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Editor's Corner

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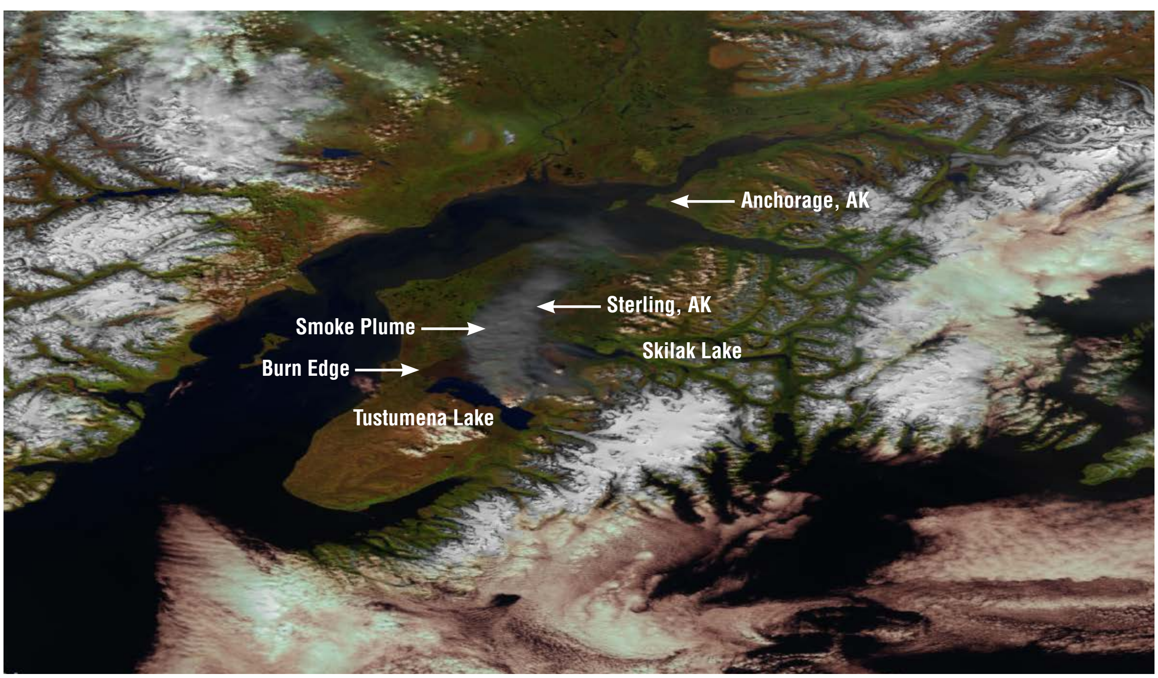
In previous issues of *The Earth Observer*, we have tracked the progress of the Global Precipitation Measurement (GPM) mission that launched on February 27. As of this writing, functional checkout activities and internal calibration of the GPM Microwave Imager (GMI) and Dual-frequency Precipitation Radar (DPR) are ongoing. Both instruments have begun collecting data on rain and snow. The GPM algorithm developers and validation team, with help from the Precipitation Processing System at NASA's Goddard Space Flight Center, have begun the process of verifying data accuracy. Early data adopters (e.g., NOAA, NRL, ECMWF) started receiving GMI data on March 21 and DPR data on April 2. The GPM team is hoping to make an early public release of GMI data in the June–July timeframe. (Also see page 22 of this issue for details on a special symposium to honor the life and career of **Arthur Hou**, former GPM Project Scientist.)

Meanwhile, the Visible Infrared Scanner (VIRS) on GPM's predecessor mission, the Tropical Rainfall Measuring Mission (TRMM), will remain off for the remainder of the mission to save power on Battery 2, which may have experienced shorts in one of its three cells. To prevent further shorts, VIRS was turned off on March 21, 2013 to reduce the power load: A primary mission objective was to maximize the duration of operations of the more critical TRMM instruments (TMI, PR, LIS). Since then, battery operations for TRMM (i.e., voltages, states of charge) have remained nominal.

continued on page 2



This image of the Funny River Fire on the Kenai Peninsula near Funny River and Sterling, AK was obtained by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership satellite on May 26, 2014. The black spruce, mixed hardwood, and grasses that dominate this region are extremely dry, and there has been extensive damage to the trees from beetle infestation, making the area prone to burning. While recent rains have provided some relief, as of June 4, 2014, more than 200,000 acres (~800 km^2) have burned. **Image credit:** NASA/NOAA

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

Recently, we've also described efforts to optimize the remaining battery life of the Solar Radiation and Climate Experiment (SORCE). In August 2013 the end-of-orbit discharge voltage fell below the level needed to maintain critical flight functions. This caused the spacecraft to assume a *safe-hold* mode, precluding the mission's ability to safely collect new science data. The SORCE team decided to implement a *campaign* mode to assure overlapping measurements between SORCE and the Total Irradiance Monitor (TIM) on the Total Solar Irradiance (TSI) Calibration Transfer Experiment [TCTE] instrument that launched in November 2013.

A hugely successful SORCE/TCTE cross-calibration campaign ran from December 22-28, 2013. All SORCE instruments made good solar observations; TIM was given a higher priority to overlap with TCTE. The SORCE battery performed so well that SORCE TIM was left on for several orbit eclipses on December 25, the day of minimum eclipse durations, allowing the instrument to achieve nominal operating temperatures. The SORCE scientists and mission operations team met daily during this intense and stressful "holiday" campaign to review the status of the instruments, spacecraft and instrument health, and experiment execution, making adjustments as needed. On April 27, the LASP team released an initial and preliminary comparison between TCTE and SORCE showing very good agreement (a difference of 244 ppm—well within their mutual uncertainties). Further, the difference between the primary and secondary TCTE channels is less than 100 ppm, indicating good internal instrument calibration consistency[1].

In the meantime, the SORCE team devised a novel approach that has allowed SORCE to resume taking solar observations during the daylight part of each orbit and entering safe-hold during eclipse. Since February 24, the spacecraft has been operating successfully in this new *hybrid* mode[2]. This approach is expected to allow SORCE to continue to fulfill its extended mission objectives. It is hard to overestimate the importance for solar irradiance studies of overlapping SORCE measurements with TCTE and, potentially, the Total Solar Irradiance Sensor (TSIS) to be launched in 2017 for installation on the International Space Station.

The reworked SORCE success aside, we regret to report that the ACRIMSAT mission [launched in December 1999 and flying the third Active Cavity Radiometer Irradiance Monitor (ACRIM3) instrument] has come to an end, likely due to battery problems. Contact with the spacecraft was lost just one week short of the mission's fourteenth anniversary. NASA/Jet Propulsion Laboratory (JPL) convened a final anomaly review board May 5 at which time the spacecraft was declared unrecoverable. NASA HQ is expected to issue a termination notice with a mission close out meeting (KDP-F) in July. A final dataset will be reprocessed with a public release anticipated sometime next year. ACRIMSAT/ACRIM3 was conceived in the challenging "faster, better, cheaper" NASA era, with an end-to-end cost of less than $50M. ACRIMSAT, along with measurements from the earlier ACRIM1 and ACRIM2 instruments onboard the Solar Maximum

[1] The TCTE uncertainties will shrink as its calibration parameters become better known. In part, this is possible because of generous cooperation from the U.S. Air Force in providing consecutive daily solar orbits for TCTE, which allows the instrument to reach its nominal operating temperature and provides one orbit per day of high quality measurements.

[2] The *hybrid* mode spins up the spacecraft for orbit night so that it still points towards the sun at orbit sunrise, so it may be possible to continue hybrid operations even if the spacecraft loses more battery cells and begins to experience *brown-out* during eclipse periods.

Mission (1980) and Upper Air Research Satellite (1991), respectively, provided observations spanning more than 90% of the 35-year irradiance satellite record that began in 1978, and thereby greatly improving our understanding of this time series. Congratulations to **Richard "Dick" Willson** ACRIMSAT Principal Investigator, and the rest of the ACRIMSAT team on the generation of this critical climate data record.

We have also tracked the progress of the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on Aqua, whose antenna stopped spinning in October 2011, likely due to aging lubricant. After extensive consultations between teams at NASA and JAXA, AMSR-E was restored to operations in December 2012 at a reduced rotation rate[3]. The data obtained since then have been used for radiometric intercomparison with the follow-on AMSR2 instrument on JAXA's Global Change Observation Mission—Water (GCOM-W1), launched on May 17, 2012. Such comparisons have been essential for establishing data record continuity across the two missions.

A new refined data calibration for AMSR2 will be released later this year. The reprocessed data will take into account information from the instrument's own calibration loads as well as from AMSR-E (rotating at 2 rpm) and GMI on the GPM Core Observatory. JAXA has made the 2-rpm AMSR-E data available to the public at *sharaku.eorc.jaxa.jp/AMSR/products/amsre_slowdata.html*. The U.S. AMSR2 Science Team is currently working on unifying all ancillary data files used in their algorithms. The AMSR-E SIPS will continue processing the data once the modified algorithms are in place. The goal is to continue the AMSR-E data records archived at NSIDC with AMSR2 data for climate research.

On May 1, the NOAA Environmental Satellite, Data, and Information Service (NESDIS) announced that the Suomi National Polar-orbiting Partnership (NPP) will be the primary [afternoon orbit] satellite for supporting NOAA's environmental monitoring mission—a designation used to manage and prioritize shared NOAA mission resources. In this role, Suomi NPP will continue its support of NOAA's operational missions and provide science data continuity for NASA's EOS missions. NOAA-19 continues to serve as the Prime Services Mission supporting the SARSAT and ADCS services.

In other news, NASA once again teamed with the Earth Day Network to commemorate Earth Day. Events took place at Union Station in Washington, DC on April 21-22. To view pictures from the event and learn more about the different kinds of topics presented on the Hyperwall, as well as other interesting outreach endeavors that took place, turn to page 11 of this issue.

This Editorial highlights the ongoing hard work to extend the life of several aging missions. The scientists and engineers involved in these efforts are to be commended for their efforts to overcome technical limitations and continue to coax further science out of the missions. Building on such efforts, NASA plans to launch five Earth Science missions in 2014 alone. In addition to describing the first of those launches (GPM), we look forward to the next launch—the second Orbiting Carbon Observatory (OCO-2), scheduled for July 1.

To read about one such effort to coax life—and science—out of data that were collected during the 1960s (from Nimbus 1, 2, and 3), turn to page 4. There you will find described a journey of discovery, recovery, processing, and analysis of a trove of *dark data*—data files "rescued" from uncatalogued archives that were untagged, untapped, unprocessed, and unanalyzed. This task would call upon the skills of a group of dedicated professionals at NSIDC. As a result of these intense efforts, these "old" data were restored to life for use by the science community.

[3] To learn more, see the "Editor's Corner" from periodic issues of *The Earth Observer* beginning in November–December 2011 and continuing to January–February 2013 [**Volume 23**, **Issue 6** through **Volume 25**, **Issue 1**].

Acronyms Not Defined in Editorial and Article Titles (in alphabetical order)

Editorial	
ADCS	Advanced Data Collection System
ECMWF	European Centre for Medium-range Weather Forecasting
EOS	Earth Observing System
JAXA	Japan Aerospace Exploration Agency
KDP	Key Decision Point
LASP	Laboratory for Atmospheric and Space Physics
LIS	Lightning Imaging Sensor
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
NRL	Naval Research Lab
PR	Precipitation Radar
SARSAT	Search And Rescue Satellite Aided Tracking
SIPS	Science Investigator-led Processing Systems
TMI	TRMM Microwave Imager
Article Titles	
CNES	Centre National d'Etudes Spatiales
ICESat-2	Ice, Cloud, and Land Elevation Satellite-2
OCO-2	Orbiting Carbon Observatory-2
OMI	Ozone Monitoring Instrument

Dark Data Rescue: Shedding New Light on Old Photons

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An example of a successful rescue effort is the recovery of NASA Nimbus satellite data by a team at the National Snow and Ice Data Center (NSIDC) at the University of Colorado, Boulder, who wanted to see if such data could be utilized to explore historical polar sea ice extent, a purpose for which the data were not originally meant.

***Dark Data?* It Sounds Ominous!**

It also sounds like something out of Edgar Allen Poe: *The Tale of the Dark Data Rescue.*

But while there is some "mystery" to *dark data,* it is really rather prosaic, usually having to do with learning about their existence, where they are stored, and what—if anything—can be done to find meaning in them.

By definition, dark data are data files, usually in uncatalogued archives, that are untagged, untapped, unprocessed, and unanalyzed. This means that these data have not been exposed to photons newer than those that provided the data signals in the first place! Often these data are stored in such a way that significant effort must be expended to find them and ascertain their utility.

There are multiple mega- and gigabytes of dark data, often stored in unvisited repositories. In worst-case scenarios technology has long since moved on, making the media inaccessible, even when they can be discovered in the first place.

An Example of the Need for Data Rescue at the Personal Level

To facilitate the discussion, let's make this more personal: Let's say you discover an old, unlabeled floppy disc of unknown capacity and format in a dark corner of a desk drawer in your office and wonder why you kept it and what you had saved on it. If the disc itself has been damaged, whatever information it once contained is lost to history, but even if there is no physical damage to the disc itself, the data are not easily accessed, since most modern computers are no longer equipped with floppy drives. It can be done, but you would have to do some work to find a way to either find someone with a functioning drive or move the information (somehow) to a different medium (e.g., compact disc (CD)) that modern computers can read—and even CD drives are frequently no longer found on some computers. And so it can be with the dark data being discussed in this article.

I'm intrigued by the dark. Out of darkness comes creation.

—Famke Janssen

Being Open to Possibilities

While there are dark data that derive from many NASA-supported research activities, this article will focus on a single example, the recovery of NASA Nimbus satellite data by a team at the National Snow and Ice Data Center (NSIDC) at the University of Colorado, Boulder, who wanted to see if such data could be utilized to explore historical polar sea ice extent, a purpose for which the data were not originally meant.

In the early days of the 1960s-era Nimbus Program, the focus was almost entirely on meteorology, with the Nimbus 1, 2, and 3 satellites carrying High Resolution Infrared Radiometers (HRIR), and Nimbus 2 and 3 also carrying Medium Resolution Infrared Radiometers (MRIR). Both instruments were designed and implemented to record twice-daily global meteorological observations. All three satellites also carried an Advanced Vidicon Camera System (AVCS) that transmitted analog data that were subsequently recorded by taking photos of the viewing monitor, and stored on 200' film rolls.

In 2007 **John Moses** [NASA's Goddard Space Flight Center (GSFC)—*Branch Head, Science Data Systems, formerly DAAC System Engineer, Earth Science Data and Information System Project*] went looking for dark data. He knew that thousands of data tapes from the HRIR on Nimbus 2 were still available at the National Archives in Washington, DC. Although it seemed unlikely when he began, Moses wondered if there might be some way to retrieve that information before it was completely lost to history.

"When we first visited the Federal Record Center where the HRIR tapes were stored, it was like walking into the last scene in *Raiders of the Lost Ark*—rows and rows of boxes as far as the eye could see. Many of our labels had faded or fallen off, with some boxes misplaced, missing, or unaccounted for in the paper catalogs. It took many hours of work by the team at GSFC to account for all of the Nimbus data," said Moses.

But there were more Nimbus 2 data than those from HRIR. Unlike the tape-based HRIR data stored at the National Archives, the boxes of AVCS-generated film ended up elsewhere, at a repository in Suitland, MD, in a shed that was partly open to the elements. In 1987, storage space being at a premium, the National Climate Data Center (NCDC) was asked to clear out the Maryland warehouse, with the option to toss the data, or to keep them. Prudently, NCDC kept the data, shipping the films to a storage facility in Asheville, NC, where they sat, unaddressed and unloved, for the next 25 years.

While the question still remained as to the nature of the data recorded on the tapes and film, there was now at least a chance of being able to discover and recover at least some of the Nimbus data.

If the data contained on these tapes and films were going to be recovered, Moses knew it would have to happen soon. For example, after spending decades in the dark, the HRIR data tapes' physical aspects were rapidly deteriorating: The iron oxide coating that stored the data was flaking off the acetate backing. Similar problems existed with the film-based AVCS data.

With this less-than-heartening situation begins a journey of discovery, recovery, processing, and analysis of a trove of *dark data.* The task would call upon the skills of the dedicated NSIDC professionals to bring these old data to new light, with eminently useful results for science already demonstrably of use to thousands of scientists. It also resulted in a competitive award for the team that made it all happen.

And therein hangs the tale.

Taming the Dark Data

At first, Moses wasn't sure how to save the deteriorating tapes described earlier, but as luck would have it, around the same time, he learned that a company called JBI—based in Montreal, Canada—had developed the capability to recover data from such media, regardless of type, format, or vintage. Not knowing the media's status or contents, JBI agreed to examine and recover the media at a cost of $10.00 per reel.

The recovery process that JBI used involved using specially-developed tape drives, tape baking, bit detection, and processing techniques to read the 800 bit-per-inch (bpi), 7-track tapes. The resultant Tape Archive Program (TAP) format data were sent to NSIDC. These data contained errors created when the data were obtained in the 1960s caused by truncating the calibration data to save space on the tapes. JBI developed software to correct each of the several million scan lines to improve feature registration. The data were then mapped to Equal-Area Scalable Earth (EASE) Grid configuration and written to the *NetCDF* format. Moses states that, "We sent a truckload of 7-track tapes to JBI and received our first set of recovered data on a thumb drive!"

That's a Definite Maybe

While the question still remained as to the nature of the data recorded on the tapes and film, there was now at least a chance of being able to discover and recover at least some of the Nimbus data.

The NSIDC team's interest began in 2009 when **Dave Gallaher** [NSIDC—*Project Principal Investigator and Technical Services Manager*], attended an American Geophysical Union meeting and saw a poster presentation created by Moses, describing the existence and availability of the Nimbus 2 HRIR data tapes. Owing to his association with the NSIDC, Gallaher wondered about the possibility of using the

HRIR data to examine polar sea ice extent from an era some 15 years earlier than the 1979 data that began the more-complete and more-consistent satellite-based remote sensing acquisition of such data. Gallaher then was awarded a seed grant from the Innovative Research Program from the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado, Boulder, to examine the possibilities.

