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the earth observer

Editor's Corner

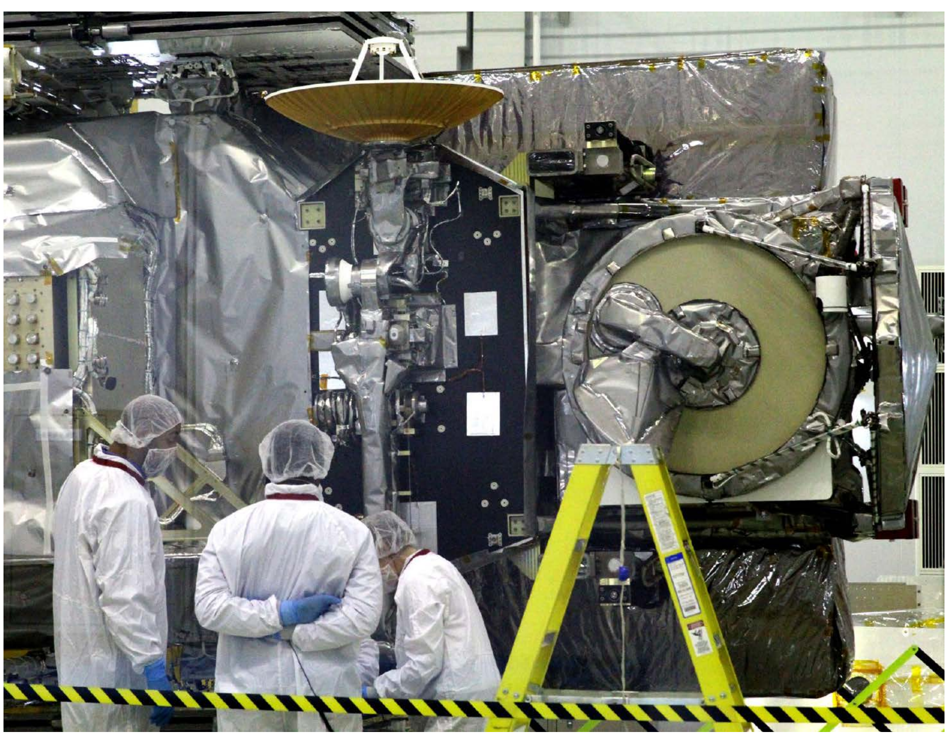
Steve Platnick
EOS Senior Project Scientist

We reported in our last issue on the preparations for the launch of the Global Precipitation Measurement (GPM) Core Observatory. The launch window has now been officially scheduled from 1:07 PM to 3:07 PM EST Thursday, February 27 (3:07 AM to 5:07 AM JST Friday, February 28). The spacecraft will launch aboard a Japanese H-IIA rocket from the Japan Aerospace and Exploration Agency's Tanegashima Space Center.

While looking forward to the GPM launch, as a community we are greatly saddened by the passing of **Arthur Hou** in November 2013. Arthur had served as the GPM Project Scientist since 2005. (For more on Arthur's career and accomplishments, please see the *In Memoriam* on page 4 of this issue.) Subsequently, **Gail Skrofronick-Jackson** [NASA's Goddard Space Flight Center (GSFC)] has been appointed as the new GPM Project Scientist. She is eminently qualified for the position having been the GPM Deputy Project Scientist since 2006 and recently appointed as the chief of GSFC's Mesoscale Atmospheric Processes Laboratory. Our best to Gail in her new position, as well as the entire international GPM team on the upcoming launch.

In this issue we have two items related to the GPM mission. The first is a report on the Iowa Flood Studies (IFloodS) that took place in northeastern Iowa from May 1 to June 15, 2013—see page 12 of this issue. Ground, radar, and satellite data collected during IFloodS will be used to quantify the size and shape of raindrops,

continued on page 2



Engineers perform precision tests on the completed GPM spacecraft prior to launch, scheduled for February 27. **Image credit:** NASA, Michael Starobin

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Reminder: To view newsletter images in color, visit: *eospso.nasa.gov/earth-observer-archive.*

the physics of ice and liquid particles throughout the cloud and below as they fall, temperature, air moisture, and distribution of different size droplets. The ultimate objective is to improve rainfall estimates from satellites, and in particular the algorithms that will interpret raw data from GPM Core and constellation satellites to help in predicting the development of floods.

The second GPM-related activity that we report in this issue is the recent GPM Applications Workshop that took place at NOAA's Center for Weather and Climate Prediction at the University of Maryland, College Park—see page 26 of this issue. Building on the legacy of its predecessor, the Tropical Rainfall Measuring Mission (TRMM), data from GPM will be used to study hurricanes, extreme rainfall events, provide inputs to climate and land-surface models, and offer new insights into agricultural productivity and world health. The workshop brought together a diverse group of scientists, data users, and end users. NASA's Applied Sciences Program intends for this to be the first in a series of workshops organized to keep the lines of communication open between the science teams and the user community.

Meanwhile, the Aquarius mission continues to perform well, two-and-a-half years after launch. To the delight of oceanographers around the world, Aquarius generates weekly maps of the global salinity field at the ocean surface. An improved salinity product (from a new version of the salinity algorithm) is being evaluated and should be available to the public early this year. In addition, the Aquarius soil moisture product is available at *nsidc.org/data/aquarius*. The Aquarius website has also been updated—*aquarius.umaine.edu/cgi/index.htm*—and contains many examples of Aquarius data including salinity maps, maps of radio frequency interference, and soil moisture maps. Turn to page 5 to learn more about Aquarius' recent achievements and plans for the future.

We reported in the last issue about the successful launch of the Total Solar Irradiance Calibration Transfer Experiment (TCTE) on the U.S. Air Force's STPSat-3 satellite. TCTE is operating nominally and *total solar irradiance* (TSI) cross-calibration activities between TCTE and NASA's SORCE satellite were successfully completed in late December. Obtaining overlap with TSI observations from SORCE (in orbit since January 2003) is crucial for continuing the longterm record of TSI, and a tremendous accomplishment given SORCE's battery-related power management issues described in our last issue[1]. Congratulations to the TCTE and SORCE teams!

With more than four decades of Earth remote sensing observations that can be used to study Earth's changing climate available from NASA and other satellite missions, *data preservation* has become an extremely important topic and a key focus area for NASA's Earth Observing System Data and Information System (EOSDIS) data centers. As an example of this important effort, turn to page 19 to learn about the Goddard Earth Sciences Data and Information Services Center's data preservation efforts for the High Resolution Dynamics Limb Sounder (HIRDLS) on Aura.

Recently, there were two high profile science-conference venues that highlighted NASA Earth Science activities. The most recent meeting of the Conference of the Parties (COP-19) of the United Nations Framework Convention on Climate Change (UNFCCC) was held November 11-22, 2013, at the National Stadium in Warsaw, Poland. The Department of State hosts and coordinates the United States' contribution each year. NASA's contribution to the *U.S. Center* featured hyperwall presentations from several senior NASA scientists and highlighted key climate programs and scientific research. Turn to page 25 to learn more about NASA's COP-19 presence.

The American Geophysical Union's (AGU) Fall Meeting took place December 9-13, 2013 in San Francisco, CA. NASA's exhibit represented the scope of the agency's science activities (including Earth science, planetary science, and heliophysics) while introducing visitors to a variety of science disciplines, research topics, data products, and programs from all of NASA's field centers. Read more about NASA's AGU activities on page 22.

While it is evident from this issue that 2013 ended with a flurry of activity, 2014 promises to be an exciting year for NASA Earth Science. In addition to the imminent launch of GPM, OCO-2 and SMAP are also scheduled for launch in 2014, as well as the deployment of CATS and RapidScat to the International Space Station. We look forward to beginning a new era in precipitation, soil moisture, clouds and aerosols, ocean topography, and related measurements, that in years to come will add to our knowledge of the state of the planet. ■

[1] See the Editorial in the November–December 2013 issue of *The Earth Observer* to learn more [**Volume 25**, **Issue 6**, p. 2].

Acronyms Not Defined in Editorial and Article Titles (in order of occurrence)

Editorial

STPSat-3	Space Test Program Satellite
SORCE	Solar Radiation and Climate Experiment
OCO-2	Orbiting Carbon Observatory - 2
SMAP	Soil Moisture Active Passive
CATS	Cloud-Aerosol Transport System
RapidScat	Rapid Scatterometer

Article Titles

GES DISC	Goddard Earth Sciences Data and Information Services Center
CERES	Clouds and the Earth's Radiant Energy System
USGS	United States Geological Survey
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations

Arthur Y. Hou

(1947–2013)

It is with profound sadness that we report the passing of **Dr. Arthur Hou**, Project Scientist for the upcoming Global Precipitation Measurement (GPM) mission. Arthur passed peacefully at home on November 20, 2013. His passing coincided with the date that GPM was shipped to Japan for its planned launch at the end of February.

Under Arthur's humble and dedicated leadership, GPM has become a truly global team effort. He excelled in providing scientific oversight for achieving GPM's many science objectives and application goals, including delivering high-resolution precipitation data in near-real time for better understanding, monitoring, and prediction of global precipitation systems and high-impact weather events such as hurricanes. Arthur successfully cultivated international partnerships around the globe, and because of his commitment to precipitation measurement science, a new capability will soon be in orbit.

Arthur began his career at NASA's Goddard Space Flight Center (GSFC) in 1990. Early on he worked in the planetary sciences, studying Venus and Uranus. Later he turned to Earth science and did pioneering work on the effect of tropical heating on the Hadley Circulation. He was also highly involved with Earth science data assimilation, and later served as the NASA deputy project scientist for the joint NASA-Japan Aerospace Exploration Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM). His research interests included dynamic meteorology, climate modeling, and data assimilation, focusing on the use of space-based observations of clouds and precipitation in global modeling through data assimilation.

Arthur was not only a superb scientist, he was also a gracious and thoughtful person. He served as a professional mentor to numerous junior- and mid-level scientists. His presence, leadership, generous personality, and the example he set as a true "team-player" will be greatly missed.

Arthur received both an S.M. (1978) and a Ph.D. (1981) in Applied Physics from Harvard University and an S.B. (1970) and S.M. (1972) in Aeronautics and Astronautics respectively from the Massachusetts Institute of Technology. He received numerous awards during his distinguished career, including the *NASA/GSFC Robert H. Goddard Exceptional Achievement Award in Leadership* in 2011. He was elected as a Fellow of the American Meteorological Society in 2014.

Arthur poured so much of his energy into the GPM mission. As the mission is prepared for launch, it is fitting that this issue of *The Earth Observer* be dedicated to his memory. On behalf of the Earth science and precipitation community, we extend our condolences to Arthur's family, friends, and many colleagues.

An Update on the Aquarius Mission: Two-and-a-Half Years and Going Strong

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Introduction

Launched on June 10, 2011, the Aquarius/Satélite de Aplicaciones Cientificas (SAC)-D mission is a partnership between NASA and the Argentine space agency [Comisión Nacional de Actividades Espaciales (CONAE)]. CONAE built the observatory bus, called SAC-D, where "D" represents CONAE's fourth partnership with NASA. Aquarius, which measures sea surface salinity, is the primary instrument onboard the observatory. SAC-D also carries CONAE-sponsored sensors, along with other international instruments—see *Other Instruments Onboard SAC-D* on page 7—that complement data from Aquarius.

Two months after launch, the Aquarius instrument was turned on, producing NASA's first global map of ocean salinity in September 2011. To the delight of oceanographers around the world, Aquarius continues to generate weekly maps of the global salinity field at the ocean surface—see **Figure 1,** for example. This article highlights some of the data products being generated by Aquarius and novel scientific findings, including tips on how to access these resources.

Two months after launch, the Aquarius instrument was turned on, producing NASA's first global map of ocean salinity in September 2011. To the delight of oceanographers around the world, Aquarius continues to generate weekly maps of the global salinity field at the ocean surface.

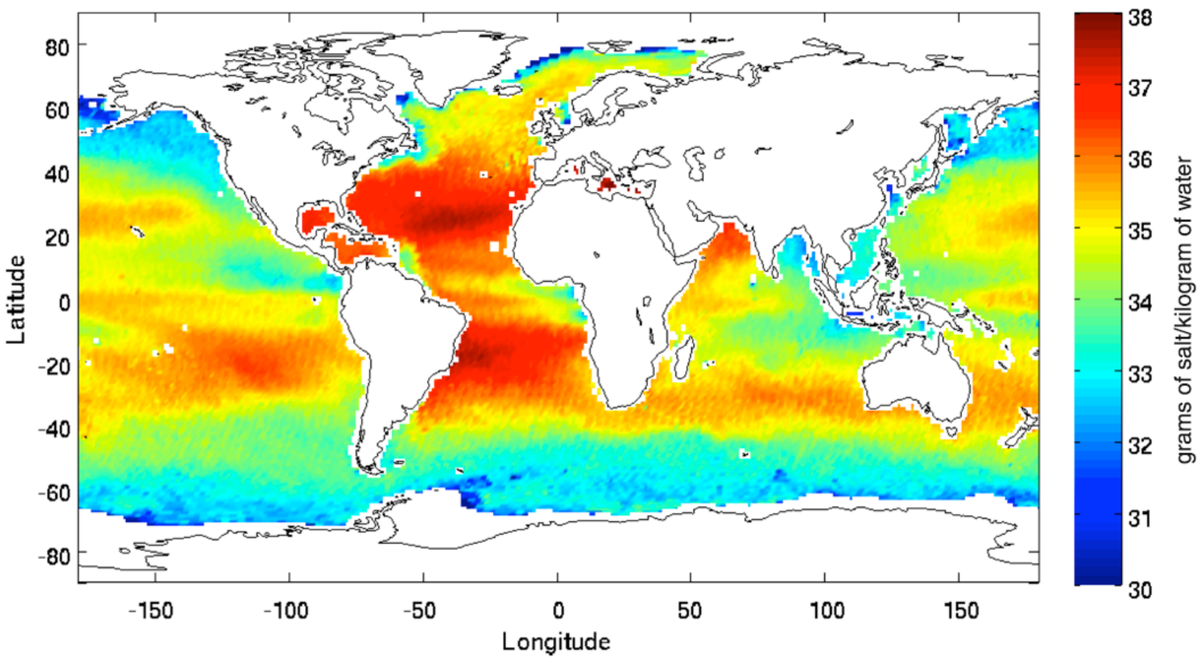


Figure 1. This map shows average, global, ocean surface salinity during spring 2013 as measured by Aquarius. **Image credit:** NASA

Ocean Surface Salinity and Soil Moisture: Data and Products

Salinity has been measured at sea for centuries, first using buckets to collect samples, and later (within the past few decades) with instruments known as "CTDs," which simultaneously measure *conductivity* (as a proxy for salinity), *temperature,* and ocean *depth* (based on pressure). This technology is used to provide *single-point samples* throughout the ocean. For example, the Argo program (*www.argo.ucsd.edu*) has over 3500 profiling floats with CTDs currently deployed in all ocean basins, used as a resource for validating Aquarius data.

Over time scales pertinent to climate, the amount of salt in our ocean basins is relatively stable; however, the amount of freshwater entering and leaving the ocean is constantly changing. Monitoring global ocean surface salinity each week is key to understanding freshwater flux and its relationship to Earth's water cycle.

The scientific objective for Aquarius is to monitor the seasonal and year-to-year variation of large-scale surface salinity features by providing monthly salinity maps with a spatial resolution of 150 km (~93 mi) and an accuracy of about 0.2 grams of dissolved salt per kilogram of seawater. Figure 1 shows that, over the open ocean, salinity ranges only from about 32 to 37 grams of salt per kilogram of seawater. Aquarius is making this very challenging measurement with a combination of passive and active L-band instruments: three radiometers at 1.4 GHz and a scatterometer at 1.26 GHz. See *Making the Measurement Possible* on page 7 for an overview of how this is done.

Aquarius' global maps provide the temporal and spatial coverage needed to discern key patterns of ocean change. Two-and-a-half years into the Aquarius mission, Argo and other conventional *in situ* sensing (e.g., from ships and buoys) continue to play an important role in complementing satellite measurements and helping ocean scientists to understand salinity, from local-to-global scales. This close relationship between satellite and conventional measurements was evident at the November 2013 Aquarius/SAC-D Science Team Meeting in Buenos Aires, Argentina, where 70% of the salinity-science oral presentations included Argo data or reports from the Salinity in the Upper Ocean Regional Study (SPURS) field experiment (*spurs.jpl.nasa.gov*).

Over time scales pertinent to climate, the amount of salt in our ocean basins is relatively stable; however, the amount of freshwater entering and leaving the ocean is constantly changing. Monitoring global ocean surface salinity each month is key to understanding *freshwater flux* and its relationship to Earth's water cycle. For example, Aquarius maps of ocean surface salinity show seasonal variation in the waters surrounding the Indian subcontinent, which is due to geography and climate. **Figure 2** shows that to the west, an arid climate and lack of freshwater input results in a salty Arabian Sea, while to the east,

continued on page 8

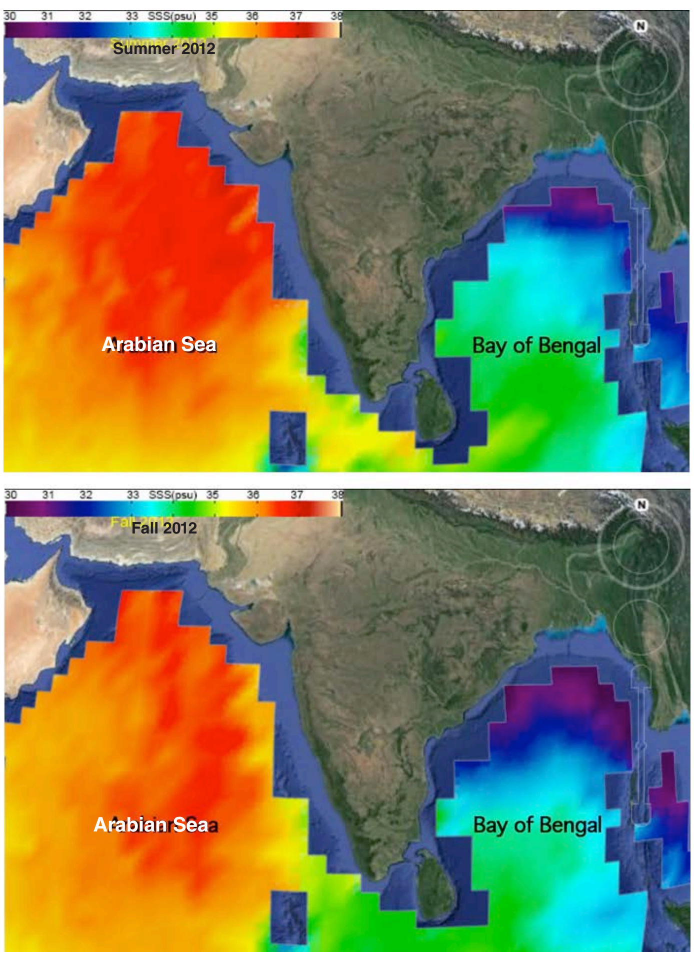


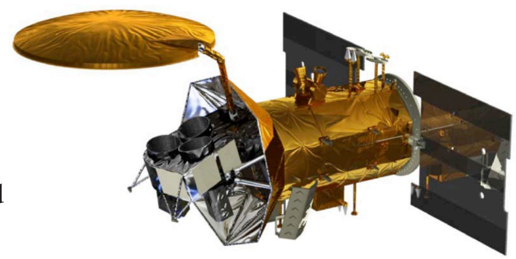
Figure 2. These maps show seasonal differences in ocean surface salinity near the Indian subcontinent measured by Aquarius. Data from June through August 2012 [*top*] and September through November 2012 [*bottom*] are shown. High salinity (dark shades) in the Arabian Sea during summer 2012 reflects increased evaporation in this region. Low salinity (light shades) in the Bay of Bengal during fall 2012 can, in part, be attributed to monsoon rains and freshwater input from major rivers. **Image credit:** NASA

Other Instruments Onboard SAC-D

The Aquarius/SAC-D mission is a true international partnership. Among the CONAE instruments on SAC-D is a Microwave Radiometer (MWR), which operates at 36.5 GHz and 23.8 GHz. Among other functions, data from MWR are being used to provide a *rain flag* for the Aquarius salinity retrieval algorithm. (The rain flag is an indicator that the accuracy of a measurement could be impacted by rain.) Other CONAE instruments include infrared and visible wavelength cameras to study forest fires and light pollution, and a data collection system. In addition, the Italian space agency [Agenzia Spaziale Italiana (ASI)] contributed an experiment called the Radio Occultation Sounder for Atmospheres (ROSA), and the French space agency [Centre National d'Études Spatiales (CNES)] contributed a space-particle-detection experiment called CARactérisation et Modélisation de l'ENvironnement (CARMEN 1).

