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Editor's Corner

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The Gravity Recovery and Climate Experiment (GRACE) celebrated the tenth anniversary of its launch on March 17. GRACE was the first of Earth System Science Pathfinder (ESSP) missions to launch. These missions complement the larger "flagship" missions (e.g., Terra, Aqua, Aura). GRACE had to be developed in a cost-capped, time-limited implementation mode, and had to meet extremely challenging scientific goals. Despite those requirements, "*GRACE has exceeded all of the mission objectives*" according to Principal Investigator, **Byron Tapley** [University of Texas, Austin, Center for Space Research].

One objective of the mission was to reduce the error in measurements of the oceanic geoid by increasing the accuracy of measurements of Earth's static gravity field. However, the team also understood the exciting potential that lay in the time variable gravity field measurements. The monthly repetition of the global, accurate, and for many applications, synoptic measurements of Earth's gravity field have shed light on the dynamic processes that underpin the complex, interrelated system of systems that regulate Earth's climate. GRACE's ability to probe beneath the land and ocean surface from satellite altitudes provides a new and unprecedented capability. Says Project Scientist, **Michael Watkins** [NASA/Jet Propulsion Laboratory], *"GRACE effectively invented a new kind of Earth remote sensing."*

The success of GRACE is also a phenomenal example of the value of teamwork and international collaboration. This milestone would not have been possible without the support of a talented and dedicated international team at every step along the way. That team has members in Pasadena, Austin, Munich, Potsdam, Paris, and all

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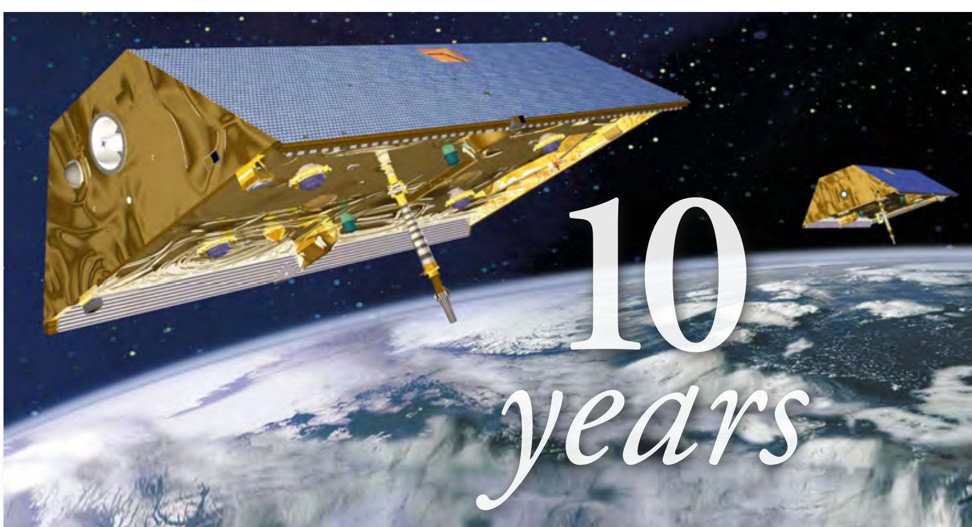

On March 17, 2002, the joint NASA–German DLR Gravity Recovery and Climate Experiment (GRACE) launched from Plesetsk Cosmodrome, Russia on a Rockot launch vehicle. Ten years later, the GRACE twins continue their intricate dance in space, reacting to tiny changes in the gravity of the surface passing beneath them, and providing the data for maps of the gravity field that are 100 times more accurate than predecessors. These measurements have led to discoveries that have improved our understanding of many processes that regulate Earth's climate and the behavior of the solid Earth. **Image Credit:** Astrium eos.nasa.gov

In This Issue

Reminder: To view newsletter images in color, visit: *eospso.gsfc.nasa.gov/eos_homepage/for_scientists/earth_observer.php*

around the globe. So to all who have worked so hard to make this mission a reality, and who have worked to derive the science from the data these past ten years, congratulations on a job well done. And best wishes for the next decade of discovery from GRACE and its planned follow-on mission.

To learn more, please see the article *Assessing The State of GRACE@10* on **page 4** of this issue.

For the past few issues we have been keeping you updated on the status of CloudSat, which was scheduled for re-entry to the A-Train in early February. Unfortunately, the first of a planned series of CloudSat maneuvers had to be aborted. The CloudSat team is developing a plan to return to the A-Train in early May—the next opportunity to do so. In the meantime, the spacecraft continues to operate nominally in the Daylight Only-Operations (DO-Op) mode, collecting radar data.

NASA's Earth Science Mission Operations (ESMO) and the Japan Aerospace Exploration Agency (JAXA) collaborated in a successful effort to restart the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) aboard the Aqua satellite with no antenna rotation on February 6, 2012. The two have started planning to resume rotation of the instrument, though the timing of the restart and rate of rotation are still being determined. This decision will involve close coordination between NASA and JAXA, plus coordination with and concurrence from the Aqua instrument teams, and Project and Program Scientists, to ensure that the spin-up activity will not cause an undue risk to the safety of the Aqua satellite and the other instruments. The ultimate goal is to enable a period of calibration between AMSR-E and AMSR2 aboard the Global Change Observation Mission-Water (GCOM-W1) satellite, recently scheduled for a May 18 launch. JAXA is hopeful that once the instrument is rotating, useful scientific data will be obtained.

With the announcement of data from the Ozone Mapping and Profiler Suite (OMPS)—see news story on **page 48** of this issue—all five of the instruments aboard Suomi NPP[1] are operating well and returning science data. Data from OMPS will help continue a decade-long, continuous data record for studying the Earth's ozone layer. Despite contamination on the Visible Infrared Imager Radiometer Suite (VIIRS) mirror reported in the last issue, the instrument should still meet its design requirements over the mission lifetime in the most affected band at 865 nm. The Direct Broadcast Antenna began to broadcast science data on February 23, signifying the end of spacecraft and instrument commissioning. On March 7, the NPP Project held the Operations Handover Review, transferring operations of the NPP observatory from the NPP Project to the Joint Polar Satellite System (JPSS) Project. The March 7 review was the final activity of the NPP Project. Congratulations to the NPP Project Scientist, **Jim Gleason** [NASA's Goddard Space Flight Center (GSFC)], Project Manager, **Ken Schwer** [GSFC], and

[1] NASA announced on January 25, 2012, at the American Meteorological Society annual meeting that the NPP mission has been renamed the *Suomi National Polar-orbiting Partnership*, or *Suomi NPP*, in honor of the late Verner Suomi, a pioneer of satellite meteorology.

the entire NPP Project staff for their efforts in getting data from NPP to the science community.

President Obama has sent his FY 2013 budget request to Congress. A comprehensive review of the budget request for Earth Science can be found at *www.nasa.gov/pdf/622651main_d%20FY13_NASA_Budget_Earth_Science.pdf.* Of course, this request is only the beginning of the process. Further details about the NASA Earth Science budget will follow in the months to come.

On the outreach front, after eight years of dedicated service to the *Earth Observatory (EO)* team, **Holli Riebeek** has taken on a new role as Education and Public Outreach Lead for Landsat. Reflecting on her tenure with the EO, Holli said "It has been a tremendous honor to write for the *Earth Observatory.* I enjoyed learning from world-class scientists, engineers, visualizers, and writers. I loved exploring a new view of Earth every day to find something unique to say about it, and I look forward to contributing to the *Earth Observatory* in my role on the Landsat education and public outreach team." Replacing Holli will be **Adam Voiland**, who has been writing for NASA's Earth Science News Team at Goddard. Welcome aboard Adam and best of luck to Holli.

In other news, staff from NASA's Earth Observing System Project Science Office have been working diligently on a new website that will provide *hyperwall*[2] material in a user-friendly format. *PowerPoint* and *Keynote* presentations of existing hyperwall content, as well as story files and presenter's notes, are being made available for download. This site includes content from all four divisions of NASA's Science Mission Directorate, which in addition to Earth Science, includes Heliophysics, Astrophysics, and Planetary Science. New content is continually being developed. This will be a great resource for those interested in using powerful visualizations and images to communicate NASA Science. The website is scheduled to go live in early April at *science.nasa.gov/hyperwall.*

Finally, NASA will celebrate Earth Day on the National Mall in Washington, DC, April 20–22. If you live in the DC area, we encourage you to visit the *NASA Village*. There will be a wide variety of science presentations, demonstrations, and hands-on activities related to NASA Earth Science including representatives from a number of NASA centers. We hope to see you there, and remember…Everyday is Earth Day at NASA. ■

[2] To see more recent examples of our hyperwall in use, see our January–February 2012 issue [**Volume 24**, **Issue 1**. pp.4-7.]

NASA's *hyperwall* is a video wall driven by sophisticated visualization software capable of displaying multiple high-definition data video and/or images simultaneously across an array of screens. Functioning as a key component at many NASA exhibits, the hyperwall is used to help explain science and observations. Shown here, **Eric Lindstrom** [NASA Headquarters—*Physical Oceanography Program Manager*] shows the ebb and flow of Earth's biosphere as measured by the Sea-viewing Wide Field-of-view (SeaWiFS) instrument. Over land, areas with the most plant life are shown in dark green while areas with little plant life are shown in tan. Over the oceans, areas with high concentrations of phytoplankton are shown in red while low concentrations are shown in blue and purple.

feature articles

Assessing the State of GRACE@10

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A remarkable range of applications has been made possible by the precise gravity field measurements flowing from GRACE. To put this in context, we provide here a brief summary of the state of GRACE as it begins its second decade of operations.

You may remember the evocative scene in *2001: A Space Odyssey,* where the PanAm Clipper craft does an intricate, graceful dance with the rotating space station, wonderfully set against a musical backdrop provided by Johann Strauss' *Blue Danube* waltz.

In a classic case of life imitating art, consider the intricacy of the dance steps provided by the Gravity Recovery and Climate Experiment, aptly shortened to *GRACE*[1], which marked its tenth year in orbit on March 17.

For the past 10 years, the two GRACE *twins* have performed a most delicate dance in low Earth orbit, mapping variations in Earth's gravity over time. Just as with a couple dancing the waltz, the key to making it all work is having a strong connection between the partners at all times. The GRACE twins aren't literally connected at the hip like two dance partners, as the two spacecraft are approximately 137 mi (220 km) apart. Nevertheless, they maintain a constant "connection" via an extremely precise microwave (K-band) ranging system that can detect even the most minute changes in the distance between them. Scientists can combine the distance changes with positioning information from global positioning system (GPS) satellites and information from other sources to create a map of Earth's gravity field every 30 days.

"…all good things…come by grace and grace comes by art and art does not come easy."
—Norman Fitzroy Maclean
A River Runs Through It

A remarkable range of applications has been made possible by the gravity field measurements flowing from GRACE. To put this in context, we provide here **a brief summary of *the state of GRACE* as it begins its second decade of operations.** We'll look back at where we were prior to GRACE, at what has been accomplished thus far, and stretch forward to glimpse what the future might hold for GRACE, specifically, and gravity measurements from space, generally.

Our Need for GRACE

There is nowhere on Earth—or for that matter our entire universe—that escapes gravity's inexorable effects. From the smallest particles and life forms to massive galaxies and black holes, gravity is felt everywhere and by everything. Gravity is an invisible force that draws two or more objects together; we can't see it, or smell it, or taste it, but nevertheless its impact is unmistakable. It is the force that keeps you from floating off the surface of the Earth (unless a greater force is applied to overcome its effect), and is so strong in the vicinity of massive objects that it literally causes light to "bend" around them.

Given that gravity exerts so much influence on our world, it should come as no surprise that since ancient times, people have sought to explain and quantify it. These efforts led to the development of the field of *geodesy*, the branch of science that seeks to accurately measure three-dimensional aspects of Earth by mapping points on its surface and studying the gravitational field of the planet.

[1] NASA and DLR (the German Aerospace Center) collaborated to design and launch GRACE. NASA provided the satellites; developed the instruments and some of the satellite components; maintains overall mission management, data validation, and storage; and has responsibility for the science data products. DLR provided the launch services, and operations activities, and collaborates in the science data production.

Since the beginning of the satellite era, there have been numerous missions that have geodetic components. The earliest observations revealed that the gravitational field was not homogeneous; later observations showed that the field was in a constant state of flux, primarily (but not solely) because of the movement of water through the *Earth system*[2]. The focus of the discussion here will emphasize these hydrological aspects.

Producing a complete map of Earth's gravity field accurate enough to understand the global water cycle has been a daunting challenge. Scientists had to combine information from a wide variety of sources; and for all their efforts, the result was still limited in its applicability. The gravity field maps produced captured the large-scale static features fairly well, but over many parts of the Earth, the small-scale details were still lacking.

The field of geodesy took a major leap forward in 2002, when GRACE was launched. The unique design of GRACE has allowed monthly gravity measurements more than 100 times more accurate than previous models, providing the much-needed resolution improvements for characterizing how Earth's gravity field varies spatially over both land and sea, and with time.

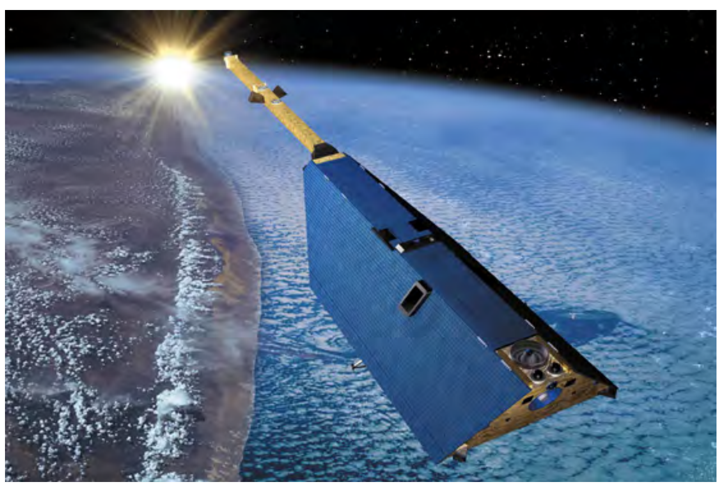
[2] The *Earth system* is a system of complex interrelated systems—e.g., atmosphere (air), hydrosphere (water), biosphere (land/life), lithosphere (solid Earth), and cryosphere (ice). Changes in any one of these systems will impact all the others.

The field of geodesy took a major leap forward in 2002, when GRACE was launched. The unique design of GRACE has allowed monthly gravity measurements more than 100 times more accurate than previous models, providing the much-needed resolution improvements for characterizing how Earth's gravity field varies spatially over both land and sea, and with time.

CHAMP: One of the Precursors of GRACE

There have been many satellite-based missions prior to GRACE that explored geodetic and geophysical phenomena—far too many to list here. (For a detailed list of missions, refer to: *ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/index.html*.) Satellite laser ranging has been the predominant tool employed in these studies.

Among all these, perhaps the tightest connection with GRACE in terms of technology evolution is DLR's Challenging Minisatellite Payload for Geoscientific Research and Applications Program (CHAMP), which was one of several "heritage" satellite missions that preceded GRACE and influenced its design[1]. CHAMP—launched in 2000—operated until 2010 and was, in many ways, a direct predecessor. CHAMP was the first mission specifically designed to measure Earth's static gravity field, and was a "testbed" for some of the satellite technologies that GRACE would later use.



Artist's rendering of the CHAMP satellite in orbit

While CHAMP was not the first mission to demonstrate the use of GPS receivers for Precision Orbit Determination (POD)—that distinction belongs to the Ocean Surface Topography Experiment TOPEX/Poseidon launched in 1992—the CHAMP POD system was the direct "predecessor" for that used on GRACE. The GPS receiver on GRACE is an improved version of the CHAMP GPS receiver that satisfies the precise positioning and timing requirements of the mission.

CHAMP was also the first satellite equipped with an accelerometer to measure the nongravitational accelerations acting on the satellite. Following this approach, GRACE employs an improved version of the CHAMP accelerometer and improves on CHAMP's measurements, utilizing its twin-satellite, formation-orbiting concept to provide intersatellite positional measurements on the order of *thousandths* of a millimeter.

[1] The GeoForschungsZentrum (GFZ)—German Research Centre for Geosciences—implemented the CHAMP mission for DLR. **Christoph Reigber** [GFZ] was both CHAMP PI and the original German Co-PI for GRACE.

Data from GRACE have led to improvements in the accuracy of both the *static* and *time-variable*[3] gravity field measurements that have in turn had important implications for many scientific measurements related to climate change. In addition to using the GRACE-measured static field to aid in determining the general ocean circulation, the time-varying gravity measurements from GRACE are being used to study such diverse phenomena as changes in groundwater storage, variations in soil moisture and the amount of water stored in large lakes, ice loss from the polar ice sheets and mountain glaciers, sea-level variations caused by the addition of water to the ocean, and changes in the distribution of mass within the solid Earth itself.

The Science of GRACE

As the mission name suggests, the pioneering concept with GRACE was that it would use gravity measurements to observe and study climate change. This had never been done before, and would require fundamentally new ways of analyzing the measurements to fully realize that potential.

Early concepts for a mission to study gravity concentrated on recovering Earth's static gravity field[4]. When combined with data from altimetry missions such as TOPEX/Poseidon, the results would primarily reduce error in the oceanic geoid, leading to improved understanding of ocean circulation. However, in the early considerations, the team realized the tremendous potential of observing changes in the gravity field due to global mass redistribution, and the mission concept evolved to what we now know as GRACE[5], which was the first of NASA's Earth System Science Pathfinder missions to launch. As the mission name suggests, the pioneering concept with GRACE was that it would use gravity measurements to observe and study climate change. This had never been done before, and would require fundamentally new ways of analyzing the measurements to fully realize that potential.

> *"We realized early on in the design of GRACE that we could measure the gravity field well enough to observe the critical indicators of climate change—sea level rise and polar ice melt."*
> —***Michael Watkins****, GRACE Project Scientist*

In short, GRACE was designed to *"…[make] detailed measurements of Earth's gravity field [to] lead to discoveries about gravity and Earth's natural systems;"* for the past decade, it has been doing just that. As the mission approaches the milestone of ten years in orbit it is natural to ask: ***How have we done?*** Have we been able to do what we thought we would? Are there things we're doing with GRACE data that we never expected to do?

In the original GRACE mission proposal, five specific areas were identified where GRACE would make important contributions[6]:

- Tracking water movement on and beneath Earth's surface;
- tracking changes in ice sheets and changes in global sea level;
- studying ocean currents both near the surface and far beneath the waves;
- tracking changes in the solid Earth; and
- using GPS receivers as atmospheric limb sounders.

The progress in achieving each of these objectives is summarized on the following pages.

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[3] **Note on nomenclature**: *Static* or mean gravity field features may change over very long (i.e., geologic) time scales, but for the purposes of GRACE and any subsequent gravity missions, can be thought of as constant. *Time-variable* features, on the other hand, have components that tend to vary much more rapidly, although they also change over longer time scales as well.

[4] The earliest concept for a mission that would measure gravity emerged in 1983. The Gravity Recovery Mission (GRM) was proposed to focus on the static gravity field only.

[5] The National Research Council's report on *Satellite Gravity and the Geosphere: Contributions to the Study of the Solid Earth and Its Fluid Envelope* (1997) was a seminal report on the potential utility of time variable gravity measurements.

[6] A prelaunch brochure described these areas: *eospso.gsfc.nasa.gov/ftp_docs/GRACE.pdf.* See especially **pp. 5-13** of this issue.

Tracking Water Movement On and Beneath Earth's Surface

Movement of water through Earth's hydrological cycle is a prime contributor to terrestrial gravitational variations. In this regard, GRACE was designed to detect month-to-month and seasonal changes in the amount of water stored on and beneath Earth's surface. This includes the water residing in the planet's soil, river basins, larger lakes, and major subsurface aquifers. It also includes the water stored in the form of ice.

"GRACE has far exceeded our expectations for observing groundwater storage changes from space. It is more accurate than we expected, and the global picture of water stress that has emerged is one that we simply could not have anticipated."
—***Jay Famiglietti*** *[University of California, Irvine]*

According to **Matthew Rodell** [NASA's Goddard Space Flight Center (GSFC)], GRACE has more than proven itself—in this area in conjunction with ground-based measurements and data from aircraft. For example, GRACE data show an increase in total water storage in the Lena River basin in Siberia. This region is an area of discontinuous permafrost; the increase in water storage may be related to shifts in the *Arctic Oscillation*—a measurement of opposing atmospheric circulation patterns over middle and high latitudes. GRACE has also pinpointed areas of long-term

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The Top 10 Achievements of GRACE

As this article was being compiled, the GRACE Education and Public Outreach team consulted three of the principal scientists involved in the GRACE mission—**Byron Tapley** [University of Texas Center for Space Research (CSR)—*Principal Investigator*], **Michael Watkins** [NASA/Jet Propulsion Laboratory—*Project Scientist*], and **Srinivas Bettadpur** [CSR—*GRACE Science Operations Manager*]—to solicit their perspectives on what they considered to be the ten most significant accomplishments of GRACE. This is a synthesis of those inputs.

1. Monthly measurements of Earth's mean gravity field that are at least 100 times more precise than predecessors.
2. Tracking changes in ice sheets—revealing a steady decline in polar ice mass over the past decade.
3. Tracking water movement on and beneath Earth's surface (i.e., in river basins and underground aquifers).
4. Tracking near-surface and deep-ocean currents to improve our understanding of ocean circulation—by coupling GRACE data with ocean surface topography data from satellite altimeters.
5. Tracking changes in the solid Earth, such as those caused by large earthquakes (e.g., the 2004 Sumatra Andaman and the 2011 Tohoku-oki earthquakes).
6. Tracking changes in the mass contribution to global sea-level change.
7. Measuring regional river run-off and ocean-bottom pressure variations to improve our understanding of Earth's fresh-water distribution.
8. Incorporating GRACE soil moisture measurements into models used for drought prediction.
9. Incorporating changes in mass observed by GRACE into models for ocean and land-surface hydrology.
10. Improving precision orbit determination of spacecraft, and improving the terrestrial and gravimetric reference frames.

water depletion—the existence of which weren't even considered previously. These data demonstrated the now well-known problematic groundwater depletion in Northern India and glacial melt along the southern coast of Alaska.

Rodell also noted that the emergence of aspects of GRACE-derived data that were not previously considered. For example, prior to launch, there was no good plan for taking coarse-resolution GRACE data and converting them to the finer scales needed to use these data for practical hydrological applications. One such innovative use of GRACE data was to distinguish gross observations of terrestrial water storage changes into specific changes in groundwater, soil moisture, snow, and surface water. The accuracy of the GRACE results has stimulated an effort to integrate GRACE data with other observations within a high-resolution numerical model via *data assimilation*—a computational tool that merges model outputs with observational data to refine analyses. Among other applications, this technique enables the use of GRACE data to monitor drought patterns[7].

The accuracy of the GRACE results has stimulated an effort to integrate GRACE data with other observations within a high-resolution numerical model via ***data assimilation***—*a computational tool that merges model outputs with observational data to refine analyses.*

Tracking Changes in Ice Sheets and Global Sea Level

Changes in ice-sheet coverage have significant implications for understanding and responding to climate change. Coverage changes affect the surface area of Earth's oceans, the planet's albedo, surface temperature, and sea-level changes. Each of these has its own consequences for our planet, and also acts in combination with the others. Of particular importance is the ability to distinguish between changes in mean ocean level due to *thermal expansion* (i.e., global warming) and increases in levels due to the amount of water itself (i.e., melting of polar ice sheets). Early attempts to tease out the individual contributions suffered from errors in temperature measurements that are still being corrected.