Serendipity Strikes at the Oddest Times

Serendipity arose by way of work unrelated to Gallaher's area of interest that was being done by the Lunar Orbiter Image Recovery Project (LOIRP), which in 2008 had started a project to resurrect data from the Lunar Orbiter Project. The LO project began in 1966 with the goal of helping to determine potential landing sites for the Apollo lunar landings. A full description of how this activity progressed is beyond the scope of this article; however, for this context, it will suffice to say that their path to recovering the LO data was anything but linear[1].

And this is where the LOIRP activity intersects with the NSIDC Nimbus dark data recovery effort: It turns out that the techniques needed to bring the LO data to light were exactly those needed for the Nimbus 2 HRIR dataset.

In summary, the journey began, as many dark data rescues do, by getting access to the archived LO tapes, which were on track to be destroyed. The team also had to track down and refurbish suitable Ampex FR-900 analog videotape decks, learning how to handle the increasingly fragile 2" tapes, and then developing the software to access the data and effect the conversions. By March 2009 the team announced their first success, a raw (*undemodulated)* image of the crater Copernicus, acquired in 1966. Since then, they have steadily marched through the rest of the tapes, with the digitized data being stored at the Planetary Data System, which archives NASA solar system data and is managed by the Solar System Exploration Data Services Office at GSFC.

And this is where the LOIRP activity intersects with the NSIDC Nimbus dark data recovery effort: It turns out that the techniques needed to bring the LO data to light were exactly those needed for the Nimbus 2 HRIR dataset.

The timing was opportune: The need to perform a similar conversion for the Nimbus data was acute, as only one third-generation tape of digital data was available, along with one copy of the Nimbus visible-band film. Further, the original scientists and engineers who had worked on the Nimbus project were aging, and their experiences and memories of the project and its implementation needed to be recorded and applied to the effort.

Applying the Magic to HRIR Data

The collaboration between the LOIRP and NSIDC data rescue teams began with the Nimbus 2 HRIR data, which were copious, but of low quality—particularly when compared to the quality of data Earth science researchers of today are used to.

Copiousness of data notwithstanding, there was significant jitter in the data, and no alignment. Furthermore, the teams found that much of the necessary calibration data had been deleted to save space, as had the needed sync pulses. These challenges conspired to make recovery efforts very difficult. Calibration data had been keyed to the scene horizon, and without the needed calibration data, the data segments simply did not line up. As a specific example, using scenes of Lake Michigan, the coastline was quite jagged and inconsistent. This is where LOIRP's "magic" came in handy. It provided a means of removing jitter caused by the instruments' scan head calibration "kick." In order to use the data for research purposes the equivalent of over 4000, 7-track tapes had to be scanned and processed using the LOIRP's techniques.

As it turns out, even after all that work, the HRIR data were not the best for the NSIDC team's research efforts. Because of variability and inconsistency in sea ice and ocean surface temperatures, it was difficult to distinguish where the ice edges were,

[1]For details of LOIRP activities, see *Moonviews: Official Website of the Lunar Orbiter Image Recovery Project* at *www.moonviews.com/archives/2011/01/analysis_of_lunar_orbiter_imag.html.*

which made the data hard to validate as regard
exception was the examination of scenes in wh
the coast of Vietnam were analyzed, validating
shown in **Figure 1**.

If At First You Don't Succeed…Try an Alternate Dataset

After this setback, the NSIDC team had to shi
its focus, turning to the visible sensing Nimbu
instrument, the AVCS. The team attempted to acquire funding from NOAA's Climate Database Modernization Program (CDMP) in 2010 but—as is often the case with data rescue efforts—agency budget changes led to a withdrawal of those funds. NOAA's NCDC in Asheville, NC, had the AVCS data and agreed to send the film to NSIDC. The film h
been stored in steel film canister, filled with 4(
boxes, with four or five tapes to a box. Each ca
contained data from several orbits.

Based on the labels, there was no way to deterr
recorded on each film roll. The only way to fin
interest (such as for 1969's Hurricane Camille) was to review every image on every roll. After searching for support, NASA agreed to fund the AVCS effort.

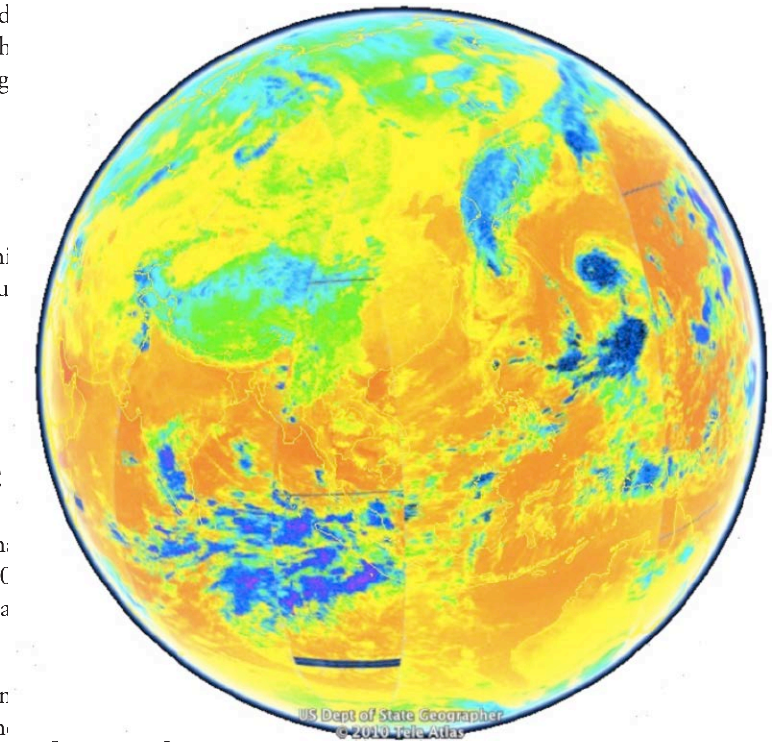


Figure 1. Nimbus 2 HRIR image from September 23, 1966, superimposed on a Google Earth scene. The color scale runs from high temperatures (in orange) to cooler temperature (in blue). Note the cooler temperatures of the Himalayan Plateau, the warm waters of the Gulf of Tonkin, and Typhoons Ida and Helen. **Image credit:** Dennis Wingo/LOIRP

Making the best use of available resources, several undergraduate students from the University of Colorado were called in to help convert the AVCS data to a usable form. To facilitate this, **Garrett Campbell** [NSIDC—*Research Scientist*] undertook to write a PC-based program that used the supply of AVCS images obtained from a used Kodak HR-500 film scanner, after having been videotaped, as described earlier. To keep the students focused and interested beyond the discovery process, Campbell wrote the computer program that was used to tag the images as a game.

The students used the game-based program to tag the center of each image and to do quality control on the images for noise. Burned into each image was a picture of a clock, from which the students had to enter into the program numbers that documented that time stamp—see **Figure 2**, next page. That's over 200,000 images—some 56 GB of data—all the while attempting to make some sense of what the data were showing. There was some basic structure, in that orbit numbers were available. Each image was time stamped, with 91 seconds between images, which helped in the time stamping identification. Further, ephemeris data for Nimbus 1, 2, and 3 were available from the North American Air Defense Command (NORAD). Confounding the situation, however, was the fact that 60% of the metadata at the bottom of each image was unreadable.

The approach worked, and the locations on the images could then be identified when used with the NORAD-supplied orbital data. Ultimately, these techniques were applied to all the recovered data from Nimbus 1, 2, and 3 under grants from NASA, and thus it became possible to explore polar sea-ice extent from times far earlier than had hitherto been possible.

Achieving the Hoped-For Results: Usable Science

The results of this data rescue, or *technoarchaeology*, effort proved eminently worthwhile—see **Figure 3**, next page. **Walt Meier** [GSFC—*Research Scientist, Cryospheric Sciences Lab*] noted that the modern (post-1979) satellite data record for the Antarctic indicates a small increasing sea ice trend. However, the early data recovered here indicate that the extent (the area of ocean with at least 15% sea ice) at least at some moments in the 1960s was similar to the data in the past several high-extent years. He

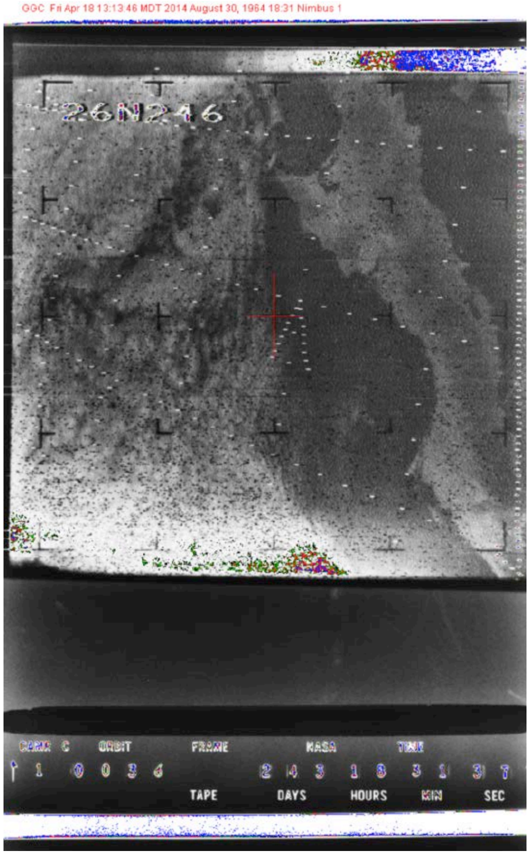


Figure 2. This image of Baja California—obtained on the third day after launch of the Nimbus 1 mission—is an example of the visible pictures produced by the Advanced Vidicon Camera System. As seen in the metadata at the bottom, this image came from camera 1, orbit number 36, day 243, 18:31:37. The location of the red crosshair was recorded to annotate the center of each picture to be used in the image-location software. This is remarkably high-resolution data for 50-year-old technology. **Image credit:** Garrett Campbell

noted that, "This suggests that the apparent trend since 1979 may simply be part of a long-term natural variation in ice extent (downward from the 1960s to late 1970s, upward since then)." In contrast, the 1960s Arctic sea ice extent data are consistent with the 1979 start of the modern satellite record, thus lending more evidence that the strong downward trend since 1979 indicates a response to *forcing* (i.e., carbon-dioxide-induced warming) and not due to natural variability.

The analysis of the NASA Nimbus 1, 2, and 3 missions has shown Antarctic sea ice extents that are both significantly greater and smaller than the modern 1979–2012 passive microwave record.

Specifically, the September 1964 ice mean area is approximately 20 x 10^6 km^2 (~8 x 10^6 mi^2). The 1964 extent is more than 1.3% greater than the approximately 19 x 10^6 km^2 (7 x 10^6 mi^2) 2012 Antarctic maximum. Strangely, the August 1966 sea ice extent reached only some 16 x 10^6 km^2 (~6 x 10^6 mi^2).

The prior record (before this analysis) was in September 1986, at 17.5 x 10^6 km^2 (~7 x 10^6 mi^2); the 1966 extent was more than 8% below this 1986 record. The change of maximum sea ice between 1964 and 1966 is over 3 x 10^6 km^2 (~1 x 10^6 mi^2). It is worth mentioning that in 1969 the August extent was higher than it was in September of that year; in the modern satellite record this has never occurred, as September's extent has been—on average—approximately 0.7 x 10^6 km^2 (~0.3 x 10^6 mi^2) greater than August.

This suggests either that 1969 was a very anomalous year, or that there are limitations on how well extent can be estimated, with the anomaly due to uncertainties in the data, relating to quality of data, sampling differences (in space and time) between the months, and the manual analysis of the ice edge. Also, while these variations appear large, they are significantly smaller than the Antarctic seasonal cycle ice extent.

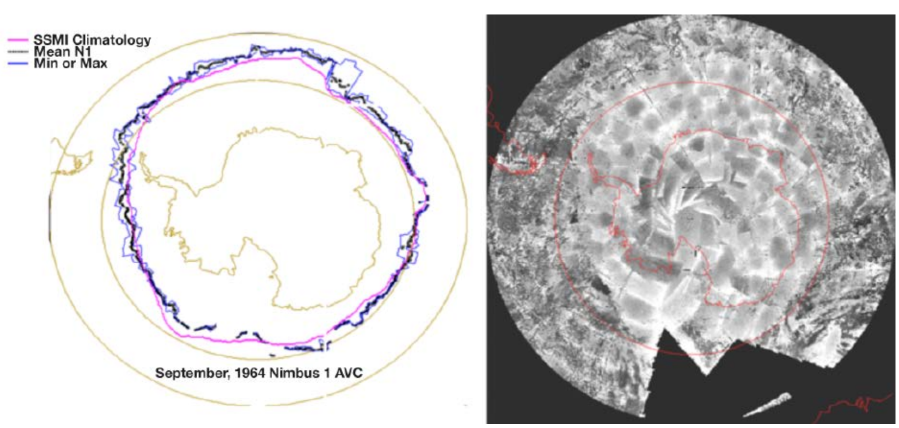


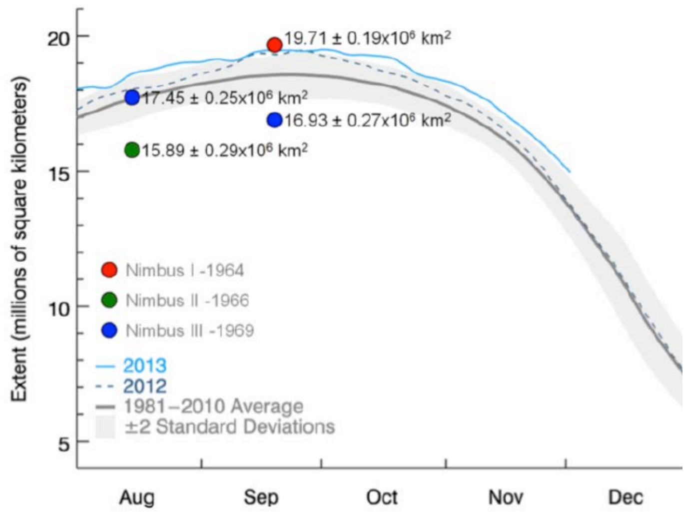
Figure 3. [*Left*] Nimbus 1 Antarctic visual detection analysis. Ice edge determinations are in blue. The 1979-2012 average ice extent (as measured by the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program satellite) is in magenta. [*Right*] AVCS Composite 7-day minimum brightness for September 1964. Note smooth grey extent of sea ice as compared to the noisy open water. **Image credit:** Dave Gallaher and Garrett Campbell

As an example of the robustness of this approach, a comparison of the Nimbus Antarctic data to the "modern" data record for the period 1979-2012 demonstrating how the Nimbus data correlates with the "modern" data is shown in **Figure 4**. Only month to month variations are compared; there is no attempt to derive trends from Nimbus to contemporary data.

Proof of the Pudding: Popularity of the Data and Acknowledgment

The recovered Nimbus data have proven very popular with researchers domestically and internationally who have requested access to them. These data are now stored in modern formats and are available for general use via NASA's data access system at *reverb.echo.nasa.gov/reverb*. The recovered tape-based HRIR data may be accessed at the GES DISC *disc.sci.gsfc.nasa.gov/nimbus* while the re-scanned analog data may be accessed at *nsidc.org/data/nimbus/order-data.html*.

Figure 4. Antarctic sea ice extent (the area of ocean with at least 15% sea ice) using recovered data from Nimbus 1, 2, and 3, as compared with data from modern sources. **Image credit:** Dave Gallaher and Garrett Campbell



For all the reasons cited above, the work described in this article by the NSIDC team was deemed worthy of *The 2013 International Data Rescue Award in the Geosciences,* organized by Integrated Earth Data Applications (IEDA) (at the Lamont-Doherty Earth Observatory of Columbia University) and Elsevier Research Data Services. The award consisted of a trophy and a cash award of $5000, and was based on review by a judging panel that included representatives from the U.S. Geological Survey, British Geological Society, Lamont-Doherty Earth Observatory, Research Data Alliance, Geoscience Australia, and San Diego Supercomputer Center.

Extensibility of the Techniques

The Nimbus data have utility in calculating many environmental parameters dating from the 1960s era, including sea surface temperature, ocean currents, cloud studies, geography, and global change studies, in general. For instance, previously unavailable images and infrared data from Hurricane Camille (1969) can now be researched. Other datasets from the 1960s and 1970s that could benefit from the tools and technology developed in this work include those from the Television Infrared Observations Satellite (TIROS) 5-8 platforms (1963-1967); the Environmental Science Services Administration (ESSA) 1, 3, 5, 7, and 9 platforms (1966-1972); and the Nimbus 4, 5 and 6 missions. (NSIDC already has the Nimbus 7 data. Also, NASA and USGS scientists analyzed the Nimbus 5 record of sea ice in detail, obtaining three-day and monthly average sea ice concentration maps for most of the four-year period 1973-1976 and compiling and analyzing them in Antarctic and Arctic sea ice atlases published in 1983 and 1987, respectively. These Nimbus 5 data are archived at NSIDC.)

Education is the movement from darkness to light.

—Allan Bloom

Also, 1970s imagery from scanning radiometer, infrared, and visible sensors on U.S. Department of Defense Meteorological Satellite Program (DMSP) platforms and the early ESSA program satellite series could potentially extend the length of the climate record at the poles by 50% from the passive microwave 1979–2013 time series.

Other Data Rescue Efforts

The 2013 award faced some stiff competition, with submissions whose data topics ranged from seismic to Seasat SAR to Landsat archives. A full list of the submissions may be found at *researchdata.elsevier.com/datachallenge/submission*.