Making the Measurement Possible

Aquarius senses energy emitted from the ocean surface, which is measured as an *equivalent brightness temperature* in Kelvin (K). To achieve the mission's science goals Aquarius detects change in brightness temperature of about 0.1 K. Careful instrument design (e.g., thermal control), data averaging, and avoidance and/or mitigation of contamination sources, such as radiation from the sun, are all required to achieve this level of precision.



Orbit Design:

Aquarius is in a seven-day repeat, sun-synchronous orbit with a 6:00 PM (ascending) equatorial crossing time and continually samples on the dark side of the day/night terminator to minimize reflected radiation and sun glint (i.e., backscatter).

Identical Radiometers:

Three onboard radiometers share a common 2.5-m (~8-ft) diameter antenna reflector. Together, the three radiometers continuously image a 390-km (~242-mi) swath, roughly perpendicular to the observatory's heading.

Rapid Sampling:

The Aquarius radiometers sample rapidly (10 microseconds per data sample) to help detect and mitigate radio frequency interference.

Polarized Measurements:

The Aquarius radiometers measure vertical and horizontal signal polarizations. The *third Stokes parameter*, a correlation between the two polarizations, is used to correct for *Faraday Rotation*, a change of the orientation of polarization in Earth's ionosphere.

Ocean Roughness Correction:

Aquarius has an onboard scatterometer with the same footprint as its radiometers. Scatterometer data help provide a correction for *ocean surface roughness*, the largest source of error for Aquarius' salinity measurements.

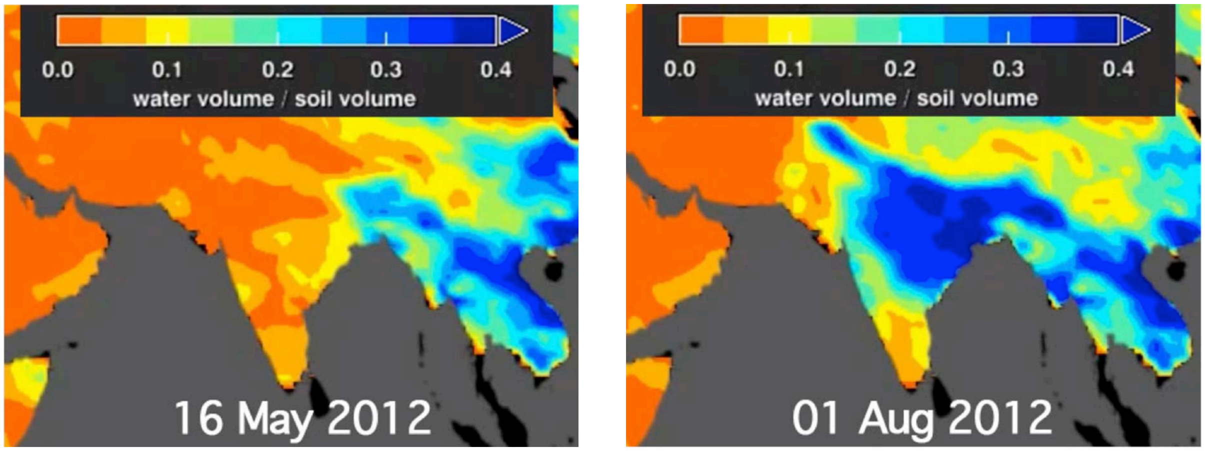


Figure 3. These maps show soil moisture as measured by Aquarius on May 16, 2012 [*left*] and August 1, 2012 [*right*]. These dates were chosen to illustrate the dry [*left*] and wet [*right*] time periods on the Indian subcontinent (seen at the center of each map). **Image credit:** NSIDC

monsoon rains and freshwater outflow from the Ganges River keep the Bay of Bengal far less salty. Aquarius salinity products and documentation are publicly available at NASA's Physical Oceanography Distributed Active Archive Center (*podaac.jpl.nasa.gov/aquarius*). These include the Level-2 orbital swath data and Level-3 gridded salinity and wind speed products (1° spatial resolution).

Aquarius salinity products and documentation are publicly available at NASA's Physical Oceanography Distributed Active Archive Center (podaac.jpl.nasa.gov/aquarius).

Aquarius data are also now being used to monitor global soil moisture conditions. Soil moisture products, derived from Aquarius's L-band horizontally polarized brightness temperature observations, were first made available by the National Snow and Ice Data Center (NSIDC) in December 2013. For example, **Figure 3** shows two Aquarius soil moisture maps centered on the Indian subcontinent: one from May 2012; the other from August 2012. The map from May is marked by dry soil conditions in India, while the map from August shows saturated conditions from monsoon rains. The Aquarius soil moisture product is available from the NSIDC (*nsidc.org/data/aquarius*). These include Level-2 orbital swath data and Level-3 gridded soil moisture products (1° spatial resolution).

"Byproducts" of Aquarius Observations: RFI Maps

Calibration and validation of the Aquarius instrument continues to be an active area of research at the current phase of the mission. For Aquarius investigators—and the microwave remote sensing community in general—one "byproduct" of Aquarius measurements is proving to be important: global maps of *radio frequency interference* (RFI). Ironically, RFI at L-band is a problem that should not exist, at least for Aquarius, since its radiometers operate at a band centered at 1.41 GHz, which is "protected" by international agreements for use in radio astronomy. Employing this frequency permits Aquarius to detect the small brightness temperature signals naturally emitted from Earth's surface. However, even very weak out-of-band signals from man-made sources, such as communications and air traffic control radar, can overwhelm the natural signal that Aquarius is designed to measure.

The Aquarius soil moisture product is available from the NSIDC (nsidc.org/data/aquarius).

Aquarius instrument designers and builders have taken special precautions to detect and mitigate RFI. Rapid sampling and a "glitch-detection" algorithm have worked well. The detected RFI is removed before processing but is used to make maps of the location and extent of RFI, which helps the research community to mitigate the problem. Among Aquarius' novel features is that it produces RFI maps not only for its radiometers, but also for the scatterometer (1.26 GHz). The problem is in some ways worse for the scatterometer because it operates in a spectral band shared with other radar instruments, in particular those used for air traffic control. **Figure 4** shows two examples of these maps, which clearly illustrate that the U.S. is relatively clean in terms of RFI that adversely impacts the radiometer; however, in the scatterometer band, the same area is overwhelmed with signals from air traffic control radar.

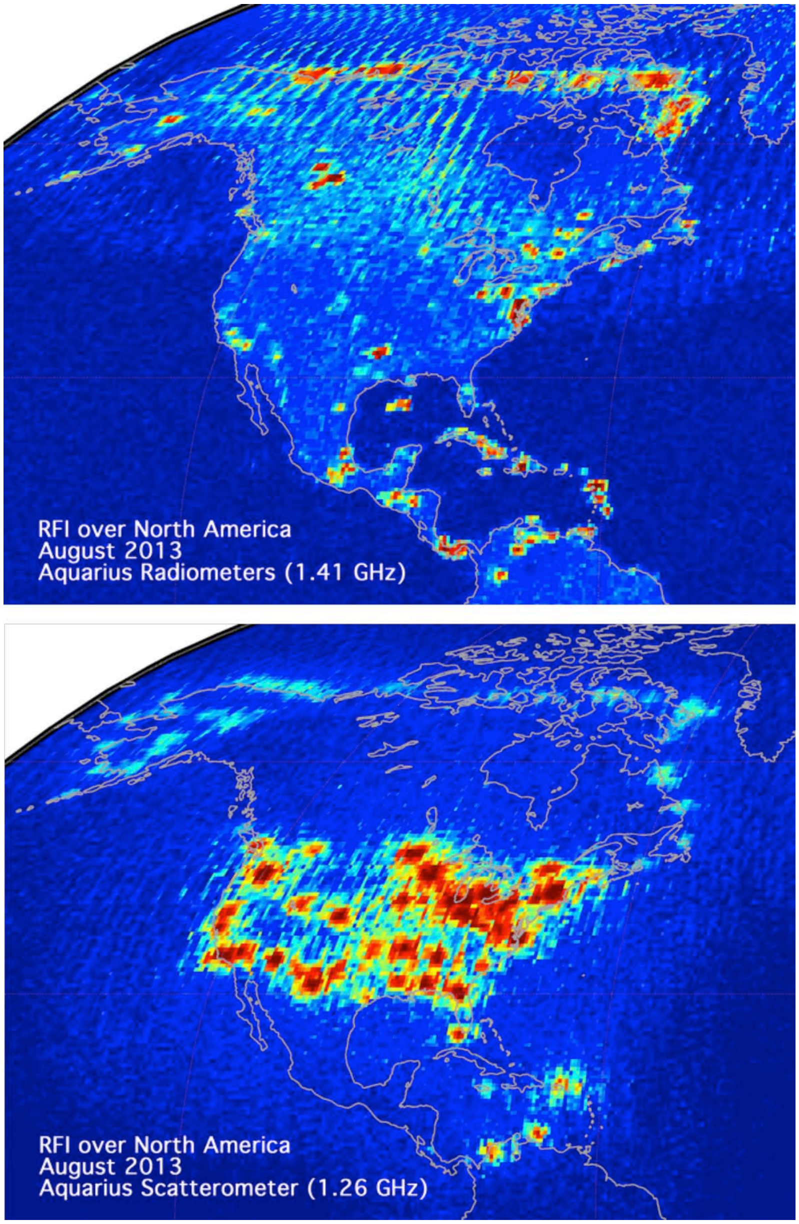


Figure 4. These maps show the location of RFI over North America during August 2013 as measured by the Aquarius' radiometers (1.41 GHz) [*top*] and scatterometer (1.26 GHz) [*bottom*]. Note the relatively "clean" RFI for the radiometers over the U.S. while the scatterometer band is swamped with signals from air traffic control radar. Notice also that ocean regions are relatively unaffected by RFI in either band. **Image credit:** NASA

Monthly Aquarius RFI maps are available from the Aquarius website for the radiometers (*aquarius.umaine.edu/cgi/gal_radiometer.htm*) and the scatterometer (*aquarius.umaine.edu/cgi/gal_scatterometer.htm*).

More (and Easier to Find) Online Products

To catalog and showcase its ever-growing inventory of science and education products, the Aquarius mission staff spent several months revamping its website, including implementing a new resource database (*aquarius.umaine.edu*). Searching the database by keyword retrieves information from or about multimedia (i.e., images, movies, slideshows, podcasts); news; mission status and events; frequently asked questions (FAQs); science meetings (e.g., presentations in PDF format); and people associated with the mission. The *Data Gallery* includes many of the global maps described previously, along with weekly ocean surface salinities and brightness temperatures at high latitudes.

Perhaps the most visible new component of the Aquarius website is the new interactive globe located on the site's homepage—see **Figure 5**. A red dot shows the real-time orbital location of the Aquarius/SAC-D observatory. The *Explore* tab opens up a control panel with various options including "Points of Interest," which highlights key locations in terms of salinity science and the mission itself. Selecting "Autoplay" begins a slideshow that rotates the globe through these points. "View Monthly Data" reveals salinity maps, which can be shown in sequence by clicking the "Play" button.

Perhaps the most visible new component of the Aquarius website is the new interactive globe located on the site's homepage.

Thematic communication and public outreach resources are also available, ranging from basic to advanced content. For example, "The Effects of Water Cycle Changes on the Ocean" link, listed under *Focus on Education* (right column) on the home page, includes climate data (e.g., 50-year trends in Argo salinity data), movies (e.g., Aquarius time-series maps on a rotating globe), hands-on activities, online data tools (e.g., monthly, seasonal, and annual Aquarius data in a Google Earth interface), and excerpts from salinity-related webinars (*aquarius.umaine.edu/cgi/ed_cycle.htm*). Thirteen salinity-themed webinars, featuring scientists and engineers from Aquarius/SAC-D and the SPURS field experiment, have proven invaluable in terms of generating high-quality online resources. In addition to engaging 529 participants from 38 states within the U.S. and 13 non-U.S. countries during live events, Aquarius and SPURS webinar archives have been accessed over 10,000 times.

What's Next for Aquarius?

Aquarius is in its third year of operation, still healthy and productive—see *A Year in the Life of Aquarius,* next page. Aquarius will reach the end of its operations phase November 30, 2014, but mission funding likely will be continued through September 2015. This ten-month extension is to synchronize the schedule with the NASA Senior Review process, during which the Aquarius team will submit its proposal for continued operations. In the meantime, Aquarius and the European Space Agency's Soil Moisture

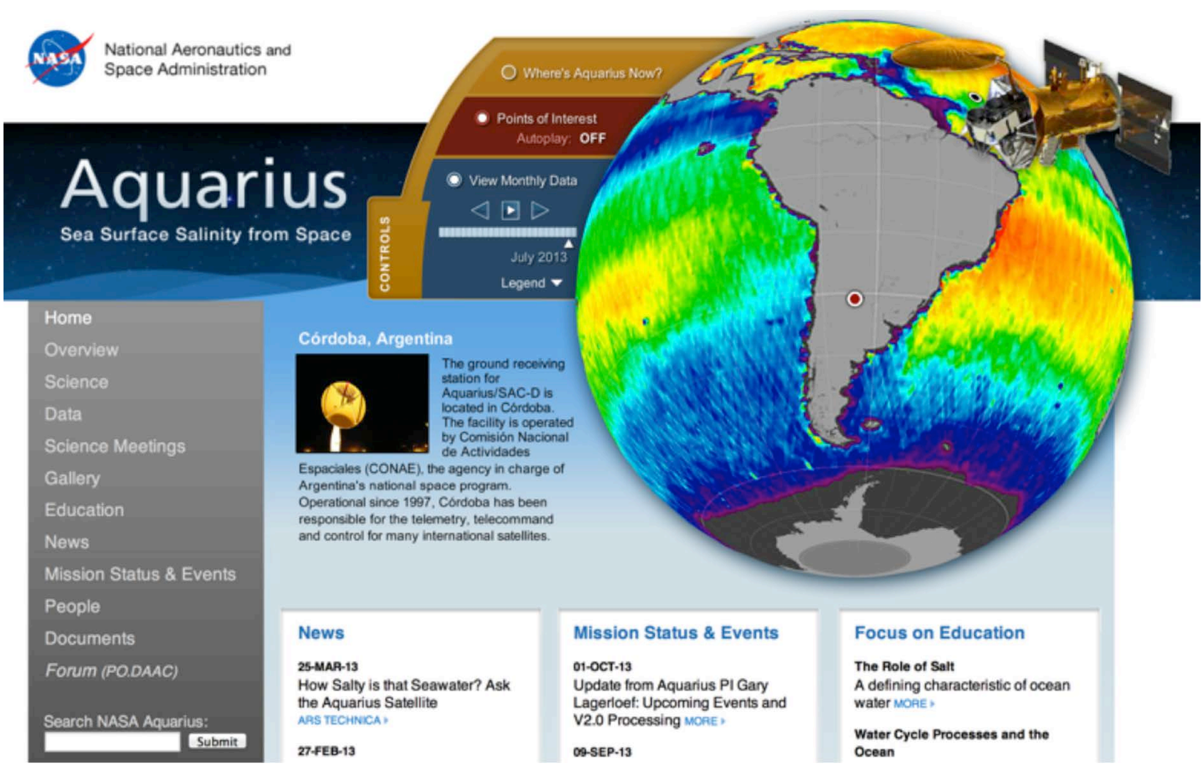


Figure 5. The interactive globe is located at the top of the Aquarius website's landing page, hosted by the University of Maine (*aquarius.umaine.edu*).

A Year in the Life of Aquarius

- The *Soil Moisture Ocean Salinity (SMOS) & Aquarius Science Workshop* was held in Brest, France, April 2013. A working group was established to intercompare salinity data products from the European Space Agency's SMOS mission and Aquarius.
- The *International Union on Radio Science (URSI) Symposium on Radio Propagation and Remote Sensing* was held in Ottawa, Canada, April-May 2013. The session on L-band remote sensing included Aquarius and RFI mitigation.
- The *International Geoscience and Remote Sensing Symposium (IGARSS),* held in Melbourne, Australia, in July 2013, had a special session dedicated to Aquarius.
- The *8th Aquarius/SAC-D Science Team Meeting*, held November 2013 in Buenos Aires, Argentina, focused on mission health and status, data analysis, scientific results, data processing, and calibration and validation.
- The *Aquarius Version 3.0 Data Release*—planned for January 2014—will include improved antenna patterns, wind and roughness models, and revised quality flags. It will also improve the correction for galaxy reflection, eliminating ascending-descending biases and quasi-seasonal signals seen in earlier data.
- There are four special sessions on "Ocean Salinity and Water Cycle Variability and Change" scheduled for the *Ocean Sciences Meeting* that will take place February 2014 in Honolulu, HI. The sessions will feature 70 oral and poster presentations.
- Manuscripts for a special volume in the *Journal of Geophysical Research (Oceans)* titled "Early scientific results from the salinity measuring satellites Aquarius/SAC-D and SMOS," are due by the end of February 2014.
- The *13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment—MicroRad 2014*—will host a meeting of the SMOS–Aquarius intercomparison working group in Pasadena, CA, March 2014.
- Two special sessions relevant to remote sensing of salinity and soil moisture are planned for the *European Geosciences Union General Assembly* in Vienna, Austria, April–May 2014.

Ocean Salinity (SMOS) mission are working to compare their respective salinity retrievals with the goal of generating products to further improve our understanding of ocean dynamics and the global water cycle. In addition, both missions are researching new cryospheric applications for their data.

With the Soil Moisture Active Passive (SMAP) scheduled to launch in November 2014, there will soon be a third L-band mission monitoring Earth. Aquarius data are already being used in preparation for SMAP, by (for example) providing data to look at active/passive algorithms over land. Aquarius will help with SMAP calibration, validating the ocean model (warm target) and celestial sky brightness temperature (cold target). A year from now (winter 2015), scientists hope to have Aquarius, SMOS, and SMAP in space together. This will mark the pinnacle of what has become the golden age of L-band remote sensing from space. ■

A year from now (winter 2015), scientists hope to have Aquarius, SMOS, and SMAP in space together. This will mark the pinnacle of what has become the golden age of L-band remote sensing from space.