Don Chambers [University of South Florida] noted that before GRACE was launched, global mean sea level (GMSL) change was measured with tide gauges on 20–30-year time scales. After 1992 satellite altimeters also measured GMSL, with increased precision at one-year intervals. Most scientists estimated that it would take

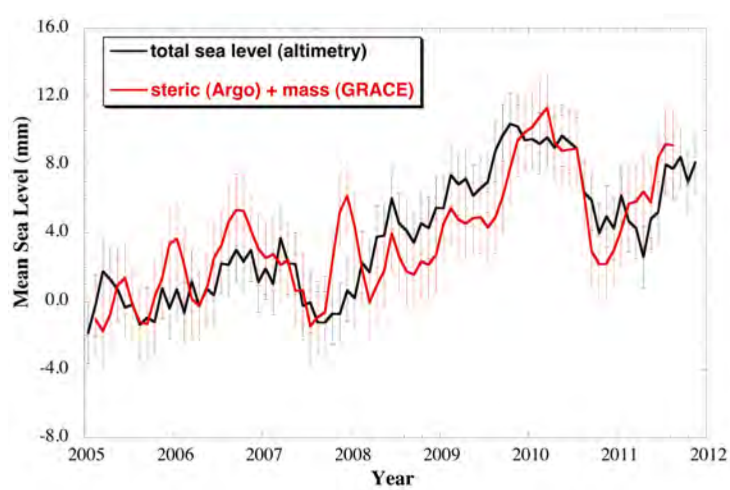
[7] See the Jan-Feb 2012 issue of *the Earth Observer* [**Volume 24**, **Issue 1**, p. 24 —Figure 2].

Figure 1. GRACE Helps to Understand the Sources of Global Sea-Level Rise

On *geological* timescales, the largest contributor to sea-level rise is the transfer of water mass that was previously frozen in ice sheets to the oceans. But there is another important contributor: 90% of the excess energy trapped by Earth's atmosphere ends up in the oceans. Simply stated, when water warms, it expands and takes up more volume. So there are two sources of sea level rise—*mass transfer* and *thermal expansion*—and scientists want to know how much of the total change can be attributed to each of these sources.

Traditionally, tide gauges were used to measure global mean sea level; more recently, satellite altimeters have been used. While these measurements could tell us how much sea level was changing, they couldn't conclusively determine the source.

In 2002 two new measurement systems were introduced that have greatly improved our understanding of the sources of sea level rise. GRACE measures ocean mass variations and Argo (see text for details) measures upper ocean temperature and salinity. The Figure offers strong evidence that the observing system as a whole is now robust. Note that the sum of the GRACE and Argo measurements (red line) matches the measurements from the Jason-1 and Jason-2 satellite altimeters (black line) within the uncertainty[1].



While the time-series is still too short to quantify the relative contributions of either mass transfer or thermal expansion to total sea level rise, we can say with confidence that since 2005, 85% of the observed trend in sea level is due to increasing ocean mass. Moreover, we can state that the large drop in 2010 and subsequent recovery in 2011 was due largely to a temporary movement of water mass out of the ocean and onto land.

[1] A three-month running mean filter has been applied to these data. The figure shown is updated from: Willis, J. K., D. P. Chambers, C. K. Shum, and C-Y Kuo, Global Sea Level Rise: Recent Progress and Challenges for the Decade to Come, *Oceanography*, **23**, 26-35, 2010.

at least 15 years of data to resolve a long-term trend to better than 0.5 mm per year, a figure of merit needed for best characterization of related phenomena. In efforts to separate the thermal- and mass-driven components of the sea-level rise, researchers commonly took the difference between altimeter-based sea-level measurements and the temperature component and estimated the mass component. This worked to a reasonable level of accuracy for seasonal scales, but did not work well for decadal and longer trends—the most important climate signals—where there was unacceptable uncertainty. Similarly, there were attempts to extrapolate mass loss from measurements of individual glacier systems to that for unmeasured glacier systems, with the assumption that water mass was going into the oceans, thus causing sea levels to rise. Throughout, owing to the inhomogeneity and sparseness of the measurements and the various assumptions required to use them, uncertainties remained large, varied, and largely undocumented.

> *"GRACE has exceeded expectations for measuring ice sheet mass balance."*
> —***Isabella Velicogna*** *[University of California, Irvine]*

But then along came GRACE! In a clear improvement to earlier efforts, GRACE—along with the Argo program that uses some 3000 robot buoys to take ocean temperature/salinity measurements—has greatly enhanced our understanding of how GMSL varies, on time scales from a few months to several years—see **Figure 1**. GRACE mass-change measurements have shown that the largest error sources in early assessments of ocean mass variability were due to altimetry and Argo uncertainties; the GRACE data, on the other hand, are thought to be solid. Six-year trends in the mass contribution of sea-level rise are measurable to a level of 0.2 mm per year, with monthly variations on the level of a few millimeters. GRACE results show that GMSL variations are largely due to the mass gain of the ocean since 2005, and that the thermal effects (heat gain) have been relatively small. Since GRACE also measures the mass over the entire Earth's surface, we also know with high certainty that the major-

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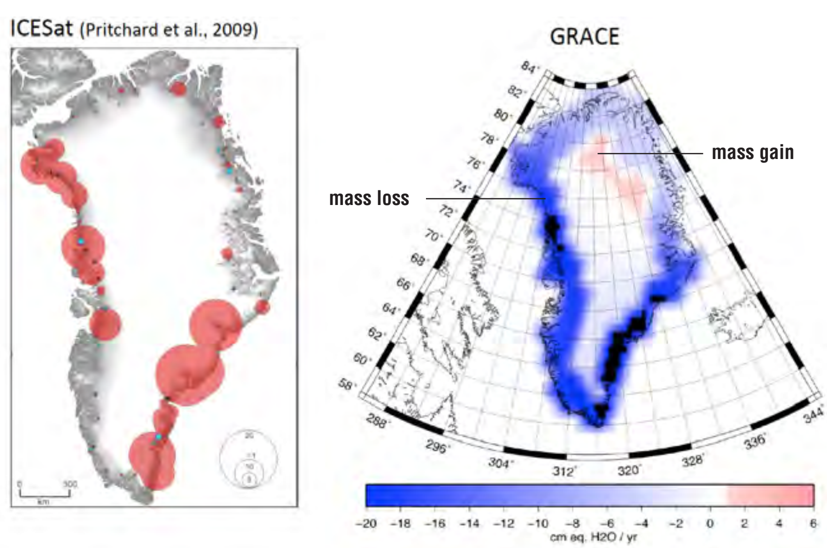

Figure 2. GRACE and ICESat Measure Greenland Ice Loss

These maps show the rate of thinning and thickening and the amplitude of the mass loss in Greenland derived from the Ice, Cloud, and land Elevation Satellite (ICESat) altimetry measurements in meters/yr [*left image*] and GRACE gravity measurements [*right image*]. The circles on the ICESat map are centered on the Greenland glaciers; the radius of each circle is proportional to the rate at which the ice is thinning in that location. These two maps from different sources show similar results—Greenland is losing ice mass at a rapid rate. The GRACE data show significant mass loss at the coasts with minimal mass gain in the interior. Data such as these help scientists understand the processes that are behind the Greenland ice-sheet melt-rate patterns. **Image credit:** Scott Luthcke ity of this mass comes from melting of the Greenland and Antarctica ice sheets—see **Figure 2**. Without GRACE, this would have all been speculation. Now that we have 10 years of GRACE data, confidence in the results has improved significantly.

Studying Ocean Currents Both Near the Surface and Far Beneath the Waves

Satellite-based altimetry, when combined with GRACE static gravity field observations, now provide significant improvements in the precision and accuracy of sea surface topography measurements. For example, GRACE has opened a window for observing the mass change over the whole Arctic Ocean, revealing seasonal Arctic Ocean mass fluctuations that were not even suspected.

It comes as a surprise to many people that the ocean surface is not really as smooth as it might appear. In fact, the oceans' surface topography varies more than can be accounted for by static gravity contributions such as those that result from the presence and location of undersea mounts, deep trenches, and the like. The oceans' so-called *dynamic topography*—topographic changes that occur due to the oceans' general circulation patterns—makes measurable contributions to the oceans' surface shape, and provides structure to ocean current vectors.

Both accurate measurements of sea-surface height from satellite altimeters and an accurate model for the Earth's *geoid* are required to measure dynamic topography. Since 1992, the altimeter measurements have been provided by altimeters on satellites like TOPEX/Poseidon, Jason-1, and the Ocean Surface Topography Mission (OSTM) on Jason-2. However, prior to GRACE, the decade-long set of very-accurate altimeter measurements of sea-surface height could not be used to determine the general ocean circulation because of errors in the geoid over the oceans. One of the first significant contributions of GRACE was to eliminate this deficiency and allow the determination of global maps of the oceans' general circulation. Satellite-based altimetry, when combined with GRACE static gravity field observations, now provides significant improvements in the precision and accuracy of sea-surface topography measurements.

"Oceanographic results from GRACE have been revolutionary."
*—**Jamie Morison** [University of Washington]*

Another significant GRACE contribution is the ability to use ocean-bottom pressure changes to infer changes in the *ocean-bottom currents*. This provides an important additional measurement for ocean studies in regions where it is difficult to make *in situ* measurements. For example, GRACE has opened a window for observing the mass change over the whole Arctic Ocean, revealing seasonal Arctic Ocean mass fluctuations that were not even suspected.

GRACE data have shown preliminary indications of shifts in fundamental patterns of water-mass distribution in the ocean. In the early 1990s, a change in Arctic Ocean circulation and freshwater distribution was noted, and investigators have been trying to track the evolution of those changes ever since. The region of greatest change, on the Russian side of the Arctic Ocean, remains particularly inaccessible and data-sparse. Arctic sea-ice cover has always made gathering basic hydrographic data, temperature and salinity, difficult. Most hydrographic data are taken during the summer and limited to the margins of the Arctic Ocean, particularly the Canada Basin.

Jamie Morison [University of Washington] and his colleagues have examined GRACE data and determined that forces beyond the regional—indeed, at the hemispheric scale—are responsible for the incursion of record-breaking amounts of freshwater into the Beaufort Sea. These data are important because pathways of freshwater affect *ocean heat flux* to the sea ice and the global ocean *thermohaline circulation* of heat. Ongoing data acquisition and data from future missions will provide an even clearer picture of changes in the Arctic Ocean and its relation to terrestrial and atmospheric processes. Continuation of the GRACE measurements of ocean-bottom pressure, the melting of the ice sheets, and the measurements of Russian river fresh water discharge will provide a more-detailed understanding of this important process.

Tracking Changes in the Solid Earth

Two of the most interesting solid-Earth applications of time-variable gravity measurements are recognized to be *glacial isostatic adjustment* (GIA)—the Earth's ongoing viscous response to the disappearance of giant ice sheets at the end of the last ice age—and the mass displacements associated with large earthquakes.

While GRACE can measure the signal from these effects, understanding these and other phenomena related to Earth's *lithosphere*—the nonhydrous, solid components of Earth—can't be accomplished with GRACE data alone, but rather requires additional data about its thermal nature, its composition, component distribution, thickness, and mechanical properties. Moreover, such phenomena do not exist in isolation. For example, the GIA changes are occurring in regions where there are significant exchanges of liquid water and ice, as noted earlier.

GRACE contributions to the study of GIA have proven to be extremely useful. The largest GIA signal is concentrated over northern Canada, and appears in GRACE data as a steadily increasing mass anomaly centered over the Hudson Bay. The amplitude and pattern of this signal provide information about the shape and deglaciation history of the ancient ice sheet in this region, and about Earth's *viscosity*—an important parameter in controlling the characteristics of thermal convection in Earth's mantle. The GRACE results are being used to better understand both these things.

GRACE data have also recorded *coseismic deformation* from several large earthquakes, most recently the catastrophic 2011 Tohoku-oki (Japan) event—see **Figure 3**. GRACE was able to track continuing slow deformation that occurred in the aftermath of the 2004 Sumatran earthquake over months to years following the event. These data have provided insight into the poorly understood postseismic processes that often follow such earthquakes. Such processes are extremely difficult to see with ground-based instrumentation, particularly if the earthquake occurs in an oceanic setting, as is often the case with large thrust-type events.

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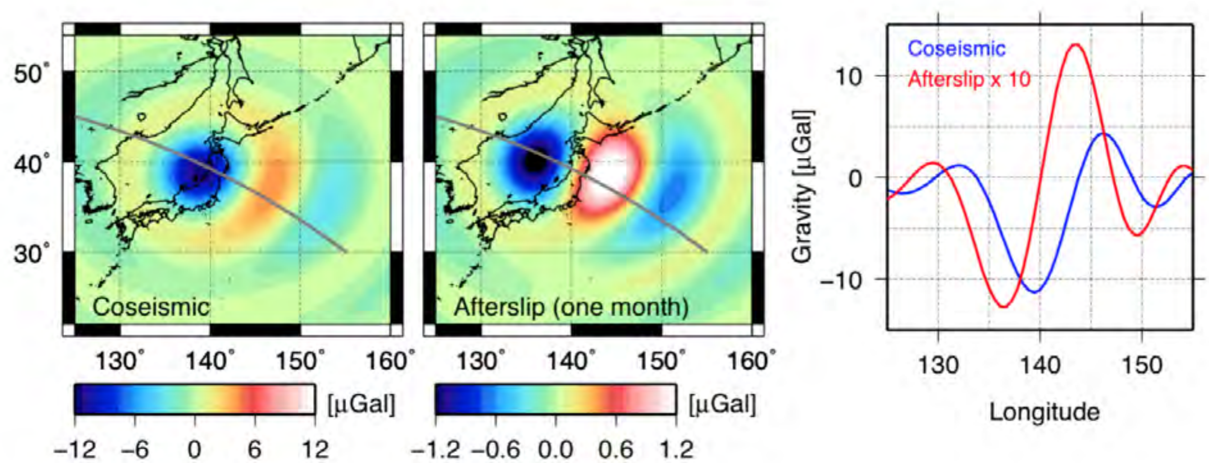


Figure 3. GRACE Detects the Impact of the Japan Earthquake

GRACE is able to detect the slight fluctuations in the gravity field caused by a major earthquake. Similarly to the use of GRACE data following the 2004 Sumatra–Andaman and the 2010 Maule, Chile earthquakes, GRACE data have been used to measure *crustal dilation* resulting from the 2011 Tohoku-oki (Japan) earthquake. GRACE data, when analyzed in combination with other seismic data, offer the possibility of more-accurately determining an earthquake's *seismic moment*—a parameter used to measure the size of a quake based on a variety of factors.

The maps shown here depict the gravity change measured by GRACE during the 2011 Tohoku-oni quake [*left*] and one month afterward [*center*] in *microgals*. (A *gal* or "Galileo" is a non-Systeme Internationale measure of gravitational acceleration equal to 0.01 m/s^2; 1 μgal = 1 x 10^{-8} m/s^2.) The right panel shows the gravity difference between the *coseismic* (during the earthquake) and *afterslip* (a month after the earthquake) along the gray curve depicted in the left and center panels. Note that for ease of interpreation, the afterslip values have been mulitplied by 10. **Image credit:** Shin-Chan Han

Using GPS Receivers as Atmospheric Limb Sounders

The Global Positioning System (GPS) flight receivers on GRACE were provided to allow for precise orbit determination, and also accommodate a GRACE Occultation Co-Experiment that measures the change in the signals from the GPS satellites as they move into and out of Earth's atmospheric limb relative to the GRACE satellites' positions—known as *occultation*. The GPS signals are composed of radio waves, and these waves are altered slightly as they pass through Earth's atmosphere owing to refractive effects. These changes can be analyzed to create profiles of atmospheric vertical and globally distributed bending angles, refractivity, temperature, pressure, and humidity. The radio occulation measurements complement and continue a long series of similar data obtained by sensors on other satellites[8] and are used in weather forecasting and climate research studies.

"GRACE has pioneered the use of GPS measurements for operational weather forecasts."
—***Jens Wickert*** *[German Research Centre for Geosciences (GFZ), Potsdam]*

GRACE provides approximately 120 daily near-real-time occulations—data that are used operationally worldwide by several leading weather centers (e.g., European Center for Medium Range Weather Forecasts, U.K. Met Office, Japan Meteorological Office) to improve their global numerical weather forecasts. Over longer time scales, the GPS radio-occultation data are contributing to climate variability studies and further understanding of Earth's ionosphere.

A Serendipity of GRACE: Using GRACE Satellites as Atmospheric Neutral-Density Probes

Often in the course of scientific research, unplanned-for findings arise. These serendipitous discoveries allow for an entirely unexpected application of the data to be developed that benefits the science community.

Often in the course of scientific research, unplanned-for findings arise. These serendipitous discoveries allow for an entirely unexpected application of the data to be developed that benefits the science community. Such has certainly been the case with GRACE. Several of these *serendipities* have been mentioned in the preceding summaries, but there have been others that don't fall neatly under any of the areas described previously.

"The GRACE accelerometer data represent the best measurements of atmospheric drag and radiation pressure forces acting on the spacecraft."
—***Minkang Cheng*** *[University of Texas, Austin]*

One such example is the use of the twin GRACE satellites as neutral-density probes. While atmospheric density was not a primary science goal for GRACE, analyses of density estimates based on high-resolution and high-accuracy accelerometer data, have suggested that GRACE density data provide better characterization than earlier approaches of the way the *thermosphere* responds to solar and geomagnetic variations across a broad range of time scales. The GRACE-derived densities have contributed to development of a new international atmosphere density model that is being used in current efforts to manage the cluster of Earth-orbiting satellites. Many recent studies have made use of GRACE-derived accelerometer data and the precursor CHAMP mission data to study the thermosphere's response to solar flares, geomagnetic storms, and solar wind streams.

"GRACE is arguably the most interdisciplinary Earth science satellite mission ever launched."
—***John Wahr*** *[University of Colorado, Boulder]*

[8] While the GPS occultation measurements from GRACE are not unique, the accurate Ultra Stable Oscillator carried by GRACE (to support the high-accuracy intersatellite range measurement) allows GRACE occultation data to be used to calibrate other occultation measurements.

The Future of GRACE

In June 2010, NASA and DLR signed an agreement to continue the mission through 2015—a full 10 years past the planned mission duration. The 2011 Earth Science Senior Review extends the GRACE mission for four more years (although funding for years three and four are contingent on the outcome of the next Senior Review). Many members of the GRACE team are also working on the GRACE Follow-On Project, now in development phase for launch in 2017. It is specifically intended to continue the measurements pioneered by GRACE well into the next decade. The science team is hopeful that GRACE can continue to operate until the Follow-On mission is in orbit to allow for inter-comparison between the two missions.

Conclusion

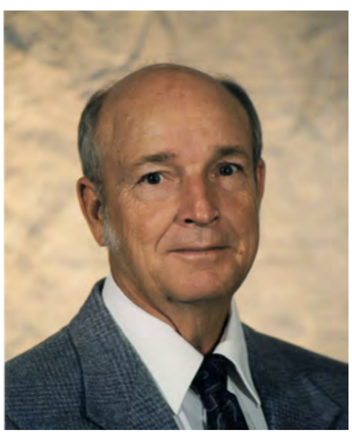
The exquisite dance performed by the twin GRACE satellites continues. The mission has not only exceeded its planned lifetime, but in most cases it has exceeded performance figures of merit. On this tenth anniversary, Byron Tapley, Frank Flechtner (the GRACE German principal investigator), and Michael Watkins, along with all the other original GRACE team members, share a strong sense of gratitude—for the spectacular science return from the mission, the remarkable engineering required to design and build the satellites and instruments, and of course the friendships and respect built among team members from Pasadena to Austin to Potsdam, Munich, Paris, and across the globe.

continued on page 25

The exquisite dance performed by the twin GRACE satellites continues. The mission has not only exceeded its planned lifetime, but in most cases it has exceeded performance figures of merit.

A Reflection on GRACE@10 from the Principal Investigator

Byron Tapley noted that the GRACE mission, while conceived in a cost-capped, time-limited implementation mode with extremely challenging scientific goals, has exceeded all of the mission objectives. The global, accurate, and for many applications, near-synoptic measurements of the Earth's mass flux provides unique insight into the dynamical processes involved in Earth's multiple system interactions. The measurements provide a new and important contribution to the overall suite of NASA climate measurements. The ability to probe beneath the land and ocean surface from satellite altitudes is a new and unprecedented capability.



At the ten-year interval, it is important to note that the success described in this document has been achieved through the successful collaboration of a talented and dedicated international team. Excellence permeated all elements of the GRACE mission, beginning with the conceptual studies on which it was based, and continuing with the exemplary mission implementation effort. At every step in the process, challenges of the cost- and time-implementation constraints, along with the challenging instrument development requirements, have been met without compromising the quality of the science objectives. The excellence continues with the outstanding mission operations effort that has satisfied the challenge of operating the satellites to achieve the micron-level intersatellite ranging accuracy requirement and the need to extend the mission well past the original mission lifetime. Excellence also shines through in the extensive and highly successful data-system effort required to develop, validate, and deliver the accurate gravity products that have been the basis for the science advances described here.

"It has been both a wonderful experience and a significant and appreciated privilege to be involved with the GRACE mission and the outstanding team of collaborators that are responsible for the accomplishments to date. The scientific contributions from the measurement suite obtained during the past 10 years provide a strong impetus for continuing the measurements and underlie the effort to bridge to the GRACE Follow-On Mission and the science achievements residing in the multidecade measurement sequence that awaits," Tapley said.

feature articles

DEVELOP Students Use NASA Earth Observations to Monitor Wildfires from Space

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Thanks to NASA's investment in satellite remote-sensing platforms like Terra, Aqua, Landsats 1–7, and the Earth Observing-1 (EO-1) mission, wildfire monitoring capabilities have grown in spatial and temporal scale, and have provided the means by which to acquire more-accurate—and thus cost-effective and lifesaving—measurements.

Introduction

Each year millions of acres of land are impacted by wildfire in the U.S. In 2011 alone, nearly nine million acres burned—an area larger than the state of Maryland. The high economic and human toll associated with wildfires calls for accurate monitoring before, during, and after fires. Multiple facets are involved in wildfire monitoring and management, including the enhanced understanding of environmental conditions that drive fires, monitoring the intensity and extent of fires, and predicting potential fire risks. NASA and its domestic and international partners have invested in satellite remote-sensing platforms like Terra, Aqua, Landsats 1–7, and the Earth Observing-1 (EO-1) mission, that have enabled wildlife monitoring capabilities to grow—i.e, improved spatial and temporal resolution. These new observations have provided the means to acquire more-accurate—and thus cost-effective and lifesaving—measurements. Employing instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) to track and monitor wildfires has given scientists, emergency managers, local governments, and decision makers an entirely new arsenal of tools to draw from as they battle these potential disasters.

The DEVELOP National Program, a component of NASA's Earth Sciences Applied Sciences Program, provides internships to students and young professionals with the goal of using NASA's Earth observations in real-world applied research projects. These research projects address various topics of national concern that are aligned with the Applied Sciences Program's main focus areas of Disasters, Health & Air Quality, Ecological Forecasting, and Water Resources. Interns work on short-term (10-week-long) projects under the guidance of science advisors from NASA and partner organizations. Throughout the years, DEVELOP projects have focused on a variety of natural disasters, but a common thread running through many of the projects has been a focus on remote-sensing-based monitoring of wildfires. The interns have focused their research on the development of tools for local and regional agencies and decision makers to enhance their emergency management practices through the use of NASA Earth observations.