Other remote-sensing data that could benefit from such recovery efforts include examination of Antarctic data from the Argon series of Declassified Intelligence Satellite Photographs (DISP). Unfortunately, some data are no longer available, such as those from the pre-1973 DMSP platforms.

Concluding Remarks

All these efforts point up three conclusions: First, funding to perform such rescue is virtually (if not actually) impossible to find. In their efforts to find and secure funding, researchers would do well to focus on the utility of the data, rather than the data themselves. As in all things, data are not enough; they must be used.

Second, as noted by **Gary Alcott** [GSFC—*Goddard Earth Sciences (GES) Data and Information Services Center (DISC) Operations Manager*], who took over managing the Nimbus (and other) recovery efforts from John Moses, "…another significant hurdle is lack of documentation, some with regard to mission specifics, but also the lack of commercial off-the-shelf documentation or at least identification. Older equipment and media each had their own unique standards and so one needs to understand what system the tapes were written on. In addition, in cases when they were later copied to other media one needs to understand both the system/media it was copied from and the system/media it was copied to."

All these efforts point up three conclusions: First, funding to perform such rescue is virtually (if not actually) impossible to find. In their efforts to find and secure funding, researchers would do well to focus on the utility of the data, rather than the data themselves. As in all things, data are not enough; they must be used.

The third conclusion is that too many organizations feel the recovery task too daunting and/or that the data are of too poor a quality to answer modern problems. Looking at general phenomena rather than exactness would be the key. The counterargument to this criticism would be that as long as time travel does not exist, whatever the data are, they are better than the voids that exist in the record we currently have.

The results described here amply testify to this approach. Indeed, data from other regions of the globe could be used as a baseline for several latter-day research, for example, to establish what the Amazon Basin looked like before clear cutting, or what Lake Baikal looked like with water in it.

The techniques developed bring dark data back into the light, with contemporary formats, where they can help model long-term climate issues. The processes used in this specific case may be applied to other historic data from other Earth-observing satellites (i.e., not limited to Nimbus instruments) and lead to more dark data rescues in the future.

Acknowledgments

We would like to thank **Tom Wagner** [NASA HQ] for his vision and support for the scanning of the analog data. We would also like to thank **John Moses**, **Gary Alcott**, and **Steve Kempler** for their review and helpful comments.

Suggestions for Further Reading

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NASA Celebrates Earth Day at Union Station

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

Earth's environment is in a constant state of flux. Components of the environment—including the atmosphere, hydrosphere, lithosphere, cryosphere, and biosphere—are all connected and interact in complex ways that we do not fully understand. At NASA, the goal of activities in the Earth sciences is to study the Earth as a system and understand how both natural and human-induced changes impact Earth's environment over time.

In commemoration of Earth Day, an annual event begun in 1970, this year NASA teamed with the Earth Day Network to share stories with the public about how our planet is changing and what the agency is doing to better understand and predict these changes. Events took place at Union Station in Washington, DC, April 21-22. NASA's Hyperwall and Science Gallery exhibits were on display, and a variety of hands-on demonstrations and activities were located in the Main Hall—see **Table 1,** pages 12-13.

[*Left to right*] **Kathryn Roger**, **Mark Polhemus**, **Gwen Camp**, and **Michael Freilich** stand next to the Hyperwall stage and answer questions from enthusiastic onlookers. **Image credit:** NASA/Jason Hong

NASA Administrator Charles Bolden spoke to students and other Earth Day attendees about NASA's bold initiative to launch five Earth science missions in one year, beginning with the Global Precipitation Measurement (GPM) Core mission that launched in February 2014. NASA also plans to launch OCO-2, SMAP, ISS-RapidSCAT, and ISS-CATS before the end of 2014[1]. **Image credit:** NASA/Jason Hong

The *Dynamic Planet*, *Space Racers*, *Science Casts*, *iSat*, and *Eyes on the Earth 3D* demonstrations were located in the *NASA Earth Tent* inside Union Station's Main Hall. **Image credit:** NASA/Jason Hong

One-thousand participants completed 5 or more of the 18 hands-on demonstrations and activities to receive a special take-home NASA information packet. The participants included approximately 300 students from at least 11 schools in the region, at grade levels ranging from elementary to high school.

Presentations in front of NASA's Hyperwall took place on Tuesday, April 22 (the official Earth Day). To kick off the event, **Kathryn Roger** [Earth Day Network—*President*], **John Grunsfeld** [NASA Headquarters (HQ)—*Associate Administrator, Science Mission Directorate*], **Mark Polhemus** [Union Station—*General Manager*], **Michael Freilich** [NASA HQ—*Director, Earth Science Division*],

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[1] SMAP stands for Soil Moisture Active Passive; OCO-2 stands for the second Orbiting Carbon Observatory; ISS-RapidSCAT stands for International Space Station Rapid Scatterometer; ISS-CATS stands for ISS-Cloud-Aerosols Transport System.

and **Gwen Camp** [Federal Emergency Management Agency (FEMA)—*Director, Individual and Community Preparedness*] provided opening remarks and welcomed attendees to the celebration. A series of science presentations using the Hyperwall followed, including a warm and informative welcome from **NASA Administrator Charles Bolden** [NASA HQ]. Nearly 20 scientists, mainly from NASA, used the Hyperwall to present the "big picture" and to help tell fascinating stories about our changing planet —see **Table 2**, page 14.

Students visiting the *Earth Connection via Suborbital Platforms* station were able to touch and feel the materials used to make NASA's scientific balloons. They also observed how the material behaves while the cylinder balloon expands as its altitude increases. **Image credit:** NASA/Jason Hong

At the *Sensors, Circuits, and Satellites* station**, Ginger Butcher** [GSFC] described how instruments onboard the Aura satellite measure gases and particles in the atmosphere. Visitors assembled their own energy-sensing circuit using *littleBits*™ electronic components and then took measurements of light shining through milky water that simulates scattering by gases and particles in the atmosphere. **Image credit:** NASA/Jason Hong

Students enjoyed watching colorful science animations and images on the Hyperwall. **Image credit:** NASA/Jason Hong

Table 1. Hands-on demonstrations and activities took place inside Union Station's Main Hall. *Demonstration/activity available on April 22 only.

Hands-On Demonstrations and Activities	
Title	**Description**
Dynamic Planet	Participants drove via touchscreen interface a spherical display that showed a variety of remote sensing satellite datasets.
Eyes on the Earth 3D: Come Fly with NASA	Participants were immersed in a three-dimensional (3D) visualization experience that let them "fly along" with NASA's fleet of Earth science missions and observe climate data from a global perspective in an immersive, real-time environment.
*What on Earth?	Participants looked closely at Earth photos to determine just "What on Earth" was being shown. They got clues from the Earth Science Picture of the Day.
Space Racers	Space Racers is a new animated television program following young Space Rocket cadets as they soar through the solar system, learning about scientific investigation and observation, space exploration, and the importance of working together as a team.
Science Casts	Participants watched short videos about fun, interesting, and unusual science topics encountered during NASA's science missions.

Table 1. Continued

Hands-On Demonstrations and Activities	
Title	**Description**
iSat	Interactive Satellite Tracker (iSat) is a browser-based application that allows participants to track all NASA Science Satellite Missions and satellites from other agencies.
Calculate Your Carbon Footprint	Participants calculated their carbon footprint and discovered where they fall on the “Green-o-Rometer.” They also received tips on ways to reduce their carbon consumption.
UV Detecting Beads	Participants became “UV detectives” using specially designed ultraviolet (UV)-sensitive beads, and walked away with their very own UV-detection bracelet.
Learning Remote Sensing with Puzzles	Participants helped NASA piece together images taken of Earth from space, including the popular “Earth at Night” image.
Know Your Earth	Participants found out how well they knew their planet as they took quizzes and earned a prize if they correctly answered each question. Through these quizzes, they learned about NASA’s Earth Science activities.
Digital Photo Booth	Participants walked away with a real keepsake: a photo of themselves in a simulated space environment.
Earth Connection via Suborbital Platforms	Participants navigated though NASA science activities and explored various research platforms using two touchscreen kiosks. They could touch and feel the materials used to make NASA’s scientific balloons, and inflate a cylinder made of the balloon film to observe how the material behaves while the cylinder expands as it climbs into the atmosphere.
Are You a Super Sleuth? Take the Earth Imagery Challenge	Participants learned that NASA satellites are taking measurements of planet Earth from space and followed “clues” to solve the “mystery” in the images.
Sensors, Circuits, and Satellites	Participants assembled an energy-sensing circuit and discovered how NASA’s Aura satellite studies the chemistry of our atmosphere.
*Cloud in a Bottle: GLOBE Program	Participants learned about clouds and made a cloud in a bottle. They also played a Cloud Cover Estimation game.
Puzzling Changes in the Land	Participants arranged a time series of Landsat images and/or pieced together a Landsat scene to explore Earth’s changing landscape.
Aviation and the Environment	Participants learned how pilots and astronauts protect themselves as they travel to the very edge of Earth’s atmosphere—and beyond.
Measuring Precipitation: On the Ground and From Space	Participants learned how rain gauges work, how the technology of the Global Precipitation Measurement (GPM) satellite measures precipitation from space, and why it’s important to look at precipitation patterns around the globe.

Dalia Kirschbaum showed model output of Hurricane Sandy on the Hyperwall and described how measurements from NASA’s newly launched GPM Core satellite will help improve atmospheric models. **Image credit:** NASA/Jason Hong

The large nine-screen Hyperwall displayed various Earth science visualizations, including this one that shows how aerosols are transported across the globe. **Image credit:** NASA/Jason Hong

Table 2. Hyperwall presentations took place on Tuesday, April 22 inside Union Station's Main Hall.

Hyperwall Science Stories	
Presentation Title	**Presenter**
NASA's View of Earth from Space	**Jack Kaye** [NASA HQ]
Believe it or Not, Spring is Coming Earlier!	**Compton Tucker** [NASA's Goddard Space Flight Center (GSFC)]
Observing Earth's Poles	**Thomas Wagner** [NASA HQ]
Measuring Rain and Snow for Science and Society	**Dalia Kirschbaum** [GSFC]
Our Planet is Changing: Perspective from Space	**Michelle Thaller** [GSFC]
2014: A Big Year for Earth at NASA	**NASA Administrator Charles Bolden** [NASA HQ]
Continuing the 40-Year Legacy with Landsat 8	**James Irons** [GSFC]
Protecting Earth from Solar Storms	**Lika Guhathakurta** [NASA HQ]
Changes in the Antarctic Peninsula	**Chris Shuman** [GSFC]
Measuring Air Pollution from 440 Miles Above the Earth's Surface	**Edward Celarier** [GSFC]
Eyes on the Earth 3D: Come Fly with NASA	**Kevin Hussey** [NASA/Jet Propulsion Laboratory]
The Universe in Earth Day	**Rachel Osten** [Space Telescope Science Institute (STScI)]
Earth's Biodiversity: The View from Space	**Allison Leidner** [NASA HQ]
Hubble and Spitzer's Frontier Fields	**Dan Coe** [STScI]
Journey to Mars	**Michelle Thaller** [GSFC]
NASA's Search for Other Earth-Like Worlds	**Debra Wallace** [NASA HQ]
Looking Homeward	**Ellen Stofan** [NASA HQ—*NASA Chief Scientist*]
America's PrepareAthon!	**Gwen Camp** [Federal Emergency Management Agency (FEMA)]
Weather Ready and Climate Smart Nation	**Dan Pisut** [National Oceanic and Atmospheric Administration]

Several teachers from schools in the area brought their entire class to Union Station to celebrate Earth Day. The students received information packets after completing several hands-on demonstrations and activities. **Image credit:** NASA/Jason Hong

The many interactions between participants and presenters that took place at Union Station gave NASA representatives the opportunity to celebrate Earth Day with individuals of all ages and from around the globe. The celebration ended at around 4:00 p.m. EST Tuesday evening. NASA looks forward to celebrating Earth Day again in Washington, DC, next year. Details will be provided in a later issue of *The Earth Observer*. ■

Improving Operational Awareness Through ICESat-2 Applications Workshops: Cross-Mission Development

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Introduction

NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) mission is the second generation of the ICESat laser altimetry mission, the first of which operated from January 13, 2003 to August 14, 2010. ICESat-2 is one of the four, *first-tier* missions recommended by the National Research Council's (NRC) Committee on Earth Science and Applications from Space in its 2007 NRC Decadal Survey[1].

Projected to launch in July 2017, ICESat-2 will carry the Advanced Topographic Laser Altimeter System (ATLAS), a micropulse, multibeam, photon-counting altimeter that will continue the important observations of the Earth's ice, land, and ocean surfaces, begun by ICESat. The mission is expected to provide improved elevation measurements over high slope and rough areas of glaciers and ice sheets, and improved ability to detect and measure the elevation of leads in sea ice, which will improve estimates of *sea-ice freeboard*—the amount of ice and snow that protrudes above the water surface.

Just as with the original ICESat data, ICESat-2 measurements are expected to provide added value to science and applications beyond their primary purpose. While ICESat-2's data products are extensive—see **Table** on pages 18–19 for complete list—highest-level data products will be seasonal maps of ice-sheet elevation for Greenland and Antarctica; monthly maps of sea-ice freeboard for the Arctic and Southern oceans; and high-precision elevation measurements over land to determine global vegetation height. ICESat-2 data will also have significant value for determining mean sea surface height, lake and inland water elevations, and cloud and other atmosphere layer heights. High-precision ice, land, and ocean surface information will enable improvements to various applications across areas such as agriculture, climate, disaster mitigation, ecological forecasting, navigation, and water management.

With guidance from the Applications Team, ICESat-2 has developed and implemented a diverse range of mission-specific prelaunch applications activities and strategies for engaging end users. These activities are modeled after the highly successful application strategies implemented for NASA's Soil Moisture Active/Passive (SMAP) mission

NASA's Applied Sciences Program actively seeks to connect NASA's Earth-observing satellite data to societal applications and encourages each mission to come up with a plan to connect its science to user needs[2]. To that end, the ICESat-2 mission established an ICESat-2 Applications Team to organize and develop a mission applications program that will help establish these vital links between ICESat-2 science and society. Its members include **Molly Brown** [NASA's Goddard Space Flight Center (GSFC)—*ICESat-2 Mission Applications Coordinator*], **Vanessa Escobar** [GSFC—*ICESat-2 Mission Applications Deputy Coordinator*], and **Sabrina Delgado Arias** [GSFC—*ICESat-2 Mission Applications Contact Lead*].

With guidance from the Applications Team, ICESat-2 has developed and implemented a diverse range of mission-specific prelaunch applications activities and strategies for engaging end users. These activities are modeled after the highly successful application

[1] The NRC completed its first decadal survey for Earth science, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" (NRC, 2007) in January 2007 at the request of NASA, NOAA, and USGS. It can be found at *www.nap.edu/catalog.php?record_id=11820*.
[2] To learn more about the Applied Sciences Program, see "NASA's Applied Sciences Program—Earth Science Serving Society" in the January–February 2012 issue of *The Earth Observer* [**Volume 24, Issue 1**, pp. 8-11].

strategies implemented for NASA's Soil Moisture Active/Passive (SMAP) mission[3] and are intended to provide a fundamental understanding of how ICESat-2's data products can be best integrated into operational procedures to improve decision-making efforts across multiple disciplines.

The team also facilitates activities that encourage productive dialogue between the project science team, product developers, and user groups to discuss their goals and clarify their needs and requirements. To that end, in August 2013 the ICESat-2 Applications Team organized two meetings with researchers and operational users from the U.S. Naval Research Laboratory at the John C. Stennis Space Center (NRL-SSC), the U.S. Naval Oceanographic Office (NAVO), and the National Ice Center (NIC). These meetings provided an opportunity for participants to identify possible opportunities for collaboration to develop ICESat-2 applications. The remainder of this report will describe these two meetings and their outcomes.

Early Adopter Program

Feedback from users who attended the two meetings described in this article is expected to accelerate the integration of ICESat-2 data products after launch of the satellite. In an effort to leverage this feedback, the ICESat-2 Applications Team also promotes the Early Adopter (EA) program, through which groups and individuals who have a direct or clearly defined need for ICESat-2 data, and/or who have an existing application for the data, and/or who are capable of applying their own resources to use the data, can do so. Potential users should also commit to prelaunch research to demonstrate the utility of ICESat-2 data in their respec tive system or model. Both the NRL-SSC and the NIC have accepted nominations as ICESat-early adopters. The Applications Team is now working with the NRL-SSC as the first ICESat-early adopter and is planning a future session focusing on sea ice that will extend and develop the topics already established from meetings with NIC, NAVO, and NRL-SSC. This future engagement with the user community will focus on the SMAP radar/radiometer product applications and is scheduled for late summer of 2014.

Meeting with NRL-SSC and NAVO

On August 20, 2013, the ICESat-2 Applications Team met with representatives of NRL-SSC and NAVO to discuss the ICESat-2 Mission Applications goals and to answer questions about the Applications Program and Early Adopter Program—see *Early Adopter Program,* left. This meeting was a follow-on to an initial discussion that took place during the SMAP/ICESat-2 Joint Mission Tutorial at the University of Alaska Fairbanks in September 2012. That meeting hosted 28 people, including representatives from the Alaska National Park Service and Bureau of Land Management[4]. At that time, NRL-SSC outlined its needs for additional satellite data, which led to the establishment of a sea ice advisory committee to provide guidance on the synergistic links between SMAP and ICESat-2 data that could be leveraged to develop an operational sea ice thickness product for the NRL-SSC. **Kyle McDonald** [NASA/Jet Propulsion Laboratory] and **Sinead Farrell** [ESSIC, University of Maryland, NASA-GSFC, NOAA-NCWCP] represented the SMAP and ICESat-2 missions, respectively, at the joint mission tutorial, and worked together with the ICESat-2 Applications Team to provide support to NRL-SSC.

The meeting also was an opportunity for continued discussion about potential collaborations between the ICESat-2 mission and SMAP. The following summary is divided into two sections that describe the mission and requirements of each organization, and what ICESat-2 data products the mission representatives anticipate will be most helpful to their respective activities.

