions of scientists[16] versus U.S. adults on a variety of questions related to biomedical science, climate, energy, and space sciences. Just to give one example: 87% of scientists believe human beings are making significant contributions to climate change, whereas only 50% of the wider adult population share that opinion. Shepherd explained that "too many scientists are comfortable in the ivory tower, journal space, and conferences. However a gale of misinformation rushes in to replace the void if scientists are not communicating to the public, stakeholders, and students." Furthermore said Shepherd, "I think many scientists are stuck in the old perception that scientists that also do outreach are selling out or not "true" scientists." Shepherd would like to change that perception. He closed by saying that topics being discussed in this workshop is what public and policymakers care about—i.e., applications not algorithms. However, by and large, they don't read science journals or go to our conferences. His advice was not to be afraid of using media formats to get your message out; a show like WxGeeks demonstrates that it is possible to maintain a high science standard while at the same time making the information "consumable".

Jason Samenow [The Capital Weather Gang] was featured on an episode of WxGeeks that focused on weather and social media. The Capital Weather Gang (www.washingtonpost.com/blogs/capital-weather-gang/) is part of the weather team for *The Washington Post*. They are meteorologists and science writers who focus on the weather in the Washington, DC metropolitan area as well as on national and international weather and climate, astronomy, and space weather-related stories. They place emphasis on reader engagement and communicating uncertainty. Samenow showed a series of images called "The Ten Most Amazing Images from Hurricane Isaac"[17], from August 2012, which included two TRMM images. The "gang" also did a news story about the GPM launch and on a rainy week for otherwise dry California in December 2014. Based on his experience, Samenow provided some advice about effective communication. He said that timely (as close after the event as possible) and compelling visuals are very important to capturing the public's attention. Whatever the story is, it needs to be communicated quickly, as the public's attention span tends to be quite short. If the consumer has to "think too much" then the communication will probably be less effective. The images provided need to be easily accessed and explained. Three-dimensional images are cool, but they are often more difficult to understand. He said that imagery ought to be able to stand on its own—i.e., apart from the accompanying story. To do this, good captions are important, as are easy to understand legends and clear labeling. Metric measurements are indeed commonly used in science, but they are not commonly used in other areas, so for an audience in the U.S. it is essential to provide English units in addition to or even in lieu of metric units. Samenow ended with some information on how to engage with The Capital Weather Gang through various social media outlets: e.g., blog, *Facebook*, *Twitter*.

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[16] The survey defined *scientist* as members of the American Association for the Advancement of Science (AAAS).

[17] http://www.washingtonpost.com/blogs/capital-weather-gang/post/hurricane-isaac-15-most-amazing-images/2012/08/30/4cb5f084-f2da-11e1-adc6-87dfa8eff430_blog.html

Water Resources, Food Security, and Agriculture

Gary Eilerts [U.S. Agency for International Development (USAID)] described the connections between the Famine Early Warning Systems Network (FEWS NET) and NASA. FEWS NET seeks to prevent famine and mitigate food insecurity by providing decision makers with information that is accurate, credible, timely, and actionable; they also seek to strengthen the ability of member countries and organizations to provide timely early warning and vulnerability analysis. Eilerts introduced the concept of food security mission creep, where food security ends up dovetailing into a variety of different areas—e.g., food and nutrition security, chronic food insecurity, resilience and development in the most difficult places, water security, and unresolved conflicts. It is difficult to set priorities when so many areas can fall under the "umbrella" of food security, so FEWS is both a product and a tool to address these issues.

FEWS has more resources to work with than ever before, including 30+ years of satellite observations, more socioeconomic data, and more data and insights about people and their problems. He then went on to describe the FEWS Land Data Assimilation System (LDAS), which is an example of a "spreadsheet" that helps users organize their data so they can ask new questions and get them answered in a timely fashion. He also showed a distribution of monthly grain prices in Africa, emphasizing that they now have a long enough time series of data to not just track change over time but also to tell whether a particular change is "out of the ordinary". His next example showed how having access from automatic transponders on ships (purchased from a web site) arriving into Yemen grain imports provided vital additional information that helped improve the accuracy of FEWS NET famine forecast for the area. This is an example of the value of having more people collecting and organizing data—and making it available to the public.