With the help of NASA's Earth Science satellites and related technology, DEVELOP students have taken on such fire-related topics as pre- and post-fire land-surface conditions, fire extent and intensity, fuel loading and vegetation content, potential fire risk, and impacts upon local and regional air quality—all using space-based remote sensing. These projects have looked at fires around the globe, including the 2009 Station Fire in California, the 2010 Russian Federation fires, and the 2011 Possum Kingdom Lake and Bastrop Complex fires in Texas. Students have also investigated monitoring prescribed burns of agricultural fields and marshlands in Louisiana, and the associated air quality risks. Each of these will be discussed in some detail, following.

The 2009 California Station Fire

California consistently has one of the most active fire seasons within the U.S. each year. Several factors contribute to this, including fire suppression, fuel loading, and a climate that is often dry, warm, and windy. In 2009 California was ravaged by the Station Fire that destroyed over 160,000 acres in Los Angeles County and negatively impacted air quality in nearby areas. The Station Fire burned from August 26–October 16, 2009, a year that was ranked the tenth largest fire season in California history.

During the Summer 2010 term, a team of five DEVELOP students focused their research on applying NASA's Earth observations to help land managers develop future policy and decision-making tools. DEVELOP partnered with the U.S. Forest Service at the Angeles National Forest to use the Station Fire as a case study to enhance decision making for handling future fires in the region. The team used a suite of sensors and datasets, including Landsat's Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+), Terra's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and MODIS, along with the U.S. Department of Agriculture (USDA)/U.S. Geological Survey (USGS)'s Landscape Fire and Resource Management Planning Tools (LANDFIRE) dataset and the National Oceanic and Atmospheric Administration (NOAA)'s HYbrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model.

The team began by assessing the health of the land, using a rapid analysis of change in vegetative distribution by way of a land-cover classification and Normalized Difference Vegetation Index (NDVI) analysis. They selected Landsat images from before (August 6), during (September 7), and after (October 25) the fire for analysis. This allowed the team to identify vegetation loss due to the fires and, through multiple unsupervised classifications, create a time series of land-cover change, which demonstrated the impact of fire on vegetation extent—see **Figure 1**. The team also used Landsat imagery to improve the understanding of the impacts of a dry season on vegetation moisture content—an integral factor directly impacting ignition time, rate of spread, energy release, and production of smoke. Normalized Difference Moisture Index (NDMI) calculations were used to analyze average moisture values to characterize the environmental conditions leading up to the Station Fire—see **Figure 2**. Through use of NDMI from Landsat TM data, the team was able to analyze average moisture values for the study area and plot trends, providing a means of understanding the changes in live vegetation moisture content that preceded the fire.

Emissions from the Station Fire greatly impacted air quality in the local region, posing health risks and causing subsequent increases in respiratory illnesses, according to hospital data. Using the HYSPLIT model, the team ran forward and backward trajectories from multiple biomass burning sources at 24-hour intervals at multiple altitudes. This provided information on the extent and direction of smoke plumes from the Station Fire and allowed for better understanding of the geographic locations impacted by the fires—see **Figure 3**, next page.

The broad examination of so many factors relating to wildfire monitoring provides land and emergency managers a *synoptic* (i.e., large-scale) view of conditions, further enhancing their decision making process in a rapid manner—when time counts. Beyond the immediate benefits, this research was able to pioneer a vein of fire research at the DEVELOP office at NASA's Langley Research Center (LaRC).

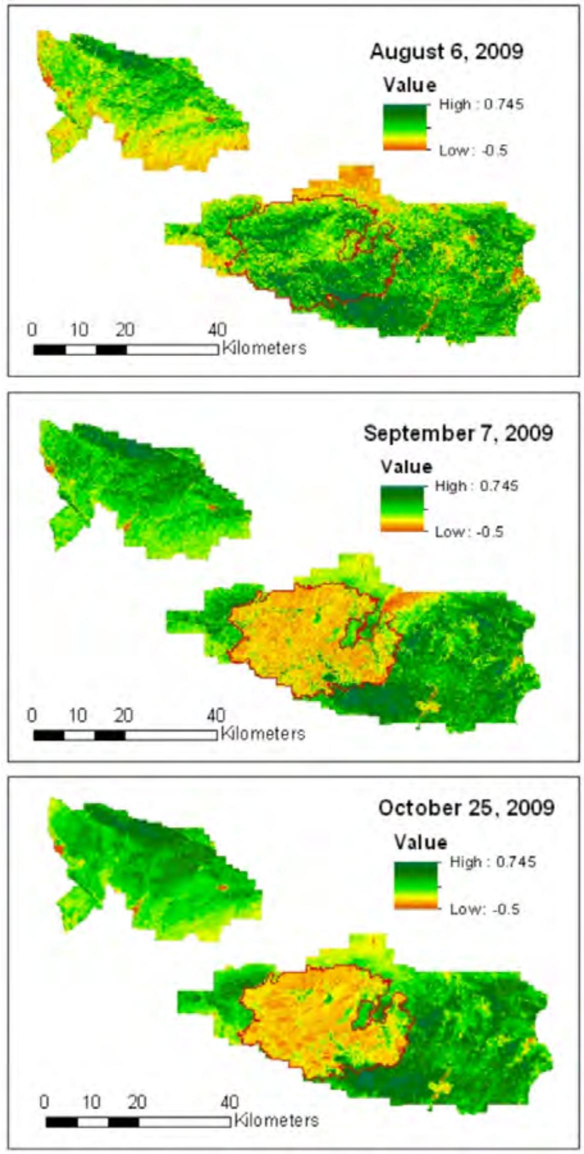

Figure 1. The three images above show the NDVI analysis of Landsat 5 TM data of the Angeles National Forest in California before [*top*], during [*middle*], and after [*bottom*] the Station Fire. There was a substantial decrease in vegetation health within the fire perimeter (red outline) associated with the fire. **Image credit:** DEVELOP National Program

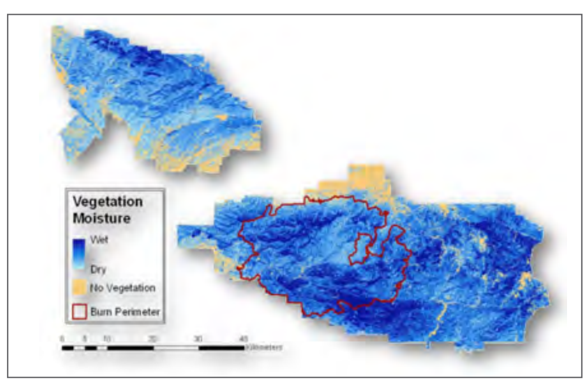

Figure 2. This image shows vegetation moisture conditions derived from Landsat 5's TM before ignition on August 6, 2009. The Station Fire burn scar has been outlined with a red line. Fire managers can use these maps to help assess potential fire risk. **Image credit:** DEVELOP National Program

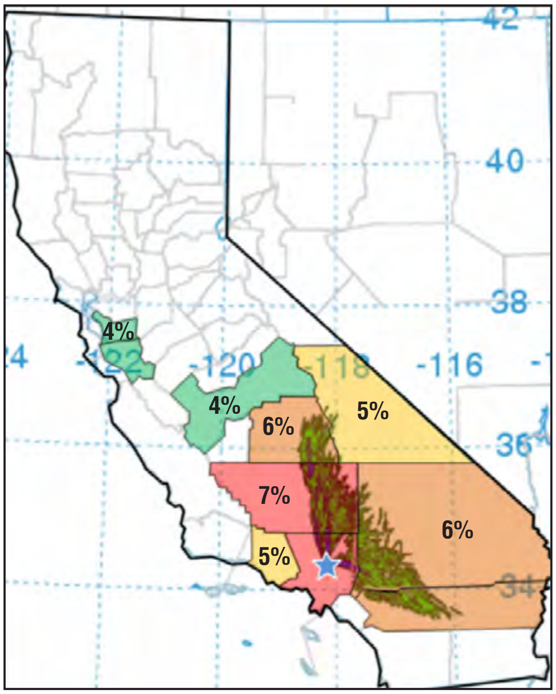

Figure 3. This image shows HYSPLIT trajectories for particulate matter originating from the Station Fire region (lines emanating from blue star). Nearby counties are labeled with percent increase in hospitalizations due to respiratory health aliments during and after the fire compared to July 2009. **Image credit:** DEVELOP National Program

Acknowledgements to the California Disasters Team: Malcom Jones [Christopher Newport University (CNU), *Team Lead*]; **Joseph Reedy** [Chadron State College]; **Samiah Moustafa** [University of Florida]; **David Brundage** [University of Tennessee at Knoxville]; and **Kevin Anderson** [University of Virginia (UVa.)].

The 2010 Russian Wildfires

During the summer of 2010, the Russian Federation saw a few localized peat bog fires erupt into a large-scale regional wildfire that scorched the landscape and caused severe deterioration in air quality across much of the eastern extent of the country. The draining of the peat bogs during the 1960s and the dismantling of the Russian National Fire Service in 2002 had already left the region vulnerable to a fire outbreak. A relentless heat wave only served to exacerbate the problem and created the perfect set-up for the massive wildfire outbreak that occurred. More than 196,000 hectares in the countryside near Moscow were scorched, causing an estimated $15 billion in damage.

A team of DEVELOP students at LaRC focused their Summer 2011 research on investigating how these factors facilitated the disaster, and how data from NASA's Earth Observing System (EOS) could play a role in future forest-fire mitigation and response management.

The team began by analyzing the pre- and post-fire land conditions. Land-cover data were gathered from the Landsat 5 TM and Landsat 7 ETM+ instruments and were used to classify vegetated land cover and urban areas within the region. During the classification process, the investigators made a very intentional effort to accurately identify the peat bogs that were the original source of the wildfires. To best use remote-sensing capabilities to assess another important factor in fire risk—moisture—the DEVELOP team ran a NDMI analysis that provided quantifiable data on soil moisture levels to identify areas of low moisture content and therefore higher fire risk. Three NDMI data layers were combined with a fourth layer depicting roadways in the area—an indicator of human activity. The result of aggregating these layers was a risk map for potential fires in the study area, thus establishing an effective method for land managers to use EOS data to enhance monitoring capabilities for areas susceptible to future fires—see **Figure 4**, next page.

Due to the degraded air quality caused by the 2010 Russian fires and the associated impacts on respiratory health in the region, the team also generated methods to track and model smoke plumes from the fires. The team chose to approach this phase of their project by compiling Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and MODIS aerosol optical depth (AOD) and visible imagery to identify smoke plume evidence. To better quantify their observations, the group used the HYSPLIT model to investigate the vertical distribution of particulate matter in the atmosphere and to study how the smoke plumes were likely transported locally and regionally. Information like this helps fire managers accurately predict where smoke plumes might impact communities. Health-care decision makers may also be able to identify relationships between reported cases of respiratory health ailments and known plume tracks.

At the conclusion of the project, the team created a tutorial for decision makers that provided training in the necessary steps to recreate this type of work and help facilitate the sustainable use in future fires. The Russian wildfire project also initiated the follow-on DEVELOP project that focused on the 2011 Texas wildfire season, discussed in the next section of this article. The methodologies used to study the 2010 Russian fires provided a foundation for the next team to build on.

Acknowledgments to the Russia Disasters and Public Health Team:
Derek Doddridge [George Mason University, *Team Lead*]; **Shalika Gupta** [University of California, Berkeley]; **Kenneth Hall** [CNU]; **Kathryn Morel**, [CNU]; **Raven Moreland** [UVa]; **Katie Overbey** [University of North Carolina]; **David Arczynski** [Walsingham Academy]; and **Jonathan Wilson**[Brigham Young University, Idaho].

The 2011 Texas Wildland Fires

During the Fall 2011 term, a group of four DEVELOP interns began work on one of the most ambitious fire-related projects undertaken by the program—the incredibly destructive 2010-11 Texas wildfire season, which burned nearly four million acres of land across the state. The project specifically focused on the fires near Bastrop County and the Possum Kingdom Lake. Excessive heat and prolonged drought (driven by La Niña conditions) made the region vulnerable to fire, and strong winds from Tropical Storm Lee helped to fan the flames, leading to a historic wildfire season that ignited over 26,000 separate fires resulting in the loss of over 5000 structures and the lives of four people.

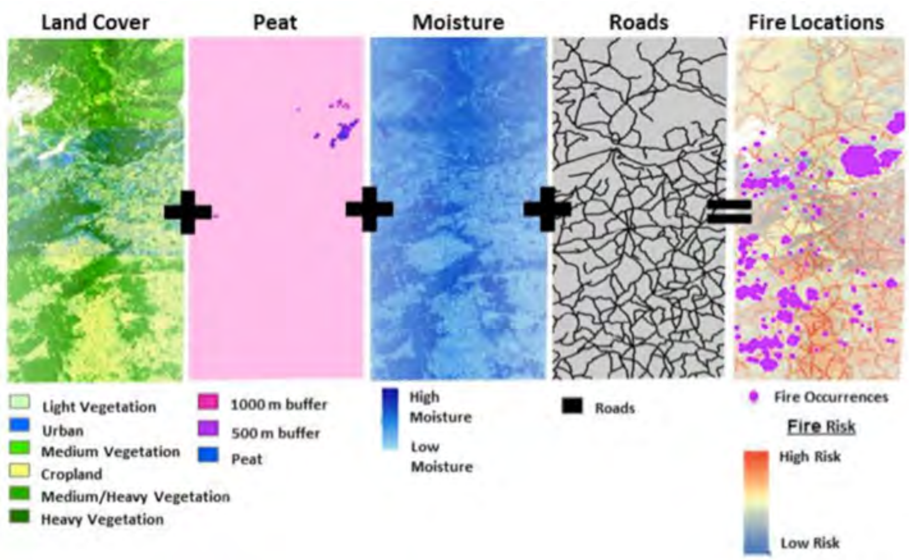

Figure 4. A potential fire-risk map *[far right]* with reported fire occurrences (purple dots) was created using four weighted layers *[left to right]*—land cover classification data, peat marsh locations and buffers, soil moisture, and roadways as an indicator of human activity—for the Russian Federation region. The three left images show data from Landsat 5 TM and Landsat 7 ETM+. **Image credit:** DEVELOP National Program.

The DEVELOP research team partnered with the Texas Forest Service (TFS), which is responsible for directing all matters pertaining to forestry within the state. Prior to this project, the only Earth-observations that TFS used in their predictive risk was previously processed Advanced Very High Resolution Radiometer (AVHRR) and ground-based weather radar data. Daily maps of select fire weather and fire danger components were also produced, but these are done at the national level, and TFS desired to be able to conduct this type of analysis in-house to better address their unique concerns.

To enhance current TFS practices, the DEVELOP team began work on constructing burn extent and severity maps for the Bastrop County and Possum Kingdom Lake Fires. Using burn-scar imagery and calculating the difference Normalized Burn Ratio (dNBR) and Relative dNBR (RdNBR), the team was able to apply NASA Earth-observing assets to assist in fire monitoring during and after the wildfire events—see **Figures 5** and **6**. The team also calculated the NDVI of the local surface vegetation to investigate the impact of the drought on the local ecosystem and the magnitude of ecological changes the fires caused. Having determined that the drought had a major impact on the system, the team continued their investigation by analyzing soil moisture by conducting a NDMI for each of the study areas. All of these separate analysis techniques were then combined to generate a composite fire-risk map—see **Figure 7**—and a time-lapse representation of the changing conditions of surface water resources during the duration of the fires. This type of information provided the TFS with a more timely and cost-effective aid for fire prediction and prevention.

dNBR for Possum Kingdom Lake (April 2001–May 2011)

Figure 5. The dNBR created from Landsat 5 TM shows multiple levels of burn severity in the Possum Kingdom Lake for April–May 2011, indicating fire-induced ecological change levels. **Image credit:** DEVELOP National Program

Possum Kingdom Lake dNBR
- Enhanced Regrowth, Low
- Burned
- Low Severity
- Moderate-Low Severity
- Moderate-High Severity
- High Severity

The DEVELOP team created a tutorial demonstrating how to acquire the necessary data and conduct the proper analysis for the TFS. During future fires, TFS can use this product to determine the best use of their resources.

The success of the 2011 Texas wildfire project led to the development of a follow-on project that investigated the use of EOS data to monitor 2011 Texas fire season impacts on air quality in nearby metropolitan areas. The project also won the People's Choice Award in an online virtual poster session contest on IEEE's Earthzine website. To view a video created by the team, visit: *www.earthzine.org/2011/11/10/using-nasa-earth-observations-to-assess-burn-severity-and-perform-risk-mapping-of-the-2011-texas-wildfires*.

Acknowledgments to the Texas Disasters Team:
Kenneth Hall [CNU, *Team Lead*]; **Ande Ehlen** [CNU]; **Taylor Beard** [CNU]; and **Myles Boyd** [Phoebus High School].

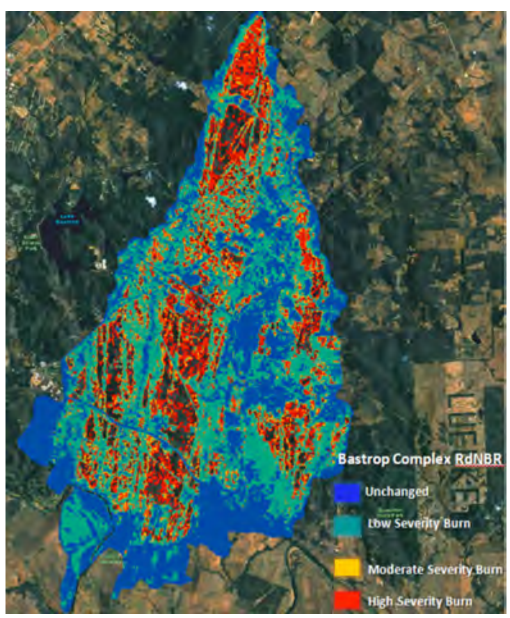

Figure 6. Landsat 5 TM derived RdNBR displays four levels of burn severity in the Bastrop Complex fire, providing a more-robust and accurate means of monitoring burn severity than the dNBR. **Image credit:** DEVELOP National Program

Prescribed Louisiana Sugar Cane and Marsh Burns (2008-2009 Burn Season)

Even when fires are prescribed—i.e., engineered by humans—they require proper management and monitoring. Each year portions of sugar cane fields and marshes in Florida, Texas, and Louisiana are burned to remove approximately three-billion metric tons of excess biomass quickly and effectively. The sugarcane industry in Louisiana has surpassed all other agriculture commodities in size for the state, and to maintain a high yield and maximum efficiency requires burning during the harvest period. Louisiana also contains approximately 30% of the total coastal marsh in the U.S., which is also periodically burned as an ecologically important management tool. Biomass burning produces particulate matter smaller than 10 µm in diameter (PM_{10}), which has been shown to have negative impacts on human health. To take steps towards alleviating some of these health concerns, the Louisiana Department of Agriculture and Forestry has put in place burning guidelines, but as yet these guidelines are only voluntary.

During the summer of 2010, a DEVELOP team at NASA's Stennis Space Center partnered with the Environmental Protection Agency (EPA) Region 6 Regional Haze Program, the University of Louisville, and Nicholls State University to investigate the use of Terra ASTER, Landsat TM, and Terra/Aqua MODIS data products for monitoring prescribed burns in coastal Louisiana and to examine the resulting air quality impacts.

The team began its work by developing methods to accurately identify fires and their spatial extent within the marshlands of Southern Louisiana—specifically, looking at Iberia and Cameron Parishes. The investigators conducted NDVI analyses of Landsat and ASTER scenes to locate the burned areas in the sugarcane fields. (The scenes were subsetted and masked to show only the sugcarcane fields in the study area.) Using the Fire Information for Resource Management System (FIRMS), MODIS point data were queried for fire locations that had over 50% confidence level and composited into images showing all fire points from 2005–2009 in Louisiana—see **Figure 8**. By mapping fire density information from the MODIS Rapid Response System, the team was able to show that the majority of the fires across the state were correlated with agriculture and marsh areas—see **Figure 9,** next page. The project also incorporated datasets from partner agencies, such as NOAA's Coastal Change Analysis Program (C-CAP) dataset, USDA's Geospatial Data Gateways land-cover dataset, USDA's 2009 Cropland Data Layer (CDL), and sugarcane statistics from the National Agricultural Statistics Service.

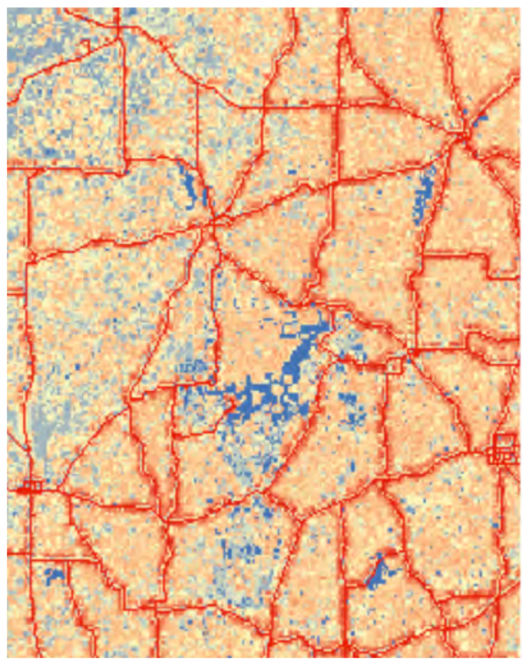

Figure 7. Risk assessment maps were created using RdNBR burn severity maps and four pre-fire risk factors (soil moisture, wildland-urban interface, fuel cover, and proximity to roads as an indication of human activity) for the Possum Kingdom Lake region. **Image credit:** DEVELOP National Program

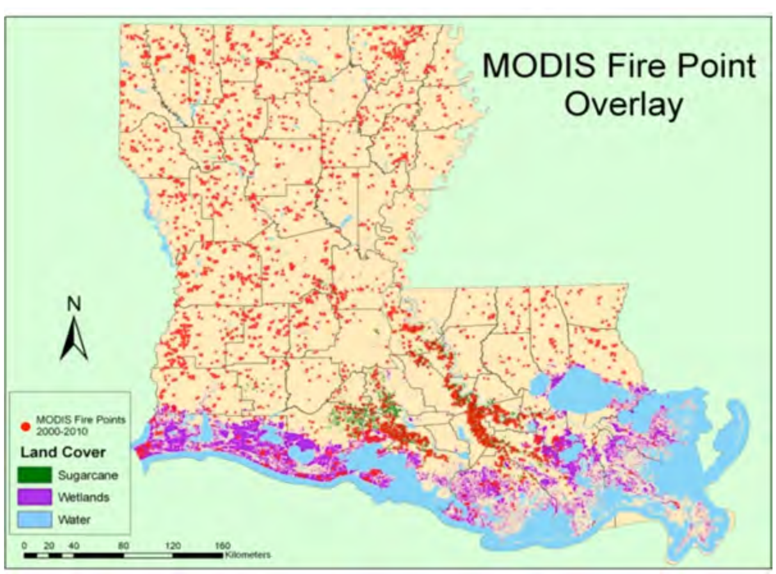

Figure 8. Using data from the MODIS Rapid Response System, active fire points (black dots) were compiled for the years 2005–2009, showing highest density near fields devoted to sugarcane cultivation and marshland. **Image credit:** DEVELOP National Program

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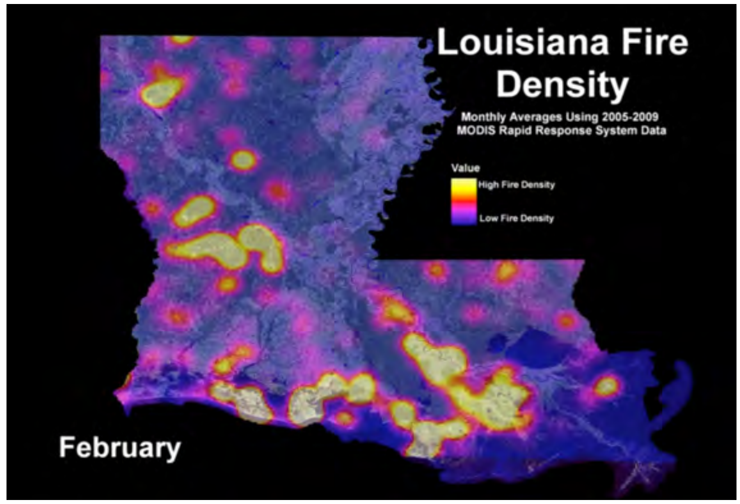

Figure 9. MODIS Rapid Response System data provided a means to map fire densities, which helped visualize the high fire densities in the agricultural and marsh areas during the peak of the burning season. **Image credit:** DEVELOP National Program

Figure 10. A burned-field detection analysis using ASTER data between September 1–November 4, 2009, shows that approximately 19,760 hectares of sugarcane fields were burned in Iberia Parish. **Image credit:** DEVELOP National Program

were further refined using NDVI analysis on data from ASTER—see **Figure 10**—and Landsat 5 TM—see **Figure 11,** next page—the team used algorithms to estimate emissions from the biomass burning to enhance decision making and future policy. Using a bottom-up methodology developed by Seiler and Crutzen, the project estimated pyrogenic emissions from biomass burning for each parish. They found that gaseous emissions produced by biomass burning in Louisiana are higher than previously estimated, and that Earth observations could clearly show monthly trends: Sugarcane fires occur mostly from October through December with a November peak, and marsh fires occur mostly during January through February.