NRL-SSC

NRL-SSC is recognized as the world's center for naval oceanography, as it is the largest community of operational and research oceanographers, globally. The main activities at NRL-SSC are research and development (R&D) in oceanography, marine geology, geophysics, geoacoustics, geotechnology, as well as geodesy, mapping, and charting. As

[3] For example, see "SMAP Applications: Improving Communication for the Palo Verde Nuclear Generation Station" in the July-August 2013 issue of *The Earth Observer*, [**Volume 24**, **Issue 4**, pp. 10-11].

[4] Learn more about the SMAP/ICESat-2 Joint Mission Tutorial in the January–February 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 1**, pp. 16-17].

a key player in the development of the Arctic Cap Nowcast/Forecast System (ACNFS) the NRL-SSC finds value in data they can use for model validation and assimilation, for the long term—see the *Arctic Cap Nowcast/Forecast System*.

Since the ACNFS is an operational system of the U.S. Navy, one of the main concerns for the NRL with regard to ICESat-2 is *data latency*—the approximate time it takes from data acquisition on a satellite until it reaches an individual in a usable format—and to identify the latency requirements for NRL-SSC. (These latencies are listed in the Table on pages 18–19.) In particular, NRL-SSC needed to know if it was possible to receive ICESat-2 data in *real-time*, since there is a 72-hour data latency for data to be incorporated into the ACNFS requirement. For NRL-SSC, the real-time requirement means up to three days after ICESat-2 data acquisition.

With data latency clarified, it became possible to have an open dialogue about how NRL-SSC would be able to best use ICESat-2 data products. The ACNFS currently ingests a 25-km (~15.6-mi) resolution ice-concentration product that makes it possible to model sea-ice area and ensure the correct identification of the sea-ice edge. NRL-SSC expressed keen interest in the Arctic/Antarctic Elevation (*ATL07*, 45-day latency) and Arctic/Antarctic Sea Ice Freeboard (*ATL10*, 45-day latency) products—because they will cover nearly the full Arctic region. Other ice thickness observation sources compared by the NRL-SSC are limited to certain regions; thus, the ICESat-2 products have the potential to be extremely useful in validating the ACNFS output.

The NRL-SSC also expressed interest in the ICESat-2 Global Geolocation Photon Data (*ATL03*, 21-day latency) and the Arctic/Antarctic Sea Ice Elevation (*ALT07*, 45-day latency) products for improving the resolution and accuracy of sea ice forecasts by the ACNFS in the *marginal ice zone* (MIZ). Through direct comparison with ACNFS's sea ice geolocation/height measurements, the NRL-SSC could use the ICESat-2 products to train the algorithm used to retrieve the MIZ from the sea ice model.

The NRL-SSC expects that it will use ICESat-2 data products primarily for validation purposes with regards to the MIZ—due to the 21-day and 45-day latency of the products. However, for ice thickness the NRL-SSC could potentially improve the real-time information distribution of the ACNFS by re-initializing the model seasonally, using a 45-day-old data restart field provided by ICESat-2.

Arctic Cap Nowcast/Forecast System

The Arctic Cap Nowcast/Forecast System (ACNFS) is a coupled sea ice and ocean model that produces daily analysis (*nowcasts*, or near real-time information) and forecasts of ice conditions for all sea ice covered areas in the Northern Hemisphere at a horizontal resolution of one-twelfth of a degree.

During its daily run, the ACNFS performs a three-day hindcast to collect all satellite data produced in the last 72 hours, a nowcast, and a seven-day forecast. The ACNFS also produces approximately 50 products including ice concentration, ice thickness, ice drift, sea surface temperature, surface salinity, surface ocean currents, areas of convergence and divergence, and snow thickness.

Information from ACNFS is critical to ice and weather forecasters as they communicate potential storm impacts to coastal communities and supply real-time ice information for navigable guidance to icebreaker ships. It is also of essence for predicting minimum sea ice extent and giving naval warfighters a technological advantage over other countries.

The NRL-SSC, NAVO, and NIC all eagerly anticipate the ICESat-2 launch. A number of its data products can be input into ACNFS and should help improve the accuracy of the nowcasts/forecasts it makes, which will benefit applications that depend on information from ACNFS.

NAVO

NAVO supports national security by providing a range of oceanographic products, focusing primarily on coastal regions. Its modeling system consists of a suite of models that are used to support several Navy missions including anti-submarine warfare, mine warfare, and naval special warfare, as well as fleet operations. The modeling system includes global circulation models, three-dimensional (3D) coastal circulation models, vertical profile models, wave models, and two-dimensional (2D) coastal circulation models. These models require daily global, regional, and local data to describe various properties (e.g., elevations, currents, temperature and salinity, waves and surf) at different dimensions (e.g., deep water, coastal, 2D, 3D) and with different forcings (e.g., variations with time, air-sea exchanges, friction, nesting levels).

Table. ICESat-2 science data products. The rows are shaded light gray to dark gray to represent Level 0 (light gray), Level 1, Level 2, and Level 3 (dark gray) data products. The ICEsat-2 mission will not have a Level 4 (value-added-model) product.

Product Number	Name	Short Description	Latency
ATL00	Telemetry Data	Raw ATLAS telemetry in packet format.	Downlinked 8 times per day
ATL01	Reformatted Telemetry	Parsed, partially reformatted into HDF5, and generated daily. Segmented into several-minute granules.	2 days
ATL02	Science Unit Converted Telemetry	Photon time-of-flight, corrected for instrument effects. Includes all photons, pointing data, spacecraft position, housekeeping data, engineering data, and raw atmospheric profiles. Segmented into several-minute granules.	2 days
ATL03	Global Geolocated Photon Data	Precise latitude, longitude, and elevation for every received photon, arranged by beam in the along-track direction. Photons classified by signal vs. background, as well as by surface type (i.e., land ice, sea ice, land, ocean), including all geophysical corrections (e.g., Earth tides, atmospheric delay). Segmented into several-minute granules.	21 days
ATL04	Calibrated Backscatter Profiles	Along-track atmospheric backscatter data—25 times per second. Includes calibration coefficients for polar regions. Segmented into several-minute granules.	21 days
ATL06	Land Ice Height	Surface height for each beam with along- and across-track slopes calculated for each beam pair. Posted at 40 m (~131 ft) along-track; segmented into several-minute granules.	45 days
ATL07	Arctic/Antarctic Sea Ice Elevation	Height of sea ice and open water leads at varying length scale based on returned photon rate for each beam—presented along-track.	45 days
ATL08	Land Water Vegetation Elevation	Height of ground—including canopy surface—posted at fixed-length scale, for each beam presented along-track. Where data permit, include canopy height, canopy cover percentage, surface slope and roughness, and apparent reflectance.	45 days
ATL09	ATLAS Atmosphere Cloud Layer Characteristics	Along-track cloud and other significant atmosphere layer heights, blowing snow, integrated backscatter, and optical depth.	45 days
ATL10	Arctic/Antarctic Sea Ice Freeboard	Estimate of sea ice freeboard over specific spatial scales using all available sea surface height measurements. Contains statistics of sea surface and sea ice heights.	45 days
ATL11	Antarctica/ Greenland Ice Sheet *H(t)* Series	Time series of height at points on the ice sheet—calculated based on repeat tracks and/or crossovers.	45 days from receipt of last data in product
ATL12	Ocean Elevation	Surface height at specific length scale. Where data permit, include estimates of height distribution, roughness, surface slope, and apparent reflectance.	45 days from receipt of last data in product
ATL13	Inland Water Elevation	Along-track inland water elevation based on specific inland water mask. Where data permit, include roughness, slope, and aspect.	45 days from receipt of last data in product
ATL14	Antarctica/ Greenland Ice Sheet *H(t)* Gridded	Height maps of each ice sheet for each year, based on all available elevation data.	45 days from receipt of last data in product
ATL15	Antarctica/ Greenland Ice Sheet *dh/dt* Gridded	Height change maps for each ice sheet, for each mission year, and for the whole mission.	45 days from receipt of last data in product

Product Number	Name	Short Description	Latency
ALT16	ATLAS Atmosphere Weekly	Polar cloud fraction, blowing snow frequency, and ground detection frequency.	45 days from receipt of last data in product
ATL17	ATLAS Atmosphere Monthly	Polar cloud fraction, blowing snow frequency, and ground detection frequency.	45 days from receipt of last data in product
ATL18	Land/Canopy Gridded	Gridded ground surface height, canopy height, and canopy cover estimates.	45 days from receipt of last data in product
ATL19	Mean Sea Surface (MSS)	Gridded ocean height product.	45 days from receipt of last data in product
ATL20	Arctic/Antarctic Gridded Sea Ice Freeboard	Gridded sea ice freeboard.	45 days from receipt of last data in product
ATL21	Arctic/Antarctic Gridded Sea Surface Height within Sea Ice	Gridded monthly sea surface height inside the sea ice cover.	45 days from receipt of last data in product

A key consideration when developing a model for NAVO is the Navy's operational schedule. At sea, the admiral onboard delivers two briefings daily—a *morning briefing* at 0800 UTC to discuss the day's plans, and an *evening briefing* at 2200 UTC to discuss the next day's plans. Forecasts have to be available to meet the morning schedule and require two-day, three-day, and seven-day products. There is also a daily hindcast that requires a reanalysis using an assimilation of the latest observations. To determine fleet risks[5] for ocean-related actions, the Navy also requires that model capabilities be assessed using uncertainty indicators and model-to-model comparisons. The Hybrid Coordinate Ocean Model (HYCOM), developed by NRL-SSC jointly with the Los Alamos National Laboratory and the University of Miami, is one of the models NAVO uses, and is the ocean model component in the ACNFS. To validate HYCOM's sea surface height, NRL has expressed interest in the ICESat-2 gridded fields of freeboard (*ATL20*) and the ocean height/sea surface height products (*ATL19* and *ATL21*). According to the NRL-SSC, HYCOM's sea surface height currently is constrained only by altimeter data outside the Arctic.

Overall, NAVO would benefit operationally through the improvements that NRL-SSC can make to the ACNFS ice edge forecasts for the entire Arctic MIZ, with the successful implementation of ICESat-2 products in their models. As ICESat-2 Early Adopters, the NRL-SSC will work with Multiple Altimeter Beam Experimental Lidar (MABEL[6]) data and mission-generated simulated data (when available) to better understand which mission products will be most valuable for improving models and forecasting operations.

Overall, NAVO would benefit operationally through the improvements that NRL-SSC can make to the ACNFS ice edge forecasts for the entire Arctic MIZ, with the successful implementation of ICESat-2 products in their models.

Meeting with NIC

The second meeting of the series described here took place on August 23, 2014, in Suitland, MD, with representatives of the U.S. NIC. The U.S. Navy, National Oceanic and Atmospheric Administration, and U.S. Coast Guard jointly operate the NIC, which provides daily, weekly, and special-support snow and ice products for

[5] Products for fleet operations include amphibious landings, nearshore currents, and surf zone fleet risks that describe how the maritime battle space could be affected by the current ocean and atmosphere environments; most fleet support is classified. **Source:** Frank L. Bub, Naval Oceanographic Office, *hycom.org/attachments/082_3_Bub.pdf*.

[6] To learn more, see "MABEL and the ICESat-2 Mission: Photon-counting Altimetry from Air and Space" in the September–October 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 5**, pp. 4-10].

the Arctic, Antarctic, and the U.S. Great Lakes, among other areas, to meet the U.S. Navy's strategic, operational, and tactical requirements. On a daily basis, the NIC provides tailored support (e.g., sea ice concentration products) for submarines and other operational units, as well as ice edge and MIZ identification and forecasts[7]. Their biweekly sea ice analysis data includes hemispheric or regional sea ice thickness and sea ice freeboard measurements. In addition, the NIC provides special support for areas such as Alaska and the White Sea (an inlet of the Barents Sea, on Russia's northwestern coast), and includes seasonal/tailored ice forecasts, high-resolution annotated imagery depicting ice concentrations and ice types, and generates messages delineating areas of fractures, leads, and polynyas[8]. The NIC also performs weekly monitoring of icebergs (length of at least 10 nmi) in the Southern Hemisphere.

During the meeting the NIC expressed interest in the ICESat-2 freeboard and sea ice thickness products to improve the characterization of sea ice, icebergs, and lake ice, and for long-term outlooks for and predictions of melting days. As a user of the ACNFS model, the NIC would also benefit from the potential improvements implemented by the NRL-SSC by employing ICESat-2 data.

These two ICESat-2 Applications meetings provided much-needed opportunities for science team members, product developers, and potential users of ICESat-2 data to discuss objectives and expectations for the mission and data applications.

Key Outcomes

These two ICESat-2 Applications meetings provided much-needed opportunities for science team members, product developers, and potential users of ICESat-2 data to discuss objectives and expectations for the mission and data applications. The meetings provided opportunities to learn about all aspects of the mission including an update on launch status, location of future ICESat-2 data and DAAC services, details about the volume of data that will be downloaded per day, required storage for products, and the frequency bands being used for ICESat-2. The meetings also allowed joint formulation for organizing a future sea ice focus session and the opportunity to learn about how prelaunch research, through the Early Adopter Program, can accelerate the integration of ICESat-2 products into applications after launch.

Specifically, the meeting with NRL-SSC and NAVO provided important feedback and clarification regarding *data latency*. NRL-SSC and NAVO representatives expressed their data latency requirements and defined what *real-time* meant for them. In addition, NRL-SSC and NAVO discussed how direct observations from satellites are highly valued for their respective modeling applications. Opportunities to work with data products in the early stages of ICESat-2 mission development has provided NRL-SSC and NAVO insight as to how longer-latency products can be leveraged. Such feedback is essential to both users and developers to allow them to understand how the products can be used and improved. The ICESat-2 Applications Team, the SMAP Science Team, and the ICESat-2 Science Definition Team will continue engaging with these groups and ensure that they are provided with necessary information for developing operational products.

Working toward this goal, the SMAP and ICESat-2 Applications Coordinators (Molly Brown and Vanessa Escobar) will host a sea-ice-focused meeting at the NRL-SSC with SMAP and ICESat-2 scientists and early adopters to discuss product implementation and the modeling infrastructure needed by NRL-SSC and NAVO as they develop operational products.

Conclusion

As part of the ICESat-2 applications effort, the Applications Team will continue to strengthen the connections between the ICESat-2 mission and NRL-SSC, NAVO, and NIC to help enhance the development of data products towards relevant

[7] To learn more, visit *nsidc.org/noaa/iicwg/presentations/IICWG_2011/Clemente-Colon_Antarctic_Activities_at_the_NIC.pdf.*

[8] To learn more, visit *www.star.nesdis.noaa.gov/star/documents/2009Ice/Day1/KruseNICSymposium_day1.pdf* .

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Blog Log

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

This periodic installment features entries in blogs related to NASA's Earth-science research and fieldwork, and provides links to access the full blog and view color photographs online. In this issue, we highlight two recent entries in *Notes from the Field* blogs and invite you to revisit the *Operation IceBridge* blog, which began a new 11-week Arctic mission on March 10, 2014.

If you know of any blogs that should be shared in the Blog Log—perhaps one of your own—please email Heather Hanson at *heather.h.hanson@nasa.gov*.

[Blog introductions are modified from text in the featured blogs, which are also the sources for the images provided here.]

South Pacific Bio-optics Cruise 2014

Aimee Neeley, from the Ocean Ecology Laboratory (OEL) at NASA's Goddard Space Flight Center, blogs from afar about the experiences of **Joaquin Chaves**, **Scott Freeman**, and **Mike Novak**, all part of OEL's Field Support Group, on their 45-day journey from Hobart, Tasmania to Papeete, Tahiti, aboard the icebreaker *R/V Nathaniel B. Palmer*. During their trek across the South Pacific they have been collecting biogeochemical samples and bio-optical data. These data will eventually be ingested into NASA's Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Bio-optical Archive and Storage System (SeaBASS), and subsequently used for ocean color satellite validation activities.

The group set sail on March 20, 2014. Within six days, they deployed the first *Bio-Argo* float of the campaign. A Bio-Argo can collect measurements of chlorophyll-a and light backscattering in regions where there is little or no chlorophyll-a, in addition to salinity and temperature profiles. Neely explains how deployment of Bio-Argo floats is particularly important for validating ocean color remote sensing data.

To learn more about the science and some of the other fascinating tools oceanographers use today, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/south-pacific-bio-optics-cruise-2014*. You'll also read about the daily life of a seagoing scientist and find out how you can follow their ship track online.

Water intrusion during recovery of the *inherent optical properties* (IOP) package. The IOP package is an assemblage of instruments that collect data for temperature, salinity, depth, and light absorption due to particulate and dissolved components. **Image credit:** NASA

GPM in Japan, the Road to Launch

Ellen Gray, science writer for the joint NASA/Japan Aerospace Exploration Agency (JAXA) Global Precipitation Measurement (GPM) mission, recounts her pre-launch journey with the GPM Core spacecraft and the engineering team that accompanied it during its shipment to Japan. Gray tells the behind-the-scenes story of GPM's road trip to the Tanegashima Space Center in Tanegashima, Japan. During the trip, she posted several photos and told stories of each leg of the journey.

To learn more about the road to launch, and to read about what it's like to live and work in Tanegashima, Japan, visit *earthobservatory.nasa.gov/blogs/fromthefield/category/gpm-road-to-launch*. In addition to sharing the excitement that comes along with a successful satellite launch, you'll learn the story behind the one-eyed Daruma doll.