Eilerts next described how all this new information has allow researchers to formulate new questions that "we never thought we could ask". He showed three

examples focusing respectively on water scarcity, the actual costs of risk and disaster, and the benefits of alternate strategies. He ended by stressing the need for more and better information and tools, the need for innovation (which is usually driven by necessity—i.e., responding to specific needs. Communication between scientists and users can be really difficult but it is essential to find out and respond to what users really need—and progress is being made.

Wade Crow [U.S Department of Agriculture (USDA), Agricutural Research Lab] described a global root-zone soil moisture data assimilation (DA) system designed so that the soil moisture (SM) and rainfall (RF) products mutually compensate for their random errors. This DA system has been operational since the spring of 2014 in the USDA's Foreign Agricultural Service's Crop Explorer System (www.pecad.fas.usda.gov/cropexplorer/). The marginal value of SM is (roughly) proportional to the ratio: skill of SM/skill of RF. Crow then described the Global Precipitation Enhancement System, which uses the SM time series as an additional informational source for multisensor, real-time precipitation. He pointed out that the SMAP mission is now underway, and incorporating its data should lead to improvements in SM retrievals. In addition, the "friendly competition" Crow described above used TRMM data, so the integration of data from GPM/IMERG should lead to improvements RF data. He indicated that the latency requirements for this kind of hydrological application are not as stringent as those for NWP, so the IMERG Late run is likely ideally suited for use in this model. On the other hand, this comparison is based fundamentally on looking at interannual anomalies, so establishing continuity between TRMM and GPM is essential, perhaps more so than with NWP applications.

Amy McNally [GSFC] discussed joint NASA/USAID water security activities related to FEWS NET. She discussed the FEWS NET approach, which brings together data from a variety of sources and synthesizes it so that is can be used for food security decision support. Remotely sensed rainfall is essential for USAID Applications in data poor areas. Rainfall data (e.g. from TRMM and GPM/IMERG) is used to force land surface models, with that output as input for other water and energy balance models used to study drought and agriculture; such data also help with estimates of the start of the growing season[18] in places where rainfall is the determining factor. McNally stressed (as Gary Eilert had also discussed during the keynote) that food security is much more than agricultural monitoring. Her example was from a water crisis where water levels behind the Gaborone Dam fell to record lows in Botswana in early 2015, leading to a water crisis. *Google Earth* images from 2008 and 2014 dramatically illustrated the change in water level that resulted. After this, she went on to discuss the Weekly Hazards Assessment product, which allows researchers to put this drought in context—i.e., they can see how conditions in 2015 compare to other years. The drought can be classified by looking at soil moisture percentages from 1981 through 2015. So, for example, in Botswana, the data reveal that 2013

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[18] In this context, the *start of the growing season* is defined as the first *dekad* (~10 day period) with more than 25 mm (~0.4 in) of total rainfall followed by a combined total of more than 20 mm (~0.8 in) in the next two dekads.

and 2015 are part of a longer-term drought, similar to what happened between 2002 and 2005, when the Garborone Dam water level dropped to 16% of normal. The IMERG product is likely to be an important source of additional information for near real time drought monitoring. However, longer term analysis has to be done with older rainfall products—until IMERG is consistent with TMPA

Curt Reynolds [USDA, Foreign Agricultural Service (FAS)] began his presentation with an overview of the activities of FAS. They primarily focus on USDA's overseas activities, market development and information, international trade agreements and negotiations, and collection and analysis of crop production and trade statistics. He described USDA's economic information system and economic intelligence system, showing a series of slides indicating that wheat, corn, and soybean prices continue to rise over time; low supply of crops leads to increases in prices; global production of soybeans has surpassed that of wheat and grain; and the largest market for soybeans are shipments from Brazil to China. He then discussed monthly crop estimates and trade reports that are released at specific times to commodities markets. The FAS's Office of Global Analysis' (OGA) International Production Assessment Division (IPAD) was created to produce the most objective and accurate assessment of global agricultural production outlook and conditions impacting global food security. USDA's Production and Supply (PSD) database (https://apps.fas.usda.gov/psdonline/) is used for market intelligence. IPAD builds on the heritage established by previous NASA–USDA–NOAA collaborations on LACIE[19] (1970s) and AGRISTARS[20] (1980s). Reynolds summarized IPAD data sources, emphasizing the "strategic intelligence" that comes from satellite information. He then reviewed the Global Agricultural Monitoring System (GLAM), which is a USDA–NASA collaboration to produce crop area and yield estimates from remotely sensed data. He next discussed efforts to map crop type using Landsat imagery, pointing out that the size of croplands can correlate with incidences of food insecurity. He also described the Crop Explorer database (www.pecad.fas.usda.gov/cropexplorer/) that provides maps and time series graphs of major crop regions, and showed some example of precipitation maps from Crop Explorer for May 21-31, 2015 from a variety of sources. He also discussed operational weather, soil moisture, and process crop yield models, which use both World Meteorological (WMO) station data and satellite derived data as input.   The WMO's Station Explorer gis.pecad.fas.usda.gov/WmoStationExplorer/) has station data from around the world. Reynolds closed with a list of the NASA satellites that FAS currently uses (he described Landsat 7 and 8 and MODIS onboard Terra and Aqua as their "left and right arms"); he also discussed some of the limitations when using TRMM products.