A Flood—of Information—Is Needed

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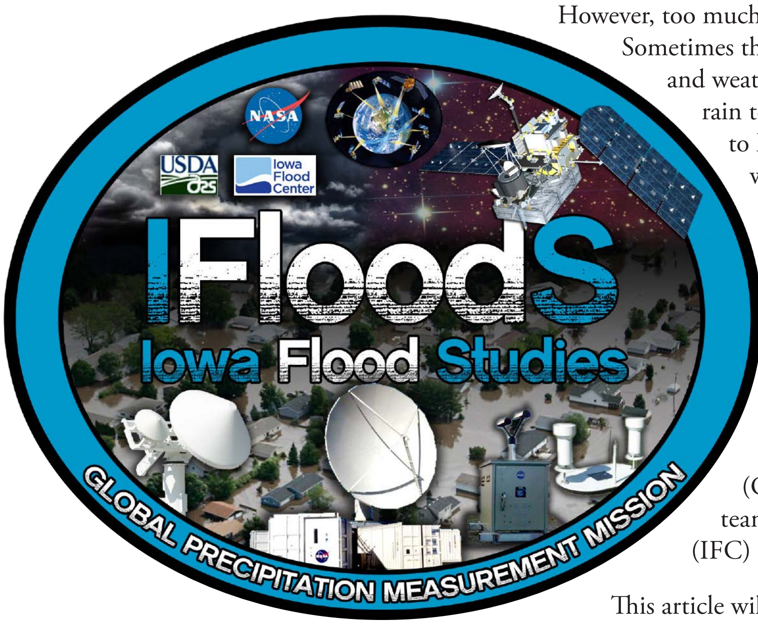
Rain. It is frequently welcome, and particularly by farmers, for whom it forms a significant source of the water they need for plant and animal growth.



However, too much of a good thing can be a problem. Sometimes the confluence of topography, geography, and weather patterns allows massive amounts of rain to turn into floods. Floods frequently lead to loss of life and property and, at times, wholesale alteration of the landscape.

A recent successful effort to help explore the underlying phenomena that lead to floods—the *Iowa Flood Studies (IFloodS)* field campaign—took place in eastern Iowa from May 1 to June 15, 2013. The study is a partnership between representatives of NASA's Global Precipitation Measurement (GPM) mission ground validation (GV) team and members of the Iowa Flood Center (IFC) at the University of Iowa.

This article will describe the IFloodS campaign, its role in the GPM mission, its implementation, and early results. Resources for additional reading are found throughout and at the end.

GPM Background

The GPM mission has been addressed in *The Earth Observer* elsewhere[1,2] in more detail than is provided in this article, but a simple summary is provided here for context.

The GPM mission's *constellation* of satellites (see **Figure 1**, next page), coupled with ground- and air-based field campaigns, will provide significant amounts of information about precipitation as part of the larger Earth system. The internationally supported GPM mission has been organized and co-led by NASA and the Japan Aerospace Exploration Agency (JAXA). The GPM Core Observatory "anchors" the constellation and is scheduled for launch from Tanegashima Space Center in Tanegashima, Japan aboard a JAXA H-IIA rocket on February 27, 2014. Instrumentation on the Core Observatory includes an advanced precipitation radar and a microwave radiometer that will measure precipitation and help unify precipitation measurements among all satellites in the constellation by acting as a reference standard.

> *No individual raindrop ever considers itself responsible for the flood.*
> *—Anonymous*

The GPM Core Observatory "anchors" the constellation and is scheduled for launch from Tanegashima Space Center in Tanegashima, Japan aboard a JAXA H-IIA rocket on February 27, 2014.

The GPM mission builds on the success of the Tropical Rainfall Measuring Mission (TRMM), launched in 1997, which will still provide data about precipitation over tropical and subtropical regions (i.e., 35° N to 35° S latitude). Importantly, however,

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[1] For details, see *GPM Core Observatory: Advancing Precipitation Instruments and Expanding Coverage,* in the November-December 2013 issue of *The Earth Observer*, [**Volume 25, Issue 6**, pp. 4-11], found at *eospso.gsfc.nasa.gov/earthobserver/nov-dec-2013*. Also, a pre-launch brochure about the GPM Core Observatory is available online at *eospso.gsfc.nasa.gov/sites/default/files/publications/GPMmissionBrochure_508_sm.pdf.*

[2] See also *Measuring Rain for Society's Gain: A GPM Applications Workshop* on page 28 of this issue.

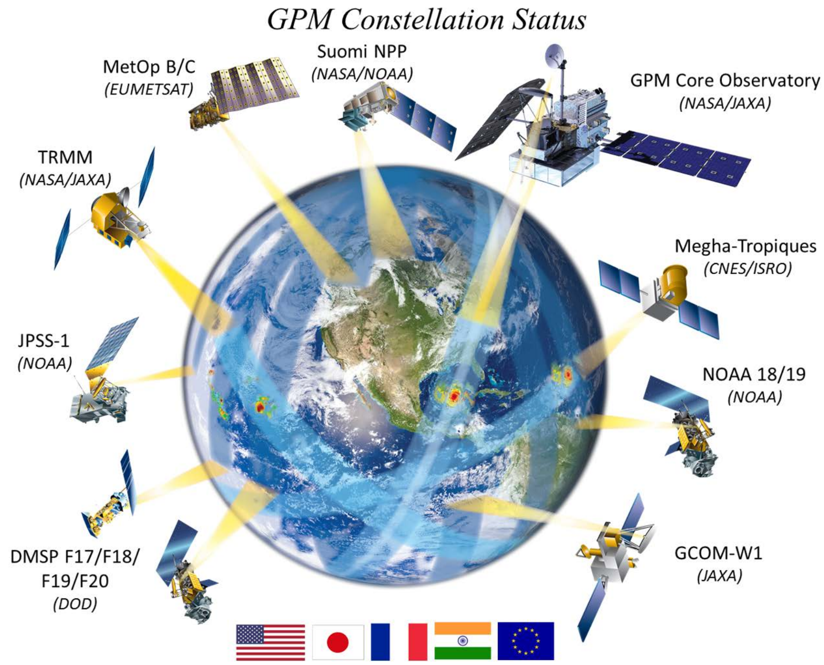

Figure 1. *GPM Constellation of Satellites.* This internationally supported mission will make significant contributions to our understanding of precipitation in the Earth's systems. **Image credit:** NASA

the GPM Core Observatory will significantly extend coverage to about 65° N to 65° S latitude. Its orbit, in combination with the rest of the constellation, means global precipitation observations will be made at a more frequent interval of approximately every three hours, collecting a larger volume of more accurate data than were earlier available, thereby making significant contributions to our understanding of Earth's energy and water cycles.

Field Campaigns

Like all satellite-based observation platforms, remotely sensed data require *validation* to ensure that space-based measurements accurately reflect what is happening at locations closer to the actual phenomena than the orbiting instruments, and that the algorithms used to convert satellite remote sensing measurements (e.g., radiances) into the parameter of interest (e.g., a rain rate) are physically consistent. These validation efforts also help scientists and engineers understand their technologies not only for the reality check relative to a ground measurement, but also to provide clues about the physics being observed and about how better to design and build future instruments, should there be discrepancies between the satellite-based measurements and *in situ* data.

Like all satellite-based observation platforms, remotely sensed data require ***validation*** *to ensure that space-based measurements accurately reflect what is happening at locations closer to the actual phenomena than the orbiting instruments, and that the algorithms used to convert satellite remote sensing measurements (e.g., radiances) into the parameter of interest (e.g., a rain rate) are physically consistent.*

The locations and activities for validation field campaigns generally vary, depending on the nature of the data being taken (for direct measurements) and the applicability of remotely sensed data to computer models. The campaign data are used to validate those models for accuracy and precision in describing current phenomena. Whether airborne (e.g., balloon- or aircraft-based instrumentation) or on Earth's surface (e.g., ocean-based buoys, submersibles, or ground-based instrumentation), field campaigns play a vital role in the larger suite of measurements, observations, and models of Earth's systems and their myriad interactions.

IFloodS

The 2013 IFloodS field campaign took place in northeastern Iowa. Over the course of six weeks the science team, lead by NASA's GPM and the IFC, included representatives from a number of institutions, collected and analyzed high-quality and high-resolution field data for rain and stream flows in concert with supporting data from ground-based radars and satellites. These data will be used to provide integrated ground reference precipitation and hydrologic products for GPM data validation using a combination of instruments and computer models, and to support improvements in flood prediction and, perhaps, mitigation.

Iowa is an excellent choice for such studies, as the topography is largely constant (i.e., no mountains to confound the data analysis). Northeastern Iowa particularly—with emphasis on the river basins between Waterloo and Iowa City—was chosen for this important field campaign for several reasons, the most important of which, operationally, was the distribution of extant instrumentation across wide swaths of this part of the state, thanks to the IFC. In addition, a robust flood forecasting system is in place, as well as a significant pool of researchers with expertise in hydrometeorology and flood hydrology and the use of satellite data in such disciplines.

"…probably the most daunting aspect of [IFloodS] is that there's so much data…and there's only a relatively small community to analyze them. It'll be quite the experience, I think."
*—**Walt Petersen,** GPM Ground Validation Science Manager*

All these factors combine to support the highest priority for the campaign: to get the best possible rain-rate measurements from the ground network.

Northeastern Iowa particularly—with emphasis on the river basins between Waterloo and Iowa City—was chosen for this important field campaign for several reasons, the most important of which, operationally, was the distribution of extant instrumentation across wide swaths of this part of the state thanks to the Iowa Flood Center.

IFloodS Instrumentation

The research team used ground-based instruments to characterize aspects of precipitating systems, including:

- high space/time resolution, regionally mapped rainfall rates and accumulations;
- raindrop physical characteristics (size and shape);
- physical changes in water particles (liquid, as rain; and solid, as snow, sleet, and ice) in clouds and during transport to Earth's surface; and
- atmospheric conditions, such as moisture content, size and distribution of precipitation throughout the cloud, and air temperature.

Because ground-based research and measurement activities do not bring with them the enormous cost of designing, building, and launching satellites, many more supporting technologies may be called into service. Such technologies run the gamut from comparatively simple rain gauges to technologically complex radars, operating at several frequencies and in dual-polarization modes. Also involved were several space-based assets, including radar and microwave radiometers on over-passing satellites.

Tables 1–4 describe the suite of ground instrumentation, radar, model output, and space-based remote sensing instruments used during IFloodS, and the investigators.

Table 1. Radars used in and associated products from the IFloodS field campaign.

Instrument Name	Investigators	Description
NPOL radar	Walt Petersen [NASA's Wallops Flight Facility (WFF)] David Wolff [WFF]	NASA S-band dual-polarimetric radar, useful for improving precipitation estimates over conventional radars.
D3R radar	Matt Schwaller [GSFC] V. Chandrasekar [Colorado State University—Cooperative Institute for Research in the Atmosphere]	NASA K_a/K_u band scanning radar, useful for providing insight into precipitation microphysical processes.
X-band radars	Witold Krajewski [IFC]	X-band radar, used to obtain profiles of water droplets and ice particles.

Table 1 (continued). Radars used in and associated products from the IFloodS field campaign.

Instrument Name		Investigators	Description
*NEXRAD Level-II**		National Weather Service (NWS)	NEXRAD Polarimetric Doppler radar systems at the listed locations in northeast Iowa. NEXRAD Level II (base) data include reflectivity, mean radial velocity, and spectrum width.
KDMX	Des Moines, IA		
KDVN	Davenport, IA		
KMPX	Minneapolis, MN		
KARX	La Crosse, WI		
NEXRAD rainfall composite		Witold Krajewski [IFC]	Hourly-rainfall estimates, at approximately 16 km^2 (~6.2 mi^2) resolution from the NWS; used primarily for the detection and modeling of extreme-weather events.
NEXRAD *Level III**		James Smith [Princeton University]	WSR-88 Digital Precipitation Rate dual-polarimetric radar (DPR): Instantaneous precipitation rate and one-hour accumulations, using the dual-polarization quantitative precipitation estimation algorithm.

*NEXRAD Level II and Level III data are produced by the NWS and described in more detail at *www.ncdc.noaa.gov/oa/radar/radarproducts.html*.

Table 2. Ground instruments used during the IFloodS field campaign.

Instrument Name	Investigators	Instrument Type	Description
Autonomous Parsivel units	Walt Petersen [WFF] Mathew Wingo [WFF]	Disdrometer	Measures rain *drop size distribution* (DSD), particle phase, and fall-velocity of particle sizes from 0.3 mm (~0.01 in) to 20 cm (~8 in).
Micro rain radar	Walt Petersen [WFF] Patrick Gatlin [NASA's Marshall Space Flight Center (MSFC)]	Profiling radar/ disdrometer	DSD profiling, precipitation rate, melting layer; retrieves quantitative rain rates, DSD, radar reflectivity, fall velocities on vertical profiles up to several km above the unit, operating at 24 GHz.
Rain gauges - NASA	Walt Petersen [WFF] David Wolff [WFF]	Rain gauge network	Twenty-five dual tipping bucket rain gauge platforms directly measure rainfall. Twenty gauges were located in Turkey River Watershed, five in the Agricultural Research Service's South Fork network.
Rain gauges - Iowa	Witold Krajewski [Iowa Flood Center (IFC)]	Rain gauge network	Forty dual tipping bucket rain gauge platforms located in the Clear Creek Watershed.
Rain gauges - ARS	Mike Cosh [United States Department of Agriculture- Agricultural Research Service (ARS)]	Rain gauge network	Fifteen dual tipping bucket rain gauge platforms located within the ARS South Fork Watershed network (also used for SMAP validation).
Stream gauges - Iowa	Witold Krajewski [IFC]	Stream gauge	Stream flow product.
Stream gauges - USGS	Witold Krajewski [IFC]	Stream gauge	Stream flow product.
Soil moisture sensors - Iowa	Witold Krajewski [IFC]	Soil moisture sensors	Soil moisture and temperature sensors placed at 5-cm (~ 2 in) and 10-cm (~4 in) depth at each NASA and Iowa rain gauge location.

Table 2 (continued). Ground instruments used during the IFloodS field campaign.

Instrument Name	Investigators	Instrument Type	Description
Soil moisture sensors	Mike Cosh [ARS]	Soil moisture sensors	Twenty soil moisture and temperature profile sensors placed at 5-cm (~ 2 in), 10-cm (~4 in), and 50-cm (~20 in) depth within the South Fork ARS network (also used for SMAP validation).
Two-dimensional video disdrometer (2DVD)	Walt Petersen [WFF] Patrick Gatlin [MSFC]	Disdrometers	Particle size and concentration measurements for particles of 0.3–8-mm (~0.01–0.3 in) diameter [bin resolution of 0.25 mm (~ 0.01 in)], axis ratio distribution, and fall-velocity information.

Table 3. Computer model output used during the IFloodS field campaign.

Data Type	Investigators	Description/Source
NWP data	Christa Peters-Lidard [GSFC] Di Wu [GSFC]	Data from the NASA unified Weather Research and Forecasting (Nu-WRF) Model.
Precipitation data	Pedro Restrepo [National Oceanic and Atmospheric Administration/ National Weather Service]	Quantitative Precipitation Forecast (QPF) output from the NWS's River Forecast Center.
Flood maps	Robert Adler [U. Maryland, ESSIC) Huan Wu [U. Maryland, ESSIC) Hal Pierce [GSFC]	Global Flood Monitoring System derived from the TRMM Multi-satellite Precipitation Analysis (TMPA).

Table 4. Spacecraft/instruments used during the IFloodS field campaign.

Spacecraft/Instrument Name	Investigators	Data Products Used
Tropical Rainfall Measuring Mission (TRMM) Satellite		
Multisatellite radiometer/radar platform data	George Huffman [GSFC]	TMPA product
TRMM Microwave Imager (TMI)	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	TMI data subset Goddard Profiling algorithm (GPROF) products
NASA A-Train (CloudSat, CALIPSO, Aqua)		
Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	AMSR-E data subset GPROF products
Defense Meteorological Satellite Program (DMSP)		
Satellites F-15, 16, 17, 18	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	Special Sensor Microwave Imager (SSM/I), SSMI/ Sounder data subset GPROF products
Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	AMSR-E data subset GPROF products
NOAA Polar Orbiters		
NOAA 16, 18, 19	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	Advanced Microwave Sounding Unit A/B/MHS, GPROF Products

Table 4 (continued). Spacecraft/instruments used during the IFloodS field campaign.

Spacecraft/Instrument Name	Investigators	Data Products Used
Suomi National Polar-orbiting Partnership (NPP)		
Advanced Technology Microwave Sounder (ATMS)	Christian Kummerow [CSU-CIRA] Phillip Partain [CSU]	Advanced Technology Sounding Unit GPROF Products
Geostationary Operational Environmental Satellites (GOES)		
GOES IR	George Huffman [GSFC, by way of UC Irvine, NOAA CPC, and NOAA NESDIS]	Hydro-estimator product, Climate Prediction Center Morphing (CMORPH), Precipitation Estimation from Remote Sensing Information using Artificial Neural Network (PERSIANN) products*

* The CMORPH and PERSIANN datasets are produced by the NOAA Climate Prediction Center and the University of California, Irvine, respectively.

A top-level representation of the distribution of instrumentation is found in **Figure 2**. As noted at a source site (*pmm.nasa.gov/node/784*), the NASA Polarimetric Radar (NPOL) and rainfall measurement devices are located in the Cedar and Iowa River basins at Benton, Blackhawk, Hamilton, Hardin, Iowa, Linn, Marshall, and Tama. At the South Fork of the Iowa River, there is a network of rain gauge and soil moisture instruments, deployed in concert with the Agricultural Research Service and NASA's Soil Moisture Active-Passive (SMAP) mission community. Finally, the Turkey River Basin was targeted with some 20 rain gauges and soil moisture probes to support the extant Iowa Flood Center X-band Polarimetric Doppler (XPOL) weather radars.

IFloodS in the Field

Concerns that Iowa's 2012 drought would continue were allayed early on, when the rain began in earnest in April 2013, and many streams and rivers experienced high water. The science team collected both useful rainfall data and

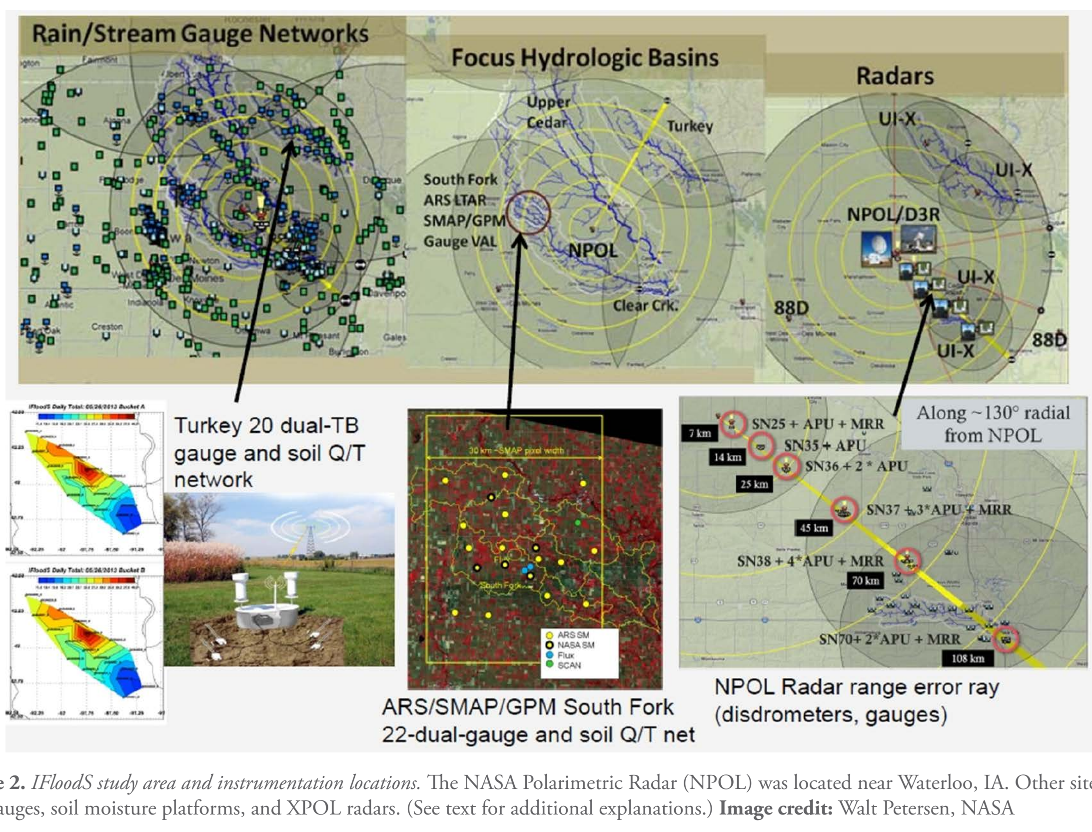

Figure 2. *IFloodS study area and instrumentation locations.* The NASA Polarimetric Radar (NPOL) was located near Waterloo, IA. Other sites had rain gauges, soil moisture platforms, and XPOL radars. (See text for additional explanations.) **Image credit:** Walt Petersen, NASA

observations on flood conditions on the ground that they could use to evaluate flood models based on the data—as shown in **Figure 3**. In addition, several severe convective storms passed through the area, including tornado-generating thunderstorms. Radar observations at three wavelengths and dual-polarimetry allowed for comprehensive monitoring of the formation of deep convective clouds and broad anvils, with data acquired that explored the mechanics of cloud formation in addition to the presence, distribution, and fate of hydrometeors within the cloud.