The team's methods provide a means of using much-higher-resolution data than previously used, with results suggesting that biomass burning for the state of Louisiana may have been underestimated—information useful for Louisiana's decision and policy makers.

Acknowledgments to the Louisiana Air Quality Team:
Chad Robin [Florida State University, *Team Lead*]; **Robert Clark** [University of New Orleans (UNO)]; **Ross Reahard** [UNO]; and **Jared Zeringue** [UNO].

Conclusion

When wildfires occur, quick decisions must be made. To make those decisions, emergency managers require prompt, accurate information. The vantage point that space offers puts NASA Earth-observing satellites in a unique position to address this need. The DEVELOP National Program's work to address wildfire concerns has fostered many new users of NASA's Earth-observation data, and will assist decision makers in places like California and Texas during future fires. The training of a new generation of NASA science-literate decision makers continues this coming Summer term as a new class of DEVELOP students take on a range of projects, including wildfire monitoring in places like North Carolina and Virginia.

Efforts to build capacity to use these national resources are imperative to enhancing future decision making and appropriate response to emergencies. The DEVELOP National Program addresses this need by training the next generation of scientists and policy makers in the use of Earth observations. DEVELOP is expanding the future capabilities for and benefits from NASA satellites to address societal concerns. With each project that partners with new organizations and agencies, the students are directly passing on knowledge and further expanding the user base for NASA Earth observations. As the "ambassadors" for the application of NASA's Earth-science technology, DEVELOP students and young professionals are making an impact that far exceeds what might be expected from a relatively short, 10-week internship.

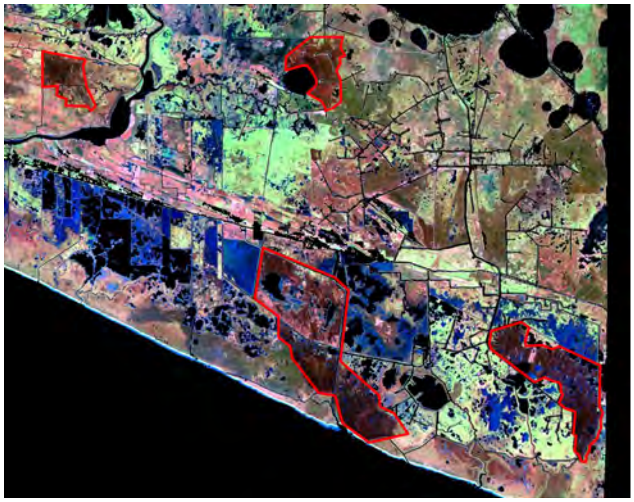

Figure 11. Landsat 5's TM allowed for burn-scar detection in the coastal marshes in Cameron Parish, identifying approximately 23,160 hectares of marshland burned during the project's study period. **Image credit:** DEVELOP National Program

For more information about the DEVELOP National Program, visit: *develop.larc.nasa.gov*.

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40th ASTER Science Team Meeting Report

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The 40th Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Science Team Meeting was held December 12-15, 2011, in Pasadena, CA.

Opening Plenary Session

H. Tsu [Earth Remote Sensing Data and Analysis Center (ERSDAC)—*Japan ASTER Science Team Lead*] and **M. Abrams** [NASA/Jet Propulsion Laboratory (JPL)—*U.S. ASTER Science Team Lead*] welcomed almost 50 U.S. and Japanese Science Team members and interested participants to the 40th ASTER Science Team Meeting.

M. Abrams summarized the latest news from NASA Headquarters (HQ), and also presented ASTER science highlights. The Terra mission received a two-year extension following the 2011 NASA Earth Science Senior Review, with funding through September 2013. NASA and the Japanese Ministry of Economy, Trade, and Industry (METI) jointly released the ASTER Global Digital Elevation Model version 2 (GDEM2) on October 17, 2011. Improvements incorporated into the new version include better spatial resolution, elimination of most artifacts, reduction in data gaps, and superior water-body coverage and detection. Abrams concluded by displaying several ASTER images acquired in response to natural disaster tasking, and highlighted some recent publications and conference presentations.

M. Kikuchi [Japan Resources Observation System and Space Utilization Organization (JAROS)] reported on ASTER instrument status, addressing lifetime management and radiometric calibration.

T. Matsunaga [National Institute for Environmental Studies (NIES)], provided an update on METI's Hyperspectral Imager Suite (HISUI)[1], a spaceborne instrument with hyperspectral and multispectral imagers.

M. Hato [ERSDAC] reported on ERSDAC Ground Data System (GDS) status, providing updates on observation scheduling, data processing, and product distribution. Additional topics included the completion of the ASTER Operation Segment (AOS) replacement, release of the Level-1A Plus (L1A+) Tool to correct nighttime thermal infrared (TIR) geolocation error, and a brief suspension of GDS operations in January 2012 due to facilities relocation.

D. Meyer [U.S. Geological Survey Land Processes Distributed Active Archive Center (USGS LP DAAC)] reviewed LP DAAC ASTER activities, including data processing and access initiatives, GDEM2 validation, and distribution metrics.

M. Fujita [ERSDAC] presented the Science Scheduling Support Group/Operations and Mission Planning (SSSG/OMP) report. Fujita reviewed the status of major Science Team Acquisition Requests (STARs), such as Global Mapping (GM), nighttime TIR GM (TGM), and the Underserved Area (UA) and Gap-filler STARs.

J. Kargel [University of Arizona] demonstrated the use of ASTER visible and near-infrared (VNIR) and GDEM2 data in mapping animal habitats, specifically, determining an Optimum Suitability Index (OSI) for the Tibetan snowcock.

The opening plenary concluded with **M. Abrams** and **Y. Yamaguchi** [Nagoya University] proposing a list of issues for discussion in the working groups, including: data acquisition monitoring status; ASTER instrument power-reduction plan; and GDEM updates following the release of v2.

Level-1/DEM Working Group

H. Fujisada [Sensor Information Laboratory Corporation (SILC)] reported no appreciable problems for instrument inter- and intratelescope registration. The implementation of L1A+ software corrects nighttime TIR geolocation error.

M. Abrams presented media coverage and publicity activities for the newly released GDEM2.

D. Meyer compared LP DAAC distribution metrics for GDEM2 and GDEM v1. First-month GDEM2 demand was on par with v1 distribution. **M. Hato** reported similar GDEM2 distribution demand at ERSDAC.

R. Crippen [JPL] summarized his GDEM2 validation results, reporting improvements over earlier products, with finer resolution and reduced glitches, but with more random noise. Work is underway to produce a new version of the Shuttle Radar Topography Mission (SRTM) DEM by filling voids with GDEM2, as well as developing a GDEM with reprocessed SRTM data and additional enhancements.

H. Fujisada set forth SILC's proposal to develop GDEM v3. GDEM quality will be further enhanced with additional input scene DEMs, smaller inland water body recognition, and the correction of large lake anomalies.

M. Abrams discussed two special ASTER GDEM2 sessions being organized for the XXII Congress of the

[1] HISUI will fly on the Advanced Land Observation Satellite (ALOS-3), which is scheduled to launch in 2018.

International Society of Photogrammetry and Remote Sensing (ISPRS), to be held August 25–September 1, 2012, in Melbourne, Australia. **M. Abrams**, **Y. Yamaguchi**, and **J.P. Muller** [University College London] will act as cochairs, and will edit a special journal issue compiled from the presentation material.

Geology Working Group

C. Laukamp [Commonwealth Scientific and Industrial Research Organisation (CSIRO)] reported on the Centre of Excellence for 3D Mineral Mapping's (C3DMM) ASTER project. A suite of publicly accessible ASTER-derived geoscience mineral map products of the Australian continent is under development. Version 1 (v1), covering Western Australia, was released to the public on November 15, 2011. The full v1 map covering the entire Australian continent will be released at the 34th International Geological Congress (IGC) in August 2012.

J. Mars [USGS] discussed a basin and range mineral-mapping project that identifies hydrothermal silica-rich rocks using shortwave infrared (SWIR) and TIR ratios obtained from ASTER data. Goals of the project are to detect potential economic deposits of gold, molybdenum, and copper, and to identify rocks that affect the pH of surface waters in watersheds.

J. Kargel analyzed the role of ASTER and Global Land Ice Measurements from Space (GLIMS) in composing accurate maps depicting Greenland's ice loss.

A. Melkonian [Cornell University] presented ongoing work conducted with **M. Pritchard** [Cornell University] analyzing glacier velocities and elevation changes in Patagonian icefields. Results show each icefield is losing volume; despite high variability, rates agree with Gravity Recovery and Climate Experiment (GRACE) measurements. Next, Melkonian updated the audience on the Cornell Andes Project. The principal investigator (Pritchard) and the team combined ASTER TIR data with Interferometric Synthetic Aperture Radar (InSAR) data and seismic observations to identify background activity at 200 volcanoes in the Southern and Central Andes region.

M. Ramsey [University of Pittsburgh] provided an update on the ASTER Urgent Request Protocol (URP) program, a rapid-response volcano-alert system. The system will expand from monitoring volcanic activity in the North Pacific to a global scale, following integration and testing using Moderate Resolution Imaging Spectroradiometer (MODIS) IR data and the MODIS Volcano (*MODVOLC*) algorithm. Ramsey also speculated on the evolution of volcano remote sensing in the coming decade.

V. Realmuto [JPL] presented *Plume Tracker*, a new toolkit for mapping volcanic plumes with multispectral TIR remote sensing. Plume Tracker allows for interactive data analysis through the use of multiple instruments and ancillary data sources, thus providing multi-resolution analysis.

M. Urai [Geological Survey of Japan (GSJ)/National Institute of Advanced Industrial Science and Technology (AIST)] discussed the ASTER time series DEM and orthorectified image dataset, accessible to contracted researchers for applications such as disaster monitoring and land-use classification. The dataset, consisting of the time-series image, DEM, cloud mask, and image-shift data, is currently available for Asia and Africa, with additional areas to be included in coming years.

D. Pieri [JPL] provided updates on several ASTER-related projects. Pieri reviewed ASTER Volcano Archive (AVA) statistics, challenges, and future plans. He also presented work on low-temperature anomaly detection using pixel probability distributions. Pieri ended with a progress report on *in situ* gas-sampling activities at Turrialba Volcano in Costa Rica. Field data are combined with satellite measurements for detailed volcano-emission analysis.

Operations and Mission Planning Working Group

M. Fujita analyzed ASTER observation resources and provided status updates for various STARs. GM4 acquisitions are leveling off, prompting the recommendation to start GM5 to increase global coverage. TGM5 is successfully acquiring nighttime TIR data, and will proceed as submitted. The UA2011 STAR is underway. This request was generated during GDEM2 development and targets rarely observed areas. The Gap-filler STAR is designed to fill the cloudy holes of GDEM. Areas for a 2012 version will be determined by analyzing GDEM2, with additional input from **R. Crippen**. The presentation concluded with updates for GLIMS, urgent observations, and pointing status.

T. Tachikawa [ERSDAC] provided preliminary results assessing the efficiency of cloud avoidance in the late-change one-day schedule.

M. Hato announced completion of the AOS replacement, and detailed the GDS office relocation plan.

M. Kikuchi presented six possible scenarios for ASTER if a power-reduction plan is mandated for Terra.

D. Meyer reviewed Long-Term Archive (LTA) plans for ASTER data following the end of its mission. The draft plan for the LTA, outlining procedures beyond three years of post-mission data production, was delivered to the Earth Science Data and Information System (ESDIS). NASA HQ will revisit the proposal at a later date.

M. Ramsey expanded on integrating *MODVOLC* triggers into the current rapid-response volcano alert system. Five volcanoes will act as test cases before implementing a worldwide monitoring system.

J. Kargel discussed GLIMS acquisition status and strategies to boost data collection.

Temperature-Emissivity Separation Working Group

G. Hulley [JPL] began with an update on global ASTER emissivity grids. North America and Africa products are complete. The worldwide emissivity database should be complete by December 2012.

H. Tonooka [Ibaraki University] reviewed features of the Satellite-based Lake and Reservoir Temperature Database in Japan (SatLARTD-J). Beta v1, which uses ASTER TIR data, is publicly available, and includes all major lakes and many small water bodies in Japan. Tonooka then discussed AIST's ASTER time-series orthorectified products and Ibaraki University's role in generating land-surface temperature and emissivity (TE) products.

A. Gillespie [University of Washington] provided continued validation results for ASTER TE products over water. **H. Tonooka** followed with validation results obtained from data collected by permanent stations at select lakes in Japan. **S. Hook** [JPL] completed the presentations involving TE product validation over water bodies with data retrievals from Lake Tahoe and the Salton Sea.

H. Tonooka detailed the use of ASTER TIR nighttime data in flood analysis, providing application results from extensive flooding in Queensland.

T. Tachikawa presented validation results following the correction of the TIR geolocation error in nighttime data using the L1A+ process.

G. Hulley discussed the use of principal component regression in generating a high-spectral-resolution ASTER emissivity spectrum. Applications include the validation of hyperspectral IR sounder emissivities and land-surface temperature from IR sounders using a radiance-based method.

S. Kato [NIES] presented work on the relative accuracy of the ASTER emissivity product using data collected at one of several vicarious calibration sites for ASTER TIR, located in Railroad Valley, NV.

K. Iwao [AIST] presented research conducted by **N. Yamamoto** [AIST] on a Sensor Alert Service (SAS) for ASTER data using volcano *hotspot* detection as a case study. An event triggers an automatic processing chain, with results published using a spatiotemporal Web-feed format (GeoRSS), with event information easily obtainable via visualizations in *Google Earth*.

M. Fujita provided observation completion rates for TGM3 and TGM4, and status updates for the active TGM5 STAR.

H. Tonooka explained the TGM5 area-of-interest (AOI) generation process and cloud assessment. TGM5 achievement is based on analyzing the number of clear nighttime scenes acquired.

Radiometric Calibration/Atmospheric Correction Working Group

F. Sakuma [JAROS] reviewed VNIR, SWIR, and TIR instrument status. The radiometric response of VNIR and TIR has been decreasing gradually. Radiometric Calibration Coefficient (RCC) parameters for VNIR and TIR will be updated from v3.11 during the first quarter of 2012 to prevent further deviation from the fitting curve. Sakuma also reported on the influence the Inclination Adjustment Maneuver (IAM) has had on the VNIR and TIR sensors. The effect was not remarkable for VNIR, while a small change was observed for TIR. Sakuma ended by comparing ASTER VNIR degradation with degradation trends for other sensors.

A. Iwasaki [University of Tokyo] analyzed ASTER VNIR odd/even stripe noise, apparent in L1A data after radiometric correction. Investigations into the relationship between detector temperature and the odd/even difference are ongoing.

S. Tsuchida [AIST] presented research conducted by **H. Yamamoto** [AIST] that evaluated ASTER gains and offsets using long-term Terra ASTER/MODIS cross-calibration over Committee on Earth Observing Satellites (CEOS) reference standard test sites. Relative differences between ASTER and MODIS top-of-atmosphere (TOA) reflectance are increasing as a function of mission elapsed time.

B. Eng [JPL] reviewed U.S. ASTER L2 software status. V3.4 has been delivered and tested at the LP DAAC, and will be implemented following a transition from 32-bit to 64-bit hardware. V3.5 is under development.

S. Biggar [University of Arizona], **S. Tsuchida**, and **K. Arai** [Saga University] reported on their respective VNIR field campaigns. **H. Tonooka**, **T. Matsunaga** [NIES], and **S. Hook** presented TIR field campaign results. Plans for upcoming field campaigns were discussed.

The session concluded with a power-limit discussion, assessing the impact to onboard calibration in the event that long-term calibration can no longer be carried out.

Ecosystem/Oceanography Working Group

The meeting began with an announcement from **T. Matsunaga** that he is resigning from his position as working group cochair. **K. Iwao** will assume the role of cochair alongside **G. Geller** [JPL].

L. Prashad [Arizona State University (ASU)] discussed the ASU 100 Cities Project's *beta* release of Java Mission-planning and Analysis for Remote Sensing (JMARS) for the Earth (J-Earth). This open-source geographic information system (GIS) application allows users to search for and analyze multispectral remotely sensed data.

J. Kargel demonstrated the combined use of ASTER data and field observations to document vegetation destruction and primary succession as part of the glacier-climate-Earth surface process system.

D.D.G.L. Dahanayaka [Ibaraki University] presented work aimed at estimating the concentration of chlorophyll-a (Chl-a) in Sri Lankan tropical coastal water bodies using ASTER data and *in situ* measurements. ASTER bands 1 and 2 were found to be useful for monitoring Chl-a, and results were compared to estimates obtained from other instruments.

S. Kato [NIES] presented an analysis of shaded and sunlit surface temperature in Tokyo, estimated by using ASTER VNIR and TIR data.

K. Iwao reviewed AIST's hotspot detection system and provided Group on Earth Observation (GEO) activity updates. The ASTER GDEM2 and human settlement map were highlighted at the GEO-VIII Plenary held in Istanbul, Turkey in November 2011.

T. Matsunaga described research conducted by **Y. Sakuno** [Hiroshima University] monitoring water mass change around Tachinaba Bay using ASTER Multi-Channel Sea Surface Temperature (MCSST) data. The cold-water movement observed in ASTER data aligns with *in situ* measurements of surface residual flow.

T. Matsunaga presented research conducted by **E. Suwandana** [Hiroshima University] on assessing accuracy for the ASTER GDEM and SRTM DEM in watershed delineation, using West Java as a test case. When compared to Differential Global Positioning System (DGPS) data and Topographic DEMs (Topo-DEM), agreement with space-based DEMs is generally good.

G. Geller provided an update on *TerraLook*, a program that provides no-cost access to ASTER and historical Landsat georeferenced *jpeg* images, along with a suite of simple visualization and analysis tools. Discussions are underway with the USGS Earth Resources Observation Systems Data Center (EROS) and the LP DAAC to increase the number of sensors involved.

STAR Committee

One new STAR proposal was presented, reviewed, and conditionally accepted, pending resubmission with GLIMS sponsorship.

Closing Plenary Session

The meeting concluded with summaries from each working group chairperson and commentary on the issues proposed at the opening plenary. **S. Hook** spoke on the Hyperspectral Infrared Imager (HyspIRI) and Hyperspectral Thermal Emission Spectrometer (HyTES), and **M. Ramsey** discussed the Mineral and Gas Identifier (MAGI). The 41st ASTER Science Team Meeting is tentatively scheduled for June 11–14, 2012, in Tokyo, Japan. ■

Assessing the State of GRACE@10

continued from page 13

Acknowledgements

In addition to writing original material, many representatives of the GRACE community made significant contributions to this article. These include members of the GRACE Education and Public Outreach team (Margaret Baguio, Alan Buis, and Margaret Srinivasan); and members of the GRACE Science Team, including Byron Tapley, Mike Watkins, Srinivas Bettadpur, Don Chambers, Minkang Cheng, Jay Famiglietti, Jamie Morison, John Ries, Matt Rodell, Mark Tamisiea, Isabella Velicogna, John Wahr, Jens Wickert, and Victor Zlotnicki. The authors wish to thank you all for your contributions and congratulate you on a job well done. ■

Resources and Additional Information

GRACE Program – *www.nasa.gov/grace*
GRACE Mission Project – *www.csr.utexas.edu/grace*
GRACE Tellus – *grace.jpl.nasa.gov*
NASA Mission Update GRACE 2009 – YouTube *www.youtube.com/watch?v=9vdvkGFkhWs*
Background on Gravity Missions (CHAMP, GRACE, GOCE) – *www.ggos-portal.org/lang_en/GGOS-Portal/EN/Topics/SatelliteMissions/GravityField/GravityField.html*

2011 CLARREO Science Definition Team Meeting Summary

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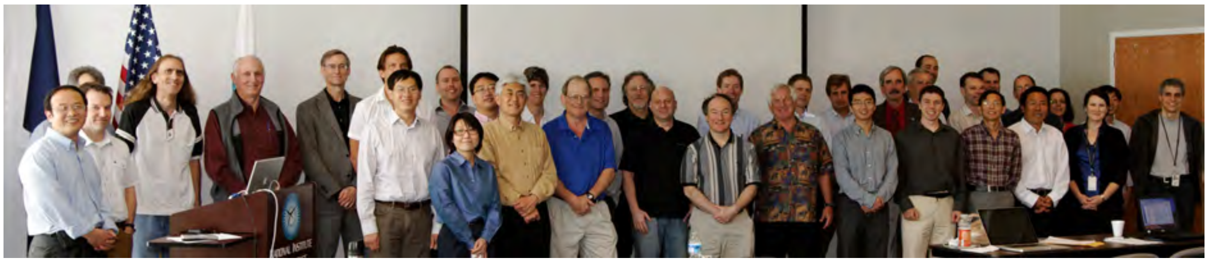

CLARREO Science Definition Team meeting participants.

The second meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at The Pyle Center at the University of Wisconsin (UW)-Extension Conference Center in Madison, WI, from October 12-14, 2011. CLARREO SDT members from the UW-Madison graciously hosted the meeting and provided the team with a tour of the laboratories and facilities at the Cooperative Institute for Meteorological Satellite Studies.

David Young [NASA's Langley Research Center (LaRC)—*CLARREO Project Scientist*] and **Ken Jucks** [NASA Headquarters (HQ)—*CLARREO Program Scientist*] welcomed attendees and provided a mission status update, which included plans for the SDT during the extended Pre-phase A period. Jucks emphasized that the CLARREO science objectives remain a high priority for the Earth science community; he also provided guidance for the current CLARREO budget. Following Young and Jucks, members of the SDT provided updates on their CLARREO-specific activities since the last CLARREO SDT meeting, held in Hampton, VA, in May 2011.