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[19] LACIE stands for Large Area Crop Inventory Experiment, which was implemented in the 1970s to study how to utilize Landsat and NOAA satellite data to study agriculture.
[20] AGRISTARS stands for Agriculture and Research Inventory Surveys Through Aerospace Remote Sensing, which was created in the 1980s for the purpose of developing automated applications for Landsat, NOAA AVHRR, and weather data from the U.S. Air Force Weather Agency (AFWA).

Public Health and Ecological Forecasting

Ben Zaitchik [John's Hopkins University—*Assistant Professor, Earth and Planetary Science Program*] gave the session's keynote presentation, delivering his thoughts on connecting Earth-observations to ecological forecasting and public health applications. He began by pointing out that most applications are highly mediated and often multi-scale systems. For example, there are several factors that influence the transmission of malaria, and climate is one of them (e.g., precipitation patterns). He noted that models have a strong empirical component and provide a consistent framework for which to compare and analyze data, e.g., the relationship between climate and malaria. He addressed this by citing an example of malaria outbreaks in the Loreto Province of Peru. Through the evaluation of multiple potential land cover variables and forcing data, the study found that 1-day rainfall from TRMM had the most significant correlation with breeding sites for mosquitos. He explained the model prediction in terms of the daily, monthly and seasonal forces acting on the breeding ground of the disease and discussed how processes of interest unfold over time. For this reason, both TRMM and GPM data as well as other earth observation products (e.g. temperature, humidity, etc.) are valuable for understanding the potential modes of variation with vector borne and other diseases. Zaitchik closed by explaining the importance of communication between data providers and end-users, pointing out that with accessibility come risk, and that data providers need to facilitate interpretation.

Molly Macauley [Resources for the Future—*Vice President for Research*] addressed the value of information attributes. She discussed the economic benefits of using GPM data, explaining how spatial, spectral, and temporal domains influence public decisions and actions. Specifically, she introduced a study that was able to define the tradeoffs between providing reliable warnings at specific lead times (in hours) before an event and the benefit or cost of making that warning. As an economist, Macauley provided a different perspective of how the decisions to issue warnings or take action can be regarded as tradeoffs with the expected frequency and severity of the event.

Anta Jutla [West Virginia University—*Assistant Professor of Civil and Environmental Engineering*] talked about the role of precipitation in creating environments for diarrheal diseases. Hydroclimate relates to diarrhea through macroscale, microscale, and ambient processes. The work he presented focuses on

macroscale—processes outside the pathogen and the person. The cholera paradigm ends up being the perfect model to understand the transmission of vector borne outbreaks. Cholera outbreaks can be epidemic, endemic, or mixed mode and Jutla described the characteristics of each. Epidemic outbreaks are most influenced by precipitation. He showed a specific example of how temperature and precipitation data can be used to predict epidemic cholera outbreaks. He showed a map of the risk of cholera in Nepal for 2015. He then went on describe a predictive endemic cholera model. Future work will expand to modeling other diarrheal pathogens utilizing earth observation data.

John Haynes [NASA Headquarters—*Program Manager for Health and Air Quality*] explained why health and air quality are connected under Applied Sciences. So many airborne pathogens lead to health impacts. NASA's Health and Air Quality Applications Area supports the use of Earth-observations in air quality management and public health, particularly regarding infectious disease and the environmental health issues. He discussed global emerging diseases and then new environmental threats that NASA is monitoring. As an example, the Aqua mission measured volatile organic compounds produced by the Gulf oil spill. He discussed the four parts of the mission statement for NASA's Health and Air Quality Program, which Haynes described as being at the intersection of epidemiology and remote sensing. He then went on to describe some of the projects that have been funded.