"…collectively we will be gathering data [and] collecting observations that will be without precedent."
*—**Witek Krajewski**, Director, Iowa Flood Center*

For more "behind-the-curtain" views of IFloodS, NASA's Earth Observatory hosts a blog describing IFloodS activities at: *earthobservatory.nasa.gov/blogs/fromthefield/category/iowa-flood-studies.*

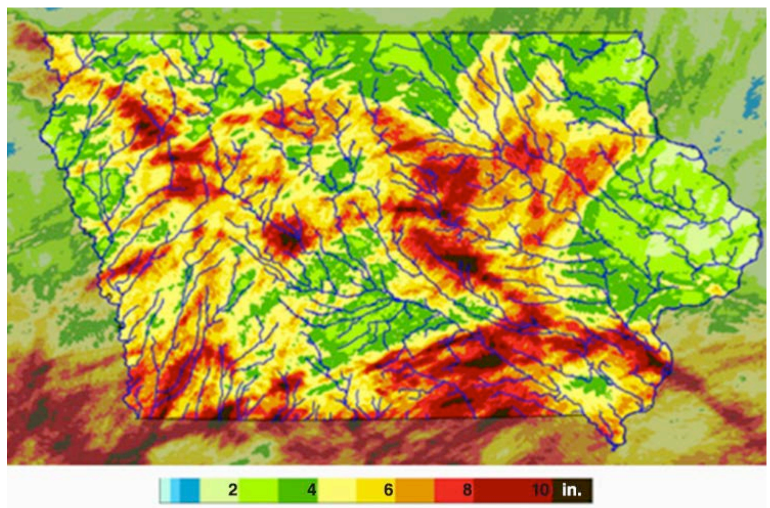

Figure 3. *Interpolation of rain gauge measurements from IFloodS.* Areas of highest rainfall are shown in dark shades, and correspond with regions where flooding potential is highest; least, in light shades. **Image credit:** Iowa Flood Center

A Successful Campaign

The six-week accumulated rain total over the entire IFloodS domain averaged approximately 250-300 mm, with several more localized areas experiencing accumulations exceeding 400 mm. The campaign ran 24/7 and some of those events lasted for several days, and often blended into the next precipitation event. For example, the first five days of the campaign consisted of cold rain and snow that then transitioned into mesoscale convective systems and frontal rain, and then into severe weather.

By all standards, IFloodS was a success. Scientists from 10 research institutions cooperated over the six weeks of the campaign to acquire data of the types described in the Tables in the preceding section, using hundreds of rain gauges and soil moisture sensors and radars. With data collection activities ended, the focus now turns to analyzing the data and applying them to flood prediction models. With the sheer amount and high quality of the collected data, the GV aspects of IFloodS are sure to provide ample support for the rest of the GPM mission and its efforts to understand the phenomena that cause flooding.

Resources for Further Reading

IFloodS Campaign: *pmm.nasa.gov/IFloodS*

GPM Ground-Validation Data Portal: *gpm.nsstc.nasa.gov*

Rain, rain, don't go away: NASA's GPM mission completes successful Iowa Flood Studies field campaign: *www.nasa.gov/content/goddard/rain-rain-dont-go-away-nasas-gpm-mission-completes-successful-iowa-flood-studies/index.html#.UgO1cLbNAxE*

Upon quality control of the IFloodS datasets and public release, the data will be available at: *gpm.nsstc.nasa.gov/ifloods* ■

Retaining Data for the Long Haul: GES DISC Manages HIRDLS Data Preservation

James Acker, NASA's Goddard Space Flight Center, james.g.acker@nasa.gov

NASA's Earth-observation missions began with the Television Infrared Observation Satellite (TIROS) series in the 1960s and continued with the Nimbus and early Landsat satellite missions in the 1960s and 1970s. Notably, the Nimbus satellites inaugurated the use of multisensor missions for environmental remote sensing. In the ensuing four decades, NASA's Earth-science activities have led to increasingly sophisticated satellite instruments, much larger data volumes, more complex data analyses, and a diverse suite of data products that were generated with increasingly sophisticated algorithms. NASA now has at its disposal a huge amount of information about the state of our planet obtained from the vantage point of polar and low-Earth orbit. For scientists seeking to study Earth's changing climate, having long-term time series of data on key climate variables is crucial and the data from these missions constitute a vital archive for Earth science research.

Making full use of this information is far from trivial. The past four decades have seen a veritable revolution in information technology. We've all seen it play out in our living rooms and automobiles as eight-track audio tapes, vinyl records, and audio and video cassettes gave way to compact discs, which in turn have yielded to digital recording devices and *mp3* players, and so on. There has been a similar rapid evolution in both the amount and the means used to collect and preserve data from satellites. As a result, data collected by an instrument operating in one period of history is not always easily compared to data from a similar instrument that operated during a different era. (One can draw an analogy with those of us who own a box of old vinyl records that we can no longer listen to—because we no longer have a record player to play them!)

Such an analogy helps understand why *data preservation* is an extremely important topic at NASA, and a key area of focus for NASA's Earth Observing System Data and Information System (EOSDIS) data centers. These data centers focus not only on keeping the "old records on the shelf"—organized and safe—but also on making sure that the means exist to access them and play them. For satellite data, this means storing satellite data in a safe, secure, and robust system and making sure that there are means available to easily access the archived data for use far into the future.

NASA has a veritable treasure trove of environmental information, but for scientists to make full use of it to study Earth's changing climate, they need help. The underlying signals of climate change are sometimes hard to distinguish from the accompanying noise that arises from Earth's variability of and the complexity of the instruments used to study such changes. The EOSDIS data centers rigorously capture and catalog data from all the elements of each NASA remote sensing mission and in so-doing, help scientists access and decipher the data when they want to use it for scientific analysis. Such efforts help to ensure that data collected by NASA instruments through time may be intercompared and correlated to provide the longest possible contiguous time series, which are needed to better understand Earth's interrelated systems.

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Data Preservation for HIRDLS

The Goddard Earth Sciences Data and Information Services Center (GES DISC) began archiving data in the early 1990s, starting with data from the Upper Atmosphere Research Satellite (UARS) and the Total Ozone Mapping Spectrometer (TOMS). With that experience, GES DISC soon established a niche in archiving atmospheric chemistry datasets. It now archives data for three of the instruments on NASA's Earth Observing System Aura platform: the High-resolution Dynamic Limb Sounder (HIRDLS); Microwave Limb Sounder (MLS); and Ozone Monitoring

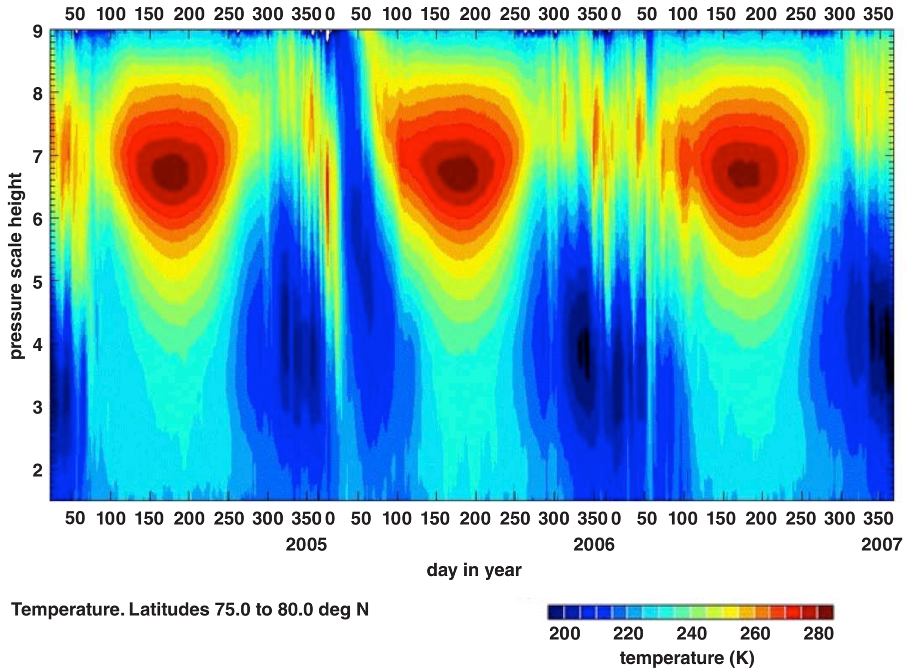

Figure. Shown here is HIRDLS *Version 5* Level-2 Data (HIRDLS2) temperature, zonal means for January 28, 2005 through January 2, 2008, averaged over 75-80° N latitude. HIRDLS2 data files contain newly added geopotential height in addition to improved atmospheric concentrations of ozone (O_3), nitric acid (HNO_3), CFC-11, CFC-12, temperature, cloud-top pressure, and aerosol extinction. For details, see *disc.sci.gsfc.nasa.gov/Aura/data-holdings/HIRDLS/hirdls2_005.shtml*. **Image credit:** Goddard Earth Sciences Data and Information Services Center

Instrument (OMI)[1]. In addition, GES DISC archives precipitation datasets, typified by the Tropical Rainfall Measuring Mission (TRMM) and the forthcoming Global Precipitation Measurement (GPM) mission. GES DISC also archives data from the Modern Era Retrospective-analysis for Research and Applications (MERRA). The GES DISC has also developed several tools that enable users to search for, order, download, and visualize NASA Earth-science datasets.

HIRDLS' high-resolution measurements provided new insights into troposphere–stratosphere interactions, chemical reactions in the atmosphere, cyclic weather events, and air pollution impacts.

The NASA GES DISC recently completed a data preservation campaign for Aura's HIRDLS—a 21-channel (6.12 - 17.76-µm) limb-scanning infrared radiometer that measures emissions from Earth's limb. HIRDLS took measurements of temperature (see **Figure**), cloud-top pressure, geopotential height, trace constituents (e.g., ozone, nitric acid, chlorofluorocarbons), aerosols, and cirrus clouds, from the middle troposphere to the mesosphere. HIRDLS' high-resolution measurements provided new insights into troposphere–stratosphere interactions, chemical reactions in the atmosphere, cyclic weather events, and air quality impacts.

Data preservation for HIRDLS encompasses eight different content elements. These include:

- **Preflight/pre-operations calibration:** This element may include instrument specifications, calibration reports, and prelaunch performance measurements.
- **Science data products:** This element can include data from the instrument at all processing levels, from Level-0 raw data to Level-3 global and Level-4 model data, as well as metadata required to allow both search and access *for* the data and understanding *of* the data.
- **Science data product documentation:** Many different types of information are included under this data preservation element, including the names of science team members, product requirements, data processing history, algorithm history, detailed algorithm descriptions, and data quality assessment.

[1] Data from the fourth Aura instrument, the Tropospheric Emission Spectrometer (TES) are kept at the Atmospheric Science Data Center (ASDC), located at NASA's Langley Research Center.

- **Mission data calibration:** There are two main categories intended for preservation here. One category is descriptions of the calibration methods used for the mission; the second category is the actual calibration data.

- **Science data product software:** Data collected for this element consist of the software description and actual code for generating the data product. Many different software versions corresponding to the corresponding data product releases must be captured.

- **Science data product algorithm input:** Many remote sensing algorithms require other (ancillary) data as input to calculate a particular data product. This information includes full descriptions of the input data and attributes covering all input data used by the algorithm, including primary sensor data, forward models (e.g., radiative transfer models, spectral-line lists, optical models, or other models that relate sensor observables to geophysical phenomena), and look-up tables.

- **Science data product validation:** Data types that are classified under this element include the data collected on validation campaigns, accuracy reports, characterization and description of the validation process, ongoing calibration and validation results, and methods used to maintain accurate calibration of the instruments collecting the validation data.

- **Science data software tools:** This often-overlooked (or undervalued) element refers to the tools (mostly software but possibly including hardware) required to read and/or display data collected under the other elements. Data can be in many different formats, requiring specific tools to read and use them. If these tools are not preserved along with the data, having the data alone becomes useless.

These elements cover all the disparate aspects of a satellite remote-sensing mission. The preserved data types can include a wide range of content: instrument specifications, prelaunch calibration reports, algorithm input data, algorithm software, data product documentation (i.e., what the data product represents and what it will be used for), data acquired on data validation campaigns, calibration data collected during the mission, and several other types. One of the complexities of this and similar data preservation efforts is that the data are definitely not all numbers and data plots; they could also be text, software code, diagrams, images, or something else.

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The HIRDLS data preservation effort provides access to applicable HIRDLS documentation on the following webpage: *disc.sci.gsfc.nasa.gov/Aura/additional/documentation/hirdls-preservation-documents*. The page includes predominantly PDF documents organized under the eight data preservation elements described above. Some of the documents are *metadata:* collections of information from other publications about the HIRDLS mission. Others are descriptions of the software code that allow understanding and potential reconstruction of the data processing software.

Conclusion

Because data from NASA's missions are valuable scientific resources, data preservation efforts such as those for HIRDLS will allow scientists to use the data in the future for comparisons with newer instrument datasets, as well as with evolving and new data analysis methods. In turn, this will increase the usefulness of Earth observations from upcoming missions by creating an improved historical comparison capability and a much better characterization of trends in Earth system data records. The results of such research allow insight into the changes affecting Earth's vital ecosystems and the natural support systems on which humanity relies. ■

NASA Science Shines at the 2013 American Geophysical Union Fall Meeting

Heather Hanson, NASA's Goddard Space Flight Center/Global Science & Technology, Inc., heather.h.hanson@nasa.gov

The forty-sixth annual American Geophysical Union (AGU) Fall Meeting took place December 9-13, 2013, at the Moscone Center in San Francisco, CA. As in past years, NASA's Earth Observing System Science Support Office organized and coordinated the NASA exhibit in the exhibition hall. The booth's displays amply represented NASA science across agencies and missions by way of several modalities, including dynamic hyperwall presentations; in-booth, side-event presentations and demonstrations; interactive kiosks stations; and several information tables that offered face-to-face interactions with NASA staff. Visitors were encouraged to explore the many flavors of NASA science, including Earth science, planetary science, and heliophysics, while being exposed to a finer-grained variety of science disciplines, research topics, data products, and programs from all of NASA's field centers.

Image 1. Ellen Stofan and **John Grunsfeld** answered questions during a media event Monday evening about NASA's ambitious plans for the future—including plans to send another rover to Mars in 2020. **Image credit:** NASA

In total, there were 26 hyperwall presentations[1] and 34 additional in-booth presentations and demonstrations[2] spread out over the five-day event. To kick off the opening of the exhibit, **John Grunsfeld** [NASA Headquarters (HQ)—*Associate Administrator for the Science Mission Directorate*] and **Ellen Stofan** [NASA HQ—*NASA Chief Scientist*] participated in a media event in front of the hyperwall at the booth during the Opening Ice-Breaker Reception, held Monday evening—see **Image 1**. Following that 30-minute event, **Michael Freilich** [NASA HQ—*Director of Earth Sciences*] and **Lawrence Friedl** [NASA HQ—*Director of Applied Sciences*] delivered dynamic hyperwall presentations to discuss ongoing science activities and results generated by researchers in NASA's Earth Science Division and Applied Sciences Program, respectively—see **Images 2** and **3**.

A series of hyperwall and other in-booth presentations continued throughout the week, along with demonstrations of *Spacecraft 3D* (a unique mobile app), *Eyes on the Solar System (eyes.jpl.nasa.gov/download.html),*

[1] To view a daily agenda of hyperwall presentations and town hall events that took place, visit: *eospso.gsfc.nasa.gov/sites/default/files/publications/AGU_hwth_sch_0.pdf.*

[2] To view a daily agenda of the other in-booth presentations and demonstration events, visit: *eospso.gsfc.nasa.gov/sites/default/files/publications/AGU2013Program508.pdf.*

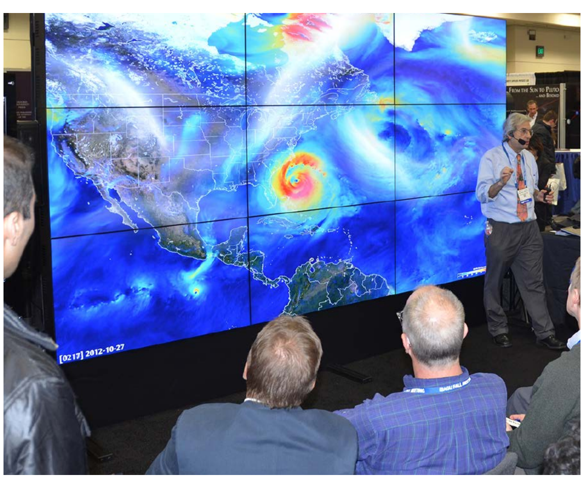


Image 2. Michael Freilich discussed how satellites have revolutionized our view of the planet. These satellites take a variety of high-resolution, frequent measurements over large areas of Earth's surface that allow us to better understand the Earth system by providing data for high-resolution models—such as the wind speeds from Hurricane Sandy, shown here. **Image credit:** NASA

Image 3. Lawrence Freidl described how NASA's Applied Sciences Program and its partners use thermal anomaly data from the Moderate Resolution Imaging Spectroradiometer (MODIS) to detect fires from space and incorporate these data into their decision-support tools. **Image credit:** NASA

and *Eyes on the Earth (eyes.jpl.nasa.gov/earth/download.html)* that took place at the two interactive kiosk stations—see **Images 4, 5,** and **6**. More than 15 additional programs delivered their messages by way of table-top displays, fact sheets, brochures, and other takeaway products. The represented programs included the Earth Science Technology Office, High-End Computing Program, Airborne Science Program, Balloon Program, Earth Science Data and Information System Project, NASA Postdoctoral Program, Virginia Space Grant Consortium, Radioisotope Power Systems, and Earth, planetary, heliophysics, and lunar science programs—see **Images** 7 and **8**. Copies of the iconic NASA Science Calendar for 2014 were also distributed twice a day—see **Image 9**, next page. The electronic version of the calendar is available at *eospso.gsfc.nasa.gov/sites/default/files/publications/2014%20calendar%20final_508_0.pdf*.