The NASA GPM transport team in Kitakyushu, Japan, November 24, 2013. **Image credit:** NASA, Michael Starobin

Operation IceBridge

Follow **George Hale**, Science Outreach Coordinator for NASA's IceBridge mission, as he braves the Arctic cold during NASA's latest Operation IceBridge campaign. The NASA P-3 Orion airborne laboratory, carrying instruments and researchers, departed NASA's Wallops Flight Facility in Virginia on March 10, 2014, to embark on an 11-week campaign to monitor elevation in rapidly changing parts of Greenland. Hale provides a bird's-eye view from the plane and shares some of the most recent scientific results from the campaign, including images that show the difference between a dynamic, ocean-terminating glacier and a land-terminating glacier that is essentially dormant. In addition to learning about "a tale of two glaciers," Hale describes activities at the Kangerlussuaq Science Support Center in Greenland, during their several week stay. For the latest updates about what's happening near the Pole, follow *blogs.nasa.gov/icebridge*. ■

Above is an image mosaic from the Digital Mapping System (DMS) aboard the NASA P-3 Orion, showing the terminus of the De Geer Glacier in eastern Greenland. The heavily crevassed terminus is to the left of the image; large icebergs that have calved from the glacier are to the right. **Image credit:** NASA/DMS/Eric Fraim

Improving Operational Awareness Through ICESat-2 Applications Workshops: Cross-Mission Development

continued from page 20

decision-making capabilities for Arctic operations. The ICESat-2 Applications Team will also continue to support joint-mission collaboration between SMAP and ICESat-2 and with the mission Early Adopters to help guide the development of NRL-SSC products. The ICESat-2 Applications Team's responsibility is to grow and enhance the community of data users so that it covers a broad range of decisions and applications, with scales from local (city) to international (policy). With full support from the mission scientists, the Applications Team has the platform to expand and leverage mission capabilities in ways relevant to society. ■

Arthur Hou Memorial Symposium

As reported previously in *The Earth Observer*, **Arthur Hou**, former Principal Investigator for the Global Precipitation Measurement (GPM) mission, passed away on November 20, 2013. Arthur was always the most positive, benevolent, humorous person. He faced his illness with great courage and grace, maintaining his sense of humor and dedication to his life's work right up to the end.

Arthur was not only a superb scientist; he was also a gracious and thoughtful person. He forged international friendships with colleagues and partners around the word, while still finding time to mentor junior and mid-level scientists. His presence, leadership, and generous personality set an example for all of us to follow. He was the consummate team player and will be greatly missed.

Arthur truly made GPM a global effort with a global team. He excelled in providing scientific oversight for achieving GPM's many science objectives and application goals, including delivering high-resolution precipitation data in near real time for better understanding, monitoring, and prediction of global precipitation systems and high-impact weather events such as hurricanes.

To honor his life and work, a memorial symposium has been planned for August 4, 2014 from 1:00 to 5:00 PM at the Embassy Suites–Grand Historic Venue in Baltimore, MD. (The symposium is being held in conjunction with the Precipitation Measurement Mission Science Team meeting that is taking place at the same venue August 4-8.) The agenda includes a series of presentations from Arthur's colleagues representing many periods of his professional career. Further details will be announced closer to the event and posted at *pmm.nasa.gov/arthur*. Meanwhile, please RSVP to **Lisa Nalborczyk** at *lisa.a.nalborczyk@nasa.gov* or (301) 614-5087 if you plan on attending.

Celebrating Ten Years of OMI Observations

Ernest Hilsenrath, University of Maryland, Baltimore County/Global Science and Technology Inc., hilsenrath@umbc.com

The Ozone Monitoring Instrument (OMI) Science Team met at the Koninklijk Nederlands Meteorologisch Instituut (KNMI) (Royal Netherlands Meteorological Institute), in De Bilt, Netherlands, March 11-13, 2014. OMI flies onboard NASA's Earth Observing System (EOS) Aura mission, which will celebrate the tenth anniversary of its launch on July 15, 2014—see *How OMI Became Part of Aura,* next page. This year's meeting was arranged to commemorate the ten years of OMI observations while also providing a glimpse into the next decade of ozone observations. The meeting began with congratulatory remarks from **Gerard van der Steenhoven** [KNMI—*Director General*] and **Ger Nieuwpoort** [Netherlands Space Office (NSO)—*Director*]. Steenhoven acknowledged OMI's contribution to two Dutch ministries: Infrastructure and Environment, and Culture and Science. A number of retired science team leaders and engineers who participated in OMI development also attended the meeting.

After the opening presentations, science team leaders from each country involved with OMI offered their summaries of the past 10 years and hints for the future. These included **Pieternel Levelt** [KNMI—*OMI Principal Investigator (PI) and Dutch Team Leader*], **Johanna Tamminen** [Finnish Meteorological Institute (FMI)—*Finnish Team Leader*], and **Pawan "P.K." Bhartia** [NASA's Goddard Space Flight Center (GSFC)—*U.S. Team Leader*], each of whom recounted the history and key findings of OMI from their organization's perspective and listed achievements in each of Aura's three science themes: *stratospheric ozone trends, climate,* and *air quality*. **Ken Jucks** [NASA Headquarters (HQ)—*Program Manager for the Upper Atmosphere Research Program*] gave the "headquarters perspective" on OMI. He pointed out the importance of international cooperation and informed the team members that Aura has engineering resources to operate until 2023, thereby providing many potential synergies with ongoing EOS missions and with future NASA Earth science missions.

The next two presentations were from Aura's two deputy project scientists: **Joanna Joiner** and **Bryan Duncan** [both from GSFC]. Joiner summarized the many facets of Aura and OMI science and synergy with two other operational Aura instruments[1], and instruments onboard the other Afternoon Constellation, or A-Train, satellites, and with aircraft field campaigns. Duncan discussed how OMI contributed to the overall Aura mission, particularly its contribution to the long record of total ozone, air quality measurements from space, and related applications.

Over the three busy days that followed, the remainder of the presentations dealt with all of the OMI science objectives that are mapped from Aura's science themes, with topics that included ozone trend monitoring, characterizing climate forcing, and assessing global and local observations of air quality. Additional topics included instrument performance and validation, improved and new algorithms, and future missions. These topics provide a framework for the summaries that follow in the rest of this article; full presentations from the meeting can be found at *www.knmi.nl/omi/research/project/meetings/ostm18/pres_ostm18_2014.php.*

Ozone Monitoring

Column ozone amounts: Data for adherence to the Montreal Protocol

Ozone (O_3) monitoring from space began in 1970 with the Backscatter Ultraviolet (BUV) instrument on the Nimbus 4 mission. Since then, measurements have continued with a variety of instruments on NASA, National Oceanic and Atmospheric Administration (NOAA), and other international agency spacecraft. An impetus for continuing these observations has been the Montreal Protocol agreement, enacted in 1987 and amended numerous times since, to monitor O_3 globally and assess the impact of ozone-depleting substances on the stratospheric ozone layer. High-quality O_3 measurements collected over more than three decades have established a record capable of tracking small trends that can be used to test predictions of ozone recovery. Data from OMI have been used to continue this record, as described in several presentations that addressed algorithm and calibration refinements. The results show that OMI continues to provide high-quality data, with no impact to long-term trends.

Once an O_3 dataset is calibrated for a given instrument, challenges remain to make O_3 data from multiple instruments consistent. However, the presentations showed that excellent consistency has been found among various ozone-measuring instruments, including OMI[2]. Extensive comparisons show agreement to better than 1% for bias and trend where the data overlap (from 2005 to 2012).

An example of how this can be accomplished is the application of the newly developed Total Ozone Mapping Spectrometer (TOMS) *Version 9* algorithm, used to reprocess the 36-year data record and make it comparable to data from OMI and the Ozone Mapper

[1] In addition to OMI, there are three other instruments onboard Aura: the High Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS), and Tropospheric Emission Spectrometer (TES). HIRDLS ended its operations in 2008 because the chopper failed.

[2] For example, NOAA's Solar Backscatter Ultraviolet (SBUV)/2 onboard NOAA-16, launched in 2000, and the European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT's) Global Ozone Monitoring Experiment (GOME-2) instruments onboard Metop-A and Metop-B, launched in 2006 and 2012, respectively.

How OMI Became Part of Aura

The original plans for Aura (formerly called EOS CHEM*) called for the Japan Aerospace Exploration Agency (JAXA) to provide a Total Ozone Mapping Spectrometer (TOMS)-type instrument to continue the TOMS ozone record, begun in 1978 with the launch of the Nimbus 7 satellite. JAXA later reconsidered and told NASA it would be unable to provide the instrument. This was obviously a setback as it left a significant gap in the proposed Aura payload. Although the TOMS on the Earth Probe satellite was still operational at the time, NASA wanted to make sure the record would continue well into the future**.

Fortunately, the Netherlands Space Office (NSO), which at that time was the Netherlands Agency for Aerospace Programmes (NIVR), and Dutch Industries, known as Fokker Space at that time, came up with a viable alternative. In fact, the instrument the Dutch proposed to contribute to Aura would exceed the capabilities of TOMS using advanced technologies that had heretofore never been flown on an Earth science mission.

After a year of negotiations, NASA and NIVR signed a Memorandum of Understanding in May 2001 that described all aspects of the collaboration. The agreement stipulated that KNMI would be the principal investigator (PI) institution and would work in conjunction with NASA's Goddard Space Flight Center (GSFC) and the Finnish Meteorological Institute (FMI). Further, KNMI would be responsible for all aspects of science and operations of the OMI instrument. GSFC would provide full support to integrate and operate OMI on the Aura spacecraft and provide a project scientist and a co-PI to collaborate on instrument pre- and post-launch calibration, algorithm development, and data analysis and dissemination. FMI would develop a near-real-time capability for ultraviolet-B (UV-B) data distribution as well as provide essential electronic components for the instrument. Scientists and engineers from the Netherlands, Finland, and the U.S. would be chosen to form the international OMI science team, which has met at least once every year since.

*The story of the development of EOS has been told previously from a variety of perspectives, most recently in *The Earth Observer*: Twenty-Five Years Telling NASA's Earth Science Story in the March–April 2014 issue [**Volume 26, Issue 2**, pp. 4-13].
**NASA launched QuikTOMS on September 21, 2001. Unfortunately the spacecraft failed to reach orbit, which made it all the more important to get a TOMS or TOMS-like instrument on Aura.

Profiler Suite (OMPS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite. The new algorithm compensates for a number of critical parameters that need to be considered when comparing data from two different instruments, e.g., viewing geometry, surface albedo, solar zenith angle, and ozone profile shape. This algorithm will provide homogeneity with future ozone instruments—e.g., the OMPS instruments onboard the two Joint Polar Satellite System (JPSS) platforms, the first of which is scheduled for launch in 2017, with a follow-on mission scheduled for 2022. The new algorithm will also aid in retrieving tropospheric O_3—see the *Ozone in the troposphere: The "hidden" ozone* section on pages 28-29.

Ozone profiles tell how ozone is changing

Algorithms used to derive ozone profiles from both *nadir view* (i.e., from OMI and OMPS) and the *limb view* (i.e., from OMPS) continue to evolve. The nadir-view measurements provide low-resolution vertical profiles in the stratosphere and were found to be comparable to those from the series of Solar Backscatter Ultraviolet Radiometer/2 (SBUV/2) instruments, the latest of which flies on the NOAA-16 polar-orbiting satellite, with measurements dating back to 1984 (NOAA-9). This compatibility means that the data record started by SBUV/2 can continue with OMI, with follow-ons to Suomi NPP and JPSS.

Performance of the ozone profiles from the OMPS limb-viewing instrument was demonstrated to be of high quality, exceeding expectations for accuracy, altitude range, and altitude resolution. The measured profiles were compared with the Microwave Limb Sounder (MLS) on Aura and found to agree in the 5-10% range—see **Figure 1**, next page. In addition to ozone profiles, presentations demonstrated that OMPS can map aerosols and their Aerosol Scattering Index[3], at 673 nm, as well as polar mesospheric, stratospheric, and cirrus clouds. OMPS profiles range from cloud tops to 60 km (~37 mi), which enables the attribution of ozone profile changes due to climate change and to the reduction of ozone-depleting substances mandated by the Montreal Protocol. The O_3 amounts measured in the lower regions of the stratosphere will enable better mapping of *stratospheric–tropospheric exchange,* which impacts climate change as O_3 is transported downward to the troposphere, where it becomes an important greenhouse gas. Finally, the improved vertical and spatial accuracy and coverage over previous ozone sounders, along with the improved algorithm, will enable better determination of tropospheric O_3—see the *Air Quality* section on page 27.

[3] Aerosol scattering tends to cool the atmosphere while aerosol absorption tends to heat the atmosphere.

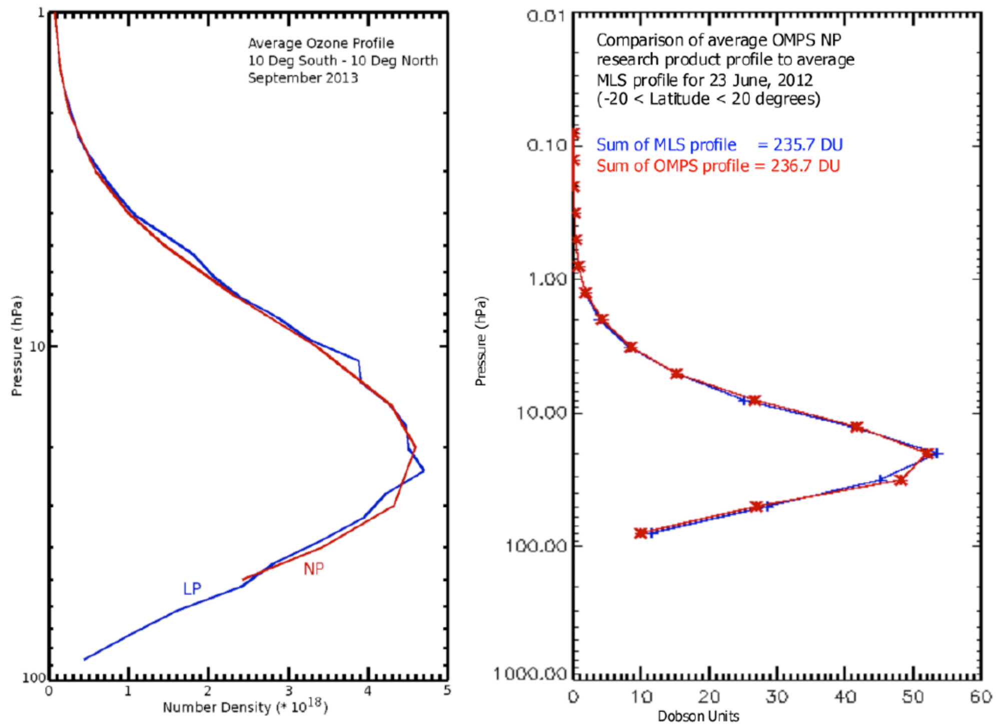

Figure 1. *A comparison of OMPS and MLS ozone profiles.* The graph on the left compares average ozone profiles for September 2013 (from 10° S to 10° N) computed using data from OMPS nadir and limb measurements. The graph on the right also shows OMPS nadir profiles, but this time compared to Microwave Limb Sounder (MLS) limb profiles for June 23, 2012. Agreement among all the measurements is at the 5% level or better. **Image credit:** Pawan Bhartia [GSFC] and Richard McPeters [GSFC]

Climate Research

Aura's second science theme is climate research, which often draws upon data from multiple instruments on Aura and other A-Train satellites, among many others. Several science team members presented their algorithm improvements and subsequent results on tropospheric ozone and aerosol variability. Aerosols, whether absorbing or reflecting, are critical uncertainties in climate forcing, since such forcing could either be positive or negative depending on the aerosol types and characteristics. Possible explanations for the observed hiatus in the longer-term global temperature rise over the past decade include changes in solar activity, changes in ocean circulation, and increased aerosol loading from pollution, either *anthropogenic* (resulting from human activity) or from natural sources, such as volcanoes.

Sulfur Dioxide: An aerosol precursor with a role in climate and air quality

Surveys of sulfur dioxide (SO_2) sources from large-scale volcanic eruptions and lower-level volcanic emissions demonstrated OMI's global SO_2 mapping capability. Byproducts of SO_2 emissions are aerosols, which upon reaching the stratosphere become long-lived and subsequently affect climate forcing. Researchers compared data from OMI with data from ground-based and aircraft-mounted instruments to validate the OMI SO_2 observations. The goal is to update global emission inventories and to include more accurate values from volcanic sources.

There was also a presentation about an improved OMI SO_2 algorithm that employs *principal component analysis* (PCA) of the full UV spectral range covered by SO_2 absorption. One feature of the improved algorithm is better temporal resolution and sensitivity. Furthermore, processing speed is more than an order-of-magnitude faster than the present algorithm, which is needed to accommodate future OMI-type instruments with higher data rates. Other improvements include fitting spectral windows that can be adjusted to optimize sensitivity, and improved continuity among instruments, thereby avoiding unique radiance correction schemes. Examples showed better sensitivity to surface emissions from power plants, improved volcanic plume tracking, and increased comparability between OMI and OMPS data.

Aerosols: The wild card that can go either way

A poster-based presentation described how OMI aerosol data can be used to map the spatial and temporal distributions and optical properties of absorbing aerosols, and subsequently how to use these data to better constrain the representation of absorbing aerosols in aerosol transport models used in climate models. OMI measurements will be compared to a recent aerosol reanalysis (MERRAero[4]) that employs an aerosol transport model with aerosol loadings constrained by Moderate Resolution Imaging Spectroradiometer (MODIS) observations from Aura and the earlier-launched Terra platforms. Simulated OMI radiances

[4] MERRAero stands for Modern Era Retrospective Analysis (MERRA) for Aerosols; MERRA is GSFC's Global Modeling and Assimilation Office's data reanalysis effort.

using the aerosol distributions from the reanalysis will be compared to the observed radiances, suggesting where improvements can be made to the input model's aerosol optical properties. After improvements, the simulated radiances will be used as inputs to the OMI aerosol retrievals to assess the quality of these observations on a global scale.