Panel Discussion
The panel fielded a number of questions from workshop participants about reducing latency times, the uncertainty of IMERG data, and restructuring data access. One of the things that all of the panelists seemed to agree on was that the increased spatial and temporal resolution of IMERG relative to TRMM as well as decreased latency is highly valuable for their models inputs. They also stressed that having a standard satellite climatological tool would be very useful, emphasizing that oftentimes the absolute value of the measurements are not important, but rather the deviation from "normal" that matters most. Another issue that the panel discussed is the communication of uncertainty.

Disasters

Frederic Zanetta [International Federation of Red Cross and Red Crescent Societies (IFRCS)] described how the IFRCS uses Earth Observations at various stages in the Disaster Cycle: relief, recovery, and response preparedness and mitigation. Earth observations are particularly useful for response preparedness. About 50% of the disasters the IFRCS responds to are natural (e.g., flood, storm, landslides). Preparedness involves having good information, effective means to disseminate this information, awareness of the local context, and capacity to turn information into shorter and longer term actions that "bridge timescales". Earth observing satellite data is an extremely useful source of information that, once made available and catered to the specific context, can be applicable to a range of topics covering a

broad temporal spectrum. For example, short term weather forecasts can warn of impending hazards that require rapid response; seasonal forecasts can assess the level of risk in the coming months and provide more lead time to take action; and climate models can suggest longer term risks and trends, with even more time to plan responses. Zanetta showed an example of how information on different timescales helps decision makers prepare for a flood hours, days, weeks, months, and even years in advance. He discussed the elements that make up an effective early warning/early action (EW/EA) system: risk knowledge, technical monitoring and warning services, dissemination and communication, and response capability.

Zanetta then broke down IFRCS's disaster response capabilities into three levels: international, regional, and national. IFRCS has limited in-house resources at the international level. Instead they rely on the expertise of others, e.g., NASA, International Research Institute for Climate and Society, Dartmouth Flood Observatory (DFO), Global Disaster Alert and Coordination System (GDAC), UNOSAT[21]. Earth observations are used to cross-check funding applications for imminent crisis and response, particularly for small and mid-scale disasters that aren't always covered by the media. IFRCS uses this information to help them plan response to disasters. They can assess the extent of floods, rainfall rates (they use TRMM currently) and winds, which can give an idea of the power of storms. On the regional level, the effort is focused on getting more precise data distributed in the languages spoken in the area impacted by the disaster. Zanetta described a partnership between IFRCS and the African Centre of Meteorological Application and Development (ACMAD) for EW/EA. ACMAD issues seasonal forecasts and weekly bulletins that are useful resources for flood preparedness in Africa. On the national level, IFCRS has an auxillary role to that of the government in disaster response. They typically establish a connection with the national disaster office and/or meteorological office, and help by relaying local information in the local language, but the government is the one implementing the response. He showed an example where IFCRS supported a response to disaster in the Caprivi Region of Namibia and another where they aided response to floods in Southern Africa.

Zanetta closed out describing limitations to making use of NASA data. Apart from some data usage issues, by far the biggest limitation is communication. He stressed that end users don't "speak science", and what is required is a commitment of those who support transformation of observations into understandable and directly usable information.

Sezin Tokar [USAID, Office of U.S. Foreign Disaster Assistance (OFDA)] described disaster risk reduction activities at USAID, where the objectives are to save lives, alleviate suffering, and reduce the social and economic impact of disasters. USAID intervenes when a situation is beyond the capacity of the impacted nation to respond, the impacted nations will accept aid from the U.S., and responding is in the interest of the U.S. Government. Tokar showed some slides that graphically illustrated why USAID implements DRR activities. The number of people killed in

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[21] UNOSAT stands for United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme.

disasters has gone down since 1900; however, the number impacted has gone up. Since the beginning of the satellite era in 1960, we have become more aware of how many people are impacted by disasters than we were prior to satellite observations. Since 1960, the reported number of biological and geophysical disasters has remained fairly constant, but there has been a big increase in number hydrometeorological (e.g., hurricanes, floods) disasters reported. Again, this is likely tied to having satellites observing and increasing our awareness of weather-related disasters around the world. She went on to discuss the requirements for data products that decision makers find useful. Data and products must be timely, accurate, specific, relevant, consistent, historic, accessible, and in a format that is easy to use. The remainder of the presentation focused on the OFDA's Flash Flood Guidance System (FFGS) that provides information on flash floods across different regions. The system utilizes satellite precipitation estimates, forecast data, snowmelt prediction, and other variables to generate flash flood forecasts.