The meeting highlighted the accomplishments made by the SDT toward the CLARREO-related science goals over the past six months. Over the two-and-a-half days of the meeting, members of the SDT delivered talks on the infrared (IR), reflected solar (RS), and Global Navigation Satellite System-Radio Occultation (GNSS-RO) instruments, as well as special-topic presentations [e.g., sampling studies based on observations from the International Space Station (ISS)]. Presentations primarily focused on the information content of CLARREO measurements; studies on using CLARREO data for reference intercalibration of other sensors; studies related to alternative, cost-effective mission architectures; and continuing technology demonstrations to achieve on-orbit, absolute-accuracy verification for the IR and RS spectrometers. The list of talks is summarized in **Table 1**.

Table 1. CLARREO SDT presentations, October 2011.

Topic	Speaker	Institution
SI traceability: Relevant Definitions and Current Implementations in the Infrared	J. Dykema	Harvard University
CLARREO IR Spectra: Achieving 0.1 K 3-sigma (SI-traceable Uncertainty Analyses and Post-launch Validation)	H. Revercomb	UW-Madison
CLARREO and IR Intercalibration	D. Tobin	UW-Madison
CLARREO: State Parameter Climate Retrieval	B. Smith	UW-Madison/Hampton University
CLARREO IR Radiance Benchmark Product Analyses	R. Knuteson	UW-Madison
8-Year Radiance Trends from AIRS and Comparison to ERA-Interim Reanalysis	L. Strow	University of Maryland, Baltimore County

Topic	Speaker	Institution
Assessing the Effects of Instrument Systematic Uncertainty in the IR Measurements on Derivation of Spectral Fingerprints Temperatures	N. Phojanamongkolkij	LaRC
Understanding Atmospheric and Cloud Property Variability Toward Top of Atmosphere Spectral Radiance Closure	S. Kato	LaRC
Radiative Transfer Model and Retrieval Algorithms for CLARREO Hyperspectral Sensor	X. Liu	LaRC
Far-IR Spectral Greenhouse Effects	D. Kratz	LaRC
Seasonal and Interannual Variability Diagnosed from Infrared Atmospheric Sounding Interferometer Spectra and Comparison to Simulations	R. Bantges/H. Brindley	Imperial College-London
Simulated Shortwave and Longwave Spectra from Models with Different Cloud Feedback Strengths	D. Feldman/B. Collins	University of California, Berkeley
Monitoring Carbon Dioxide Trends from Spectral Radiance Measurements	E. Chung/B. Soden	University of Miami
Comparing the Variability in Simulated Hyperspectral Solar Radiance with Observations	Y. Roberts/P. Pilewskie	Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder
Study of Correlations Between SCIAMACHY, MODIS and CERES Measurements for CLARREO	Z. Jin	SSAI
Update on CLARREO RS Intercalibration Activities	C. Lukashin	LaRC
Sensitivity of Radiation Polarization to Microphysical Properties of Thin Ice Clouds	W. Sun	SSAI
Science Definition Support for the CLARREO RS Instrument and Measurements: Proposed Activities and Progress	J. Xiong	NASA's Goddard Space Flight Center
Sampling Error and Resolution of COSMIC and CHAMP RO Data	S. Leroy	Harvard University
Systematic Error Analysis for GNSS RO Refractivity in the Lower Troposphere	C. Ao	NASA/Jet Propulsion Laboratory
Sampling Studies Based on the ISS	D. Doelling	LaRC
Overview of CLARREO IR Calibration Demonstration System	D. Johnson	LaRC
Overview of CLARREO RS Calibration Demonstration System	K. Thome	GSFC
Engineering Overview	P. Speth	LaRC

Presentations can be viewed online at *clarreo.larc.nasa.gov* by pulling down the *Workshops and Conferences* tab. A few of the highlights from the presentations are summarized here.

Technology Demonstrations of CLARREO Climate Change Accuracy for IR and RS Spectra

Dave Johnson [LaRC] summarized the design and construction of the IR Fourier Transform Spectrometer

Calibration Demonstration System (CDS), including National Institute of Standards and Technology (NIST)-traceable sources to achieve the desired 0.03-K (*k=1*) accuracy. **Hank Revercomb** [UW-Madison] and **Fred Best** [Space Science and Engineering Center, UW-Madison] summarized recent studies verifying this level of accuracy for a range of wavelengths and temperatures using aircraft instruments, phase-change-cell blackbodies, and NIST transfer radiometers. They also demonstrated linearity of the planned pyroelectric detectors at the 0.006% level, and performance of the heated halo and phase-change-cell technologies at the required accuracy. CLARREO is about two-to-three times more accurate than the current best weather instruments. Finally, **Kurt Thome** [NASA's Goddard Space Flight Center (GSFC)] presented a summary of the reflected solar spectrometer CDS design, build, and approach to obtaining NIST traceability at the required accuracy levels. The infrared and solar spectrometer CDS systems assembly will be completed by Spring 2012; calibration testing will begin thereafter.

Use of CLARREO Spectrometers for Reference Intercalibration of Other Sensors in Orbit

Dave Tobin [UW-Madison] presented demonstrations of the CLARREO Reference Intercalibration approach to verify accuracy and spectral shifts in the Moderate Resolution Imaging Spectroradiometer (MODIS) and High Resolution Infrared Radiation Sounder (HIRS) infrared channels; examples of Atmospheric Infrared Sounder (AIRS) and Infrared Atmospheric Sounding Interferometer (IASI) intercalibration. He also showed that the CLARREO orbit would enable the desired 0.03 K (*k=1*) accuracy in two months of orbit crossings. **Constantine Lukashin** [LaRC] showed how polarization distribution models could be used to determine and correct the polarization sensitivity of on-orbit imagers like the Visible Infrared Imager Radiometer Suite (VIIRS) or MODIS. He also demonstrated that flying CLARREO on the ISS would achieve sufficient sampling for reflected solar reference intercalibration of targeted low-Earth-orbit (LEO) and geosynchronous-Earth-orbit (GEO) sensors. **Zhonghai Jin** [Science Systems and Applications, Inc. (SSAI)] used six years of monthly reflected solar spectral data from the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) to match trends in reflected solar data from MODIS and Clouds and the Earth's Radiant Energy System (CERES). While interannual variability agreed well between all three sensors, trends differed by a factor of two to four, further demonstrating the critical need for the advances CLARREO will provide in reflected solar spectral absolute accuracy at the level needed for climate change.

Climate Observing System Simulation Experiments

Dan Feldman [University of California, Berkeley] presented the first combined reflected solar and infrared spectra Climate Observing System Simulation Experiments (OSSEs) using the National Center for Atmospheric Research (NCAR) Community Climate Model version 3 (CCM3). He also showed how OSSEs could distinguish at the 95% confidence level between climate sensitivities of 3.8 °C and 2.8 °C for doubling atmospheric carbon dioxide (CO_2). This analysis used over 30 years of observations with simple spectral fingerprinting metrics and CLARREO-level accuracy. Further studies of advancing spectral fingerprinting methods are being examined to reduce the time to detect climate sensitivity changes. **Xu Liu** [LaRC] described a new high-spectral-resolution reflected solar radiative transfer theory that could advance OSSE's computational efficiency by a factor of 10–100. The work is an extension of earlier principal component radiative transfer modeling of IR spectra, and will allow the CLARREO OSSEs to explore perturbed-physics climate models with a wide range of climate sensitivities, as well as OSSEs using results from recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) climate-model runs. **Dave Kratz** [LaRC] showed how the new CLARREO far-IR (5-50 µm) spectral observations would provide unique observations of the role of the water-vapor greenhouse effect on climate phenomena. He also noted that CLARREO will, for the first time, provide high-spectral-resolution measurements of this region. Finally, **Eui-Seok Chung** [University of Miami (UM)] and **Brian Soden** [UM] showed comparisons of CO_2 regional, zonal, and global trends, and their expression in HIRS, AIRS, and recent AR5 climate model simulations. While some consistency exists globally, zonal and regional results are currently inconsistent.

Spectral Climate Change Fingerprints and Radio Occultation

One of the key innovations provided by CLARREO is to add a new type of climate-change detection: fingerprints of IR and RS spectra. **Yolanda Roberts** [Laboratory for Atmospheric and Space Physics (LASP)] and **Peter Pilewskie** [LASP]discussed advances in this area, using a principle component analysis and comparison between the CLARREO climate OSSEs and SCIAMACHY spectra. **Seiji Kato** [LaRC] used the new A-Train merged dataset to simulate CLARREO nadir ground-track spectra to demonstrate the effects of small-scale cloud and meteorological variability on IR spectral fingerprinting. While the effects are modest, they should be included to improve the accuracy of climate change observations. **Bill Smith** [UW-Madison/

continued on page 40

The GOFC–GOLD Fire Implementation Team Workshop – Satellite Remote Sensing of Fires: Current Progress and Future Prospects

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Summary

The Global Observation of Forest and Land Cover Dynamics (GOFC–GOLD) Fire Implementation Team (IT) workshop was held in Stresa, Italy from October 18–19, 2011. The workshop reviewed the current progress, recent developments, and future prospects for Earth observations for fire science and applications. Satellite fire data continue to be widely used by the fire research and applications communities. The workshop provided opportunities for the team members to share their experiences, review the latest developments, and discuss crosscutting international issues. The workshop participants highlighted the need for:

- *The participating space agencies to continue to provide validated fire products;*
- *strengthening the Global Geostationary Fire Network through operational production of fire products from the Geostationary Operational Environmental Satellites (GOES), Multifunctional Transport Satellites (MTSat), Meteosat Second Generation (MSG), and inclusion of data from other international geostationary systems;*
- *refining fire emissions products by integrating top-down and bottom-up approaches;*
- *expanding the fire component of the GOFC–GOLD Reducing Emissions from Deforestation and Forest Degradation (REDD) Sourcebook;*
- *providing the participating space agencies with requirements for and technical input on new fire-related missions; and*
- *funding to strengthen the program's regional fire-network activities, including organizing training programs, regional data validation activities, and improved data access.*

The article summarizes the workshop's findings and important aspects of satellite fire research.

Introduction

GOFC–GOLD is an international organization with an ambitious, multifaceted strategy that integrates space-based and *in situ* observations for sustainable management of natural resources. GOFC–GOLD is a panel of the Global Terrestrial Observing System (GTOS), with the overall objective of improving the availability and utility of Earth observations of forests, land cover, and fire at global and regional scales for a variety of user communities. The main themes of the GOFC–GOLD program are fire monitoring and land-cover characterization and change. In addition to these themes, new focus-group activities are being developed focusing on biomass estimation and agricultural land-use change. GOFC–GOLD activities are guided by the executive committee, with the support and coordination of two thematic project offices supported by NASA and the European Space Agency (ESA). Over a period of years, GOFC–GOLD has facilitated the development of several regional networks that act as a forum for exchange of information, data, technology, and methods within and between regions.

The GOFC–GOLD Fire Implementation Team (IT) aims to articulate the international observation requirements and encourage the best possible use of fire products from existing and future satellite observing systems for management, policy decision making, and global-change research. The primary goals of the Fire IT are shown in **Figure 1**, next page. The Fire IT achieves these goals through emphasis on utilizing spaceborne assets for fire research; generating fire data and information products; data distribution; and capacity-building activities. The GOFC–GOLD Fire IT is continuing its strategic partnership with international organizations including the following groups and programs:

- International Geosphere Biosphere Program (IGBP);
- SysTem Analysis and Training (START);
- United Nations International Strategy for Disaster Reduction (UNISDR);

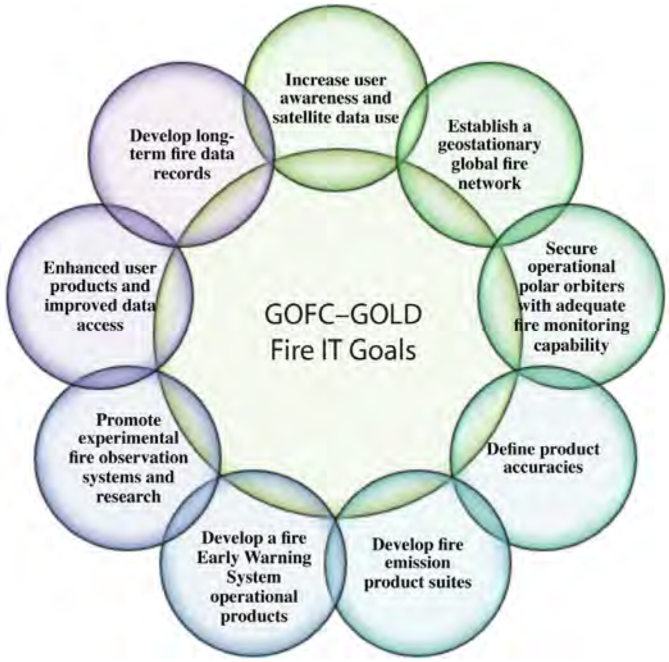

Figure 1. GOFC–GOLD Fire IT goals.

- Global Wildland Fire Network (GWFN);
- European Association of Remote Sensing Laboratories (EARSeL) Special Interest Group on Fires;
- Coordination Group for Meteorological Satellites (CGMS);
- Committee on Earth Observation Satellites-Land Product Validation subgroup (CEOS-LPV);
- International Land Direct Readout Coordination Committee (ILDRCC); and
- Global Earth Observation System of Systems (GEOSS).

The Fire IT reassesses its goals through periodically revisiting and assessing gaps in its activities and overall priorities.

The purpose of this workshop was to review current progress, recent developments, and future prospects for fire science and applications and the associated GOFC–GOLD Fire IT activities. This workshop took place in conjunction with an ESA Fire–Climate Change Initiative (CCI) technical workshop that focused on developing global burnt-area algorithms from coarse-resolution

GOFC–GOLD Fire IT meeting participants, October 2011, Stresa, Italy.

data. The workshop brought together over 40 participants, including university researchers and representatives from international government and nongovernment organizations.

The Workshop

The workshop agenda began with overview presentations on the Fire IT focus areas[1] that illustrated the current status and future needs of fire research; these presentations acted as a catalyst for subsequent discussion. The second day of the workshop ended with roundtable discussions on next steps and action items for the Fire IT program.

The workshop opened with an introductory welcome from the local host, **Jesus San Miguel Ayanz** [Joint Research Center, *Italy*], who encouraged the participants to discuss how international cooperation can help address the latest challenges in fire research. Following participant introductions, **Chris Justice** [University of Maryland College Park (UMCP)—*IT Cochair*] provided an overview of the program's organization and reviewed Fire IT progress since the previous workshops (Greece, 2008; Italy, 2010). Justice reiterated the need for comprehensive validation of satellite fire products, and noted that the LPV, a subgroup of CEOS, can help with coordinating validation activities. The CEOS-LPV strategy has been revised to include four different validation stages, starting with an assessment of product accuracies at small sets of locations (i.e., fewer than 30) and extending to a global scale, with products being regularly updated as the time series expands. Justice stressed the importance of involving regional network scientists who are familiar with local information in validation activities. In terms of recent achievements, Justice highlighted work in progress to complete the near-real-time daily global fire danger maps as a part of Global Fire Early Warning System; the GOFC–GOLD Fire IT regional network side event at the *5th International Wild land Fire Conference*, (South Africa, 2011), which more than 30 regional network scientists attended; revision of the fire chapter of the GOFC–GOLD REDD sourcebook; ongoing provision of technical input for generating fire products from geostationary and polar satellites, including new missions and instruments[2]; and technical input provided to the CEOS Climate Action response to Global Climate Observing System (GCOS) terrestrial action items. The GCOS action items for fire consist of reanalyzing historical fire-disturbance satellite data (1982–present) [T35]; continuous generation of consistent burnt-area, active-fire, and fire radiative power (FRP) products from low-orbit satellites [T36]; developing and applying validation protocols to fire-disturbance data [T37]; and developing and disseminating gridded burnt areas, active fires, and FRP products [T38].

[1] These themes are described in the September–October 2010 issue of *The Earth Observer* [**Volume 22, Issue 5**, pp. 25-30.]
[2] These include the Visible–Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (Suomi NPP), the NASA–U.S. Geological Survey Landsat Data Continuity Mission (LDCM), ESA's Sentinel 2 and 3 missions, and others.

Chris Justice also presented updates on behalf of **Johann Goldammer** [Freiburg University, *Germany—IT Cochair*], emphasizing the need to strengthen and expand regional fire network activities to support national-level fire-related policy-making strategies, and provide timely inputs to international agencies [e.g., the United Nations Framework Convention on Climate Change (UNFCCC)] in addressing global problems. Justice mentioned some fundraising activities for regional scientists and intra-organizational support, and stressed the need for demonstration projects involving multiple organizations and countries. These remarks stressed the need to address smoke-pollution issues, particularly at the urban-rural interface, including linking smoke-emissions information with the early-warning/fire-danger rating system.

Science Presentations

Louis Giglio [UMCP] reviewed fire observations from new and planned instruments, including both geostationary and polar-orbiting platforms that have visible, near-infrared (NIR), shortwave-IR (SWIR), middle-IR (MIR), and thermal-IR (TIR) channels, useful for generating active-fire and burnt-area products. He presented developments with the Visible–Infrared Imager Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP)[3]—launched October 28, 2011—explaining that the current operational algorithm for VIIRS Fire is similar to the *Collection 4* algorithm for the EOS-era Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua, and that NASA and the National Oceanic and Atmospheric Administration (NOAA) are developing a replacement algorithm to meet the needs of the science community. He stressed the need to evaluate impact of longwave infrared band saturation and mid-infrared band spectral placement on product performance. Giglio discussed both the potential and limitations of other new sensors, including the University International Formation Mission (UNIFORM) and the Mexican Infra Red Optical System (MIROS), both of which are in the planning stage.

Ivan Csiszar [NOAA] reviewed global geostationary satellite network activities. He presented details on the NOAA National Environmental Satellite, Data, and Information Service (NESDIS), Wildfire Automated Biomass Burning Algorithm (WF-ABBA), and remarked that since GOES-8 became operational in 1995, fifteen

[3] This became the new name for NPP on January 25, 2012. Prior to that the mission had been known as the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project.

years of time-series fire data are available. He explained that the entire archive of 30-minute GOES-East data for 1995–2010 has been retrieved from archive tapes and reprocessed at the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies. Csiszar outlined improvements provided by Version 6.5 of the WF-ABBA, including data in revised ASCII format, expanded metadata, and additional fire information. He then presented information on other regional geostationary satellites and also discussed the Global Biomass Burning Emission's Product (GBBEP) that is being developed from a network of geostationary satellites (GBBEP-GEO). The product consists of aerosol trace-gas emissions from fires at high temporal (i.e., hourly) and spatial resolution for air quality monitoring and modeling applications, using data from GOES-11 and 13, Meteosat-9, the Multifunctional Transport Satellite (MTSAT-1), and the Indian National Satellite System (INSAT) 3D. He also reported on the Annual Global Biomass Burning Aerosol Emissions product from satellite-derived FRP. Although this product is global in nature, there are observational gaps—especially at high latitudes—due to lack of geostationary coverage. The INSAT-3D satellite, due to launch in the coming months, is expected to fill data gaps over North Africa and India.

Martin Wooster [King's College, *U.K.*] presented updates on the FRP products. He described the FRP product from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on ESA's Meteosat 8, noting that the native fire-pixel product is available within 30 minutes of satellite overpass, as are gridded products that are adjusted for small fires and clouds (*landsaf.meteo.pt*). In addition to SEVIRI, Wooster mentioned that the GOES FRP product for North and South America is available on request in near real time from King's College. The current users of this product are European Centre for Medium-range Weather Forecasts (ECMWF) and the U.K. Met Office. Wooster remarked that more-robust global geostationary fire monitoring could be expected in the coming years, especially with the Meteosat third-generation satellites that will have improved temporal resolution, 2-km spatial resolution, and a wide-range 3.9-µm band. Wooster also reported on FRP-derived emissions, especially, the Global Fire Assimilation System (GFAS v1.0). He mentioned that the GFAS calculates global biomass burning emissions and aerosols by assimilating FRP observations from the MODIS instruments. The emissions are calculated both in real time and retrospectively from satellite-based observations of open fires. (The products are available through *www.gmes-atmosphere.eu/services/gac*.) Wooster reported that relating Fire Radiative Energy (FRE) to fuel consumption is not the same across the globe; work is in progress to validate these relationships. He also mentioned that attempts are underway to merge SEVERI FRP with MODIS FRP for better estimation of emissions.

Wilfrid Schroeder [UMCP] reviewed the availability of FRP datasets from current and future sensors. He mentioned that FRP data from geostationary sensors such as the GOES (East/West) imager (4 km), MSG (3 km), and MTSAT (2009–present) are already available. Schroeder pointed to the need to validate FRP data by integrating ground-based measurements, airborne, and fine- and coarse-resolution satellite data. **David Roy** [South Dakota State University (SDSU)] strongly endorsed this idea, noting that most satellite systems—in particular those on polar-orbiting platforms perform—subsampling of active fire activity and FRP temporal dynamics.

Olivier Arino [European Space Research Institute, *Italy*] presented updates on ESA's activities on fire research. He mentioned that reprocessed products from the Along Track Scanning Radiometer (ATSR)[4] World Fire Atlas (WFA) are available, covering twenty years of data. He explained that as a part of the ESA Climate Change Initiative (CCI) a "round-robin" exercise has been initiated to compare burned-area products using different algorithms to identify the best performance. Arino described the Globe mission project, under which global emission products[5] will be developed at a spatial resolution of between 1–50 km, with a daily-to-annual time resolution and accuracy better than 30–80%. The approach to generate these products will be based on satellite observations and inversion techniques. Arino also highlighted the forthcoming Sentinel missions, sponsored under ESA's Global Monitoring for Environment and Security (GMES) Program. Sentinel-3 will be launched during 2013 and will be placed in a sun-synchronous orbit. The Sea and Land Surface Temperature Radiometer (SLSTR) bands of the Sentinel will be particularly useful for fire studies. SLSTR has 500-m spatial resolution in the visible and SWIR channels, and 1-km resolution in the TIR channels. The data will be useful for generating land-cover, fuel-type, and fire-risk mapping.

Kevin Tansey [University of Leicester, *U.K.*] provided an update on the terrestrial observation panel for climate (TOPC)-Fire Essential Climate Variable (ECV) and the CEOS LPV protocol. He reviewed the GCOS function and scope, explaining that GCOS supports assessments, policy, research, and services, and can be viewed as the climate-observation component of GEOSS. Actions concerning fire disturbance are listed in the 2010 update to the GCOS implementation plan, whereas the active fires, FRP, burned-area requirements, and activities are listed in the GCOS-2011 supplement document. Tansey remarked that GCOS is looking forward to GOFC–GOLD Fire-IT-community inputs to

[4] ATSR flies on Earth Resources Satellite (ERS)-1 and -2.

[5] Emission products measured include: oxides of nitrogen (NO_x); methane (CH_4); carbon monoxide (CO); nonmethane volatile organic compounds (NMVOC); sulfur dioxide (SO_2); particulate matter (PM); and ozone (O_3).

update the GCOS action items documents on fires (e.g., gridded burnt-area, active-fire, and FRP products).