Image 6. Kevin Hussey [NASA/Jet Propulsion Laboratory] demonstrated *Eyes on the Earth*—a three-dimensional visual application that allows users to fly along with NASA's Earth-observing satellite fleet and view near-real-time climate datasets. **Image credit:** NASA

Image 4. Jeffery Newman [NASA Headquarters] discussed NASA's recently launched Interface Region Imaging Spectrograph (IRIS) mission and how it is producing data showing never-before-seen details of the sun's lower atmosphere, or interface region, during one of the side-event presentations. **Image credit:** NASA

Image 7. Andrea Martin [GSFC] explained how two Earth Science Technology Office-funded CubeSat projects, launched from Vandenberg Air Force Base on December 5, 2013, will help validate and test new technologies in the space environment. **Image credit:** NASA

Image 5. Eddie Gonzales [NASA/Jet Propulsion Laboratory] virtually placed a three-dimensional spacecraft on a visitor's shoulder while demonstrating Spacecraft 3D using an iPad and display monitor at one of the interactive kiosk stations. **Image credit:** NASA

Image 8. Jacob Reed [GSFC] provided information about the Global Precipitation Measurement (GPM) spacecraft, a joint NASA-Japan Aerospace Exploration Agency (JAXA) mission scheduled to launch in February 2014. **Image credit:** NASA

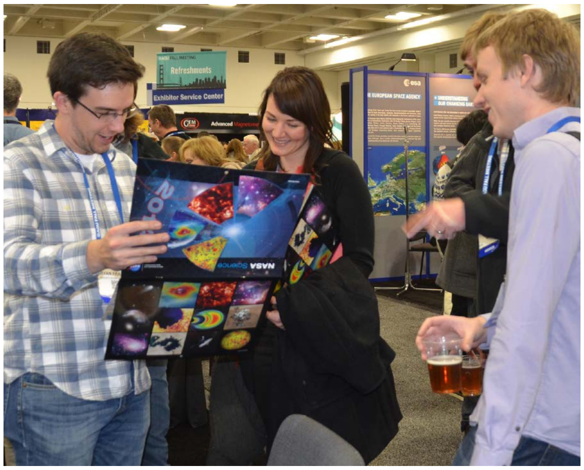


Image 9. As they do every year, AGU attendees marveled at the 2014 NASA Science calendar. **Image credit:** NASA

In addition to AGU attendees, *NASA Social*[3] participants visited the NASA exhibit on Tuesday, December 10 to enjoy presentations on the hyperwall as well as several other demonstrations and face-to-face interactions.

Jack Kaye [NASA HQ—*Associate Director for Research*] and **Michelle Thaller** [NASA's Goddard Space Flight Center (GSFC)—*Assistant Director for Science Communication and Higher Education*] gave presentations on Thursday, December 12 to close out the series of hyperwall talks—see **Image 10**. This was followed by a special hyperwall showing of a 15-minute film that showed the STS-132 Shuttle mission from start to finish, including footage of the crew onboard the International Space Station. The inspirational film was very moving for the more than 100 attendees at the booth.

As always, it was a successful, energetic, and science-packed week for NASA at the AGU Fall Meeting, and a lovely way to reflect on some of the great accomplishments achieved in 2013. We hope to see everyone at AGU again next year! ■

Image 10. Michelle Thaller [GSFC] held a dime up to a visualization of a solar coronal mass ejection to show the relative size of Earth, while discussing the impacts of such eruptions on Earth's magnetic fields. **Image credit:** NASA

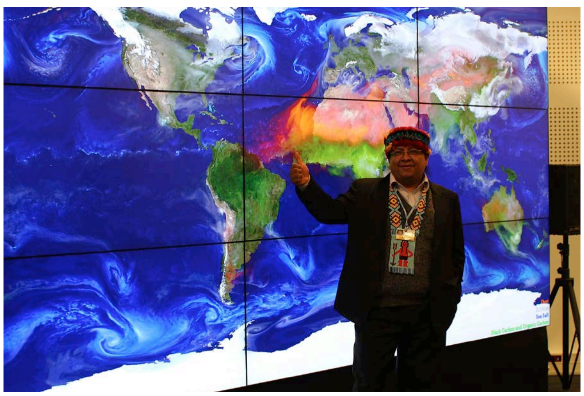
[3] *NASA Social* is a program to provide opportunities for NASA's social media followers to learn and share information about NASA's missions, people, and programs. This year NASA teamed with AGU to host a one-day event to allow 20 social media users to experience NASA science at the meeting.

NASA Joins the U.S. Center at COP-19

Heather Hanson, NASA's Goddard Space Flight Center/Global Science & Technology, Inc., heather.h.hanson@nasa.gov

The Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC)—with a near-global membership representing 194 nations—meets yearly to discuss the state of Earth's climate and how best to deal with future climate change. This year's nineteenth session, or COP-19, was held November 11-22, 2013, at the National Stadium in Warsaw, Poland.

Hosted by the U.S. Department of State, the *U.S. Center* at COP is a major public outreach initiative to inform attendees about key climate initiatives and scientific research taking place in the U.S. As has been the standard for several years, representatives from NASA, other U.S. government agencies, academic institutions, nongovernmental organizations, private-sector companies, and other stakeholders convene in the U.S. Center to highlight key climate programs and scientific research. The presentations underscored the strong actions the U.S. is taking to study, understand, and effectively plan for a changing planet.



A COP-19 attendee stands in front of NASA's hyperwall in the U.S. Center. **Image credit:** NASA

Within the U.S. Center, there were two main presentation areas: a small stage equipped with two plasma screens, typically used to accommodate panelists and other presentation events, and an area for NASA's hyperwall.

Jack Kaye [NASA Headquarters—*Earth Science Associate Director for Research*], **Carmen Boening** [NASA/Jet Propulsion Laboratory—*Scientist*], **Cynthia Rosezweig** [NASA's Goddard Institute for Space Studies—*Senior Research Scientist*], and **Bruce Doddridge** [NASA's Langley Research Center—*Head of Chemistry and Dynamics Branch*] traveled to Warsaw to support the two-week event and to deliver a variety of hyperwall and other presentations. The hyperwall content highlighted the following climate themes: Earth's Climate from Space, Oceans and Water Resources, Aerosols and Atmospheric Composition, and World of Change and Urbanization.

Jack Kaye demonstrating the three-dimensional *Eyes on the Earth* application. **Image credit:** NASA

Cynthia Rosezweig described how NASA's Earth-observing satellites and instruments have been observing human-induced and natural environmental changes from space. **Image credit:** NASA

The presenters also demonstrated the interactive *Eyes on the Earth (eyes.jpl.nasa.gov/earth/index.html)* application that delivers data and images from NASA's fleet of Earth-observing satellites to home computers. Between presentations, Kaye, Boening, Rosenzweig, and Doddridge served as docents for visualizations playing on the hyperwall, providing exhibit visitors with context for using NASA data to study Earth's climate.

Having such a strong NASA presence at the U.S. Center helped to emphasize our nation's leading role in studying and understanding the complexities of Earth's interrelated systems and the roles of ocean, atmosphere, land, and ice, globally. NASA representatives highlighted several national and international partnerships, described how NASA supports global collaboration between missions, and encouraged synergistic measurements to improve our understanding of the global Earth system. To view a collection of photos of NASA's involvement taken inside the U.S. Center, visit: *www.flickr.com/photos/eospso/sets/72157637642764353*.

To learn more about COP-19 and to read highlights from the event, visit the U.S. Department of State website at *www.state.gov/e/oes/climate/cop19*. ■

Measuring Rain for Society's Gain: GPM Applications Workshop

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Dalia Kirschbaum, NASA's Goddard Space Flight Center, dalia.b.kirschbaum@nasa.gov

With the GPM launch fast approaching (planned for February 27, 2014), NASA's Applied Sciences Program...organized an Applications Workshop that took place November 12-13, 2013, at NOAA's Center for Weather and Climate Prediction in College Park, MD. This gathering brought together a diverse group of scientists, Earth observation data users, and end users for a two-day meeting.

Workshop Rationale

In the last issue of *The Earth Observer*[1], we reported on the Global Precipitation Measurement (GPM) mission. We described its objectives; detailed the two orbiting instruments on the GPM Core Observatory, the GPM Microwave Imager (GMI) and Dual-frequency Precipitation Radar (DPR); and reviewed the spacecraft design, ground system, and data processing. Also briefly mentioned were the wide range of applications that could benefit from GPM data. It was to address these possibilities that the GPM workshop described here was held.

GPM was designed from the outset with an applications focus. Its predecessor, the Tropical Rainfall Measuring Mission (TRMM), launched in 1997, has established an impressive suite of applications. GPM will build on the TRMM legacy, generating more detailed—and in some cases, new—information for scientific research and in areas of societal benefit: The data will be used to study hurricane eyewalls and intensity, measure hazard-triggering rainfall events, provide inputs to climate and land-surface models, and offer new insights into agricultural productivity and world health.

With the GPM launch fast approaching (planned for February 27, 2014), NASA's Applied Sciences Program[2], in coordination with the University of Maryland, College Park and the National Oceanic and Atmospheric Administration (NOAA) organized an Applications Workshop that took place November 12-13, 2013, at NOAA's Center for Weather and Climate Prediction in College Park, MD. This gathering brought together a diverse group of scientists, Earth observation data users, and end users for a two-day meeting. In all, there were 133 participants onsite, with several others participating via WebEx. Participants learned how data from TRMM and GPM are already being applied to a variety of science and societal issues, and also learned of opportunities for and challenges to broadening the scope of applications for TRMM and GPM data. The meeting provided an opportunity to introduce current and potential users to the TRMM and GPM data processing systems, and for users to provide helpful feedback to the TRMM and GPM teams about what they require to use precipitation data. The Applied Sciences Program intends for this to be the first in a series of workshops organized to keep the lines of communication open between the science teams and the user community.

The remainder of this report will be a high-level summary of the workshop. PDFs of all the presentations mentioned herein can be viewed at: *pmm.nasa.gov/meetings/2013-gpm-applications-workshop/presentations*.

Workshop Summary

The workshop's opening session served to provide participants with a TRMM and GPM status update, including the perspective of the Japan Aerospace Exploration Agency (JAXA)—NASA's partner for both TRMM and GPM. There was also an overview of the merged data products for TRMM and GPM—the TRMM Multisatellite Precipitation Analysis (TMPA) and Integrated Multi-Satellite Retrievals for GPM (iMERG), respectively—along with plans for transition between the two. On the second day, there were two presentations that covered ground validation for GPM and data access and visualizations.

[1] See "GPM Core Observatory: Advancing Precipitation Instruments and Expanding Coverage" in *The Earth Observer*'s November–December 2013 issue [**Volume 25**, **Issue 6**, pp. 4-11].
[2] See "NASA's Applied Science Program—Earth Science Serving Society" in *The Earth Observer*'s January–February 2012 issue [**Volume 24**, **Issue 1**, pp. 8-11] for an overview of the program.

The remainder of the meeting was dedicated to four sessions, reflecting the four elements of the Applied Sciences Program. These are:

- Weather Forecasting;
- Water Resources, Agricultural Forecasting, and Food Security;
- Hydrological Modeling and Disaster Response; and
- Ecological Forecasting and Public Health.

Each session reviewed relevant applications from TRMM and GPM, and included a keynote address, followed by presentations on related topics. Afterwards, 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. The four sessions are summarized below.

Weather Forecasting Session

Louis Uccellini [National Weather Service (NWS)—*Director*] gave the keynote address for this session, on *Advancing Forecast Capabilities: Thoughts on the Global Observing System.* He focused on NWS's efforts to build a *Weather-Ready Nation*, one that is more weather-ready, responsive, and resilient to extreme weather, by shifting the agency's culture to incorporate *impact-based decision support services* (IDSS). Uccellini stressed the importance for other agencies and organizations to embrace and engage with the effort. He also discussed the need to support and enhance the four elements that converge for *numerical weather prediction* (NWP): global observing systems; computers (supercomputers and workstations); data assimilation and modeling science; and forecaster skill. Uccellini provided examples of how improved forecast skill helped with the prediction of Hurricane Sandy in October 2012, and showed comparisons of various model forecasts for the storm. He also reviewed the communications strategy that was used for Sandy, showing the emphasis on IDSS, and commented that, "the consistent message saved lives." Uccellini ended with the impressive list of *in situ* and satellite observations (such as those planned for GPM) that are used for NWP, and some statistics that show the individual contribution of each type of measurement, including data from satellite infrared and microwave sounders, which make the largest contribution to forecast improvements. He emphasized the role of the Joint Center for Satellite Data Assimilation (JCSDA) in accelerating the use of research data for forecasting applications and the increasing number of satellite observations that are now part of the baseline performance of the operational models. JCSDA is an avenue through which NOAA can effectively incorporate and evaluate the impact of new observation systems on operational NWP [e.g., the in-progress Joint Polar Satellite System (JPSS) and GOES-R, both scheduled for launch in 2016].

__Louis Uccellini__ [outlined] the impressive list of in situ *and satellite observations (such as those planned for GPM) that are used for NWP, and some statistics that show the individual contribution of each type of measurement, including data from satellite infrared and microwave sounders, which make the largest contribution to forecast improvements.*

The other presentations in this session were:

- *The Use of TRMM/GPM Observations at The Weather Company*, by **Peter Neilly** [The Weather Company]—see *Applications Focus: How The Weather Channel Uses Precipitation Data* on page 28;
- *GPM and Weather Forecasting*, by **Peter Bauer** [European Centre for Medium-range Weather Forecasts (ECMWF), U.K.]; and
- *The GPM Mission—An Invaluable Source for Model Evaluation and Forecast Improvement*, by **Svetla Histrova–Veleva** [NASA/Jet Propulsion Laboratory].

After the presentations, the panel led a discussion that covered topics such as: why satellite data are not routinely used in hurricane forecasts; how to make satellite data more visually interesting; how to justify expenditures for satellites, models, and related activities; and how to convince the public that forecasts are improving. All questions were answered in significant and useful detail, often engendering additional discussion amongst the participants.

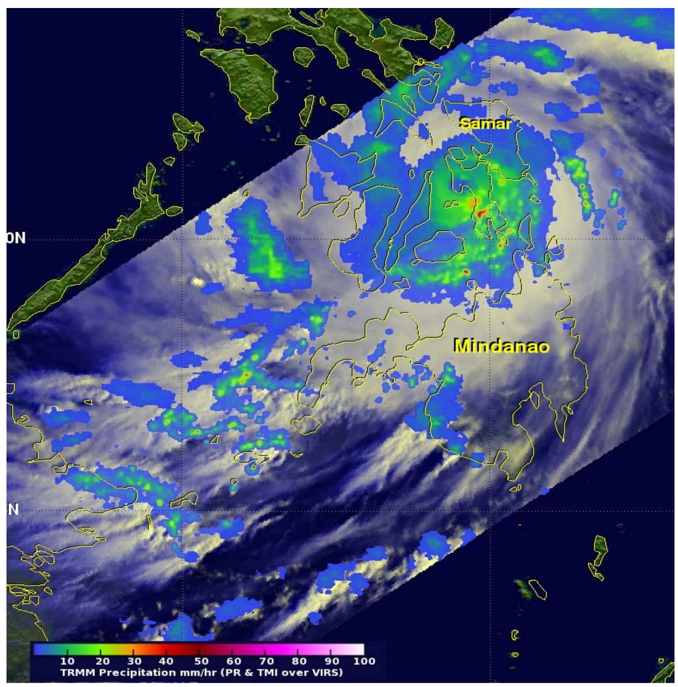
Applications Focus: How The Weather Channel Uses TRMM–GPM Data

Peter Neilly is Senior Vice President for Global Forecasting Services for The Weather Company (TWC), one of the world's largest private weather forecasting companies. TWC, which is perhaps known best for its production of *The Weather Channel,* collects data from government and other partners and augments it with their own information. They run their own numerical weather prediction (NWP) models and climate models, and the output is used to issue forecasts, which can be modified as needed by human forecasters. The results are creatively packaged to convey compelling and relevant information.

Neilly explained that TWC incorporates satellite data in three main ways:

- **forecasting situational awareness,** where satellite data, particularly geostationary data, are used to track the evolution of weather features;
- **indirect forecasting applications,** where satellite data are assimilated into TWC's models, satellite-initialized models from government centers are used, and satellite data are used in automated *nowcasting* systems; and
- **story telling,** where satellite data and derived products are used to convey weather and forecasting stories and their impact.

Currently, polar-orbiting satellite data are used significantly less often than geostationary data. TRMM data in particular are only used in very specific cases, such as for rainfall rate analyses over the ocean or data-sparse areas, and to support *ad hoc* interesting (usually international) stories. Several factors limit the use of TRMM data at TWC in general: timeliness, coverage, and frequency. These limitations become especially acute when observing rapidly evolving weather phenomena—e.g., severe weather outbreaks. In addition to these limitations, owing to their somewhat *ad hoc* organization and availability, TRMM data are also generally more difficult to access then other NWP data, making them harder to assimilate into NWP models.



TRMM image of Super Typhoon Haiyan obtained on November 8, 2013.
Image credit: NASA

As compared with TRMM, GPM will offer broader latitudinal coverage, enhanced precipitation-type identification, more accurate identification of midlatitude precipitation phenomena (e.g., detecting snow and light precipitation), and improved particle-discrimination capabilities. Neilly concluded with a "wish list" of things that would make GPM data even more appealing for TWC—and, potentially, other applications developers. These include:

- solving the previously mentioned "limitations" of polar satellite data;
- developing real-time, Internet-based, high-availability raw data streams;
- developing self-service portals to research quality data and produce graphical generation;
- creating community available data assimilation modules for WRF model; and
- establishing relationships with TRMM/GPM core science organizations for better communication of data use and opportunities for future data applications.

The issue of *data latency* became a recurring theme—not only in this session but for the three that followed. Different applications have different temporal requirements for data acquisition, access, and use. Clearly, for weather forecasting applications to make maximum use of GPM data (or any satellite data), the data have to be available in a timely fashion. Louis Uccellini stressed the need to make the GPM algorithms available to the NWS as soon as possible.

Clearly, for weather forecasting applications to make maximum use of GPM data (or any satellite data), the data have to be available in a timely fashion.

Water Resources, Agricultural Forecasting, and Food Security Session

Jim Verdin [U.S. Geological Survey's Earth Resources Observation and Science Center—*Physical Scientist*] delivered the keynote for this session, *On the Importance of Satellite Rainfall Products for Famine Early Warning*. He began with an overview of the Famine Early Warning Systems Network (FEWS NET)—*www.fews.net/Pages/default.aspx*, and stressed the crucial role that satellite observations play in "filling the gap" in places where conventional observations are sparse and/or have late-reporting. He showed how the Climate Hazards Group IR Precipitation (CHIRP) archive is used to place droughts in their historical context, and how combining data from ground stations with CHIRP produces even more accurate analysis than using satellite data alone. Verdin discussed applications tools that have been developed including the Interactive Map Viewer, Early Warning Explorer, Rolling Daily Products, and the *GeoCLIM* software and manual[3]. He showed examples of water point mapping in Yemen and of monitoring agricultural drought in Africa, which allows researchers to pinpoint exactly where drought has been recurring—an important factor in determining what farming areas are most vulnerable to drought. Verdin discussed the NASA Land Information System and its application to water availability, and ended his presentation with a discussion of the challenges associated with using satellite data for drought analysis, one of the biggest of which is lack of robust historical data records. He indicated that the International Satellite Cloud Climatology Project (ISCCP) Level-B1 Infrared Data Rescue time-series has been an invaluable resource in that regard, and wondered if something similar existed or could be developed for microwave data. There are also challenges with snow-pack modeling; however, having satellite products with "better physics," as is expected from GPM, will be helpful in addressing these concerns. Finally, while more satellite observations are always desired, Verdin said that *station support* is equally crucial—i.e., maintaining the instrumentation and validating the quality of the data collected on the ground.