Chris Chiesa [Pacific Disaster Center[22]] gave background on PDC and described how they seek to build bridges between the science and technical community and decision makers. PDC's flagship product is the DisasterAWARE Platform[23]. Chiesa showed several examples of the program in action, including its use in forecasting Eastern Pacific Hurricanes Andres and Blanca in 2015. He showed maps of track forecasts, sea surface temperature, and population density, which helps determine what populated areas are in harms way He also showed where DisasterAWARE was used to monitor the floods in the Central U.S. during May 2015. Chiesa next described the Disaster Alert App, which is essentially a version of DisasterAWARE for mobile devices. PDC routinely ingests TMPA data into their DisasterAWARE platform and showed examples of how this was used for providing information to their end users following the Nepal earthquake. He ended with a review of who is using DisasterAWARE, which has over 1.5 million users worldwide.

James Kurz [Mercy Corps—Microinsurance Catastrophe Risk Organisation (MiCRO)] presented an overview of MiCRO, a specialty insurer founded in 2011after the Haiti earthquake which focuses on natural catastrophes and impacts to low income segments of the population. They have insured clients in Haiti and now are looking to expand into Central America, particularly Guatemala. They are a world-class public private partnership with the philosophy that people build businesses, acquire assets, and improve their lives only to have their progress destroyed by disaster or weather. They need a safety net. Kurz show a slide that illustrated the massive gap between economic and insured catastrophe losses worldwide. He then showed that in Haiti, only 1% of all losses were insure, whereas in Chile, 37% of all losses were insured. The point was to illustrate the difference insurance can make in helping to expedite recovery from disasters. Kurz then reviewed MiCRO's business model and summarized their goals as they expand into Central America, as

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[22] Chiesa gave a keynote presentation during the 2013 workshop, which is summarized in the report on the first GPM Applications Workshop [Volume 26, Issue 1, p. 30].

[23] http://www.pdc.org/solutions/products/disasteraware/

well as factors that constrain them. They seek to build a "minimum viable product" that can lead to a real breakthrough. MiCRO is trying to move a product (catastrophe microninsurance) from *unappealing* to *appealing*, creating products that renew and achieve scale. They begin with the most important weather risks (e.g., drought and torrential rain) and expanding and adding others as they grow. Satellite data (e.g., TRMM) is one of the tools they use to assess risks (e.g., drought and flooding) in a particular location. Lessons learned in this endeavor include the importance of developing a value-added program and the critical importance of an innovative and enabling environment.

Panel Discussion
One question that was asked during the discussion was: *How receptive are people to using satellite data?* There is still a good deal of suspicion surrounding such data. Many in the room understand both sides and can clearly communicate the linkages between satellites and applications—but those people are relatively rare. Another issue that came up was the increasing demand to have some sort of disaster response capability at NASA. Recent incidents such as the Deepwater Horizon oil spill into the Gulf of Mexico and the earthquake in Nepal highlight the need. The program manager for Disasters at NASA Headquarters responded that NASA is in the process of preparing a disaster response plan which will involve all NASA Centers and involve most if not all of the organizations represented at the workshop as well as many more.

Meet the Developer and Poster Sessions

In addition to panel plenaries and breakout sessions described herein, there were two other opportunities for attendees to engage with GPM data providers and share research during the meeting. A *Meet the Developer* brownbag lunch took place the first day with about 40 people participating. **George Huffman** and **Owen Kelley** [GSFC/George Mason University] gave some brief opening remarks about GPM data and IMERG that led into an extended question and answer session during which end users could ask more in depth questions about GPM data, access, and quality.

Dalia Kirschbaum asked about the availability of Geographical Information System (GIS) formats, specifically with respect to which products will be provided and archived. **Owen Kelley** explained that PPS creates GIS products very quickly but only the final IMERG product will be archived for the life of the mission. GIS products for the "early" and "late" runs of IMERG will be archived for one year. There was also discussion of the use of the "early" verses "late" IMERG runs for operational forecasters. **George Huffman** explained that the "late" run had backward propagation that would reduce the error and provide smoother transitions between time slices.