The operational OMI Aerosol Optical Depth and Single Scattering Albedo algorithm (OMAERUV) was tested for comparability and long-term stability with ground-based and satellite measurements. The OMI values are quantitatively consistent with Aerosol Robotic Network (AERONET) and SKYNET[5] ground-based observations. The correlative analysis over the OMI sensor lifetime shows excellent long-term stability. OMAERUV uses a Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)-based aerosol layer height climatology and real-time Atmospheric Infrared Sounder (AIRS) carbon monoxide (CO) data for aerosol-type identification[6]. Including the AIRS CO measurements allows detection of heavy aerosols in regions covered by clouds—as shown in **Figure 2**. Future work includes combining data from Aqua's MODIS and OMI to further improve cloud contamination screening.

Clouds: Either positive or negative feedbacks, depending on where and what they are

Clouds are a major driver of climate change. Recent satellite data show that global cloud heights have slightly decreased over the past decade. In general, low clouds provide negative feedback (cooling) while high-cloud feedbacks become positive (heating). Studies using data from MODIS, CloudSat, and OMI have revealed that clouds have multiple surfaces, which complicate OMI retrievals in the troposphere. Cloud optical depths also control the amount of harmful UV radiation reaching Earth's surface. A preliminary analysis of OMI and MODIS cloud optical depths showed that UV biases can be high or low, depending on whether the cloud is made of ice or water, respectively.

Solar Irradiance: It drives everything, so it has to be right

The sun is the primary driver for Earth's climate. While variability of the *total solar irradiance* (TSI) is small, its 11-year-cycle has been detected in several climate parameters, such as sea surface temperatures and stratospheric winds, without complete explanation. Therefore, accurate measurements of TSI and its variability are needed for climate model predictions. The solar UV

[5] AERONET is an international network of sunphotometers organized to study atmospheric aerosols. More information may be found at *aeronet.gsfc.nasa.gov*. SKYNET is an observation network organized to explore atmospheric aerosol-cloud-radiation interactions. More details may be found at *www.cr.chiba-u.jp/~irielab/skynetws*.

[6] CALIOP is an instrument onboard the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite; AIRS is an instrument onboard Aqua.

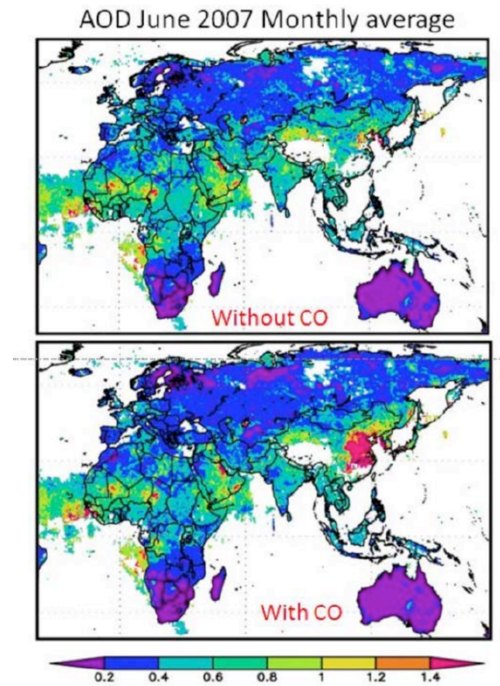

Figure 2. Incorporating CO measurements from AIRS onboard Aqua into the operational OMEARUV allows identifying heavy aerosol loads that would otherwise be indistinguishable from cloud contamination. The two maps compare aerosol optical depth measurements from OMEARUV for June 2007 without AIRS CO measurements included [*top*] to those obtained when AIRS CO is included [*bottom*]. Notice that the area of pollution over eastern China becomes much more apparent when AIRS CO data are included. **Image credit:** Torres, O. *et al., Atmospheric Measurement Techniques*, 6, 3257-3270, 2013.

component varies more than the total irradiance, so it stands to reason that changes in solar UV may have a disproportionate impact on climate, and therefore must also be carefully measured.

Solar UV variation also has a large impact on atmospheric composition through *photolysis*—the process through which ozone is created as oxygen molecules break down in the presence of UV light—and therefore has been studied intensely for many years. Until fairly recently, however, this required use of solar proxies; only in the last few decades have direct satellite measurements been made.

Since OMI's atmospheric composition measurements are dependent on measurements of reflected sunlight, OMI has been measuring incoming *solar spectral irradiance* (SSI) for nearly 10 years. (That is just a little shorter than the 11-year SSI record compiled by the Solar Radiation and Climate Experiment (SORCE) mission, launched in 2003.) OMI's long-term stability, when combined with very careful analysis of the short-term spectral irradiance associated with the 28-day solar rotation, allows scientists to use its data to determine UV solar irradiance trends over the 11-year solar cycles. OMI's solar rotation data agree very well with data from the Global Ozone Monitoring Experiment 2 (GOME-2). The recent study shows that solar irradiance variations between 280 nm and 340 nm are smaller than those measured by SORCE, but agree better with the Naval Research Center's SSI model—see **Figure 3**. There are ongoing discussions between the OMI and SORCE teams on this important result.

Air Quality

Measuring air quality using space-based remote sensing instruments and algorithms is an emerging area of study. The Environmental Protection Agency (EPA) and state air quality offices are beginning to use satellite observations for trend detection, emission estimates, reconciling nonattainment areas, and forecasting. OMI is the first instrument to fly on a U.S. satellite that measures the gas components of air quality; it also has the highest spatial resolution among all instruments ever flown. OMI measures O_3, SO_2, nitrogen dioxide (NO_2), and aerosols, four of the EPA's six Criteria Pollutants—leaving out only lead (Pb) and CO. Ground-level ozone measurements are required for pollution studies and monitoring, but OMI measures the column amount throughout the troposphere, which remains an obstacle for EPA applications. However, OMI measures precursors of ozone pollution such as NO_2, formaldehyde (HCHO), and glyoxal ($C_2H_2O_2$), which are indicators of *volatile organic compounds* (VOC). Several presentations during the meeting addressed VOCs; the reader is encouraged to visit the OMI science team website—*www.knmi.nl/omi/research/project/science_team_us.php*—for more information.

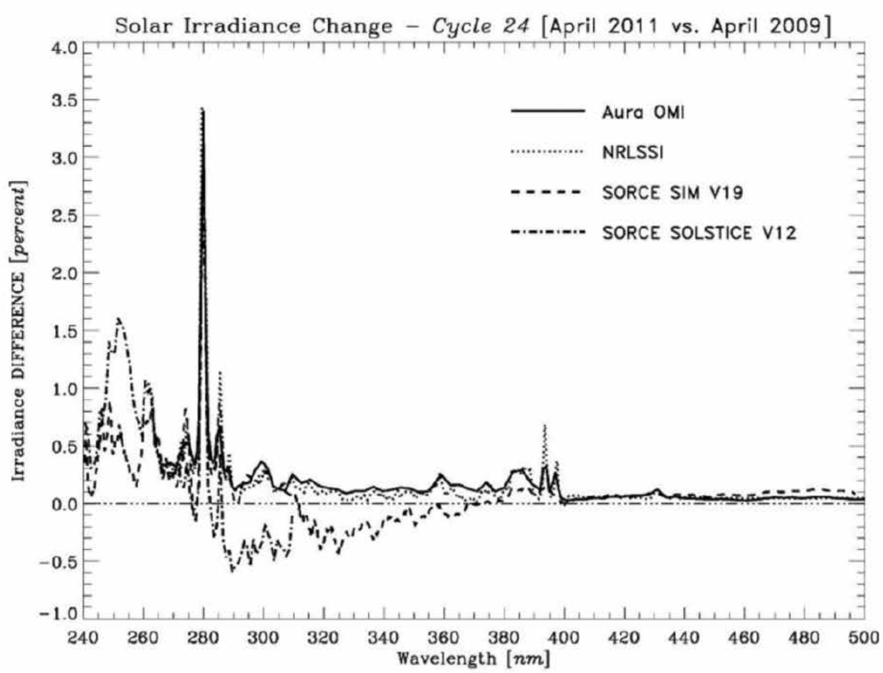

Figure 3. Comparison of changes in spectral irradiance data from April 2009 to April 2011 (Solar Cycle 24) measured by OMI [*solid line*], the Spectral Irradiance Monitor (SIM) [*dashed line*], the Solar Stellar Irradiance Comparison Experiment (SOLSTICE) [dashed–dotted line] instruments on the Solar Radiation and Climate Experiment (SORCE) satellite, and the Naval Research Center's Solar Spectral Irradiance (NRLSSI) model [*dotted line*]. **Image credit:** Marchenko and DeLand, "Solar Spectral Irradiance Changes During Cycle 24," in review at *Astrophysical Journal, 2014*.

O_3 finds itself at the nexus of climate change and air quality research; it is both a greenhouse gas and one of EPA's six criteria pollutants. While O_3 in the stratosphere is beneficial because it blocks harmful UV radiation from reaching Earth's surface, excess O_3 at ground level can have detrimental impacts on public health. Hence the primary focus of the air quality discussions was on tropospheric O_3, and included new results about improving emission inventories, detecting air quality trends, improved algorithms, and showing the excellent calibration stability over Aura's 10 years in orbit.

Sulfur Dioxide: A potent pollutant near the ground

Power plants are the main anthropogenic sources of SO_2, which causes acid rain. Further, SO_2 emitted from power plants interacts with water in the atmosphere to form sulfuric acid (H_2SO_4), which manifests as noxious aerosol clouds near the ground. While these clouds are not as long lived as those resulting from volcanic eruptions, they can still pose significant public health risks when they occur. While SO_2 trends are downward in the U.S., in rapidly developing countries in Asia the trend is upward. OMI can detect sources that still do not meet air quality standards and measure the source of upward trends from the increasing number of power plants being built in Asia. Domestically, there was a significant drop of SO_2 in Maryland in 2010 when the Healthy Air Act was implemented. This change was measured locally from aircraft data and regionally by OMI. A remaining concern, however, is that there is not a corresponding drop in small particulate matter measuring 2.5 µm or less ($PM_{2.5}$)—important because such particles can produce cardiovascular and/or respiratory distress.

While the entire OMI SO_2 dataset has not yet been reanalyzed using the novel PCA discussed in the *Climate Research* section above, the presentations revealed some significant results: OMI data have revealed SO_2 increases over the Canadian tar sands while showing decreases from power plants in the eastern U.S.—particularly over the Ohio valley—in the past decade. OMI SO_2 data are being homogenized with European satellite data for validation and improved coverage.

Nitrogen Dioxide: Pollution precursor culprits revealed

NO_2 is a brownish gas that is corrosive and toxic and is also a precursor of ground-level small-sized particulate matter and of O_3 through a complex path of chemical reactions triggered by sunlight. In addition, NO_2 is part of the highly reactive family of gases, generically referred to as NO_x, that result from combustion at high temperatures. Its principal anthropogenic sources are motor vehicle exhaust and power plants. NO_2 is detectable from space because of its unique spectral signature that can be differentiated from other atmospheric constituents. However, the concentrations are small, sensitive to surface reflectivity, and highly variable, spatially and temporally. Therefore, remote sensing of NO_2 is a continuing challenge. The presentations on this topic focused on case studies, algorithm refinements, and the detection of ten-year trends.

A summary presentation described how NO_2 concentrations over the tar sands in Alberta, Canada are increasing at a rate of 10% per year—consistent with the increase in oil mining operations. Another important area of interest for OMI NO_2 data use is to improve *emission inventories*—a measure of pollutants discharged into the atmosphere from combined individual sources. In some cases, the data calculated from OMI observations agree reasonably well with standard inventories, but in others, they do not. One aid to resolve these discrepancies is the use of chemical transport models that help researchers understand the inconsistencies between observed OMI NO_2 trends and decreases in emissions.

Other studies are underway that attempt to use OMI data directly, without models. By analyzing the downwind patterns of NO_2 over megacities for different wind conditions, lifetimes and (subsequently) emissions amounts can be calculated. Several studies are underway to improve NO_2 algorithms by testing them with similar instruments on other satellites (e.g., GOME-2), and by developing algorithms with advanced capabilities for upcoming missions, as will be discussed below.

One technique, called *cloud slicing*, employs cloud top heights and yields layer NO_2 amounts in the *free troposphere* (the upper part of the troposphere above the boundary layer), produced by lightning and brought in via long-range transport. One analysis indicated that these amounts are independent of the NO_2 concentration in the lower troposphere, where the primary source is combustion. Another study relevant to future instruments demonstrated how data artifacts due to instrument peculiarities can be removed, which results in better consistency among observing spectral windows. Another presentation showed how cloud and aerosol corrections, spectral window selection, and air mass factors were dependent on increasing amounts of NO_2.

Ozone in the troposphere: The "hidden" ozone

Observing tropospheric O_3, particularly in the boundary layer, is a continuing challenge for space-based observations. O_3 is the primary component of polluted air at this level, but stratospheric O_3 concentrations are about 10 times larger than those observed in the lower troposphere, and current instruments struggle to distinguish the small amounts at lower levels from total column values. There are several ongoing efforts to more accurately retrieve O_3 in the troposphere, and in particular to be able to discriminate O_3 in the boundary layer and in the free troposphere, where O_3 becomes a greenhouse gas. One presentation on measuring O_3 above the boundary layer over OMI's 10-year lifetime described O_3 stratospheric–tropospheric exchange and correlations with tropical cycles, observations in deep convective clouds, and anthropogenic O_3 sources.

A complementary study showed a clear correlation of OMI-observed tropospheric O_3 over eastern China, presumably in the boundary layer, with increased amounts of CO measured by the Measurements of Pollution in the Troposphere (MOPITT) between the 0 and 3 km (0 and ~1.9 mi) altitude range, with strong evidence from aircraft measurements, of transboundary pollution to Korea and Japan—see **Figure 4**. The

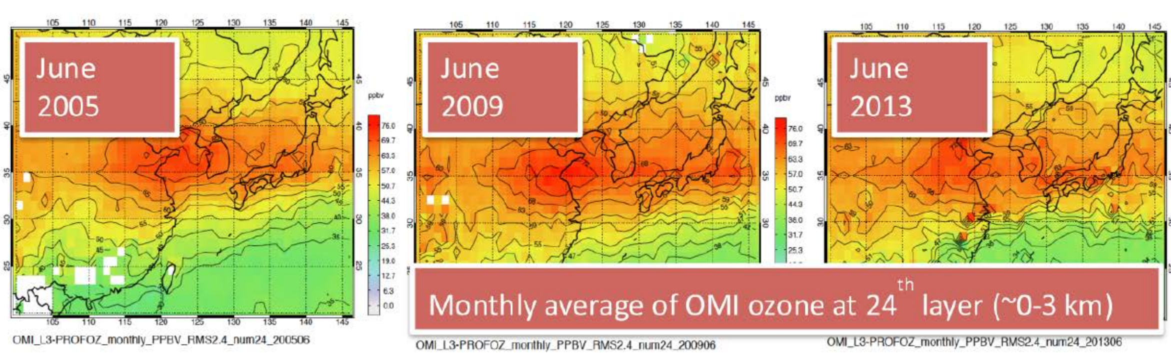

Figure 4. The maps show monthly averages of O_3 between 0 and 3 km (0 and ~1.9 mi) as measured by OMI for June 2005 [*left*], June 2009 [*middle*], and June 2013 [*right*]. Ozone builds up in the planetary boundary layer over eastern China; the prevailing westerlies in the free troposphere transport it into Korea and Japan. **Image credit:** Hayashida *et al.*, manuscript in preparation for *Geophysical Research Letters*, 2014

correlation of OMI and aircraft data at this altitude range was on the order of 0.9, indicating that OMI can measure tropospheric O_3 exiting the boundary layer and transported into the upper troposphere.

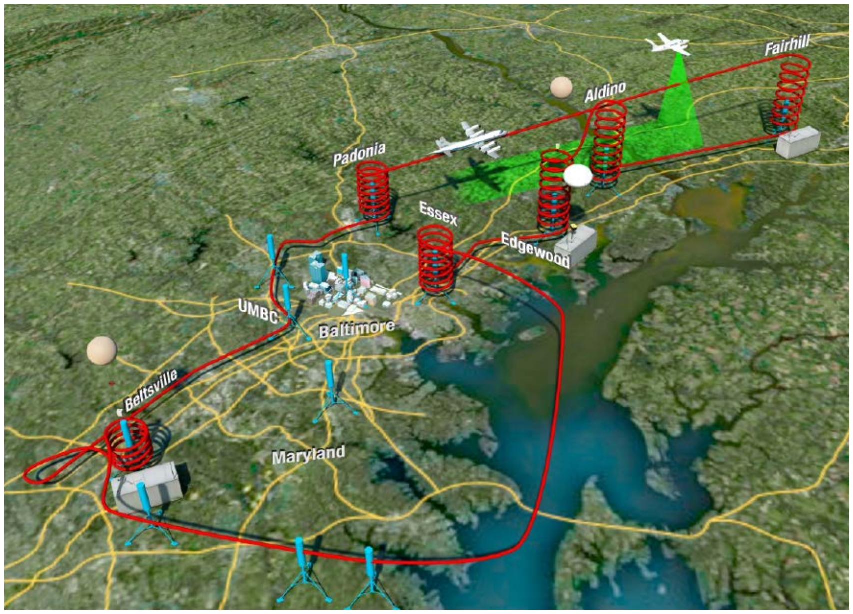

Figure 5. DISCOVER-AQ fourteen day observing strategy for July 2013 over the Baltimore, MD/Beltsville, MD/Washington, DC area. The aircraft ground track has been overlaid on a map of the region showing major roadways. The vertical spirals represent locations where aircraft made descents to measure atmospheric constituents at different levels—to construct profiles. Ground stations are indicated by the towers. **Image credit:** Timothy Marvel [NASA's Langley Research Center]

A novel result that demonstrated synergy of Aura instruments used Aura's Tropospheric Emission Spectrometer (TES)-derived tropospheric O_3 and OMI NO_2 measurements, along with a chemical transport model for the period 2005 to 2010. Tropospheric O_3 was calculated from the model using derived OMI NO_2 emissions and then compared with the TES-derived O_3 amounts; the results showed good agreement. A byproduct of this study showed that the increased emissions of pollution over China increased the free tropospheric O_3 amount over the western U.S. by a factor of two due to the strong westerly transpacific winds during spring.