Jim Verdin (speaking) responds to a question from the audience during the Water Resources, Agricultural Forecasting, and Food Security panel discussion. Other panelists included [*left to right*] **Wade Crow**, **Brian Wardlow**, and **Kingste Mo**. **Image credit:** Dalia Kirschbaum [GSFC]

The other presentations in this session were:

- *Challenges in Drought Monitoring and Prediction*, by **Kingste Mo** [NOAA's NWS Climate Prediction Center, National Centers for Environmental Prediction (NCEP)];
- *Drought Monitoring and Precipitation Data: A U.S. Perspective on Current Uses, Needs, and Opportu*nities, by **Brian Wardlow** [University of Nebraska–Lincoln, Center for Advanced Land Management Information Technologies (CALMIT)]; and

[3] See, respectively, *earlywarning.usgs.gov/adds/africa/index.php*, *earlywarning.usgs.gov/adds/ewxindex.php*, *earlywarning.usgs.gov/adds/africa/web/imgbrowsc2.php?extent=af3a*, and *chg.geog.ucsb.edu/tools/geoclim/pdfs/overview.pdf* for additional information on these applications.

- *Integration of GPM Rainfall Products into Operational USDA Crop Production Estimates*, by **Wade Crow** [U.S. Department of Agriculture's Agriculture Research Service, Hydrology and Remote Sensing Laboratory].

After the presentations the panel led a discussion, and answered questions from the audience. One topic that came up again was the critical need for station support for satellite observations, as discussed earlier by **Jim Verdin** during his keynote presentation. Other topics addressed included optimum update frequency for precipitation products, the potential applicability of GPM data for developing a global drought monitoring capability, and developing and having access to a historical drought record.

Overall, this session emphasized the importance of data consistency and longevity for accurate assessment of anomalous events that persist over time, such as droughts. For the applications presented in this session, real-time data access was less important than having very good historical records.

Hydrological Modeling and Disaster Response Session

Chris Chiesa [Pacific Disaster Center (PDC)—*Deputy Executive Director*] delivered this session's keynote presentation on, *Hazard Detection, Monitoring, Modeling, Assessment, and Warning*. Chiesa noted that PDC's mission is to reduce disaster risks and foster disaster-resilient communities, using an approach that integrates applied science, information and communications technology, and information exchange. It involves capability development, capacity enhancement, and simplified access to evidence-based information products that improve decision support for emergency managers. Often the information decision makers need to quickly and effectively issue accurate warnings of pending disasters is challenging to identify or interpret. He explained how PDC overcomes these challenges with sophisticated tools, products, and diverse services that make data easier to both find and use.

*Elaborating on a powerful early-warning and decision-support platform, called DisasterAWARE (**disasteraware.pdc.org**), **Chris Chiesa** discussed how identifying and closing information gaps throughout the disaster cycle (mitigation, preparation, response, and recovery) strengthens the ability to take appropriate action during critical moments—when there is no time to "think" about the response.*

Elaborating on a powerful early-warning and decision-support platform, called *DisasterAWARE (disasteraware.pdc.org)*, Chiesa discussed how identifying and closing information gaps throughout the disaster cycle (mitigation, preparation, response, and recovery) strengthens the ability to take appropriate action during *critical moments*—when a decision must be made quickly. PDC provides support to an array of partners, helping to develop, share, and receive information. Examples of PDC's past and present activities include independent system deployments in national disaster management organizations in Thailand, Indonesia, and Vietnam, along with regional associations at the Association of Southeast Asian Nations' (ASEAN) Coordinating Centre for Humanitarian Assistance in Indonesia, and in the Caribbean. Much of this work is made possible by a cooperative agreement with the Office of the Secretary of Defense – Policy and PDC's managing partner, the University of Hawaii. Additional funds come from national sources, like the U.S. Agency for International Development. Public users can access a range of information about hazards in DisasterAWARE online (link above) through "Global Hazards Atlas" or by downloading "Disaster Alert," a mobile application that has provided nearly 1.5 million free downloads.

The other presentations in this session were:

- *GPM in NOAA's Integrated Water Forecasting*, by **Robert Hartman** [NOAA's NWS, Office of Hydrologic Development];
- *Examples and Comments on the Use of GPM in Flood and Landslide Hazard Estimation*, by **Robert Adler** [University of Maryland, College Park];
- *FEMA Geospatial Overview,* by **Christopher Vaughn** [Federal Emergency Management Agency]; and
- *Excessive Rainfall Protection: A Parametric, Satellite-based Insurance Solution*, by **Megan Linkin** [Swiss Re Global Partnerships].

After the presentations the panel led a discussion and answered questions from the audience, on topics that included the development and progress of Adler's new Global Flood Monitoring System (GFMS) and a discussion of the importance of integrated multisatellite, NWP gauge products for improved hydrologic validation. Other questions addressed the utility of *crowdsourcing* in FEMA activities, communicating uncertainty in the discussed applications, and the suitability of using all available data in assigning uncertainty levels to data. In addition, the panelists agreed that providing links to the appropriate source information and providing more *quality control flags* are crucial to providing accurate information on hazards and related uncertainties.

Ecological Forecasting and Public Health Session

Molly Macauley [Resources for the Future—*Vice President for Research*] gave the session's keynote presentation on *The Science of Actionable Science*. She began by giving some background on what is meant by *actionable science,* identifying three focus areas: science for new knowledge, science on which to base action, and science to change a course of action. She then showed a specific example of how new science has led to an update on the "social cost of carbon." This example shows a convergence of carbon-cycle science, Earth observations, and policy. Macauley then discussed *value of information* (VOI) and how these kinds of analyses can be incorporated into research.

The other presentations in this session were:

- *The Weather, Climate, and Health Program at NCAR: Using NASA Products for Public Health Applications*, by **Mary Hayden** [NCAR];
- *GPM Applications: Public Health*, by **Pietro Ceccato** [Columbia University, International Research Institute for Climate and Society];
- *Satellite Precipitation Data, Food Security, and Nutrition Outcomes*, by **Molly Brown** [NASA's Goddard Space Flight Center]; and
- *Env-DATA: New Tools for Studying Animal Movement and Their Environment*, by **Gil Bohrer** [Ohio State University].

After the presentations, the panel fielded a number of questions from workshop participants. A significant barrier that must be overcome to get local groups to use satellite or modeled data is to overcome their inherent "distrust" of the data. The panel stressed the importance of quality control flags to accurately communicate the advantages and inherent limitations of the data. The panel also provided some helpful anecdotes of how they have been successful communicating uncertainties of their studies and data—so that local groups can better understand and use the information.

A significant barrier that must be overcome to get local groups to use satellite or modeled data is to overcome their inherent "distrust" of the data.

Breakout Session Summaries

The second day included four breakout sessions that ran concurrently, one on each of the Applied Sciences Program's focus areas, as summarized earlier in this article. These breakout sessions provided an opportunity for participants to continue the dialogue that began during the previous day's formal sessions, to expand the discussions to address issues of data latency, accuracy, and accessibility, and consideration of future applications. The meeting ended with a short plenary session, where a spokesperson from each breakout session provided a summary of the group's discussions. The session discussions and plenary are summarized below.

During the workshop **George Huffman** facilitated a GPM/TRMM data developers lunch-time "brownbag" discussion which drew lots of participants and led to lively discussion about opportunities for and challenges to broader use of precipitation data in a variety of applications. **Image credit:** Dalia Kirschbaum [GSFC]

Weather Forecasting Breakout

The Weather Forecasting breakout focused on numerical modeling, field monitoring and forecasts, and climate prediction.

A key operational issue was that budget restrictions are the most important factor in conducting applied research and the biggest impediment to fully taking advantage of potential GPM achievements for improved modeling and operations. Also needed are stronger connections between research (GPM) and operations (e.g., NOAA, ECMWF) communities.

In using GPM data, the group emphasized the need for evidence of clear added value provided by any new sensors or observation system to the improvement of weather forecasts and additional benefits to the society, especially relative to other sensors. User needs (especially operational) must be incorporated into all data discussions. The group noted the impacts to forecasts for different time scales in evaluating operational center data ingestion.

In using GPM data the group emphasized the need for evidence of clear added value provided by any new sensors or observation system to the improvement of weather forecasts and additional benefits to the society, especially relative to other sensors.

The group discussed data accuracy, spatial resolution, temporal resolution, forecast horizon, and latency recommendations/requirements for three different application areas: weather modeling/data assimilation, global and regional forecasting, and climate prediction.

Participants also discussed requirements for improving precipitation forecasts and how the planned GPM measurements will help. Weather-modeling requirements included assimilating passive microwave radiances with reasonable accuracy estimates, three-dimensional structure of water vapor from combined sensors, and vertical profiles of hydrologic variables. For climate modeling, a key requirement is to have climate land surface model runs that are forced by ground and satellite precipitation data. This is especially important when studying areas like Africa and the Amazon.

The panel also discussed operational forecast centers' needs for timely access to Level-1B GPM data. Data formats must be suitable for operational systems, with data subsetting and archiving capabilities for Level-2 and Level-3 data.

Water Resources, Agricultural Forecasting, and Food Security Breakout

This breakout session focused on how satellite precipitation products are currently used in areas of water resources, agricultural forecasting, and food security, and what products and integration mechanisms would be desirable for incorporating GPM data into these applications. The group discussed how satellite precipitation measurements were more reliable than rain gauge networks in many places where gauges are either sparsely distributed or poorly maintained. The data have also been helpful in providing an objective "referee" when there are water treaty issues or disputes between countries or states.

The group outlined several aspects of GPM projects and delivery that would be desirable in advancing applications, and then discussed what tools and information would be valuable for improved integration of GPM data into their applications. The participants emphasized that basic tools to read and write data from iMERG must be in place to make it easy to download and use the data in analysis tools like geographic information systems (GIS). Including other datasets from precipitation missions and instruments (e.g., Aqua's manifest) would be helpful in expanding the information content. Given the overlap in data needs and access amongst many of the application areas in this breakout group, participants suggested that a forum be developed for the user community to share datasets and provide more transparency for how to access, subset, and analyze products.

Hydrological Modeling and Disaster Response Breakout

A statement that **Molly Macauley** had offered during her Ecological Forecasting and Public Health keynote seemed to resonate with this group: *"Information has value if it* *can either make a current choice more secure and confident, or if it can reveal a different choice as better than the current choice."* In the context of discussing this statement, the group noted the seemingly inevitable *tradeoff* between data accuracy and real-time availability—and the hope that GPM data will help to reduce the "gap" between those two.

Discussion then moved on to discuss several applications where satellite precipitation data have been valuable for estimating flood extent, timing, and situational awareness. In many cases, developing countries use such data to prepare for flood events in the absence of dense rain and river gauge networks.

Session participants also outlined challenges and data requirements for improving hazard response and hydrologic modeling: such as better nonexpert documentation of information content and metadata, and formats that can be readily integrated into common geographic visualization applications. Hydrology and disaster response emergency managers still have issues with *data discovery* and often lack sufficient background knowledge about appropriate products and datasets.

The group emphasized that satellite and model data providers need to more clearly communicate uncertainty and error characterization for their products to more general audiences. They all agreed that the temporal and spatial resolution differences between TRMM and GPM will help to improve response times and accuracy, and the 50% decrease in data latency will also be helpful—although this will still be of little use for flash flood events. The participants concluded that there will be new opportunities for enhanced analyses and forecasts from assimilating GPM products into numerical weather prediction and hazard assessment models.

Ecological Forecasting and Public Health Breakout

This breakout discussion led to generation of an outline of the scale, latency, quality control, and gaps in current and future data for improved response to both short- and longer-term applications areas. Specifically, the group outlined the importance of satellite observations in data-sparse areas, where there are no *in situ* instruments to collect precipitation observations. Similarly, epidemiological studies conducted in urban areas require more accurate representation of vector-borne diseases and potential source areas. Consistent data with high spatial resolution can greatly improve monitoring. However, at its current spatial scale, TRMM is inadequate for *district-level* applications.

Also of note was that different applications have different data latency requirements. For example, when analyzing vector-borne disease outbreaks, a latency of days-to-weeks is acceptable, whereas assessing water quality after episodic events requires near-real-time data. End users want good, validated precipitation data and a data quality flag that nonexpert users can understand: If an end user uses inaccurate data and comes up with a bad forecast, "trust" is eroded, and future use of the data is in doubt.

End users want good, validated precipitation data and a data quality flag that nonexpert users can understand: If an end user uses inaccurate data and comes up with a bad forecast, "trust" is eroded, and future use of the data is in doubt.

Several data gaps need to be filled to better quantify issues within the ecological forecasting and public health communities; these include soil moisture, absolute and specific humidity, daytime air temperature, high-resolution biomass estimates for carbon uptake, and ecosystem structure complexity. To maximize satellite mission data and get end-to-end estimates of processes related to the surface hydrology system, there needs to be cross-cutting information from multiple missions, platforms, and instruments to develop a suite of products (e.g., the Soil Moisture Active Passive (SMAP) and Surface Water Ocean Topography (SWOT) missions, in addition to TRMM and GPM).

Workshop Summary

The objectives of the GPM Applications Workshop were to explore topics of weather forecasting, water resources, agricultural modeling, food security, hydrological mod-

The objectives of the GPM Applications Workshop were to explore topics of weather forecasting, water resources, agricultural modeling, food security, hydrological modeling, disaster response, ecological forecasting, and public health, all with respect to applications using TRMM and GPM satellite data.

eling, disaster response, ecological forecasting, and public health, all with respect to applications using TRMM and GPM satellite data. The goal was also to broaden the discussion to address the range of current and future applications of satellite data to science and societal applications and to provide feedback to the TRMM and GPM teams with respect to data access, usage, and availability. General themes that emerged from the workshop included the need for greater communication of uncertainty in measurements; quality control flags within the datasets, with metadata written in clear and more basic terms; broader engagement of boundary organizations and other partners; and increased data accessibility and ease of usage. The workshop revealed that the varied applications of satellite precipitation data result in a broad community spectrum of data latency needs—from real-time access to Level-1B products to near-real-time merged products to weekly or monthly products. The workshop also stressed the importance of data reprocessing for a homogeneous, long-term precipitation record that spans the range from TRMM through the GPM era.

The next GPM Applications Workshop is tentatively scheduled for the spring of 2015. ■

Kudos

Compton "Jim" Tucker [NASA's Goddard Space Flight Center (GSFC)—*Senior Scientist*] has been selected to receive the Vega Medal from the Swedish Society of Anthropology and Geography (*ssag.se/english*). The society created the Vega Medal in 1881 on the occasion of Adolf Erik Nordenskiöld's return to Stockholm, after he had discovered the North East Passage. Since then, the Vega Medal has been awarded to a physical geographer roughly every three years. The King of Sweden gives out this award on April 24—the anniversary of Nordenskiöld's return to Stockholm.

Please join us in congratulating Jim on this award!

CERES Science Team Meeting

Edward Kizer, NASA's Langley Research Center/Science Systems and Applications, Inc., edward.a.kizer@nasa.gov

Overview

The Fall 2013 meeting of the Clouds and the Earth's Radiant Energy System (CERES) Science Team was held October 29-31, 2013, at Scripps Institution of Oceanography (SIO) at the University of California San Diego (UCSD), in La Jolla, CA. **Joel Norris** [SIO UCSD] hosted the meeting, which was conducted by **Norman Loeb** [NASA's Langley Research Center (LaRC)—*CERES Principal Investigator*].

The major objectives of the meeting included review and status of CERES instruments and data products. These included:

- a status report on the CERES project;
- an update on calibration of shortwave (SW), longwave (LW), and total channels of existing CERES instruments, which consist of those on the Terra (2), Aqua (2) and Suomi National Polar-orbiting Partnership (NPP) platforms (1);
- an update on CERES Flight Model 6 (FM6) and the Radiation Budget Instrument (RBI)—the planned CERES follow-on instrument;
- a status report on the CERES Suomi NPP single-scanner footprint (SSF) *Edition 1*: Visible Infrared Imaging Radiometer Suite (VIIRS) Cloud Algorithm;
- a status report on the CERES GEO Cloud Algorithm;
- a status report on CERES *Edition 4 angular distribution model* (ADM) development;
- status reports from the Surface-Only Flux Algorithm (SOFA), Surface and Atmospheric Radiation Budget (SARB), and Time–Space Averaging (TISA) Working Groups;
- an update from the Data Management Team, to address Terra, Aqua, and Suomi NPP;
- an update from the Atmospheric Sciences Data Center (ASDC); and
- an update on CERES education and public outreach efforts.

These discussions are summarized here. A full copy of each presentation can be downloaded from the CERES website at *ceres.larc.nasa.gov* (click the *CERES Meetings* button on the left navigation bar).

Tuesday, October 29

The first day of the meeting consisted of a series of programmatic and technical presentations—see **Table 1**[1].

Norman Loeb [LaRC] presented the *State of CERES* and discussed the status of the CERES project and how the Terra and Aqua missions scored in the 2013 Earth Science Senior Review—submitted in March

[1] All acronyms used in presentation titles and Tables 1-3 in this article are defined in the text and/or listed at *ceres.larc.nasa.gov/acronyms_main.php*.

Table 1: CERES Programmatic and Technical Sessions, Tuesday, October 29, 2013.

Speaker	Institution	Title
Norman Loeb	LaRC	State of CERES Report
Kory Priestley	LaRC	CERES FM1-FM6 and RBI Instrument Update (Part 1)
Susan Thomas	SSAI	CERES FM1-FM6 and RBI Instrument Update (Part 2)
Patrick Minnis	SSAI	CERES Clouds Working Group Report (Part 1)
Rabindra Palikonda	LaRC	CERES Clouds Working Group Report (Part 2)
Wenying Su	LaRC	Updates on the Edition 4 ADMs
David Kratz	LaRC	Status of the Shortwave Surface-Only Flux Algorithms
Seiji Kato	LaRC	SARB Working Group Update
Dave Doelling	LaRC	TISA Working Group Report (Part 1)
Moguo Sun	SSAI	TISA Working Group Report (Part 2)
P.C. Sawaengphokhai	SSAI	FLASHFlux Update
Chris Harris	LaRC	CERES Data Management Team Update
Jonathan Gleason	LaRC	ASDC Update
Sarah Crecelius	SSAI	Status and Overview of CERES Education and Public Outreach

Table 2: CERES Contributed Science Presentations from Wednesday, October 30.

Speaker	Institution	Topic
Joao Teixeira	JPL	Looking for Climate Extremes with AIRS
K. Pistone	SIO UCSD	Albedo Decrease Caused by Vanishing Arctic Sea Ice: Observational Determination Using CERES
Kuan-Man Xu	SIO UCSD	CERES Observations of Cloud Regimes Within a Composite Madden-Julian Oscillation
Remy Roca	LEGOS	Scarab-3 on Megha-Tropiques: Mission and Products Status
Ping Yang	Texas A&M University	A Two-Habit Ice Cloud Model for Remote Sensing Applications and Radiative Forcing Studies
Sunny Sun-Mack	SSAI	Improvement of Edition 4 Clouds Over Edition 2 Using C3M Data
Fu-Lung Chang	SSAI	CERES VIIRS Multilayered Cloud Property Retrieval
Baike Xi	University of North Dakota	Investigate the Edition 4 and Edition 2 Cloud Properties Using DOE ARM Measurements at Barrow and Atqasuk Sites

2013. Highlights from a CERES *Phase F* Close-Out Plan were presented. A schedule with key milestones including software deliveries for Edition 3 and Edition 4 processing (needed to produce CERES products) were also presented.

Kory Priestley [LaRC] presented the *CERES FM1–FM6 Instrument Status Report* and the status of the RBI instrument. Priestley discussed the CERES Instrument Working Group's efforts to resolve nonuniform scatter in the FM6 Solar Diffuser Mirror Attenuator Mosaic (MAM); lamp brightening of the Internal Calibration Module (ICM); and decreased response of the ICM reference detector photodiode.