Bill de Groot [Canadian Forest Service, *Canada*] gave an overview of the Global Fire Early Warning System (GFEWS) initiative being developed in Canada, and how fire danger information can aid in implementation of fire management action plans and in preventing/mitigating wildfire disasters. He suggested that greater international collaboration is needed for sharing of resources, expertise, science, and technology, to tackle wildfire disasters. De Groot described how the EWS would provide one-to-seven-day forecasts of fire danger at a coarse scale, and that regional fire EWS products are being prototyped for Africa and South America. The next steps for the Global EWS will include refinements for fuel data, spatial rainfall, vegetation moisture content, FRP, improved accuracy, and more. He also described how European researchers are developing a Global Fire Information System with the knowledge gained from European Forest Fire Information System (EFFIS). The EFFIS contains extensive European forest-fire information, noting that 33 countries currently share these data. The ECMWF is involved in the data processing; several fire-danger indices (i.e., Canadian, U.S., and Australian) will be computed providing 1–15-day fire-danger forecasts.

Luigi Boschetti [UMCP] gave an update on the GOFC–GOLD Reducing Emissions from Deforestation and Forest Degradation (REDD) sourcebook. He reviewed the background and history of the sourcebook and mentioned that it has been regularly updated since 2005. Boschetti noted that the latest version was presented at the Conference of the Parties (COP-16) meeting held in 2010, in Cancun, Mexico. An *ad hoc* working group within GOFC–GOLD facilitates updating the sourcebook that contains methods and procedures for monitoring, measuring, and reporting anthropogenic greenhouse gas (GHG) emissions and carbon stocks in the forestry sector. The fire-related chapter titled *Methods for estimating GHG emissions from biomass burning* provides information on using remote-sensing products. Boschetti stated that burned-area mapping from satellite data has significantly improved over recent years, but that fire characterization (ground/crown) and biomass consumption needs additional information from other sources to augment satellite-derived data. He also remarked that the existing satellite products can be integrated into carbon-monitoring systems, and that moderate-resolution products provide an appropriate source for characterizing baseline global fire activity. The free access to Landsat data and for planned new satellites—such as the Sentinels—provides opportunities to generate regional fire products at a relatively high resolution in support of national inventories. The GOFC–GOLD REDD source book can be downloaded from: *www.GOFC–GOLD.uni-jena.de/redd.*

Guido van der Werf [Vrije Universiteit (VU) [University of Amsterdam], *Netherlands*] reported on the Global Fire Emissions Inventory and Combustion Completeness workshop in South Africa in 2010. He explained that biomass burning is an important source of greenhouse gas emissions, and that high-resolution inventories can aid in addressing mitigation questions. Van der Werf remarked that amongst the four important attributes governing emissions estimation (i.e., burnt areas, fuel load, combustion completeness, and emission factors), the largest uncertainties are in combustion completeness data. Also, within different biomes there is a wide range of spatial and temporal variability in fuel loads and combustion completeness. He also provided an update on the Version 3 Global Fire Emissions Database (GFED), explaining that the latest version utilizes both MODIS *MCD64A1* burnt areas—aggregated at 0.5° resolution—and the MODIS/ATSR/Tropical Rainfall Measuring Mission (TRMM) active fires products to fill gaps from 1996–2000. The fuel loads and combustion completeness data are modeled in the latest version using the Carnegie Ames Stanford Approach (CASA). The aim for the next version (GFED v4.0) is to improve resolution to 0.25°, at least for tropical regions. Van der Werf concluded by stressing the need for merging top-down and bottom-up approaches to refine the emission inventories. He shared the results obtained from Krishna Vadrevu [UMCP] and K.V.S. Badarinath [National Remote Sensing Center, *India*] on agricultural biomass variations that showed relatively low dry-matter values for GFED compared to ground-based inventory for the Punjab region of India. These kinds of user inputs are necessary to refine GFED.

Chris Justice and **Emilio Chuvieco** [University of Alcala, *Spain*] presented a summary on burnt-area validation and required next steps. Justice suggested that multiple burned-area products, obtained from different satellites with varying quality, are envisioned for the next decade, highlighting the need for standard validation procedures. Currently, MODIS *Collection 6* (C6) and Fire-CCI products are being developed, and LPV-community burned-area validation protocols are being adopted. Efforts are underway to collect reference datasets for validating MODIS C6 and Fire-CCI burnt-area products in different biomes; there is a need for data sharing. Advocacy is needed for burned-area products from Sentinel-3 and VIIRS, focusing on continuity products. Chuvieco stated that burnt-area product intercomparison studies can aid in assessing uncertainties, and that ways to merge techniques need to be explored. He highlighted the Fire-CCI project activities, stating that the intent of the round-robin activity is to facilitate comparisons of data, algorithms, and products. Chuvieco stated that fire-sensor specifications should be driven by requirements for Essential Climate Variables (ECV), and called for outreach activities to provide high-quality burnt-area data to such international organizations as the Food and Agriculture Organization (FAO), the Intergovernmental Panel for Climate Change (IPCC), the International Global Atmospheric Chemistry (IGAC) project, among others, to address policy-level questions.

Anja Hoffman [GOFC–GOLD regional network coordinator, *Germany*] provided updates on the regional networks, with information particularly from the GOFC–GOLD network meeting held at Wildfire-2011, Sun City, South Africa, May 9-13, 2011. She suggested that the GOFC–GOLD Fire IT should continue to work closely with regional networks to execute and design projects and to develop consensus algorithms and methodologies for product generation and validation. Hoffman noted that the GOFC–GOLD Southern Africa Fire Network (SAFNET), La Red Latinoamericana de Teledetección e Incendios Forestales (RedLaTIF), *Central Asia Regional Information Network* (CARIN), South East Asia Regional Research and Information Network (SEARRIN), and West Africa Regional Network (WARN) include fire-mapping and monitoring projects. The recommendations generated by the participants of the Wildfire 2011 meeting included:

- Increasing capacity-building and training activities;
- improving cooperation amongst networks and between GOFC–GOLD and the Global Wildland Fire network;
- facilitating Earth-observation data access;
- increasing knowledge-sharing among members of regional networks through Internet technologies;
- increasing funding for regional network activities; and
- developing demonstration projects, integrating top-down and bottom-up approaches, for emissions inventory; and involving different regional network researchers for satellite product validation, etc.

After the above updates on the Wildfire, South Africa meeting, the group heard presentations on the various regional GOFC–GOLD Fire Network activities:

- **Phillip Frost** [Council for Scientific and Industrial Research, *South Africa*] discussed the SAFNET remote sensing and fire management activities;
- **Isabel Cruz** [National Commission for the Knowledge and Use of Biodiversity (CONABIO), *Mexico*] reviewed the Red LaTIF activities;
- **Abdoulaye Diouf** [Université ABDOU Moumouni de Niamey, *Niger*] spoke on fire aspects of the WARN activities;
- **Mastura Mahmud** [Universiti Kebangsaan, *Malaysia*] reported on the SEARRIN;
- **Stefan Maier** [Charles Darwin University, *Australia*] summarized recent the fire research and developments in Australia.

The overview presentations described here were followed by an extended roundtable discussion, focusing on identifying key issues and fire-research needs. Some related discussion points from throughout the meeting are presented below.

Discussion

At the end of the first day, **David Roy** and **Stephen Plummer** [European Space Agency, *Italy*] coordinated a discussion session on the shifting priorities and new opportunities for the Fire IT. They addressed several topics, including the Fire IT's advocacy role for improved data access; generation of VIIRS-generated burnt-area products; fusion of polar and geostationary datasets; FRP data and relating them to biomass combustion and uncertainties; quantifying emissions from small fires; coordinating Fire IT activities with CEOS and GCOS; data-continuity issues; reconciling top-down and bottom-up approaches, etc.

Concerning advocacy, the participants felt that better coordination is needed amongst space agencies, all of which should work in concert to design and implement an international constellation of fire-monitoring satellites with standard, validated products. They cited the example of MODIS and the Advanced Spaceborne Thermal Emission and Reflection Radiometer, where the colocation of international sensors on the same platform helped to validate data for all parties. Participants showed much interest in the new sensors, and felt that the latest information on the launch dates, capabilities, availability, and coverage should be made available through a GOFC–GOLD website; the participants suggested that CEOS could facilitate such an initiative. One suggestion was to work towards establishing a fire research sub-group within CEOS. However, it was noted that there have been efforts by ESA, NASA, and the Japan Aerospace Exploration Agency (JAXA) to support international participation in their different missions. Most recently, NASA is supporting U.S. researchers' participation in the Sentinel-2 and -3 missions.

Workshop participants reiterated the need for free and open data sharing policies from space agencies—including those from India, China, Brazil, and South Korea—and reinforced meeting-opening suggestions for improved support for testing and implementing validation protocols. Participants felt that there should be a single physical—or virtual—repository for downloading global fire datasets from a wide variety of sensors, recognizing that achieving such a goal may require strong advocacy to international coordination bodies such as CEOS. There was a general discussion and recognition for the need to collaborate more closely with the atmospheric-modeling community via organizations such as the International Geosphere-Biosphere Programme, IGAC, and IPCC the better to advocate for coordinated generation of fire products across instruments from different agencies.

Fire IT participants felt that the GFEWS are important, having significant societal benefit, especially in countries that lack fire-related information or supporting services. They also reemphasized that validation—at least in some sample locations—should be done. Fire IT participants also recognized the importance of addressing uncertainties in small-fire monitoring and their emissions, especially for agricultural-residue fires. The participants also reiterated the need for promoting bilateral training and professional exchanges between regional networks (especially for developing regional capacity), and recognized the importance of GOFC–GOLD's role in supporting such activities.

Several participants felt that Fire IT was successful in implementing its goals with a clear vision and action. The Fire IT was encouraged to explore synergies with different GEO tasks (as outlined in the new GEOSS Work Plan), such as global ecosystem monitoring, global multi-model prediction systems, and global drought-monitoring systems. The majority of participants felt that regular Fire IT workshops and multi-agency round-robin exercises (similar to the ESA Fire-CCI project) could help address scientific questions on sensor issues and product validation.

On the final day of the workshop, **Ivan Csiszar** and **Tim Lynham** [Canadian Forest Service, *Canada*] chaired the discussion session, which focused on some future Fire IT activities areas, as listed below, along with suggestions for specific actions:

- **Global burnt-area validation protocols and implementation:** Continue validation of burnt-area products, especially the GCOS *T37* protocol and accuracy assessment.

- **Global fire danger, including early warning and risk:** Initiate regional validation of the fire danger indices; seek funding for continuous development and refinement of EWS activities, including regional EWS; explore and incorporate new remote sensing products (e.g., soil moisture), for fire-danger assessment.

- **Regional network issues, including capacity building and data accessibility:** Pursue funding from different sources for organizing training programs, data validation, and improved data access; contribute to the revitalization of the Southeast Asian Regional GOFC–GOLD Network (SEARIN) and Miombo regional networks.

- **Long-term data record (LTDR) generation:** Pursue funding for this activity and CEOS *T35* action plan to reanalyze historical fire disturbance satellite data from 1982–present.

- **Global fire emissions estimation:** Focus on agricultural fires and uncertainties; address geographic/vegetation type emission factor discrepancies; validate emission inventories against approved regional model outputs.

- **User outreach and feedback:** Expand the fire component of the GOFC–GOLD REDD sourcebook and regularly update it with the latest information; promote involvement of GOFC–GOLD regional networks in the REDD process.

- **Global geostationary network:** Continue NESDIS activities in pursuing operational production for GOES, MTSat, MSG data and other new sensors; explore collaborations with the Korean and Chinese meteorological administrations.

- **Data requirements for ECVs:** Complete GCOS templates for different fire action items; update information on the ECV T13 document.

- **New fire-related missions and products:** Continue to provide technical guidance to the space agencies on new fire-related missions; evaluate VIIRS, Technologie Erprobungs-Träger (TET-1) test datasets for their potential; monitor New Infrared Sensor Technology progress on the Aquarius platform.

Financial support for the workshop was provided by the GOFC–GOLD Fire IT office through NASA funds, the ESA-Fire CCI project, and NASA-supported *SysTem for Analysis Research and Training* funds. The workshop agenda and presentations can be accessed from*:* *gofc-fire.umd.edu/Stresa_meeting_Oct_2011/index.asp*.

It is with great sadness that we report the death of Fire IT member and remote-sensing expert, K.V.S. Badarinath of the National Remote Sensing Center (Indian Space Research Organization (ISRO), India, on January 20, 2012. We miss him greatly. ■

Precipitation Measurement Missions Science Team Meeting Summary

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Introduction

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

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

The PMM meeting agenda comprised:

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

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

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

Programmatic Updates

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

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

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

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

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

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

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

Partner Activities

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

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

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

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

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

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

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

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

TRMM Science

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

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

Algorithm Activities

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

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

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

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

Ground Validation

Light Precipitation Validation Experiment

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

Midlatitude Continental Convective Clouds Experiment

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

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

GPM Cold Season Precipitation Experiment

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

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

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

Other Ground Validation Activities

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

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

Closing

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

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

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

2011 CLARREO Science Definition Team Meeting Summary

continued from page 28

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

Mission Studies

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

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

NASA Sponsored Workshop on Evaluating the Impact of Earth Science

Ana Prados, University of Maryland, Baltimore County, NASA's Goddard Space Flight Center, Earth Science Information Partners, ana.i.prados@nasa.gov

Introduction

NASA and other federal agencies generate Earth science data and research results that are used by organizations to address multiple societal needs, from malaria early warnings to climate-change scenarios. Yet, how does the scientific community measure or evaluate the benefits of Earth science to society and communicate key findings to sponsoring agencies and ultimately to the public? One of the key reasons why these evaluations are often not performed is that measuring the benefits of Earth science requires a crosscutting mix of social and economic analyses that are outside scientists' main fields of expertise. For example, benefits from using NASA satellite data, models, and/or online tools can be measured in the form of dollars saved or spent, or incidence of childhood asthma, among a large number of possible metrics.

Ana Prados provided opening remarks at *The Case for Project Evaluation* workshop, held during the ESIP's Annual Winter Meeting in Washington, DC.

To help scientists and program managers seeking to implement and understand such evaluations, NASA and the Federation of Earth Science Information Partners (ESIP) partnered this past January to provide a hands-on workshop on the value of Earth Science titled *The Case for Project Evaluation*. The workshop was part of ESIP's annual winter meeting, titled *Connections Through Collaboration: Engaging Community Throughout the Data Life Cycle*[1] and was held from January 4-6, 2012.

The ESIP Federation is a broad-based, distributed community comprised of representatives from the private sector, not-for-profit organizations, government agencies, and researchers across all these groups that develop, produce, and interpret applications for Earth and environmental science data, and use these products for education at all levels in formal and informal settings. To learn more about ESIP, visit: *www.esipfed.org*.

ESIP meetings are excellent venues for learning how to measure the benefits of Earth science to society. Held twice a year, they draw increasing participation from a diverse cross section of public and private entities concerned with the overarching theme of *making data matter*. Two years ago, the Decisions Cluster (DC) within ESIP took on the task of helping ESIP members and sponsoring organizations build the skills needed to evaluate the societal impact of Earth science. The DC supported Earth science evaluation topics at both the Summer 2010 and Winter 2011 ESIP meetings, and organized sessions with decision-maker/end-user participation to help foster communication between those who produce and those who use Earth science data products.

Improving Stakeholder Collaboration

The specific objective of the January workshop was to build capacity within NASA and ESIP to integrate evaluation techniques into current and future applied environmental research and data-sharing projects. **Ana Prados** [University of Maryland, Baltimore County, and NASA's Goddard Space Flight Center (GSFC)—*ESIP Decisions Cluster Cochair*] moderated the workshop. Representatives from NASA, the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), universities, and the private sector attended the workshop. **Brian Burke** [Center for Technology in Government (CTG), University at Albany] and **Dan Ferguson** [University of Arizona (UA)] provided examples of project evaluation.

After these lectures, hands on activities—led by Burke—focused on stakeholder analysis and identifying the public value provided by Earth science initiatives. The focal point of the workshop was the *stakeholders*—the individuals and organizational entities that are impacted by Earth science activities, and who also affect or influence the ultimate success or failure of such projects. The ultimate stakeholder beneficiary is the public at large, often by way of, for example, health or disaster management agencies whose decision making is impacted by NASA Earth science data and web-based tools. Stakeholders are key to identifying the

[1] This year's meeting title was especially timely given the larger U.S. and international focus on "Open Government" and "Open Data." Governments from around the world are making it a priority to better use and share government information to help solve a range of societal problems such as poverty, financial crises, disaster recovery, poor air quality, and government corruption.

performance measures used to assess the societal benefit of NASA satellite missions, remote sensing data portals and standards, and their associated applied research projects; they are, therefore, critical to building a successful evaluation effort.

Ferguson provided the first Earth-science evaluation example, by discussing the impact of Significant Fire Potential Forecasts in the Western U.S., through the medium of the National Seasonal Assessment Workshops, that began in 2000 and have been held annually since then. Conducted by UA, this evaluation tracked not only the most critical sources of Earth-science information and the specific environmental management decisions they support, but also performed a social network analysis to capture the key stakeholder relationships that enable use of relevant climate data.

Brian Burke discussing the Public Value Assessment Tool developed by CTG.

Burke followed, with a discussion about the CTG's study of the AIRNow-International Shanghai initiative, a state-of-the-art air quality notification and forecasting system for Shanghai. This initiative was developed as a collaboration between the U.S. EPA and the Shanghai Environmental Monitoring Center in China. Key findings of this AIRNow-International study included the ways by which organizational, technological, cultural, and political contexts influence the willingness and ability of stakeholders to share knowledge and information across traditional boundaries.

Burke summarized the Open Government Public Value Assessment Tool (PVAT), developed by CTG to help government identify the value of its portfolio of open government initiatives, and guide choices for future initiatives to adjust the mix to enhance the agency's public value. Specifically, he described how PVAT might be used to help support the design, implementation, and evaluation of Earth-science information projects conducted by NASA and other agencies. During the workshop, the analysis was accomplished in a real-time exercise in project stakeholder mapping, one of the early steps in the implementation of PVAT. Workshop attendees first made a list of key stakeholders in their own Earth science projects, and then placed them on a matrix according to their relative influence and collaborative potential. Agency representatives at the workshop acknowledged that the exercise helped identify partners who were most critical to the project, or pointed out gaps that needed to be filled by working more closely with specific stakeholders. To learn more about PVAT, visit: *www.ctg.albany.edu/publications/online/pvat.*

In the CTG Public Value Framework, information technology (IT) investments can either have positive or negative impacts and are classified according to an economic, political, social, strategic, ideological, quality-of-life, or stewardship schema. In the second workshop exercise, attendees took their lists from the previous exercise and assigned each stakeholder a scaled value. This generated group discussion on the utility of such a framework for developing project metrics. For example, if a government project identifies that most stakeholders obtain overwhelming social value, then it would make sense to use that as an evaluation metric as opposed to some other public-value type.

Workshop Outcomes

During the discussion phase of the workshop it was clear that all agencies experienced a common need to learn how to identify project metrics, methodologies/techniques for data collection and analysis that enable Earth science evaluation, and how to effectively communicate evaluation results to funding agencies and the public.

The group decided that, with help from the DC, they would focus on developing a set of examples or case studies in evaluation as a resource to NASA and the ESIP community, and organizing an evaluation workshop at an ESIP meeting in the near future. The workshop should include presentations by ESIP members who are currently or newly engaged in project evaluation to allow them to share methodologies and *how-to's* with the ESIP community at large.

Chuck Hutchinson [UA] provided information on evaluation and Logic Model guide websites at the Centers for Disease Control, the Kellogg Foundation, and others. To access this information, as well as presentations from the workshop, visit: *wiki.esipfed.org/index.php/Decisions*.

At the close of the workshop, attendees were encouraged to attend evaluation conferences hosted by the American Evaluation Association and the Environmental Evaluators Network to gain a better understanding of Earth science evaluation, and to identify professionals who could offer suitable evaluation services. ■

Ocean Surface Topography Science Team Meeting

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Introduction

The 2011 Ocean Surface Topography Science Team (OSTST) Meeting was held in San Diego, CA on October 19–21. The meeting closed out a weeklong program of altimetry-related workshops in San Diego, starting with the Coastal Altimetry Workshop held October 16–18, a Surface Water and Ocean Topography (SWOT) Science Working Group Meeting held October 17, and a Joint Argo and Altimetry Workshop held October 18.

The primary objectives of the OSTST Meeting were to:

- Provide updates on the status of Jason-1 and Ocean Surface Topography Mission (OSTM)/Jason-2 (hereinafter, Jason-2);
- review the progress of science research;
- conduct splinter meetings on the various corrections, altimetry data products, and other project activities; and
- discuss science requirements for future altimetry missions.

This report, along with all of the presentations from the plenary, splinter, and poster sessions are available at the AVISO website: *www.aviso.oceanobs.com/ostst*.

Jason-2 was launched in June 2008 along the former ground track of Jason-1 and the Ocean Topography Experiment (TOPEX)/Poseidon. All systems are in excellent condition and the satellite is operating nominally. The calibration and validation of Jason-2 data have shown that all mission and Level-1 science requirements continue to be met. The cause of the 20-cm absolute bias in Jason-2 data has finally been identified as resulting from a discrepancy in antenna reference points. After correcting this, along with an error discovered in the altimeter characterization files, the absolute sea-surface-height bias for both the Jason-1 and Jason-2 missions is statistically indistinguishable from zero. The range bias correction will be applied in the Geophysical Data Record, Release D (GDR-D), which will begin production in early 2012. Finally, both Jason-2 and Jason-1 were approved for extended mission operations after agency-level reviews at both at NASA (2011 Earth Science Senior Review) and at the French Centre National d'Études Spatiale (CNES).

Jason-1, after celebrating its tenth year on orbit in December 2011, continues to meet all of its Level-1 science requirements, delivering high-quality sea-surface-height (SSH) observations along an interleaved ground track, which—in conjunction with Jason-2—provides enhanced spatial and temporal resolution. After considering recommendations made by the OSTST regarding the ongoing operation of Jason-1, NASA and CNES agreed to continue operating Jason-1 in its present orbit until the launch and validation of a new altimeter mission, such as SARAL/AltiKa[1] (scheduled for launch in 2012). After this (or at the end of 2013, whichever comes first), Jason-1 will be maneuvered into a *geodetic orbit*[2] at an altitude of ~822 mi (1324 km). There, Jason-1 will provide SSH observations that will give new information about marine gravity and will be safely removed from its current orbit, where the inoperative TOPEX/Poseidon satellite remains an important collision risk. In order to reduce any risk posed by a potential collision, and to remain in compliance with international laws designed to mitigate space debris, the aforementioned Jason-1 maneuver took place over a period of several weeks to deplete its excess fuel. These maneuvers were successfully completed on October 18 with only minor impact on the science data.

Work on the Jason-3 mission is now underway. Although the satellite is scheduled for launch in early 2014, selection of the launch vehicle and budget constraints remain critical elements for achieving a timely launch. At present, the 2014 launch will require Jason-2 to remain in operation for six-and-a-half years in order to have a six-month overlap for cross calibration. Long-term stability of the radiometers remains a concern for the Jason missions: In response to previous recommendations by the OSTST, the Jason-3 Project has proposed instituting a periodic pitch maneuver once the satellite is on orbit that would allow the radiometer to be calibrated by looking at the cold sky. The OSTST discussed the implications of this proposal both as a whole and during relevant splinter sessions, and issued a recommendation based on their discussion[3].

One of the primary themes of this OSTST meeting was the future of satellite altimetry. Along these lines, a special plenary session highlighted observations from existing and upcoming altimetry missions beyond the TOPEX/Poseidon and Jason series. The meeting's splinter sessions, particularly that focused on instrument pro-

[1] SARAL/AltiKa is a joint French (CNES)-Indian (ISRO) mission for the monitoring of the environment, altimetry (AltiKa), and a contribution to ARGOS system. SARAL stands for SAtellite with ARgos and ALtika

[2] A very-long-period repeating orbit, with finely spaced ground tracks.