There was also a discussion of data quality. **Joe Turk** asked about the effect of the quality of the ancillary data, such as model forecasts, on the quality of the resulting precipitation products. **Dave Randel** stated that the model data was only used for selecting profiles in the development of the database and would not affect the final results. There was also a question on why it appeared that the "late" run had less precipitation than the early run. **George Huffman** explained that the backward propagation provided a better representation of the precipitation and the forward-only propagation of the "early" run will simply propagated existing precipitation regardless of development or decay. Amita Mehta inquired about validation of the IMERG product in complex terrain, specifically the mountains of Nepal, with respect to understanding the quality of the precipitation estimates there. George Huffman replied that the IMERG product had not been validated in complex terrain, but we expect better performance than TMPA.

There was also a poster session held after the Weather Communication panel (at the end of the first day of the workshop). Approximately 17 different end users and algorithm developers presented their research, allowing for one-on-one interaction and more detailed discussions about current projects and activities.

Breakout Sessions

The breakout sessions were focused around the four main panels presented at the workshop. The moderators of the breakout sessions were charged with answering several key questions:
1. What GPM data / products are you / the community currently using?
2. How has the transition to from TRMM to GPM taken place? What have been the limitations and benefits or why haven't you transitioned if you are already using TRMM data?
3. Are there additional feasible data products from GPM data sets would be helpful in your science or applications tasks?
4. What are the biggest impediments limiting your use of GPM satellite data and products?
5. What are the discipline/focus area science questions or application challenges that can be addressed with GPM data?
6. Who are your key partners or end user organizations that use NASA satellite data? Who are additional potential users that the community should reach out to?
7. Looking ahead, what are the challenges/opportunities that you would like to see addressed that could impact your community? Are there some key questions that have not yet or not fully been addressed that we should focus on for the applications user communities?

Each of the breakouts sought to answer or at least address these broad questions. Each of the groups touched on what data products are most meaningful to their disciplines. The Weather Forecasting community is mostly interested in Level 1 brightness temperatures or Level 2 rain rates that they can ingest in their NWP

models. The disasters community was most interested in the "early" version of IMERG, which will ultimately be available within 4 hours of observations, whereas the ecological forecasting and agriculture groups were more interested in the "late" product for IMERG. All groups consistently stressed the need for an extended climatology from which to evaluate anomalies and validate their models. Until a reprocessing takes place to join TMPA and IMERG data, many of the end users articulated that they were less likely to transition to using the IMERG product. Another point of discussion amongst the groups was the concept of the food/water/security nexus of coupling different models for improved situational awareness. This will help both for disasters as well as outlining transboundary water issues, vulnerable areas, etc. A final main point for the breakouts was the need for clear and reliable quality control metrics and continuity of measurements for operational models.

Workshop Summary

With GPM now a year-and-a-half into its mission, this two-day workshop provided an excellent opportunity to promote applications of GPM products as well as hear feedback from the community. Presentations, posters, and discussion showcased the capabilities of GPM products and gave attendees the opportunity to explore research and applications interests. This workshop also provided the framework for better understanding of applications user needs and challenges that will be used to improve the utility of data products and information with the community. There were for main themes that arose in the workshop:

1. There is a **clear need** for a long, consistent precipitation record. Many users will not transition from TRMM to GPM products until that record, or some "bridging" data set exists.
2. Spatial and Temporal Resolution varies by field. Having an "early", "late" and "final" IMERG product is appreciated by the user community and will be utilized by different user groups.
3. Data files, formats and access are not crystal clear. Users have difficulty deciding which product to use, how to understand the error, where to access the data, etc. Additional work needs to be done to better cater to these different levels of experience in the community.
4. Continuity of precipitation measurements is now an expectation by the community. The end user community assumes that NASA will provide precipitation measurements both continuously and with global homogeneity.

This workshop enabled a broad range of discussions, networking, trainings and valuable feedback to the GPM Program which the team is actively working to create into action items for the coming years. The next workshop will be scheduled for the Fall of 2016.

Acknowledgements

A huge thank you to the following individuals for taking notes, editing the above text and providing photos and comments: George Huffman, Jacob Reed, Dorian Janney, Kristen Weaver, Dave Bolvin, Kasha Patel.

Workshop and Training Photos

Disasters breakout session led by NASA HQ program manager for disasters David Green. Here Chris Chiesa (PDC) is bringing up a point to the group of approximately 25 people who participated.

Agriculture and Food Security panel and plenary discussion led by Gary Eilerts.

Presentation made by Jason Samenow from the Capital Weather Gang in the Weather Communication Panel.

Day Three training held at ESSIC, University of Maryland, College Park. There were two, 4-hour sessions to review GPM data products, access and provide hands' on training