Susan Thomas [Science Systems and Applications, Inc. (SSAI)] discussed the Suomi NPP/CERES FM5 instrument data validation status, and concluded that the instrument continues to operate in the expected range. Thomas also reported that the CERES FM5 gains for *Edition 1* processing are being tested and validated. She stated that the Terra FM1 and FM2 instrument gains and *spectral response functions* (SRFs) were delivered for Edition 4 production processing and that Aqua FM3 and FM4 gains and SRFs were being validated.

Wednesday, October 30

The second day of the meeting featured a series of invited presentations, followed by several contributed science presentations from team members. The invited presentations are summarized below; contributed presentations are listed in **Table 2**.

Invited Science Presentations

Dean Roemmich [SIO UCSD] presented *Argo and Ocean Heat Content: Progress and Issues*. He reported how the Argo network—small drifting robotic probes designed to observe Earth's oceans—systematically measures ocean temperature globally, except in some marginal seas and on continental shelves. He reported that ocean heat gain for the years 2006-2013 is confined to south of 20° South latitude; the same pattern is likely to have held for the more sparsely sampled period in 1993. Roemmich also suggested that further investigations and longer Argo time series would yield more accurate estimates, including interannual variability.

Josh Willis [NASA/Jet Propulsion Laboratory (JPL)] presented *Ocean Constraints on the Earth's Radiative Imbalance.* He reported that the global mean sea level fell by about 5 mm (~0.2 in) between 2010 and 2011. He explained that most of the drop was due to transfer of water from ocean to land; he expects the sea level rise will likely resume in the next year, depending on La Niña processes.

Shang-Ping Xie [SIO UCSD] presented the *Current Hiatus of Global Warming,* showing evidence of a hiatus in global warming with a decadal cooling of the Pacific and a strengthening of the Walker circulation. He showed how the Southern U.S. is experiencing warming and drought as a result of the Pacific cooling. Xie also suggested that the current hiatus in global warming might continue for years.

Thursday, October 31

The final day of the meeting continued with more contributed science presentations from university researchers and CERES co-investigators and support staff, with updates on new data products and science results. Two of these presentations are summarized herein; all are listed in **Table 3**, next page.

Timothy Myers [SIO UCSD] presented *The Simulation of Interannual Variability of Subtropical Clouds in CMIP3 and CMIP5 Models Compared to Retrievals from CERES, ISCCP, and CALIPSO*. Myers

Table 3: CERES Contributed Science Presentations from Thursday, October 31.

Speaker	Institution	Topic
Patrick Taylor	LaRC	Variability of Regional TOA Flux Diurnal Cycle Composites
Zachary Eitzen	SSAI	Edition 4 Longwave Angular Distribution Models
Bijoy Thampi	SSAI	Novel Application of Random Forest Method in the CERES TOA Radiance Classification
Timothy Myers	SIO UCSD	The Simulation of Interannual Variability of Subtropical Clouds in CMIP3 and CMIP5 Models Compared to Retrievals from CERES, ISCCP, and CALIPSO
Takmeng Wong	LaRC	Comparison of CERES EBAF Edition 2.7 TOA Fluxes with Reanalysis Data
Bing Lin	LaRC	Atmospheric Heat Transport Estimations Based on Satellite and Assimilation Data
Norm Loeb	LaRC	Observing Interannual Variations in Hadley Circulation Atmospheric Diabatic Heating and Circulation Strength

showed how subtropical low-level clouds drive the uncertainty in cloud feedbacks. He also described the sensitivity of SW, LW, and net cloud radiative effects from the Coupled Model Intercomparison Project, *Phase 5* (CMIP5) model, with comparison to the CMIP3 model, noting that turbulent processes were poorly simulated in both models.

Takmeng Wong [LaRC] presented *Comparison of CERES EBAF Edition 2.7 TOA Fluxes with Reanalysis Data, Compared to 13 years of CERES EBAF TOA Radiation Budget Data with ECMWF ERA Interim Reanalysis Data*. Wong described the differences in solar incoming radiation between the products, concluding that European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis [ERA]-Interim data values are higher than the Energy Balance and Filled (EBAF) values used from Solar Radiation and Climate Experiment (SORCE). He also showed that the global mean time series are very similar. However, there are some larger differences in all-sky SW and LW time series after 2010.

Summary

The planned milestones for Suomi-NPP/CERES FM5 data products as well as the *Edition 3* and *Edition 4* data products from CERES FM1- FM4 instruments were presented to the team. The CERES team will move forward with incorporating the new *angular distribution model* (ADM) into the production software for processing the next generation Edition 4 data products. The Instrument group will be delivering the Aqua Spectral Correction Coefficients for Edition 4 process upon completing a validation process. The TISA group expressed a desire to move forward with finalizing the GEO cloud properties.

The next CERES Science Team meeting will be held April 22 - 24, 2014, at NASA's Langley Research Center. ■

in the news

NASA-USGS Landsat 8 Satellite Pinpoints Coldest Spots on Earth

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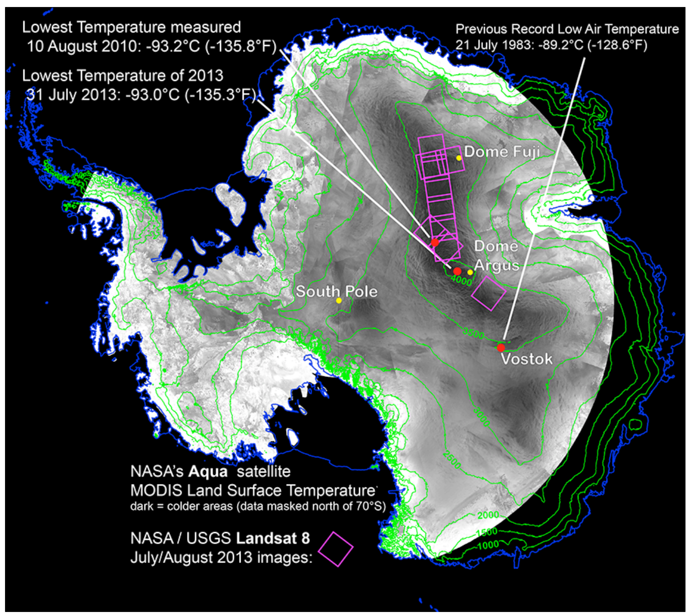
EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

What is the coldest place on Earth? It is a high ridge in Antarctica on the East Antarctic Plateau, where temperatures in several hollows can dip below -133.6 °F (-92 °C) on a clear winter night.

Scientists made the discovery while analyzing the most detailed global surface temperature maps to date, developed with data from remote sensing satellites including the new Landsat 8, a joint project of NASA and the U.S. Geological Survey (USGS). Lead scientist **Ted Scambos** [National Snow and Ice Data Center (NSIDC)] joined a team of researchers reporting the findings Monday, December 8, 2013, at the American Geophysical Union (AGU) Fall Meeting in San Francisco, CA.



With remote-sensing satellites, scientists have found the coldest places on Earth, just off a ridge in the East Antarctic Plateau. The coldest of the cold temperatures dropped to -135.8 °F (-93.2 °C)—several degrees colder than the previous record. **Image credit:** Ted Scambos

Researchers analyzed 32 years' worth of data from several satellite instruments. They found temperatures plummeted to record lows dozens of times in clusters of pockets near a high ridge between Dome Argus and Dome Fuji, two summits on the ice sheet known as the East Antarctic Plateau. The new record of -136 °F (-93.2 °C) was set on August 10, 2010. That is several degrees colder than the previous low of -128.6 °F (-89.2 °C), set in 1983 at the Russian Vostok Research Station in East Antarctica. The coldest permanently inhabited place on Earth is northeastern Siberia, where temperatures in the towns of Verkhoyansk and Oimekon dropped to a bone-chilling -90 °F (-67.8 °C) in 1892 and 1933, respectively.

"We had a suspicion this Antarctic ridge was likely to be extremely cold, and colder than Vostok because it's higher up the hill," Scambos said. "With the launch of Landsat 8, we finally had a sensor capable of really investigating this area in more detail."

The quest to find out just how cold it can get on Earth—and *why*—started when the researchers were studying large snow dunes, sculpted and polished by the wind, on the East Antarctic Plateau. When the scientists looked closer, they noticed cracks in the snow surface between the dunes, possibly created when wintertime temperatures got so low the top snow layer shrank. This led scientists to wonder what the temperature range was, and prompted them to hunt for the coldest places using data from two types of satellite sensors.

They turned to the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Terra and Aqua satellites and the Advanced Very High Resolution Radiometer (AVHRR) on several National Oceanic and Atmospheric Administration (NOAA) satellites. These sensitive instruments can pick up thermal radiation emitted from Earth's surface, even in areas lacking sensible heat.

Using these sensors to scan the East Antarctic Plateau, Scambos' team detected extremely cold temperatures on a 620-mi (998-km) stretch of the ridge at high elevations between Argus and Fuji, and even colder temperatures at lower elevations in pockets off the ridge. Then, with the higher resolution of the Thermal Infrared Sensor (TIRS) aboard Landsat 8, the research team pinpointed the record-setting pockets.

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NASA Satellite Sees Increase of India's Sulfur Dioxide Emissions

Kathryn Hansen, NASA's Goddard Space Flight Center, Earth Science News Team, kathryn.h.hansen@nasa.gov

EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Power-plant emissions of sulfur dioxide (SO_2)—an atmospheric pollutant with both health and climate impacts—have increased across India in recent years, according to a new analysis of data from a NASA satellite.

The analysis of data captured by an instrument on NASA's Aura satellite found that emissions of SO_2 from Indian power plants have increased by more than 60% between 2005 and 2012, according to new research led by **Zifeng Lu** [Argonne National Laboratory]. The study was published online on December 5, 2013, in the journal *Environmental Science & Technology*.

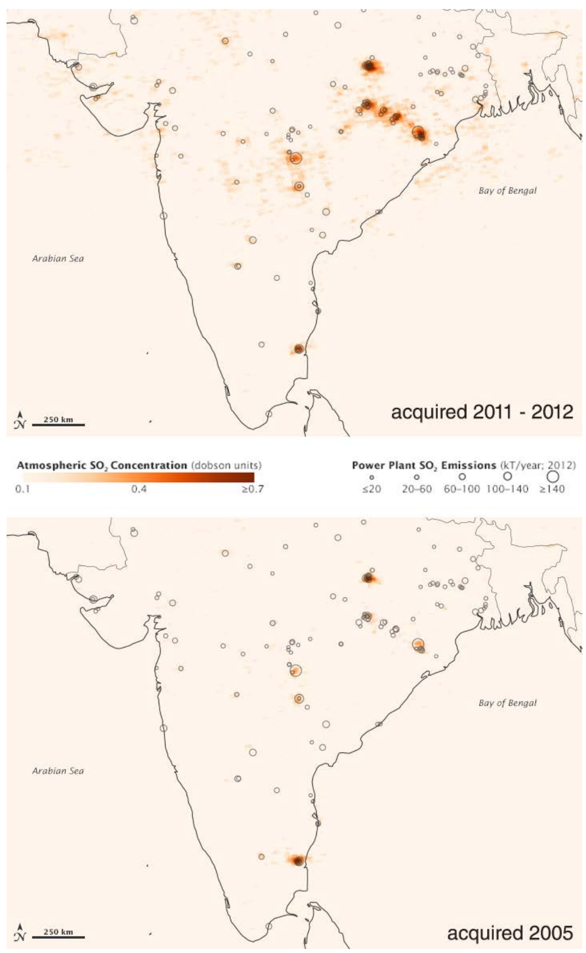
India surpassed the U.S. in 2010 to become the world's second largest emitter of SO_2, after China, according to emission estimates previously published by Lu and scientists from universities and the U.S. Environmental Protection Agency. That same research showed that about half of India's emissions come from the coal-fired power sector.

While atmospheric SO_2 is produced in nature primarily by volcanoes, humans emit it to the atmosphere from the combustion of fuels with significant amounts of sulfur-containing impurities and from the smelting of metals such as copper and nickel. The gas contributes to the formation of acid rain and in high concentrations can cause respiratory problems. It is also a precursor for one type of suspended particles—sulfate aerosols—which can affect the microphysical and optical properties of clouds, an effect that remains difficult to measure and a large cause of uncertainty in climate models.

India's Central Pollution Control Board noted in a 2012 report that the national mean concentration of SO_2 has declined from 2001 to 2010, an estimate based on data from 361 ground-based monitoring stations. However, most of the stations are located in urban areas, where regulations have indeed reduced pollution locally. Only about 70 stations in India collect measurements in the industrial areas near the source of power plant emissions.

"It's an issue of monitoring locations," Lu said. "We should know air quality not only in populated cities, but also in industrial areas, where coal-fired power plants truly dominate national SO_2 emissions. On the one hand, local residents are still influenced by these emissions; on the other hand, long-lifetime, sulfur-containing air pollutants such as sulfate can be transported long distances to affect public health and the environment at a regional scale."

The scientists' look at India's SO_2 emissions came two years after researchers developed a method to observe power plant emissions using measurements captured by an instrument on NASA's Aura satellite, launched in 2004. The Ozone Monitoring Instrument (OMI) measures ozone and other key air quality components



The maps above depict SO_2 concentrations in 2011-12 [*top*] and 2005 [*bottom*] and the relative size of power plants in India. Darker shades depict greater concentrations of SO_2 in the atmosphere, while the size of the circles indicates the amount of emissions from the local power plant smoke stacks. **Image credit:** NASA's Earth Observatory including SO_2 and nitrogen dioxide (NO_2), and collects data over the same locations at the same local time daily.

With the eight-year record of repeat measurements, the researchers averaged measurements of sulfur from 65 power plants in 23 regions. Over time, a pattern emerged that allowed scientists to distinguish relatively constant power plant emissions from the more variable background concentrations of SO_2.

Researchers used OMI measurements and the same technique in a 2011 study to show that average SO_2 emissions from large U.S. coal-fired power plants fell by nearly half from 2005-2007 to 2008-2010. In that study, three-year averages were needed to confidently tease out power plant emissions from variable background concentrations. However, India's lower latitude provides more favorable satellite observing conditions, allowing scientists to track the emissions year by year.

Results from the satellite analysis are in line with results of a ground-based inventory, which shows a 71% emission increase from 2005 to 2012 over India. Lu and colleagues developed the ground-based inventory for previous work that used power plant- and unit-level information to calculate nitrogen oxide (NO) emissions. The researchers adapted the technique for application to SO_2 emissions, and considered factors from boiler size to coal type to emission control technology. ■

NASA-USGS Landsat 8 Satellite Pinpoints Coldest Spots on Earth

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The team compared the sites to topographic maps to explore *how* it gets so cold. Already-cold temperatures fall even more when the sky clears. If clear skies persist for a few days, the ground chills as it radiates its remaining sensible heat into space. This creates a layer of super-chilled air above the surface of the snow and ice. This layer of air is denser than the relatively warmer air above it, which causes it to slide down the shallow slope of domes on the Antarctic plateau. As it flows into the pockets, it can be trapped, and the cooling continues.

"By causing the air to be stationary for extended periods, while continuing to radiate more heat away into space, you get the absolute lowest temperatures we're able to find," Scambos said. "We suspected that we would be looking for one magical site that got extremely cold, but what we found was a large strip of Antarctica at high altitude that regularly reached these record low temperatures."

The study is an example of some of the intriguing science possible with Landsat 8 and the TIRS instrument, which was built at NASA's Goddard Space Flight Center (GSFC). Since its launch on February 11, 2013, Landsat 8 has captured approximately 550 scenes per day of Earth's land surface. The USGS processes, archives, and distributes the images free of charge over the Internet.

"With Landsat 8, we expect to see more accurate and more detailed maps of the landscape than we've ever been able to see," said **James Irons**, [GSFC—*Landsat 8 Project Scientist*]. "If change is occurring, I think we'll be able to detect it earlier and track it." Researchers also are eager to see what new results come out of Landsat 8, both from icy plateaus and Earth's warmer regions. "What we've got orbiting Earth right now is a very accurate and consistent sensor that can tell us all kinds of things about how the land surface of Earth is changing, how climate change is impacting the surface of Earth, the oceans of Earth, and the icy areas of Earth," Scambos said. "Finding the coldest areas on Earth is just the beginning of the discoveries we're going to be able to make with Landsat 8." ■

Enormous Aquifer Discovered Under Greenland Ice Sheet

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Buried underneath compacted snow and ice in Greenland lies a large liquid water reservoir that has now been mapped by researchers using data from NASA's Operation IceBridge airborne campaign.

A team of glaciologists serendipitously found the aquifer while drilling in southeast Greenland in 2011 to study snow accumulation. Two of their ice cores were dripping water when the scientists lifted them to the surface, despite air temperatures of -4 °F (-20 °C). The researchers later used NASA's Operation IceBridge[1] radar data to confine the limits of the water reservoir, which spreads over 27,000 mi^2 (69,930 km^2)—an area larger than the state of West Virginia. The water in the aquifer has the potential to raise global sea level by 0.016 in (0.4 mm).

"When I heard about the aquifer, I had almost the same reaction as when we discovered Lake Vostok [in Antarctica]: it blew my mind that something like that is possible," said **Michael Studinger** [NASA's Goddard Space Flight Center (GSFC)—*Operation IceBridge Project Scientist*]. "It turned my view of the Greenland ice sheet upside down—I don't think anyone had expected that this layer of liquid water could survive the cold winter temperatures without being refrozen."

Southeast Greenland is a region of high snow accumulation. Researchers now believe that the thick snow cover insulates the aquifer from cold winter surface temperatures, allowing it to remain liquid throughout the year. The aquifer is fed by meltwater that percolates from the surface during the summer.

The new research is presented in two papers: one led by **Rick Forster** [University of Utah] that was published on December 22, 2013, in the journal *Nature Geoscience* and one led by glaciologist **Lora Koenig** [GSFC] that has been accepted for publication in the journal *Geophysical Research Letters*. The findings will significantly advance the understanding of how melt water flows through the ice sheet and contributes to sea level rise.

When a team led by Forster accidentally drilled into water in 2011, they were not able to continue studying the aquifer because their tools were not suited to work in an aquatic environment. Afterward, Forster's team determined the extent of the aquifer by studying radar data from Operation IceBridge together with ground-based radar data. The top of the water layer clearly showed in the radar data as a return signal brighter than the ice layers.

Koenig co-led another expedition to southeast Greenland with Forster in April 2013 specifically

Glaciologist **Lora Koenig** [*left*] operates a video recorder that has been lowered into the bore hole to observe the ice structure of the aquifer in April 2013. **Image credit:** University of Utah/Clément Mièg

A thin section of a core extracted from the aquifer by Koenig's team is held in front of the sun. **Image Credit:** GSFC, Ludovic Brucker

[1] Operation IceBridge is an ongoing NASA airborne campaign studying changes in ice at the poles.

designed to study the physical characteristics of the newly discovered water reservoir—see photos. Koenig's team extracted two cores of *firn* (aged snow) that were saturated with water. They used a water-resistant thermoelectric drill to study the density of the ice and lowered strings packed with temperature sensors down the holes, and found that the temperature of the aquifer hovers around 32 °F (0 °C), warmer than they had expected it to be.

Koenig and her team measured the top of the aquifer at around 39 ft (12 m) under the surface. This was the depth at which the boreholes filled with water after extracting the ice cores. They then determined the amount of water in the water-saturated firn cores by comparing them to dry cores extracted nearby. The researchers determined the depth at which the pores in the firn close, trapping the water inside the bubbles; at this point, there is a change in the density of the ice that the scientists can measure. This depth is about 121 ft (37 m) and corresponds to the bottom of the aquifer. Once Koenig's team had the density, depth, and spatial extent of the aquifer, they were able to come up with an estimated water volume of about 154 billion tons (140 metric gigatons). If this water were to suddenly discharge to the ocean, this would correspond to 0.016 in (0.4 mm) of sea level rise.