[3] The Recommendations of the Ocean Surface Topography Science Team are summarized in the sidebar on page 44.

cessing, gave considerable attention to new data from the European Space Agency (ESA)'s CryoSat-2 mission. These interactions were of mutual benefit to both the OSTST and the CryoSat-2 Project. In light of this, the OSTST made a recommendation concerning availability of CryoSat-2 data similar to that which was made at the 2010 Meeting in Lisbon, Portugal—see Recommendation #2 below.

Recommendations from the 2011 Ocean Surface Topography Science Team Meeting

1) The Jason-3 Project should proceed with plans to perform a maneuver during flight in order to periodically calibrate the Jason-3 radiometer. In addition, the Jason-2 Project should study the feasibility of performing a similar calibration maneuver on Jason-2.

2) ESA and the CryoSat-2 Project shall make all efforts to:

- Allow free and open distribution of currently generated value-added science products; and
- provide a global seamless product over the ocean [low-resolution mode (LRM) and synthetic aperture radar (SAR) regions] as soon as possible.

Program and Mission Status

Speaking on behalf of the project scientists[4], **Josh Willis** opened the meeting, presented the agenda, and discussed logistics. In addition, **Rosemary Morrow** announced that Pascal Bonnefond would be taking over responsibilities as project scientist for the Jason missions and OSTST meeting organization for the coming year. Next, Willis introduced the program managers, to speak on the status of altimetry and oceanographic programs at NASA, CNES, EUMETSAT, NOAA, and ESA.

Eric Lindstrom [NASA Headquarters—*Physical Oceanography Program Scientist*] reported on NASA program status, noting the launch of Aquarius on June 10 and the upcoming Salinity Processes in the Upper Ocean Regional Study (SPURS) *in situ* salinity campaign in 2012. He noted that the NASA Mission Concept Review for SWOT would occur in March 2012, and that the Jason-3 launch date had been moved to Spring 2014. Finally, Lindstrom noted that the next NASA Research Opportunities in Space and Earth Science (ROSES) solicitation for the Ocean Surface Topography Science Team would have proposals due March 23, 2012.

Juliette Lambin [CNES] reported on the CNES program status. Lambin described the extensive involvement that CNES has in the current and upcoming constellation of satellite altimeters. These include the Chinese mission Haiyang (HY)-2A, and the upcoming missions SARAL/ALtiKa and SWOT, as well as the China-French Oceanography Satellite (CFOSAT), due for launch in 2014 that will make wind and wave observations. Lambin also announced that she would be replacing **Eric Thouvenot** as CNES Oceanography Program Manager. Finally, she noted that the CNES OSTST solicitation would be scheduled to be in phase with that of NASA.

Francois Parisot [EUMETSAT] and **Laury Miller** [NOAA] jointly reported on the status of the EUMETSAT and NOAA programs. They discussed the slip of the Jason-3 launch date, and the implications of that delay for the Jason-2 mission. Launch of the Jason Continuity of Service (CS) mission is planned for 2017 with a bus based on the CryoSat platform. Parisot also discussed areas for potential U.S. cooperation on Jason-CS. Finally, Miller announced the retirement of **Stan Wilson** [NOAA] and thanked him for his 35 years of service to the oceanography community. In 2011 *Oceanography Magazine* published a special issue focusing on sea-level rise that was dedicated to Wilson[5].

Jerome Benveniste [ESA] reported on the status of the ESA program. Benveniste noted the passivation of ERS-2 in September, and noted the upcoming symposium (titled *20 Years of Progress in Radar Altimetry*) to be held in conjunction with the next OSTST September 24-29, 2012, in Venice, Italy. He also gave updates on the status of ESA's Environmental Satellite (ENVISAT) and the Gravity field and steady-state Ocean Circulation Explorer (GOCE), reporting that both missions continue to operate successfully. GOCE operations are expected to continue at its present altitude until at least April 2012, with continued release of updated gravity fields.

Jason-1/2/3 Project Status

Glenn Shirtliffe [NASA/Jet Propulsion Laboratory (JPL)] provided an overview of Jason-1 status. Jason-1 continues to exceed all Level-1 science requirements in its present interleaved orbit, despite loss of its GPS receivers and some redundant systems. In May 2011 Jason-1 went through its fourth NASA Senior Review and was approved and funded for operation through 2013. Consistent with a similar REDEM[6] review process by CNES, the guidance given to the Jason-1 project was to continue operation in its present orbit through the end of 2013, or until data from another mission—such as SARAL/AltiKa—can be validated,

[4] These include **Lee-Lueng Fu** and **Josh Willis** [NASA's/Jet Propulsion Laboratory (JPL)]; **Rosemary Morrow** and **Pascal Bonnefond** [CNES]; **John Lillibridge** [National Oceanic and Atmospheric Administration (NOAA)]; and **Hans Bonekamp** [European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)]

[5] See inset on page 45.

[6] French acronym for Mission Extension Review Steering Committee.

unless the spacecraft experiences additional technical anomalies. After this time, it will be maneuvered into a geodetic orbit at ~822 mi (1324 km) altitude, which will serve as a "graveyard" orbit while still providing observations of SSH that will be of high value for marine geodesy. These directions were in line with the consensus recommendation for Jason-1 that were adopted by the OSTST in Lisbon in 2010.

The project was also directed to resume fuel-depletion activities to minimize the risk of catastrophic breakup, should a collision occur. These maneuvers were completed on October 18, 2011, affecting Science Cycles 358, 359, and 360. First assessments showed that less than 10% of ocean data were impacted due to maneuvers—a level that was less than anticipated. Jason-1 has retained ~8.2 lbs (3.7 kg) of hydrazine to continue its mission.

Shirtliffe also announced that JPL has developed a near-real-time SSH product that combines data from Jason-2, Jason-1, and ENVISAT, and is now available from the JPL-based Physical Oceanography Distributed Active Archive Center (PODAAC).

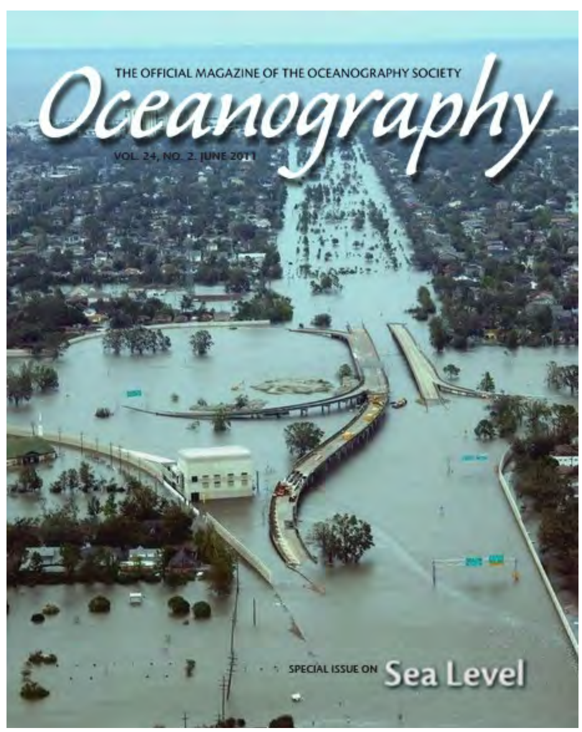
Speaking on behalf of **Thierry Guinle** [CNES], Shirtliffe also reported on the status of Jason-2. Operations are nominal, with the spacecraft and its core payloads remaining fully operational after more than three years in orbit. Fully 100% of all data products are being archived and distributed to users by CNES; Archiving, Validation and Interpretation of Satellite Oceanographic Data (AVISO)[7]; and NOAA data services. All satellite and system performance requirements are being fulfilled with large margins.

Gerard Zaouche [CNES] provided an overview of Jason-3 mission status. The Jason-3 mission will provide continuity of the observations begun by TOPEX/Poseidon, and carried on by Jason-1 and Jason-2 in support of oceanographic, climate, and operational applications. The operational agencies (i.e., EUMETSAT and NOAA) are taking the lead on this mission, with CNES and NASA building and launching the satellite. NASA, in conjunction with EUMETSAT, NOAA, and CNES will support science team activities. The satellite will be nearly a duplicate of Jason-2, with improvements to the orbital accuracy in near real time (5-cm, as opposed to 10-cm accuracy, with three-hour

[7] AVISO is the CNES Data Center.

Special Issue of "Oceanography" Focuses on Sea Level Rise

The June 2011 issue of *Oceanography* magazine was a special issue on the topic of sea level. The study of sea level rise touches many scientific disciplines outside of oceanography. These research areas include, but are certainly not limited to; the cryosphere, climate science, geography, paleontology, glaciology, geophysics, and more. Edited by, **Josh Willis** [JPL—*Jason-3 Project Scientist*], **Laury Miller** [NOAA], and **Gregory Mountain** [Rutgers University], an important goal of the issue is *"to spark the embers of discussion across these disciplines by providing a jumping-off point for those bold enough to explore the others…that young researchers will be inspired to follow the threads of these scientific challenges and close some of the major gaps in our ability to predict sea level rise."*



This issue was dedicated to **Stan Wilson** [NOAA] in honor of his retirement, and in recognition of his 35 years of service to the oceanography community

Reference

Willis, J., L. Miller, and G. Mountain, 2011, Sea level: An introduction to the special issue. *Oceanography* 24(2):22–23, doi:10.5670/oceanog.2011.24.

URL: *tos.org/oceanography/archive/24-2.html* latency). The project continues to consider the possibility of improving Advanced Microwave Radiometer (AMR) stability, as recommended by the OSTST in 2010 in Lisbon. Zaouche reported that the Jason-3 satellite development is nominal. However, 2012 will be a key year for Jason-3 project due to the need to select a launch vehicle and the impact this decision will have on the associated project schedule.

Keynote Talks and Discussion Points for Splinters

There were six invited keynote lectures during the meeting, covering a wide range of topics of interest to the altimeter community. **Dean Roemmich** [University of California, San Diego (UCSD)—*Argo Steering Team Cochair*] presented an overview of the Argo program and its synergy with the Jason satellites. **Caroline Katsman** [Koninklijk Nederlands Meterologisch Instituut (KNMI), *Netherlands*] discussed projections of sea-level change over the twenty-first century driven by anthropogenic climate change. **Pierre-Yves Le Traon** [Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), *France*] presented science and operational advances made possible by the current constellation of satellite altimeters. **Paolo Cipollini** [National Oceanography Centre (NOC), *U.K.*] reported on new science and open questions from the coastal altimetry workshop held October 16-18—immediately prior to the OSTST. **Shannon Brown** [JPL] presented scientific results based on the 19-year record of water vapor and cloud liquid water data based on altimeter radiometer observations. **Josh Willis** presented a summary of scientific highlights based on data from the Jason-1 satellite in honor of its tenth anniversary.

All of the keynote talks can be found at the AVISO website at: *www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/ostst-2011-presentations/index.html*.

Prior to the beginning of the splinter sessions, meeting participants heard two brief presentations to provide key information for consideration in some of the splinter sessions.

Shannon Brown [JPL] and **Veronique Couderc** [CNES] addressed a recommendation for a potential satellite maneuver to calibrate the AMR instrument on Jason-3. A periodic pitch maneuver (to be done approximately once every two months) would provide a cold-sky target for absolute calibration and aid in identifying any long-term drifts in the radiometer. Simulations suggest that the drift uncertainty for AMR could approach 1 mm/yr after only eight months of operation.

Richard Francis [ESA—*CryoSat-2 Project Manager*] briefly described the operational modes of the CryoSat-2 altimeter, which include a mode that mimics conventional pulse-limited operation LRM, an along-track "delay-Doppler" SAR mode, and an interferometric SAR (SARIN) mode that provides a narrow across-track swath by using two antennas. Selection of the SAR mode operation areas over the ocean remains somewhat flexible. Francis requested input from the science team in selecting these areas.

Plenary Session on New Frontiers in Satellite Altimetry

A special plenary session highlighted upcoming and existing altimeter missions outside of the TOPEX/Poseidon and Jason family, and included a discussion on the future roles for the OSTST.

Duncan Wingham [University College London, Centre for Polar Observation and Monitoring—*CryoSat Principal Investigator*] provided an update on the mission status of CryoSat-2. Although the primary science objectives of CryoSat-2 involve observing the cryosphere, ocean observations are also collected. Wingham reported that ESA should release ocean data products sometime during 2012.

Jerome Benveniste described the status of Sentinel-3, which will launch in the first quarter of 2014 and provide continuity of sea-surface-height observations with the same resolution as ENVISAT on a 27-day repeat cycle, along with ocean-color and surface-temperature observations. The spacecraft will be placed in a Sun-synchronous orbit near ~497 mi (800 km) altitude. Like CryoSat, it will have SAR capabilities near the coastline.

Richard Francis [ESA—*CryoSat/Jason-CS Project Manager*] provided an update on the status of Jason-CS, which will be the follow-on mission to Jason-3, scheduled for launch in 2017. Jason-CS will use the same bus as CryoSat and include an altimeter capable of both standard LRM SAR-mode observations, similar to CryoSat and Sentinel-3. Calibration targets for the radiometer are under consideration to improve its long-term stability. Jason-CS will be operated in the same orbit used by TOPEX/Poseidon and Jasons-1, -2, and -3 with an increased design lifetime of five years (as opposed to three for the earlier missions).

Pierre Sengenes [CNES] presented the status of the SARAL/AltiKa program. This joint French and Indian mission will follow the same ground track as ENVISAT with a 35-day repeat period. SARAL/AltiKa is scheduled for launch in 2012.

Charon Birkett [Earth System Science Interdisciplinary Center (ESSIC)/University of Maryland, College Park] discussed the ICESat-2 Mission, which will carry a laser altimeter and measure cross-track slope and along-track height, and is slated for launch in 2016.

Ocean-water science requirements for ICESat-2 have not yet been defined.

Lee Lueng Fu [JPL—*SWOT Project Scientist*] gave an overview of the SWOT Mission, scheduled for launch in 2019. It will provide centimeter-scale accuracy SSH observations at a resolution of one km. Aircraft campaigns, called AirSWOT, will provide a platform for testing the instrumentation in the coming years, with observations off the coast of Southern California and in the Mediterranean Sea. A joint NASA/CNES solicitation for the formation of a Science Definition Team is scheduled for release in February 2012 through NASA ROSES.

All of these talks are available at the AVISO website, given previously.

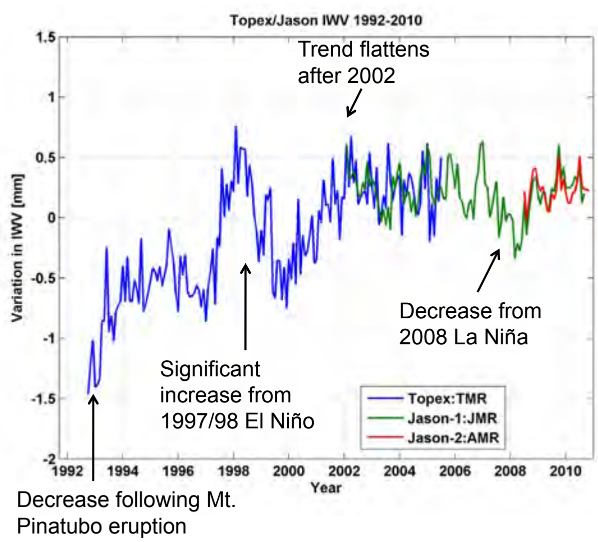
In addition to the talks on future and current missions, **Eric Lindstrom** and **Juliette Lambin** led a discussion on the future of the OSTST. They mentioned the growing importance of missions other than the TOPEX/Poseidon and Jason series, and the need to develop the topics handled by the splinter sessions. There was a suggestion that the OSTST consider submitting a proposal to the Committee on Earth Observation Satellites (CEOS) to become the new "Ocean Surface Topography Virtual Constellation." This would broaden the scope of the OSTST to include other missions and give it a larger international presence. While no formal recommendation was adopted at this meeting, there seemed to be a consensus among members of the OSTST that the move to broaden its scope and that to apply for "Virtual Constellation" status within CEOS was in the best interest of the team.

Presentations and detailed summaries of the splinter sessions can be found in the full report at: *www.aviso.oceanobs.com/en/courses/sci-teams/ostst-2011/index.html*.

Tracking Water Above the Oceans: A 19-year Water Vapor and Cloud Water Climatology from Altimeter Radiometers

The amount of water vapor in Earth's atmosphere at any given time accounts for only a very small portion of the total atmospheric content (approximately 0.4% over the entire atmosphere). Nevertheless, this trace amount has a profound impact on weather and climate. Climate models consistently show that water vapor provides a stronger climate feedback mechanism than any other trace gas.

The radiometers on the TOPEX/Poseidon and Jason-series of ocean altimeter missions of ocean altimeter missions were designed to provide an important correction for the sea surface height observations. However, scientists recently began using the radiometric measurements to gain valuable information related to the atmosphere's precipitable water and cloud liquid water content.



As of today, nearly 20 years of precipitable water vapor and cloud liquid water data have been collected, compiled, and incorporated into climate models, leading to improved representation of water vapor in these models—see **Figure**. These carefully calibrated, continuous radiometer data record include complete sampling across the diurnal cycle, and are complementary to climate data records produced from other sensors.

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in the news

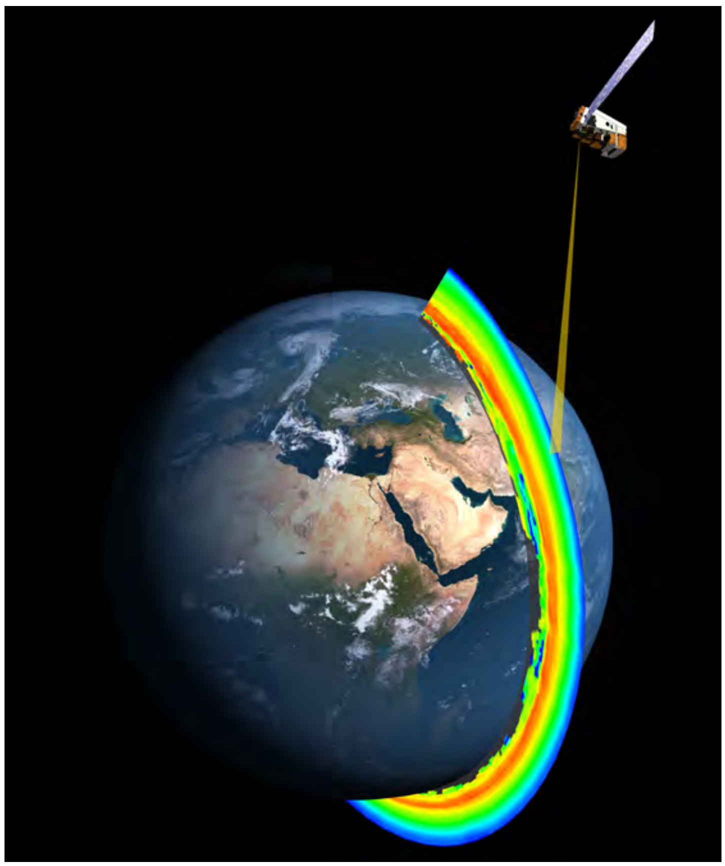
Ozone Suite on Suomi NPP Continues More Than 30 Years of Ozone Data

Cynthia O'Carroll, NASA's Goddard Space Flight Center, cynthia.m.ocarroll@nasa.gov
John Leslie, National Oceanic and Atmospheric Administration, john.leslie@noaa.gov

A new satellite instrument suite is now sending back detailed information about the health of the Earth's ozone layer, the shield that protects the world's population from harmful levels of the sun's ultraviolet radiation.

The Ozone Mapping and Profiler Suite (OMPS) is one of five new instruments flying aboard the Suomi National Polar-orbiting Partnership satellite (Suomi NPP), which was launched on October 28, 2011. Suomi NPP is the result of a partnership between NASA, the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD).

OMPS continues an over three-decade-long partnership between NASA and NOAA in studying ozone. OMPS consists of three instruments: the downward-looking *nadir mapper* and *nadir profiler*, and a new instrument called the *limb profiler*.



A cross-section of the Earth's ozone layer as measured by the *limb profiler*, part of the Ozone Mapping and Profiler Suite that's aboard the Suomi NPP satellite. A new instrument, the limb profiler makes high-vertical-resolution measurements of the *ozone layer*, a shield that protects the Earth's surface from the sun's dangerous ultraviolet radiation. **Image credit:** NASA/NOAA

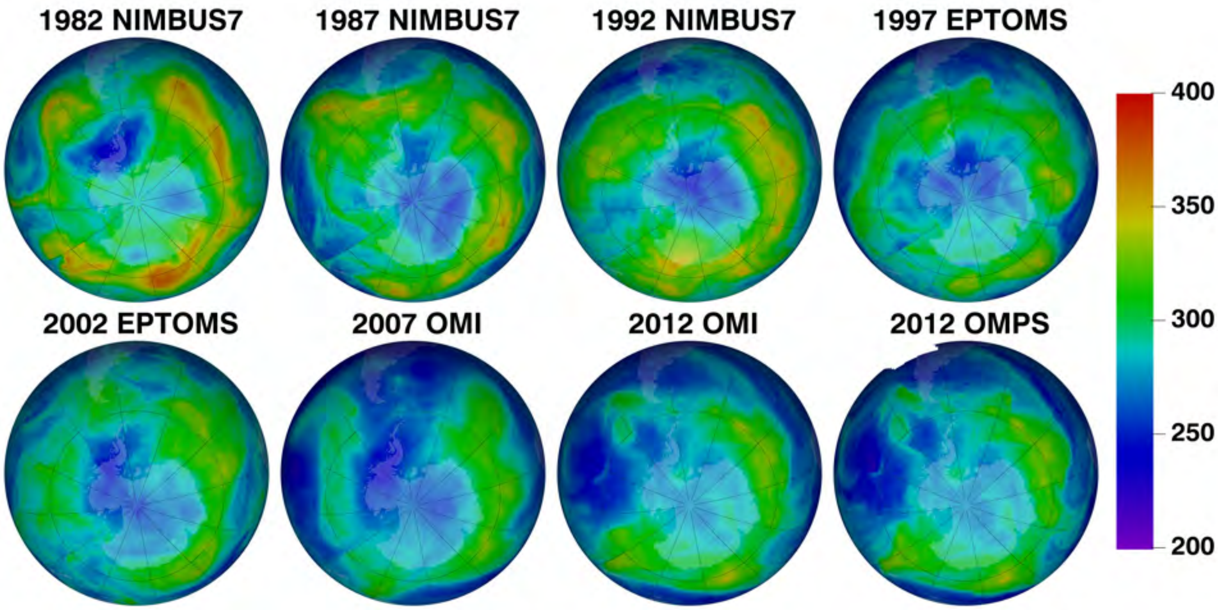
OMPS data will contribute to observing the recovery of the ozone layer in the coming years. The layer is expected to recover from the effects of the ozone depleting substances like halons and chlorofluorocarbons (CFCs) over the coming few decades. This recovery comes as a result of the *Montreal Protocol*—a world-wide agreement in 1987 that phased out the use of these ozone-depleting substances.

"Ozone depletion has been a major concern for decades," said **Mary Kicza**, assistant administrator for NOAA's Satellite and Information Service. "Scientists need reliable observations of ozone from space and OMPS provides them."