Using the OMI Algorithms on OMPS

Despite the fact that the priority for OMPS on Suomi NPP was to measure stratospheric O_3 only to meet NOAA requirements, OMI algorithms for measuring the array of atmospheric constituents discussed above have been put to use on OMPS data. For example, the application of the SO_2 algorithm to OMPS clearly showed SO_2 hot spots and their daily variations over the Ohio Valley, eastern China, and from most volcanic emissions, worldwide. The OMI NO_2 algorithm was also tested on OMPS, and also showed seasonal variations similar to those detected by OMI. Other results showed excellent agreement of monthly zonal averages between OMI and OMPS, thereby assuring the needed consistency between the two datasets to detect global trends in air quality across satellite missions.

Validation

Validation of OMI data products is an ongoing process, but significant progress already has been made. Uncertainties have been quantified and systematic effects characterized. Since 2011, 18 papers on validation results have been published; several more have been submitted or are in preparation. Gaps in validation results have been identified for almost all products. The main issues are with the latest versions of the KNMI cloud products, HCHO, bromine monoxide (BrO), and chlorine dioxide (ClO_2)—particularly over snow/ice and under partly cloudy conditions.

DISCOVER-AQ: A field campaign to validate OMI and other instruments

A major NASA aircraft-based field campaign is called *Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality* (DISCOVER-AQ[7]). It is designed to improve the use of satellites to monitor air quality for public health and environmental benefit. Specific regions in the U.S. were selected to measure the horizontal, vertical, and temporal variations of key air-polluting substances. Measurements were conducted using two NASA aircraft, several ground stations, and balloons, and then correlated with OMI and other instruments on the A-Train satellites. The key objectives of the four-mission campaign are to quantify the relationships between tropospheric columns amounts as measured by the satellites to ground-level amounts of air constituents of interest to the air quality data user, improve satellite retrievals, and advance regional air quality models and forecasts. The aircraft deployment strategy and location of ground stations are illustrated in **Figure 5**. Key findings from the

[7] DISCOVER-AQ has been discussed previously, most recently in "NASA's Venture Continues: An Update on the EV-1 Investigations," *The Earth Observer*, July–August 2013 [**Volume 25**, **Issue 4**, pp. 19-32].

first mission over the Baltimore, MD/Beltsville, MD/Washington, DC area include these:

- The boundary layer is not as well mixed as may have been expected.
- Satellite column and surface-measured NO_2 are not well correlated, but correlations with O_3 are much better.
- There is close agreement between OMI-derived, ground-based remote sensors, and aircraft-based column levels at most sites.
- Regional NO_2 is important for O_3 production (as a combination of sources and sinks), and spatial gradients are weaker than expected from model results.
- Levels of mobile-source NO_x emissions used in regional models are too large.

Follow-on flights sought to quantify the relationship of satellite measurements to ground-level measurements. Models are being used to supplement this work as additional measurements and analyses continue. Subsequent flights have taken place in the San Joaquin Valley, CA, in January 2013, and Houston, TX, in September 2013. A fourth flight is planned for the Front Range, CO, in July 2014. The campaigns include investigators from NOAA, EPA, several universities, regional air quality consortiums, and three NASA field centers (GSFC in MD, Langley Research Center in VA, and Ames Research Center in CA).

Instrument Performance—A Key to Data Product Quality

The OMI instrument has been essentially problem free and has been shown to be stable over time with only moderate correction updates needed for stray light and wavelength shift. The exception to this is the *charge-coupled device* (CCD) detector *row anomaly*, a result of which a part of the instrument field-of-regard became obscured in 2008 by an as yet to be identified external obscuration. The loss of spatial data from the row anomaly results in two-day coverage rather than the planned one-day coverage. The instrument mechanisms and temperature remain within specifications, and for all practical purposes the instrument is operational full time (99.99%); the last time instrument commands were necessary was in June 2012. Daily updates of background images to correct for small increases in dark current and automatic updates of pixel quality maps are included in the engineering diagnostics. After 10 years, 0.8% of pixels are unusable (dead) and 2.0% have reduced performance, exceeding expectations.

Instrument sensitivity is very stable and detector dark current noise remains within specifications. Radiometric calibration is checked with a multisurfaced solar diffuser and is very stable. Radiance trends, determined by observing icecaps, show degradation for all three channels to be less than 1% over 10 years. Calibration lamps exceed their long-term stability specification. The 10-year trend in wavelength calibration is less than 0.015 nm in the UV and visible channels.

Future Missions and Societal Benefits

OMI's success has paved the way on both sides of the Atlantic for new missions; descriptions of these missions closed out the meeting. The application of OMI algorithms to the OMPS flying on Suomi NPP and for future JPSS missions, as discussed earlier, has shown that while not originally planned, air quality measurements are possible from U.S. operational satellites. Europe's Sentinel 5 Precursor[8], slated for launch into polar orbit in the 2016 time frame, will carry an OMI-type instrument that will include infrared channels to augment tropospheric measurements. NASA's launch in the 2019 time frame of the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission[9] will employ technology and algorithms developed for OMI and GOME-2 for air quality observations from geostationary orbit. It is anticipated that, while their orbital lifetimes overlap, TEMPO will become part of a constellation of three air quality instruments flying on geostationary satellites that also includes the Korean Geostationary Environment Spectrometer (GEMS)/Multi Purpose Geostationary Satellite (MP-GeoSat), scheduled to launch in the 2017-2018 window, and the European Sentinel 4 mission, scheduled for launch in 2024. (All three of these missions use similar technology.) Because of their geostationary orbits, this constellation will provide hourly coverage during daylight hours over much of the Northern Hemisphere. Sentinel 5, planned for launch in 2020, will be an enhanced, polar-orbiting "precursor" mission. The atmospheric composition measurements from Sentinel 5 will continue the data record that began with Envisat in 2002.

Summary

The OMI Science Team members were very pleased with the instrument's performance after 10 years in orbit; based on this performance, the team members considered what the next decade might bring. Trend data for both the stratosphere and troposphere were uncovered, and refinement of subsequent long-term data will continue. The three days of presentations showcased new applications of OMI data for aerosols, clouds, and pollution. The team expects to apply the lessons learned from OMI to similar instruments in upcoming missions in both the U.S. and Europe. ■

[8] To learn more, see "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July-August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15].

[9] To learn more, see "NASA Ups the TEMPO on Monitoring Air Pollution" in the March-April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10-15].

NASA-CNES Move Forward with Global Water and Ocean Surface Mission

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

NASA and the French space agency Centre National d'Études Spatiales (CNES) have agreed to jointly build, launch, and operate a spacecraft to conduct the first-ever global survey of Earth's surface water and to map ocean surface height with unprecedented detail.

NASA Administrator Charles Bolden [NASA Headquarters (HQ)] and **Jean-Yves Le Gall** [CNES—*President*] signed an agreement May 2, 2014, at NASA Headquarters to move from feasibility studies to implementation of the Surface Water and Ocean Topography (SWOT) mission. The two agencies began initial joint studies on the mission in 2009 and plan to complete preliminary design activities in 2016, with launch planned in 2020.

NASA Administrator Charles Bolden [*left*] and **Jean-Yves Le Gall** [*right*] sign an agreement to move from feasibility studies to implementation of the SWOT mission, May 2, 2014 at NASA Headquarters. **Image credit:** Bill Ingalls [NASA HQ]

"With this mission, NASA builds on a legacy of Earth science research and our strong relationship with CNES to develop new ways to observe and understand our changing climate and water resources," said Bolden. "The knowledge we'll gain from SWOT will help decision makers better analyze, anticipate, and act to influence events that will affect us and future generations."

SWOT is one of the NASA missions recommended in the National Research Council's 2007 decadal survey of Earth science priorities. The satellite will survey 90% of the globe, studying Earth's lakes, rivers, reservoirs, and ocean to aid in freshwater management around the world and improve ocean circulation models and weather and climate predictions.

This new agreement covers the entire life cycle of the mission, from spacecraft design and construction through launch, science operations, and eventual decommissioning. NASA will provide the SWOT payload module, the Ka-band Radar Interferometer (KaRIn) instrument, the Microwave Radiometer (MR) with its antenna, a laser retroreflector array, a GPS receiver payload, ground support, and launch services. CNES will provide the SWOT spacecraft bus, the KaRIn instrument's Radio Frequency Unit (RFU), the dual frequency Ku/C-band Nadir Altimeter, the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receiver package, satellite command and control, and data processing infrastructure.

NASA and CNES began collaborating on missions to monitor ocean surface changes in the 1980s. From the TOPEX/Poseidon mission launched in 1992 to the Jason-1 mission launched in 2001 to the Jason-2/Ocean Surface Topography Mission launched in 2008, the collaboration has produced critical information on sea-level rise as well as El Niño causing worldwide impact[1].

The SWOT mission will use wide-swath altimetry technology to produce high-resolution elevation measurements of the ocean surface and the surface of lakes, reservoirs, and wetlands. A more complete inventory of Earth's lakes and the changing amount of water they hold will yield improved assessments of how climate-induced changes can impact freshwater resources worldwide. Only 15% of lakes around the world are currently measured from space. SWOT will inventory a majority of medium-to-large lakes as well as the discharge volumes of rivers.

SWOT will be able to measure the ocean's surface with 10 times the resolution of current technologies. This will allow scientists to study small-scale features that are key components of how heat and carbon are exchanged between the ocean and atmosphere. The higher resolution of SWOT observations also will enable researchers to compute the velocity and energy of ocean circulation. A better understanding of small-scale ocean currents and eddies is also important to impacts on coastal regions such as navigation, erosion, and dispersing pollutants.

For more information on the SWOT mission, visit *swot.jpl.nasa.gov*. ■

[1] **Editor's Note**: NASA and CNES will also collaborate on Jason-3 (planned for 2015) and two Jason-Continuity of Service (CS) missions (launch dates TBD).

How Does Your Garden Glow? NASA's OCO-2 Seeks Answer

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

Science is full of *serendipity*—moments when discoveries happen by chance or accident while researchers are looking for something else. For example, penicillin was identified when a blue-green mold grew on a Petri dish that had been left open by mistake.

Now, satellite instruments have given climate researchers at NASA and other research institutions an unexpected global view from space of a nearly invisible fluorescent glow that sheds new light on the productivity of vegetation on land. Previously, global views of this glow from chlorophyll were only possible over Earth's ocean, using NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Terra and Aqua spacecraft.

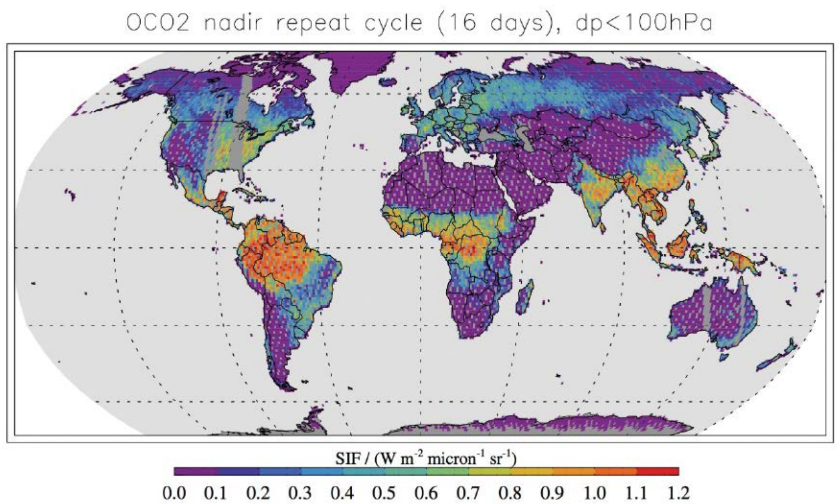
When the Japanese Greenhouse gases Observing SATellite (GOSAT), known as "IBUKI" in Japan, launched into orbit in 2009, its primary mission was to measure levels of carbon dioxide (CO_2) and methane (CH_4), two major heat-trapping greenhouse gases in Earth's atmosphere. However, NASA researchers, in collaboration with Japanese and other international colleagues, found another treasure hidden in the data: fluorescence from chlorophyll contained within plants. Although scientists have measured fluorescence in laboratory settings and ground-based field experiments for decades, these new satellite data now provide the ability to monitor what is known as *solar-induced chlorophyll fluorescence* on a global scale, opening up a world of potential new applications for studying vegetation on land.

A "signature" of photosynthesis, solar-induced chlorophyll fluorescence is an indicator of the process by which plants convert light from the sun into chemical energy. As chlorophyll molecules absorb incoming radiation, some of the light is dissipated as heat, and some radiation is re-emitted at longer wavelengths as fluorescence.

Researchers who study the interaction of plants, carbon, and climate are eagerly awaiting fluorescence data from NASA's Orbiting Carbon Observatory-2 (OCO-2) satellite mission, scheduled to launch in July 2014. The instrument onboard OCO-2 will make precise measurements of CO_2 in the atmosphere, recording 24 observations a second versus GOSAT's single observation every four seconds, resulting in almost 100 times more observations of both CO_2 and fluorescence than GOSAT.

"Data from OCO-2 will extend the GOSAT time series and allow us to observe large-scale changes to photosynthesis in a new way," said **David Schimel** [NASA/Jet Propulsion Laboratory (JPL)—*Carbon and Ecosystems Research Program, Lead Scientist*]. "The fluorescence data may turn out to be a unique and very complementary dataset of the OCO-2 mission."

"OCO-2's fluorescence data, when combined with the observatory's atmospheric carbon dioxide measurements, will increase the value of the OCO-2 mission to NASA, the U. S., and the world," said **Ralph Basilio** [JPL—*OCO-2 Project Manager*].



Shown here is a simulated map of typical fluorescence data expected from OCO-2. The information will be used to infer details about the health and activity of vegetation on the ground. **Image credit**: JPL/NASA's Earth Observatory

Turning the Sun Off

Being able to see fluorescence from space allows scientists to estimate photosynthesis rates over vast scales, gleaning insights into vital processes that affect humans and other living things on Earth. "The rate of photosynthesis is critical because it is the process that drives the absorption of carbon from the atmosphere and agricultural [food] production," said **Joseph Berry** [Carnegie Institution for Science—*Department of Global Ecology, Researcher*].

Measuring the fluorescent "glow" may sound simple, but the tiny signal is overpowered by reflected sunlight. "Imagine that you're in your child's bedroom and they have a bunch of glow-in-the-dark stars on the ceiling," Schimel said. "Then you turn the lights on. The stars are still glowing, but looking for that glow with the lights on is like looking for fluorescence amidst the reflected sunlight." Retrieving the fluorescence data requires disentangling sunlight that is reflected by plants from the light given off by them—i.e., figuring out a way to "turn the sun off."

Researchers found that by tuning GOSAT's *spectrometer* (an instrument that can measure different parts of the spectrum of light) to look at very narrow channels, they could see parts of the spectrum where there was fluorescence but less reflected solar radiation. "It's as if you had put on a pair of glasses that filtered out the radiation in your child's room except for that glow from the stars," said Schimel.

Scientists are excited about the new measurement because it will give them better insight into how Earth's plants are taking up CO_2. According to the Global Carbon Project, a non-governmental organization devoted to developing a complete picture of the carbon cycle, our burning of fossil fuels on Earth had produced nearly 35 billion tons of CO_2 by 2011. This is almost 5 tons of CO_2 for every one of Earth's seven billion inhabitants.

About half of that CO_2 remains in the atmosphere. The other half is dissolved in the ocean or taken up by Earth's *biosphere* (living organisms on land and in the ocean), where it is tucked away in carbon reservoirs, or *sinks*. These sinks are shielding us from the full effect of our emissions.

Plants in a High-Carbon World

"Everybody that's using fossil fuels right now is being subsidized by the biosphere," said Berry. "But one of the key unknowns is—what's going to be happening in the long term? Is it going to continue to subsidize us?"

The future of Earth's plants depends largely on one of the carbon cycle's key ingredients: water. Plants need water to carry out photosynthesis. When their water supply runs low, such as during times of drought, photosynthesis slows down.

For the past quarter century, satellite instruments such as MODIS and the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellites have enabled researchers to monitor plant health and productivity by measuring the amount of "greenness," which shows how much leaf material is exposed to sunlight. The drawback of using the greenness index, however, is that greenness doesn't immediately respond to stresses—e.g., water stress—that reduce photosynthesis and productivity.

"Plants can be green, but not active," said **Christian Frankenberg** [JPL—*Member of the OCO-2 Science Team*]. "Imagine an evergreen needle-leaf forest at high elevation in winter. The trees are still green, but they're not photosynthesizing."

Solar-induced fluorescence data would tell you straight away that something had happened, explains Schimel, [whereas] greenness doesn't tell you until the plants are already drooping and maybe dead.

About 30% of the photosynthesis that occurs in Earth's land regions takes place in the tropical rainforest of the Amazon, which encompasses about 2.7 million mi^2 (7 million km^2) of South America. The Amazon is home to more than half of Earth's terrestrial biomass and tropical forest area—making it one of the two most important land regions for carbon storage (the other being the Arctic, where carbon is stored in the soil).

Recent studies in the Amazon using fluorescence measurements have examined how photosynthesis rates change during wet and dry seasons. Most of the results show that during the dry season, photosynthesis slows down. According to Berry, when the air is dry and hot, it makes sense for plants to conserve water by closing their *stomates* (pores). "During the dry season when it would cost the plants a lot of water, photosynthesis is dialed down and the forest becomes less active," he said.

In 2005 and 2010, the Amazon basin experienced the type of droughts that historically have happened only once in a century. Greenness measurements indicated widespread die-off of trees and major changes to the forest canopy (treetops) after the droughts, but fluorescence data from GOSAT exposed even milder water stress in the dry season of normal years. "There is the potential that as climate change proceeds, these droughts will become more severe. The areas that support tropical rainforest could decrease," said Berry. Less tropical forest means less carbon absorbed from the air.