Researchers think that the perennial aquifer is a *heat reservoir* for the ice sheet in two ways: melt-water carries heat when it percolates from the surface down the ice to reach the aquifer. And if the trapped water were

An ice core segment extracted from the aquifer by Koenig's team, with trapped water collecting at the lower left of the core. **Image credit:** GSFC, Ludovic Brucker

to refreeze, it would release latent heat. Altogether, this makes the ice in the vicinity of the aquifer warmer—and warmer ice flows faster toward the sea.

"Our next big task is to understand how this aquifer is filling and how it's discharging," said Koenig. "The aquifer could offset some sea level rise if it's storing water for long periods of time. For example after the 2012 extreme surface melt across Greenland, it appears that the aquifer filled a little bit. The question now is how does that water leave the aquifer on its way to the ocean and whether it will leave this year or a hundred years from now."

announcement

CALIPSO Lidar Level-2 Polar Stratospheric Cloud Product

The Atmospheric Science Data Center (ASDC) at NASA's Langley Research Center in collaboration with the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission team announces the release of a new data product:

CAL_LID_L2_PSCMask-Prov-V1-00

This new ensemble CALIPSO lidar Level-2 Polar Stratospheric Cloud (PSC) data product describes the spatial distribution and optical properties of PSC layers observed by the CALIPSO lidar. The product contains profiles of PSC presence, composition, optical properties, and meteorological information along CALIPSO orbit tracks. Each file contains data from all nighttime orbit segments from a single day reported on a 5-km (~3.1-mi) horizontal by 180-m (~0.1-mi) vertical grid. This new product is available beginning with data date June 13, 2006 (start of the mission) to current.

Information about the CALIPSO product including data availability, user documentation and quality statements, relevant links, sample read software, and tools for working with the data, etc., can be found at the following ASDC link: *eosweb.larc.nasa.gov/project/calipso/calipso_table*.

What Goes Around Comes Around

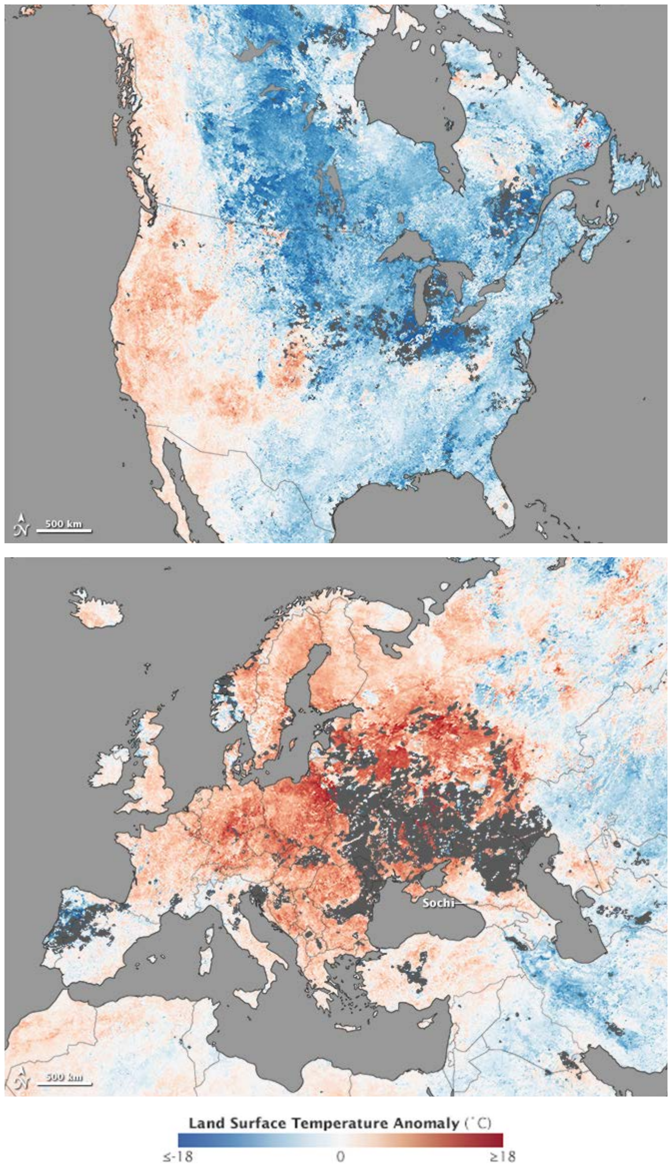
Adam Voiland, NASA's Earth Observatory, adam.p.voiland@nasa.gov

Earth's atmosphere is many things, but it is certainly not uniform. In many cases, while one part of the world freezes, another broils; while precipitation pummels one region, drought grips another.

One of the underlying features connecting seemingly opposite weather outbreaks are giant meanders in high-altitude winds known as *Rossby waves*. These planetary-scale waves define the *jet stream* and do much to determine the type of weather any given area will face over periods of days to weeks. However, the waves are also governed by fundamental laws of fluid dynamics and thermodynamics that ensure the total amount of energy circulating through the global atmosphere doesn't change, despite the weather extremes in one area or another.

In early January 2014, temperature patterns in the Northern Hemisphere offered a good example of how the atmosphere can simultaneously produce starkly contrasting weather extremes. In North America, a swirling mass of Arctic air moved south and brought bitterly cold temperatures—and much discussion of the *polar vortex*. At the same time, Europe faced a stretch of unusually warm weather, prompting discussions about whether there will be enough snow for the upcoming winter Olympics in Sochi, Russia.

Shown here are land surface temperature anomalies in North America [*top*] and Western Europe [*bottom*] for January 1–7, 2014. Based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite, the maps depict temperatures for that period compared to the 2001–2010 average for the same week. Areas with warmer-than-average temperatures are shown in dark gray; near-normal temperatures are light gray; and areas that were cooler than the base period are medium gray. Bright white indicates areas where clouds blocked the satellite from collecting usable data.



Land surface temperature anomalies in North America [*top*] and Europe [*bottom*], January 1-7, 2014. **Image credit:** NASA's Earth Observatory

Europe and the Western U.S. weren't the only areas that experienced warm temperatures in late-December 2013 and early January 2014. Australians sweated through an intense heatwave that brought record-breaking temperatures to nearly 9% of the country. And in South America, Argentinians faced a two-week heatwave that elevated temperatures more than 15 °C (27 °F) above average in some areas, producing widespread power and water shortages. ■

NASA Earth Science in the News

Patrick Lynch, NASA's Earth Science News Team, patrick.lynch@nasa.gov

HyperSpectral Imager for Climate Science makes first weather balloon flight, November 1; *redorbit.com.* Determining the amount of sunlight reflecting off Earth's atmosphere is a key measurement to better understand climate change—a measurement that could be advanced even more by weather balloons with new instrumentation. NASA's Earth Science Technology Office is supporting the development of the HyperSpectral Imager for Climate Science (HySICS). This instrument made its inaugural engineering balloon flight at the end of September, providing realistic, space-like conditions at a fraction of the cost of launching an instrument into space. A 60-story tall balloon helped take HySICS to an altitude of nearly 122,000 ft (~37.2 km), which is far above the bulk of Earth's atmosphere. HySICS was able to make measurements of Earth, the sun, and the moon during both daylight and nighttime hours. Data from this engineering flight will be used to improve the instrument over the next year and to help advance the algorithms used to process the data. The imager was able to collect radiance data for nearly half of its eight-and-a-half-hour flight, during which it also periodically calibrated itself by performing accurate radiance scans of the sun and moon.

Scientists at NASA and NOAA develop new technique to accurately monitor ice on the Great Lakes, November 14; *International Business Times.* Two scientists from NASA and the National Oceanic and Atmospheric Administration (NOAA) have developed a technique to monitor ice cover on the Great Lakes, using satellites hundreds of miles in space. The technology is said to be of high enough spatial resolution to detect an icebreaker cutting open a channel of water through the ice at night. "In the dark, it's difficult to read a map that's right in front of you," said **Son Nghiem** [NASA/ Jet Propulsion Laboratory (JPL)], one of the developers of the new technique. "Yet we now have a way to use satellite radars almost 500 mi (800 km) out in space to see through clouds and darkness and map ice across the Great Lakes." Ice on the Great Lakes is a major concern for regional economies in the U.S. and Canada, which are home to the five lakes that account for more than a fifth of the planet's fresh water. Ice on the lakes affects shipping, fishing, and public safety (when winter and spring flooding are caused by ice jams) and has a significant impact on the regional environment and ecosystems.

High-resolution global maps show increasing forest loss in tropics, November 4; *Los Angeles Times.* The first fine-scale mapping of global forest cover shows a 12-year-long increase in the rate of forest loss in the tropics. The use of remote sensing satellite data to chronicle changes in global land cover is not new. Using data from the NASA–U.S. Geological Survey (USGS) Landsat satellites, researchers have provided an exceptionally detailed account of gains and loses in global forest cover from 2000 to 2012. Geographical sciences professor **Matthew Hansen** [University of Maryland, College Park], led a group of 15 university, private sector, and government researchers who used Landsat data to map tree cover globally at a spatial resolution of 98 ft (~30 m). The images document the effects of forest disturbance—from logging, wildfire, insect damage, and storms—and forest regrowth. The total global loss in tree cover of 888,034 mi^2 (~2,300,000 km^2) was nearly three times the total gain during the same period. Of the world's four climate zones—tropical, subtropical, temperate, and boreal—the tropical zone was the only one to exhibit a statistically significant trend. Overall, forest loss in the tropics rose by 811 mi^2 (~2,100 km^2) a year.

New way to measure Sierra snowpack—by airplane, December 8; *San Francisco Chronicle.* A high-altitude aircraft is making significant contributions to the important work done by humans who brave frosty Sierra winters to measure annual snowpack. Flying at 22,000 ft (~6.7 km) above the High Sierra's Tuolumne River watershed last spring, an instrumented NASA plane measured the depth of the winter snowpack and estimated its water content across hundreds of square miles. Leaders of the project said their experimental Airborne Snow Observatory project could eventually provide the most accurate forecasts yet of summer water availability for more than 2 million Bay Area users. The scientists said the plane's instruments enabled them to estimate how much total water from the melting snows would reach Hetch Hetchy reservoir, the source of San Francisco's water supply. The scientists flew each week from early April through early June aboard a twin-engine Otter aircraft carrying a laser instrument to measure snow depth and a light sensor to estimate the melting snow's water content. "For the first time the data are telling us the total amount of water in the entire snowpack across the entire watershed," said project leader **Thomas Painter** [JPL].

***Antarctica records unofficial coldest temperature ever,** December 10; *USA Today.* There's cold, and then there's Antarctica cold. How does a frosty reading of -135.3 °F sound? Based on the NASA-USGS Landsat 8's remote satellite measurements in July 2013, scientists recently recorded that temperature at a desolate ice plateau in East Antarctica. It was one of the lowest temperatures ever recorded on Earth, although it may not get that recognition in the official record books. The World Meteorological Organization only recognizes surface-based weather measurements, so the "official" coldest temperature on Earth remains -128.6 °F, recorded in Vostok, Antarctica, on July 21, 1983.

Earth's ozone on bumpy road to recovery, December 11; *nationalgeographic.com.* Last year the "hole" in the ozone layer above Antarctica was surprisingly small. But do not get used to that, say atmospheric scientists. Rather than signaling a speedy recovery, the shrinkage was likely a sign of variable weather. The so-called "ozone hole" still has decades of variation before it finally closes. **Susan Strahan** [NASA's Goddard Space Flight Center (GSFC)] says that we should begin to see signs of recovery in the next 10 years, and the hole should vanish entirely by 2070. Strahan and **Natalya Kramarova** [GSFC] looked at vertical profiles of stratospheric composition to determine what weather factors—aside from simply the amount of ozone-depleting substances present—have been responsible for both very large (2006, 2011) and relatively small (2012) ozone holes in recent years. The findings show that the impact of the 1987 Montreal Protocol is not yet seen in a diminishment of the annual ozone hole's extent, although the researchers expect to see evidence of that within the next decade or so.

***India's sulfur dioxide emissions on the rise,** December 29; *Times of India.* Sulfur dioxide (SO_2)—an atmospheric pollutant with health and climate impacts—emitted from power plants in India increased by over 60% between 2005 and 2012, as shown by new data from the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite. In 2010 India surpassed the U.S. as the world's second highest emitter of SO_2 after China, according to estimates previously published by **Zifeng Lu** [Argonne National Laboratory], lead author on the new study, and coworkers. Their research showed that about half of India's emissions came from the coal-fired power sector. The research team, which included co-author **Nikolay Krotkov** [GSFC], used OMI's eight-year record of observations to average measurements from 65 power plants in 23 regions. Over time, a pattern emerged that allowed scientists to distinguish the nearly constant power plant SO_2 emissions from the more variable background concentrations. The study was published in the journal *Environmental Science & Technology*.

California tests natural disaster early warning system, January 1; *bbc.com.* Scientists are using satellite-based sensors and global positioning system (GPS) technology to detect the impending threat of natural disasters. The network is installed in Southern California and has already helped scientists to alert emergency services to the risk of flash floods. The system builds on existing networks of GPS stations to make very precise measurements of ground movement, and have installed seismic sensors and other instruments that can track changes in weather conditions. The scientists say these sensor suites could help prepare for events such as earthquakes and tsunamis. **Angelyn Moore** [JPL] said, "It might be surprising that we are using GPS to monitor weather hazards, but GPS is a weather instrument. Fundamentally, a GPS station is measuring the time it takes a signal to travel from the GPS satellites to the receiving stations on the ground, and that travel time is modified by the amount of moisture in the air. Whenever we measure the position of a GPS station, we are also measuring the amount of water vapor above it."

*See news story in this issue for more details.

Interested in getting your research out to the general public, educators, and the scientific community? Please contact ***Patrick Lynch*** *on NASA's Earth Science News Team at* ***patrick.lynch@nasa.gov*** *and let him know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of* ***The Earth Observer****.* ■

NASA Science Mission Directorate – Science Education and Public Outreach Update

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NASA Postdoctoral Fellowships

Deadline—March 1

The NASA Postdoctoral Program offers scientists and engineers unique opportunities to conduct research in space science, Earth science, aeronautics, exploration systems, lunar science, astrobiology, and astrophysics.

Awards: Annual stipends start at $53,500—with supplements for specific degree fields and high cost-of-living areas. There is an annual travel budget of $8000, a relocation allowance, and financial supplement for health insurance purchased through the program. Approximately 90 fellowships are awarded annually.

Eligibility: An applicant must be a U.S. citizen, lawful permanent resident, or foreign national eligible for J-1 status as a research scholar to apply. Applicants must have completed a Ph.D. or equivalent degree before beginning the fellowship, but may apply while completing the degree requirements. Fellowships are available to recent or senior-level Ph.D. recipients.

Fellowship positions are offered at several NASA centers. To obtain more information and to apply for this exciting opportunity, visit: *nasa.orau.org/postdoc*.

NASA's REEL Science Communication Contest—Grades 9-12

Entries due—February 21

Students are consuming over 10 hours of media each day, and video is increasingly important when engaging this young audience in science. NASA Earth missions are kicking off the second annual REEL Science *Science Communication Contest*, inviting talented high-school students to produce a two-minute video for middle-school students communicating one of the following three Earth science topics: How Climate Impacts Ice and Ice Impacts Climate; Forest Fire Effects on Air Quality; or Water of the Water Planet. Winning videos will be posted on the NASA website, and winners will have the opportunity in 2014 to be a NASA producer working with scientists and communication experts to produce an Earth-science feature video. For more information and to enter, please visit: *1.usa.gov/1aPpkuC*.

AMS Climate Studies Diversity Project for Faculty

Apply by—March 14

The American Meteorological Society's (AMS) Education Program invites faculty members at minority-serving institutions to apply for the *AMS Climate Studies Diversity Project*. Accepted applicants will have the opportunity to attend two expenses-paid workshops and learn the latest in climate science and education from scientists at NASA, the National Oceanic and Atmospheric Administration, and universities. Following the workshops, the participants will help increase climate literacy by teaching the AMS Climate Studies course at their home institution. For more information, visit: *bit.ly/1jqpbrC*.

Project ATMOSPHERE for K-12 Educators

Apply by—March 28

Project ATMOSPHERE is a two-week teacher enhancement workshop offered by the American Meteorological Society's Education Program at the National Oceanic and Atmospheric Administration, National Weather Service Training Center in Kansas City, MO. The workshop, to be held July 13-25, 2014, will introduce teachers to the latest technologies and techniques for sensing, analyzing, and forecasting weather, and to explore ways these concepts can be implemented in the classrooms. Following the workshop, attendees will help to promote weather education in their hometown regions by conducting training sessions in atmospheric science during the following school year. Teachers of grades K-12, who cover weather and related concepts, are encouraged to apply. Selected applicants will receive three free graduate credits following completion. For more information and to apply, visit: *bit.ly/V0kPIS*.

GPM Rain EnGAUGE Events

Celebrate the launch of NASA's Global Precipitation Measurement (GPM) Core Observatory by hosting a *GPM Rain EnGAUGE Event*—a family science night for your school, outdoor education center, library, or museum, or with your scout troop, summer camp, or extracurricular club. For a full electronic toolkit, including an activities menu, planning schedules, sample advertising flier, and more, visit: *go.usa.gov/ZYxV*. The *Activities Menu* has a variety of choices to teach about precipitation and its importance to our lives; these options cover all age levels and range from hands-on labs to interactive computer applications so that you can select the ones that best suit your needs.

The GPM Core Observatory launches in February 2014—Rain EnGAUGE celebrations may start as early as March, so be sure to get an event on the calendar for your organization as soon as possible. If you plan to host an event, contact **Kristin Weaver** (*kristen.l.weaver@nasa.gov*) to receive a supply kit containing GPM stickers, water droplet handouts, lithographs, and other materials to help support your activities. ■

EOS Science Calendar

March 17–19, 2014
AIRS Science Team Meeting, Pasadena, CA.
airs.jpl.nasa.gov

April 9–10, 2014
SMAP Applications Workshop, Boulder, CO.
www.signup4.net/Public/ap.aspx?EID=3RDS10E

April 22–24, 2014
CERES Science Team Meeting, Hampton, VA.
ceres.larc.nasa.gov/science-team-meetings2.php

April 23–25, 2014
Land-Cover/Land-Use Change Science Team Meeting, Rockville, MD.
lcluc.umd.edu/meetings.php?mid=52

Global Change Calendar

February 23–28, 2014
AGU Ocean Sciences Meeting, Honolulu, HI.
www.sgmeet.com/osm2014

March 23–28, 2014
American Society for Photogrammetry and Remote Sensing Annual Conference, Louisville, KY.
conferences.asprs.org/Louisville-2014/blog

April 27–May 2, 2014
European Geosciences Union General Assembly 2014, Vienna, Austria.
www.egu2014.eu

April 28–May 2, 2014
Japan Geoscience Union Meeting, Yokohoma, Japan.
www.jpgu.org/meeting_e/information.html

May 22–23, 2014
Remote Sensing for Conservation, London, UK.
remote-sensing-biodiversity.org/zsl-symposium

July 13–18, 2014
IEEE International Geoscience and Remote Sensing Symposium, Québec, Canada.
igarss2014.com

July 28–August 1, 2014
Asia Oceania Geosciences Society, Sapporo, Japan.
www.asiaoceania.org/aogs2014

August 2–10, 2014
40th COSPAR Scientific Assembly, Moscow, Russia.
www.cospar-assembly.org

December 15–19, 2014
American Geophysical Union Fall Meeting, San Francisco, CA.
meetings.agu.org

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 15th of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

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