"With the large ozone layer depletion seen in the Arctic in March 2011, it was critical to get OMPS into orbit for measurements in the Northern Hemisphere in March 2012," said **Paul Newman**, NASA scientist and co-chair of the United Nations Montreal Protocol Scientific Assessment Panel.

The nadir profiler measures the vertical distribution of ozone in a way that continues the long-term atmospheric ozone data record generated by the NOAA operational Solar Backscatter Ultraviolet (SBUV/2s) instrument. Ozone mapping from space-based observations began in 1978 with NASA's Total Ozone Mapping Spectrometer (TOMS). The OMPS' nadir mapper transitions ozone mapping measurements from NASA research to NOAA operations, ensuring that this critical measurement will continue into the future.

The limb profiler is a experimental instrument that measures the distribution of ozone at higher vertical resolution by looking through the atmosphere at an angle. It's designed to continue NASA's measurements of high-vertical-resolution ozone profiles from the Microwave Limb Sounder on the EOS Aura. These are data key to



These images show the thickness of the Earth's ozone layer on January 27 for selected years covering the period 1982–2012. This atmospheric layer protects Earth from dangerous levels of solar ultraviolet radiation. The thickness is measured in Dobson Units; smaller amounts of overhead ozone are shown in purples and blues, while larger amounts are shown in orange and reds.

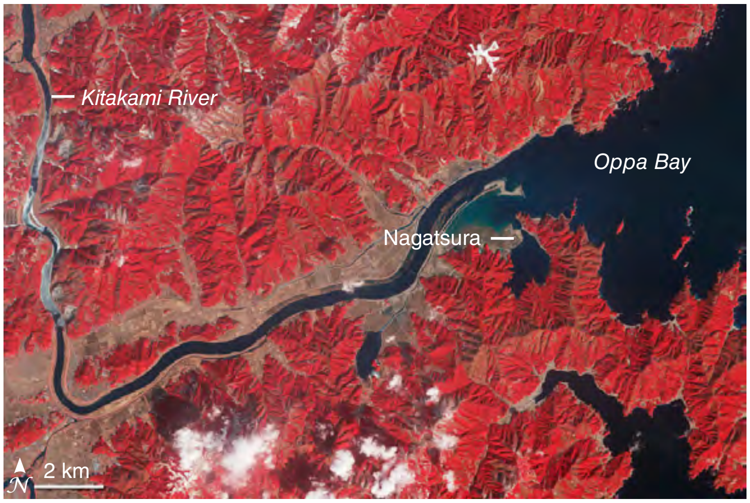
These ozone measurements begin with the Nimbus 7 satellite; continued with the Earth Probe Total Ozone Mapping Spectrometer (EP TOMS); the Ozone Monitoring Instrument (OMI) aboard the Aura satellite; and the most recent, the Ozone Mapping and Profiler Suite (OMPS) aboard the Suomi (NPP) satellite, a partnership between NASA, NOAA, and the Department of Defense. **Image credit:** NASA/NOAA

understanding how changing greenhouse gases affect the recovery of the ozone layer.

The Suomi NPP team will continue initial checkouts as part of its commissioning activities until early March and then handoff operations to NOAA. NOAA will continue calibration and validation activities leading to the processing and distribution of data to users around the world. The Suomi NPP mission is the bridge between NASA's Earth Observing System satellites and NOAA's Polar Operational Environmental Satellite (POES) to the next-generation Joint Polar Satellite System (JPSS), which NOAA will operate. The JPSS program, funded by NOAA, provides the ground segment for Suomi NPP.

NASA's Goddard Space Flight Center manages the Suomi NPP mission for the Earth Science Division of the Science Mission Directorate at NASA Headquarters. NOAA and the Department of Defense funded the OMPS instrument.

The Suomi NPP mission enables scientists to advance our knowledge of how the entire Earth system works by providing enhanced data for our nation's weather forecasting system and providing extended Earth system data records insight to scientists to better understand climate. ■



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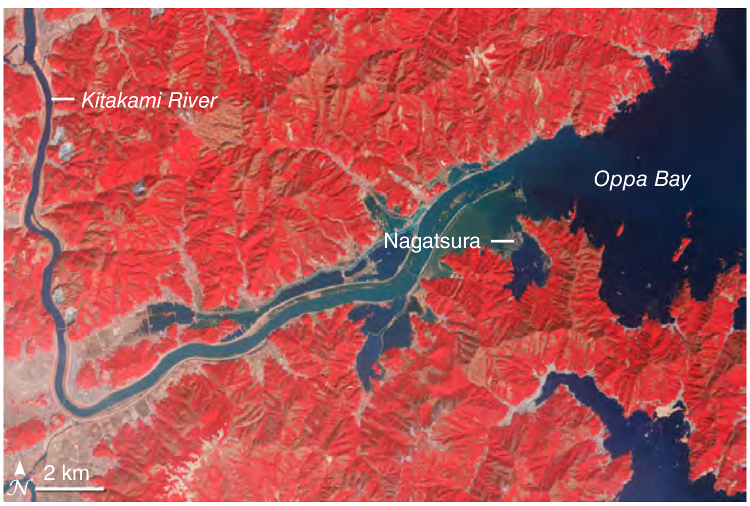

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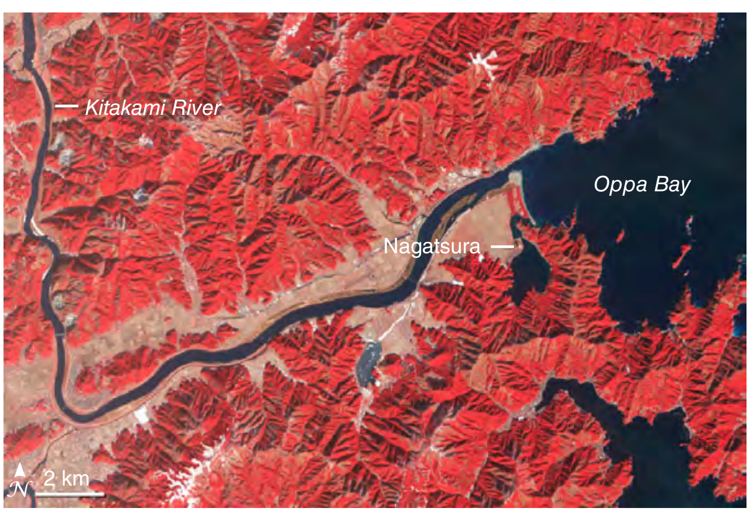


January 16, 2011

In March 2011, a magnitude 9.0 earthquake—the fourth largest recorded since 1900—triggered a powerful tsunami that pummeled the northeastern coast of Japan. The earthquake occurred offshore, about 80 mi (130 km) east of Sendai at 2:46 PM (local time) on March 11. Within 20 minutes, massive swells of water started to inundate the mainland.

The tallest waves and most devastating flooding from the 2011 Tōhoku-oki tsunami occurred along the jagged coast of northern Honshu, a landscape dimpled with bays and coves known as ria coast. The steep, narrow bays of *ria coasts*[1] trap and focus incoming tsunami waves, creating destructive swells and currents that can push huge volumes of water far inland, particularly along river channels.

That's exactly what happened in the days before the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), an instrument on NASA's Terra satellite, captured the middle image (on March 14, 2011). It shows severe flooding along the Kitakami River three days after the earthquake struck.

The top image, captured by the Advanced Land Imager on NASA's Earth Observing-1 (EO-1), shows the same scene a year later. And the bottom image, captured by ASTER, shows what the area looked like before the earthquake struck.

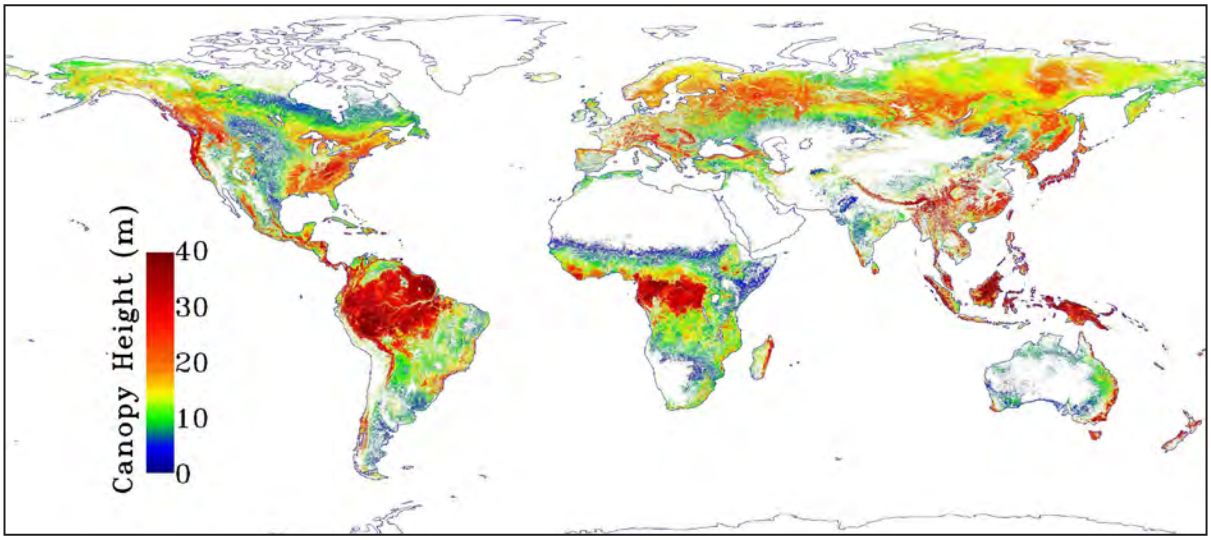
In the image from March 2011 [*middle*], wide swaths of flood water cover the north and south banks of the river channel, and sediment fills the river's mouth. Some of the most dramatic flooding occurred just to the south of the river, where floodwater washed across large tracts of farmland and the small village of Nagatsura. Notice how far up the river the flooding occurred: Research conducted by scientists at Tōhoku University suggests that waves from the tsunami traveled nearly 30 mi (50 km) upstream from the mouth of the Kitakami River.

One year after the tsunami [*top*], floodwaters had subsided, the river was back within its banks, and many of the agricultural fields along the Kitakami were dry again. However, the landscape near the mouth of the river remains irrevocably altered in comparison to how it looked before [*bottom*]. The farmland immediately north and east of Nagatsura has become river bottom. The width of the river mouth has widened. And water from Oppa Bay has crept inland, leaving only a narrow strip of land and new islands near the river mouth. **Credit:** NASA's Earth Observatory

[1] A *ria coast* is a series of partially submerged river valleys (caused by sinking landmass and/or rising sea level) that run parallel to each other along the coast that typically results in an estuary surrounded by steep hills.

NASA Map Sees Earth's Trees in a New Light

Alan Buis, NASA/Jet Propulsion Laboratory, alan.buis@jpl.nasa.gov



Global map of forest height produced by combining data from NASA's ICESAT/GLAS, MODIS, and TRMM sensors. **Image credit:** NASA/JPL-Caltech

A NASA-led science team has created an accurate, high-resolution map of the height of Earth's forests. The map will help scientists better understand the role forests play in climate change and how their heights influence wildlife habitats within them, while also helping them quantify the carbon stored in Earth's vegetation.

Scientists from NASA/Jet Propulsion Laboratory (JPL), the University of Maryland, and Woods Hole Research Center, created the map using 2.5 million carefully screened, globally distributed laser pulse measurements from space. The light detection and ranging (lidar) data were collected in 2005 by the Geoscience Laser Altimeter System (GLAS) instrument on NASA's Ice, Cloud and land Elevation Satellite (ICESat).

"Knowing the height of Earth's forests is critical to estimating their biomass, or the amount of carbon they contain," said lead researcher **Marc Simard** of JPL. "Our map can be used to improve global efforts to monitor carbon. In addition, forest height is an integral characteristic of Earth's habitats, yet is poorly measured globally, so our results will also benefit studies of the varieties of life that are found in particular parts of the forest or habitats."

The map, available at *lidarradar.jpl.nasa.gov*, depicts the highest points in the forest canopy. Its spatial resolution is 0.6 mi (1 km). The map was validated against data from a network of nearly 70 ground sites around the world.

The researchers found that, in general, forest heights decrease at higher elevations and are highest at low latitudes, decreasing in height the farther they are from the tropics. A major exception was found at around 40° S latitude in southern temperate rainforests in Australia and New Zealand, where stands of eucalyptus, one of the world's tallest flowering plants, tower much higher than 130 ft (40 m).

The researchers augmented the ICESat data with other types of data to compensate for the sparse lidar data, the effects of topography, and cloud cover. These included estimates of the percentage of global tree cover from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite, elevation data from NASA's Shuttle Radar Topography Mission, and temperature and precipitation maps from NASA's Tropical Rainfall Measuring Mission (TRMM) and the WorldClim database. *WorldClim* is a set of freely available, high-resolution global climate data that can be used for mapping and spatial modeling.

In general, estimates in the new map show forest heights were taller than in a previous ICESat-based map, particularly in the tropics and in boreal forests, and were shorter in mountainous regions. The accuracy of the new map varies across major ecological community types in the forests, and also depends on how much the forests have been disturbed by human activities and by variability in the forests' natural height.

"Our map contains one of the best descriptions of the height of Earth's forests currently available at regional and global scales," Simard said. "This study demonstrates the tremendous potential that spaceborne lidar holds for revealing new information about Earth's forests. However, to monitor the long-term health of Earth's forests and other ecosystems, new Earth observing satellites will be needed."

Results of the study were published recently in the *Journal of Geophysical Research – Biogeosciences*. ■

NASA Earth Science in the News

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

Climate Proposal Puts Practicality Ahead of Sacrifice, January 16; *The New York Times*. After looking at hundreds of ways to control pollutants, researchers led by **Drew Shindell** [NASA Goddard Institute for Space Studies (GISS)] determined the 14 most effective measures for reducing climate change. They include encouraging a switch to cleaner diesel engines and cook stoves, building more-efficient kilns and cook ovens, capturing methane at landfills and oil wells, and reducing methane emissions from rice paddies by draining them more often. Shindell was lead author on the study, published in *Science*.

Suomi NPP Commissioning Resumes After VIIRS Anomaly, January 20; *Aviation Week*. Engineers found that the mirror on Suomi NPP's Raytheon-built Visible Infrared Imager Radiometer Suite (VIIRS) was contaminated with tungsten oxides, possibly as a result of nonstandard processing when the mirror was coated. The irreversible contamination appears limited to the VIIRS mirror, and managers expect mirror darkening to stop at a level that will permit it to operate within design requirements. It will take about six weeks to complete commissioning, which resumed on January 18.

NASA Releases New 'Blue Marble' Image of Earth, January 25; *msnbc.com.* NASA released a brand-new 'Blue Marble 2012,' based on image data from VIIRS aboard Suomi NPP, the most recently launched Earth-observing satellite. This MSNBC story was one of many in the most prominent media outlets worldwide. The image has garnered more than 3.7 million hits on *Flickr*, a photo-sharing web site, making it already the most-viewed image ever on the popular site.

NASA's GCPEx Mission: What We Don't Know About Snow, February 3; *RedOrbit*. **Gail Skofronick-Jackson** [NASA's Goddard Space Flight Center (GSFC)] is part of a team of scientists from NASA and Environment Canada who are running a large airborne experiment in Southern Ontario, Canada, to improve snow detection. The GPM Cold-season Precipitation Experiment (GCPEx), including NASA's DC-8, supports the new Global Precipitation Measurement (GPM) mission whose Core satellite is scheduled to launch in 2014.

NASA: La Niña Peaks, Southwest Drought Looms, January 20; *Summit County Citizens Voice.* NASA scientists say this winter's La Niña episode is peaking, increasing the odds that the Pacific Northwest will have more stormy weather this winter and spring, while the Southwestern and Southern U.S. will be dry. "Conditions are ripe for a stormy, wet winter in the Pacific Northwest and a dry, relatively rainless winter in Southern California, the Southwest, and the southern tier of the United States," said **Bill Patzert** [NASA/Jet Propulsion Laboratory (JPL)].

NASA: 2011 Among Top-Nine Warmest Years Since 1880, January 20; *Voice of America.* NASA says average global surface temperatures continued an alarming upward trend in 2011, which has been ranked among the top nine warmest years since 1880. Scientists worldwide overwhelmingly agree that billions of tons of man-made carbon dioxide emissions pumped into the Earth's atmosphere over the last 100 years are largely to blame for increasing global warming. NASA GISS in New York says new data analysis indicates that surface temperatures in 2011 climbed ~0.94 °F (0.52 °C) above the average mark from the mid-twentieth century.

From Two Satellites, The Big Picture On Ice Melt, February 8; *The New York Times*. A new paper from researchers at the University of Colorado, Boulder, based on data from NASA's Gravity Recovery and Climate Experiment (GRACE) mission, offers the most up-to-date and comprehensive numbers on glacier and ice cap melt worldwide. The research, published in *Nature*, calculates that from 2003–2010 the world's glaciers and ice caps lost about 150 billion tons of ice each year. This ice loss was responsible for an average rise of 0.4 mm in sea level every year over the eight-year study period.

New NASA Instrument Measures Earth's Energy Budget, February 14; *Newport News, Virginia, Daily Press*. The fifth Clouds and the Earth's Radiant Energy System (CERES) instrument, launched in October 2011 aboard Suomi NPP, will continue a long and important data record of the Earth's energy budget, said **Norman Loeb** [NASA's Langley Research Center]. According to NASA, the Sun annually provides the planet about 340 watts per square meter—roughly the energy radiated from six incandescent light bulbs on every square meter of the Earth's surface. If the planet returned an equal amount of energy to space, temperatures would be constant, Loeb said. That is not occurring; instead, roughly 0.8 watts per square meter stays on Earth.

*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 your upcoming journal articles, new satellite images, or conference presentations that you think the average person would be interested in learning about.* ■

This composite image, named 'Blue Marble 2012' uses a number of swaths of the Earth's surface taken from the VIIRS instrument aboard Suomi NPP on January 4, 2012. **Image credit:** NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring

NASA Science Mission Directorate – Science Education and Public Outreach Update

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Expedition Earth and Beyond Webinar—Grades 4-12

March 27, 2012; 12:15–1:30 p.m. ET

NASA's Expedition Earth and Beyond (EEAB) Program promotes student-led research investigations in the classroom using NASA data and resources. It also provides opportunities to connect with NASA or university scientists. Throughout the year, the program offers a number of free online teacher trainings, as well as classroom connection opportunities for teachers and students with scientists.

Join this distance-learning event—*Viewing Auroras from Space*—for an interactive presentation connecting students with a scientist at NASA's Johnson Space Center. Information about auroras, including video and astronaut imagery of auroras on Earth will be presented. Presentations will be approximately 50 minutes long. For more information on the Classroom Connections webinar and to register, visit: *1.usa.gov/zei1tt*.

Terra and Landsat Outreach Specialist

Sigma Space Corporation is looking for an outreach specialist to lead the Terra mission education and public outreach (EPO) effort, and to participate as part of a team performing EPO activities for Landsat and the Landsat Data Continuity Mission (LDCM). The work is part of the Hydrospheric and Biospheric Sciences (HBS) support contract that supports the Science and Exploration Directorate at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD.

EPO-related duties will include:

- Designing, developing, coordinating, and executing education and science outreach efforts in coordination with HBS laboratory research and management personnel, and intended outreach audiences;
- designing and developing mission-specific EPO products targeted for NASA management, news media, scientists, students, educators, and the general public;
- representing Terra and Landsat/LDCM missions at public events; and
- conducting or copresenting workshops in classrooms and for informal educators, based on existing Terra and/or Landsat materials.

In addition to these duties, there are mission-specific duties, as well.

Qualified candidates will have a B.S. or B.A. degree in Earth systems science, science education, or history of science from an accredited university, plus three years of experience in engaging the public in both formal and informal Earth science education communities. Strong collaborative and project-planning skills are required, along with excellent written and oral communication skills. Knowledge of the needs of formal educators for Earth science materials, as well as knowledge of exhibit design and informal education is highly desirable.

For a full list of qualifications and to apply, visit: *bit.ly/wu5zT6*.

Symposium on Climate Change Education at NARST Conference

March 25, 2012; 1:00-2:30p.m. ET; JW Marriott, Room 303, Indianapolis, IN

As part of the National Association for Research in Science Teaching Annual Conference, the symposium *Climate Change Education: Curriculum, Controversy, Culture, and Critical Review,* will explore why we should understand the factors that contribute to climate and climate change, and how changes in climate can affect our lives. In particular, we need to understand how our uses of and policies for energy, land, and natural resources interact with climate, how to prevent the most disruptive effects of climate change, and how to adapt to changes that cannot be avoided. These issues cross multiple science domains. The discussion will explore how to address many of theses issues in the classroom, including how NASA's Innovations in Climate Education (NICE) program can provide insight. This symposium will be facilitated by **Anna Lewis** [University of South Florida, Coalition for Science Literacy]; **Susan Buhr** [University of Colorado]; **Julie Thomas** [Oklahoma State University]; and **Anne L. Kern** [University of Ohio.]

If you cannot attend the symposium but would like access to the meeting notes and outcomes, please email Anna Lewis at *arlewis@usf.edu*. To find out more about the National Association for Research in Science Teaching Annual Conference, visit: *bit.ly/vZ1xXb*. ■

EOS Science Calendar

April 11–13, 2012
7th Aquarius/SAC-D Science Team Meeting, Bueno Aires, Argentina. URL: *www.conae.gob.ar/AQ_SAC-D_7thScienceMeet/index.html*

April 17–19, 2012
HDF and HDF-EOS Workshop XV, Riverdale, MD. URL: *hdfeos.net/workshops/ws15/workshop_fifteen.php*

May 11–14, 2012 (tentative)
41st ASTER Science Team Meeting Tokyo, Japan. URL: *Not yet available*

June 1–3, 2012
CERES Science Team Meeting, Newport News, VA. URL: *ceres.larc.nasa.gov*

September 17–21, 2012
GRACE Science Team Meeting, Potsdam, Germany. URL: *www.csr.utexas.edu/grace/GSTM*

October 1–3, 2012
Aura Science Team Meeting, Pasadena, CA. URL: *Not yet available*

October 16–18, 2012
HyspIRI Workshop, Pasadena CA. URL: *hyspiri.jpl.nasa.gov/events/2012-hyspiri-workshop*

Global Change Calendar

May 7–11, 2012
The 44th International Liège Colloquium on Ocean Dynamics, Liège, Belgium. URL: *modb.oce.ulg.ac.be/colloquium*

May 7–11, 2012
4th WCRP International Conference on Reanalyses, Silver Spring, MD. URL: *icr4.org/index.html*

August 5–10, 2012
34th International Geological Congress, Brisbane, Australia. URL: *www.34igc.org*

August 6–10, 2012
2012 International Radiation Symposium: Current Problems in Atmospheric Radiation, Berlin, Germany. URL: *www.irs2012.org*

August 25–September 1, 2012
XXII Congress of the International Society of Photogrammetry and Remote Sensing (ISPRS), Melbourne, Australia, URL: *www.isprs2012.org*

September 11–14, 2012
ForestSAT 2012, Oregon State University, Corvallis, OR. URL: *www.forestsat2012.com*

November 5–9, 2012
PORSEC-2012: Water and Carbon Cycles, Kochi, India. URL: *www.porsec2012.incois.gov.in*

December 3–7, 2012
American Geophysical Union Fall Meeting, San Francisco, CA. URL: *www.agu.org/meetings*

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