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NASA Begins Field Campaign to Measure Rain in Southern Appalachians

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

Rain, ice, hail, severe winds, thunderstorms, and heavy fog—the Appalachian Mountains in the southeast United States have it all. On May 1, 2014, NASA began a campaign in western North Carolina to better understand the difficult-to-predict weather patterns of mountain regions. The field campaign serves as a ground truth experiment for measurements made by the Global Precipitation Measurement (GPM) mission's Core Observatory.

GPM is an international satellite mission to observe rain and snow around the world. The advanced instruments on the GPM Core Observatory satellite, launched February 27, 2014, provide the next generation of precipitation measurements, including the new capability to detect snow and light rain.

"What we're trying to do is study and learn about the precipitation from the summit to sea, how it evolves as it moves from the mountains to the plains," said **Walt Petersen** [NASA's Wallops Flight Facility], who is leading the field campaign. "Then we use that information to improve satellite observations of precipitation and determine how those observations can best be used in applications like hydrologic models."

Hydrologic models are used by water managers to predict where rainwater goes after it hits the ground—underground and into streams and rivers where it supplies freshwater to the region, or becomes a natural hazard. Evaluating and improving these models is an important part of the field campaign.

During the Integrated Precipitation and Hydrology Experiment, NASA's high-altitude ER-2 aircraft carries three radars and a radiometer to measure rainfall from 65,000 ft (~20 km). **Image credit**: Tony Landis [NASA's Armstrong Flight Research Canter]

Set up on a ranch in Rutherford County, NC, NASA's Dual-frequency, Dual-polarization, Doppler Radar (D3R) is one of several ground radars measuring rain as it falls from clouds. It has the same two frequencies as are on the GPM Core Observatory satellite. **Image credit**: David Wolff [NASA's Wallops Flight Facility]

"This is a region that is always under some sort of threat," said precipitation scientist **Ana Barros** [Duke University]. (Duke University is hosting the field campaign.) Barros has been working with local authorities in the Upper Tennessee, Catawba-Santee, Yadkin-Pee Dee, and Savannah River basins, who are very interested in the outcome, to set up the rain-monitoring network for the campaign. "They have landslides, they have flash floods, they have severe windstorms, they have lots of hail storms in the summer time, they also get hurricanes and tropical storms. So they really value and appreciate the data because they feel they can make good use of it."

Mountain precipitation is difficult to measure—even from satellites. The shape of the rugged slopes interacts with and produces a wide variety of rainfall, through poorly understood processes specific to mountains, said Barros. On the ground, rain gauges have to be set up and maintained in remote areas only accessible by foot or on horseback, and ridges block weather radars from seeing very far across the mountains.

Nevertheless, the Integrated Precipitation and Hydrology Experiment field campaign, running from May 1 to June 15, 2014, combines intense ground coverage with airborne sensors flying through and above rain clouds. When a storm moves in, they'll snap pictures of precipitation from the top of the clouds to the bottom of valleys.

Satellite overpasses from the Tropical Rainfall Measuring Mission (TRMM) and GPM Core Observatory provide the view from space. In case satellites are not overhead during a storm, NASA's ER-2 high-altitude research plane flying at 65,000 ft (~20 km) and managed by the agency's Armstrong Flight Research Center (formerly Dryden), carries several sensors including two that simulate measurements made by the GPM Core Observatory. At 10,000 to 25,000 ft (~3 to 8 km), the University of North Dakota's Citation aircraft flies through clouds to measure raindrops and ice particles where they form.

Multiple weather radars—including the NASA's transportable Polarimetric Radar and Dual-Frequency, Dual-Polarimetric Doppler Radar, as well as a National Oceanic and Atmospheric Administration (NOAA) polarimetric radar—measure rain as it forms in clouds and falls to the ground. Then, researchers from Duke University, NOAA's Hydrometeorological Test Bed, NASA, and others have set up a dense network of rain gauges and other equipment to measure fallen precipitation at ground level. Additional sensors to detect soil moisture underground and stream height then follow the water as it flows downstream from the mountains to the plains.

"That's our dream scenario," Petersen said. "We'll learn something more about how and where rain water is actually made in the clouds, how much of it falls out of the cloud to the ground, and then what happens to the rainfall when it gets into our hydrologic network."

If the weather cooperates, the science team expects to end the six-week campaign with detailed and scientifically robust data to improve their understanding of both the fundamental science of mountain rainfall and how to best estimate rainfall using satellite observations over these remote and rugged regions.

"In a way remote sensing is the only hope to observe the hydrologic cycle over mountains," said Barros. "The potential to do this from space is great and resolves a great problem because we can look at the larger area without having to deal with these obstacles."

For more information, visit *pmm.nasa.gov/iphex* and *iphex.pratt.duke.edu*.

How Does Your Garden Glow? NASA's OCO-2 Seeks Answer

continued from page 35

In addition, as trees decay, they release CO_2 back into the atmosphere, creating a scenario whereby the biosphere potentially becomes a source of carbon rather than a sink. "If there is a dieback of the tropical rainforest, that might add to the effect of fossil fuel CO_2 on climate change," said Frankenberg.

Because photosynthesis is one of the key processes involved in the carbon cycle, and because the carbon cycle plays an important role in climate, better fluorescence information could help resolve some uncertainties about the uptake of CO_2 by plants in climate models. "We think fluorescence is going to help carbon cycle models get the right answer," said Berry. "If you don't have the models right, how can you get the rest of it right?"

"We really don't understand the quantitative relationship between climate and photosynthesis very well, because we've only been able to study it at very small scales," said Schimel. "Measuring plant fluorescence from space may be an important addition to the set of techniques available to us."

NASA Earth Science in the News

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

NASA Study Projects Higher Temperatures Despite Recent Slowdown in Global Warming, March 11; *Bloomberg*. Despite a recent slowdown in the rate of global warming, a new study by **Drew Shindell** [NASA Goddard Institute for Space Studies (GISS)] suggests that global temperatures will likely continue to rise in coming decades, on track with earlier estimates of increasing temperatures. Shindell and his colleagues sought to reconcile different estimates for the Earth's *climate sensitivity*, or how temperatures change in response to changes in radiative forcing. Some studies estimate low climate sensitivity, based on the assumption that global average temperatures would respond uniformly to increases of carbon dioxide (CO_2) and other greenhouse gas emissions. But the NASA study showed that global temperatures are more sensitive to changes in aerosols and ozone in the atmosphere than was thought. This higher sensitivity could mean a larger and faster temperature response. Shindell said the study's findings could have "a really profound impact" on the amount of greenhouse gas emission reductions needed for countries to meet an international goal of limiting temperature increases to 2 °C (3.6 °F). "I wish it weren't so," said Shindell, "but forewarned is forearmed." Global temperatures have increased at a rate of 0.12 °C (0.22 °F) per decade since 1951, according to the NASA GISS temperature record. This trend has been interrupted since 1998, as since then the rate of warming has slowed to only 0.05 °C (0.09 °F) per decade—even as atmospheric CO_2 continues to rise.

Amazon Rainforest Breathes In More Than It Breathes Out, March 20; *LiveScience.com*. A new study further confirms that pristine Amazon forests pull in more CO_2 than they put back into the atmosphere, helping to reduce global warming by lowering the planet's greenhouse gas levels. When scientists account for the world's CO_2, their totals suggest some of the greenhouse gas disappears into land-based carbon traps. These natural carbon *sinks*, such as forests, absorb and store CO_2, helping to lower the greenhouse gas levels in the atmosphere. To better measure the carbon flux from the Amazon, researchers tracked tree death throughout the Amazon. Lead study author **Fernando Espírito-Santo** [NASA/Jet Propulsion Laboratory (JPL)—*Research Scientist*] combined satellite data, airborne lidar data (i.e., laser surface imagery), and tree counts to compare carbon consumed by living trees with emissions from dead trees. Espírito-Santo found that dead Amazonian trees emit an estimated 1.9 billion tons (1.7 billion metric tons) of carbon to the atmosphere each year. In a normal year, the Amazon rainforest absorbs about 2.2 billion tons (2 billion metric tons) of CO_2, studies suggest. The study also found that big storms that can blow down millions of trees at once barely budge the forest's carbon output.

Arctic Melting Is Lasting Longer and Affecting More Ice, April 2; *UniverseToday.com*. The Arctic melt season is averaging five days longer with each passing decade, a new study by NASA and the National Snow and Ice Data Center reveals. More ice-free days mean that the water (which is darker than the surrounding ice) is exposed longer and can absorb more of the sun's heat and further increase the melting rate and extent. The study shows that the Arctic ice cap has shrunk by as much as 4 ft (~1.2 m). The news comes as the result of a study of satellite data from 1979 to 2013. By the end of this century, scientists believe there will be a fully melted Arctic Ocean during the entire summer. This news comes in the same week that the Intergovernmental Panel on Climate Change released its own report on global warming. Data were collected with NASA's (long-deceased) Nimbus-7 Scanning Multichannel Microwave Radiometer and instruments onboard Defense Meteorological Satellite Program spacecraft. Scientists can measure the changes in the ice's microwave emissivity using a formula developed by co-author **Thorsten Markus** [NASA's Goddard Space Flight Center (GSFC)—*Chief, Cryospheric Sciences Laboratory*].

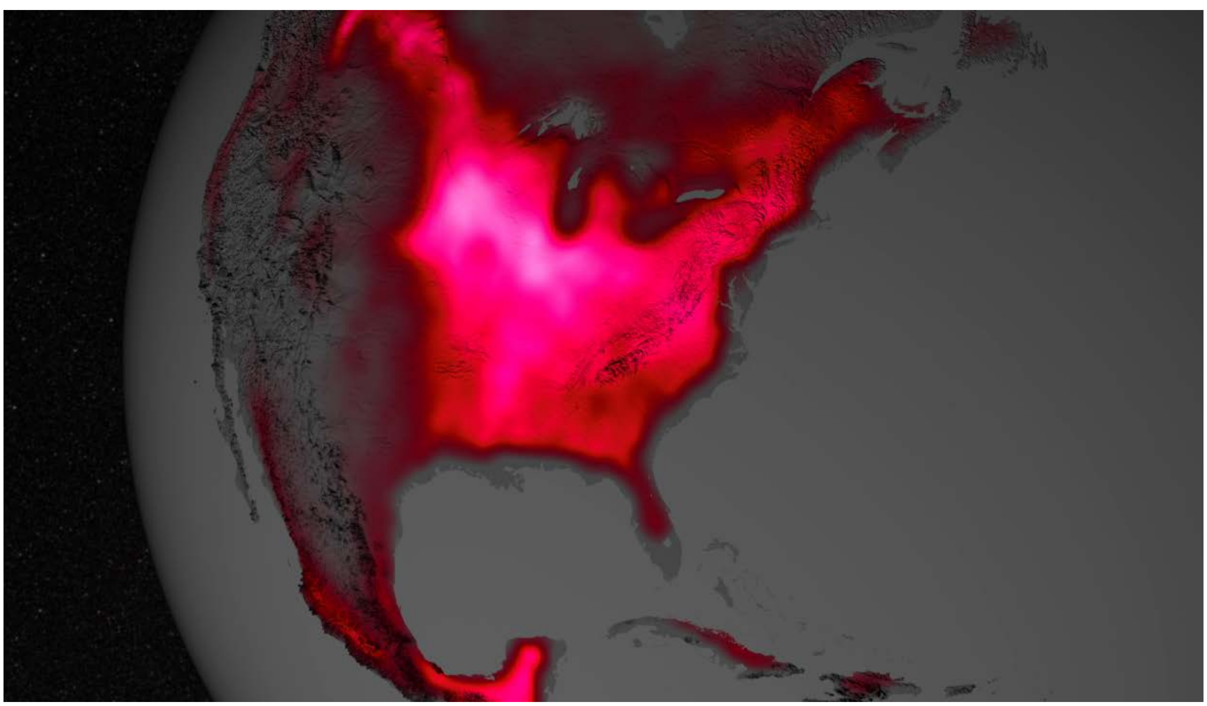
Under the Summer Sun, the Corn Belt Is the Most Biologically Productive Place on Earth, April 8; *Smithsonian Magazine (online)*. Rainforests, whether in the Amazon, Southeast Asia, or Central America, are hotspots of organic productivity, teeming with life. Fueled by abundant rain and a reliable stream of nutrients, the Amazon blooms year-round. For a brief period each summer, however, the ingenuity of humankind trumps even the mighty rainforests at biological production. A group of researchers, including **Christian Frankenberg** [JPL] and **Joanna Joiner** [GSFC], have determined that during the peak growing season, the Midwest U.S. Corn Belt is the most productive place on Earth—i.e., there's more photosynthesis going on here than in the Amazon. When plant cells photosynthesize, part of the energy they produce is emitted as fluorescent light—see image on next page made using data from the Ozone

Monitoring Instrument. By measuring the strength of this fluorescence from space, scientists can get a measure of plant productivity.

'Night Clouds' Give Clues to Weather, Climate on Earth, April 11; *NatureWorldNews.com.* The silver-blue clouds that hover near Earth's poles at night could give scientists clues to understand the weather and climate of the rest of the planet. After being first spotted in 1885, the nature of the phenomenon seemed to change throughout the twentieth century, occurring at increasingly lower latitudes. As a result, scientists wondered if these *noctilucent clouds* had shifted in the region they are found. A NASA mission called Aeronomy of Ice in the Mesosphere (AIM) was launched in 2007 to observe noctilucent clouds but currently only has a view of the clouds near the poles. However, according to a release from NASA, scientists have been able to gather information from several other missions and combine it with computer simulations to show that, over a decade, the presence of these bright, shining clouds has increased in the region between 40 and 50 °N latitude—which covers the northern third of the U.S. and the lowest parts of Canada. **Jim Russell** [Hampton University] and his team will perform additional research to determine if the newly observed frequency increase and temperature decrease in addition to the positional changes could be due to a reduction in the sun's energy and heat, which naturally occurred as the solar output went from solar maximum in 2002 to solar minimum in 2009.

NASA: Building Better Soybeans for a Hot, Dry, Hungry World, April 18; *Global AgInvesting (online).* A recent study at JPL led by **Darren Drewry** [JPL], using advanced vegetation models and high performance computer optimization techniques, shows that soybeans can be redesigned to increase productivity by 7% without the use of any additional water. The study also shows that soybean plants can be redesigned to either use 13% less water or to reflect 34% more light back to space without the loss of crop yield. This study concludes that there is a combination of traits that can accomplish increased productivity without trading off water conservation, and that the two goals can be achieved simultaneously. The model used in the study was developed by Drewry to study Midwest agricultural systems, but can be modified to do research on other types of vegetation. The model quickly finds results that would have taken decades of crossbreeding in the field to conclude.

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



The magnitude of fluorescence portrayed in this image prompted researchers to take a closer look at the productivity of the U.S. Corn Belt. The glow represents fluorescence from land plants in early July, from 2007 to 2011. **Image credit:** GSFC

NASA Science Mission Directorate – Science Education and Public Outreach Update

Theresa Schwerin, Institute for Global Environmental Strategies, theresa_schwerin@strategies.org
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NASA Postdoctoral Fellowships

Deadline: July 1

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

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

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

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

Know Your AQ: Discover Air Quality Professional Development Workshop

Application Deadline: June 20

Dates: August 6-7

As part of NASA's Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) campaign, the Cooperative Institute for Research at the University of Colorado Boulder invites middle and high school science educators in Colorado to take part in a two-day, field-based workshop to learn about the science of air quality. The workshop will take place at the National Center for Atmospheric Research's Mesa Lab in Boulder, CO, August 6-7, 2014.

Participants will learn about ongoing air quality issues and research, engage in conversations with atmospheric scientists, visit field sites to experience real-world research, and learn more about resources and programs for the classroom. Participants will earn continuing education credits upon completion of the workshop.

For registration and additional workshop information, please visit *bit.ly/1j3uB5U*.

Climate Bingo

NASA's *Climate Kids* brings you its latest activity—Climate Bingo! In this game kids will be on the lookout for things that are good for Earth's climate and environment and things that can sometimes hurt climate and the environment. A specially designed bingo-card generator creates a unique card for each player. At the website (below), players can learn about different phenomena and how they impact the environment.

To learn more about the game and to generate bingo cards, visit *climatekids.nasa.gov/bingo*.

Know Your Earth: 2014

The *Know Your Earth* Campaign is a large-scale, NASA-wide campaign that seeks to engage and educate the general public about NASA's Earth science missions and goals. The campaign centers on the release of monthly quizzes to gauge how much participants know about environmental systems on planet Earth. The quizzes, which began in February 2014, focus on current NASA Earth science research topics and feature a new Earth science theme each month, including the launch of five new NASA Earth science missions. Participants can share their quiz results through their Facebook and Twitter accounts.

Monthly quizzes can be taken online at *www.nasa.gov/content/know-your-earth-2014/#.U3ypBV7rXpg.* ■

EOS Science Calendar

July 8–11, 2014
ESIP Federation Summer Meeting, Frisco, CO.
esipfed.org/meetings

July 15, 2014
Aura 10th Anniversary TED-Style Talks, Greenbelt, MD.
aura.gsfc.nasa.gov

August 4–8, 2014
Precipitation Measurement Mission Science Team Meeting, Baltimore, MD.
pmm.nasa.gov/meetings/all/2014-pmm-science-team-meeting

September 15–18, 2014
Aura Science Team Meeting, College Park, MD.
acdb-ext.gsfc.nasa.gov/People/Witte

September 29–October 2, 2014
GRACE Science Team Meeting, Potsdam, Germany.
www.csr.utexas.edu/grace/GSTM

October 28–31, 2014
Ocean Surface Topography Science Team Meeting, Lake Constance, Germany.
www.ostst-altimetry-2014.com

November 3-7, 2014
CloudSat/CALIPSO Science Team Meeting, Greenbelt, MD.
www.hou.usra.edu/meetings/cloudsat2014

Global Change Calendar

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

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

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

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

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

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