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Editor's Corner

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At present, there are nearly 22 petabytes (PB) of archived Earth Science data in NASA's Earth Observing System Data and Information System (EOSDIS) holdings, representing more than 10,000 unique products. The volume of data is expected to grow significantly—perhaps exponentially—over the next several years, and may reach nearly 247 PB by 2025. The primary services provided by NASA's EOSDIS are data archive, management, and distribution; information management; product generation; and user support services. NASA's Earth Science Data and Information System (ESDIS) Project manages these activities.[1] An invaluable tool for this stewardship has been the addition of Digital Object Identifiers (DOIs) to EOSDIS data products.

DOIs serve as unique identifiers of objects (products in the specific case of EOSDIS). As such, a DOI enables a data user to rapidly locate a specific EOSDIS product, as well as provide an unambiguous citation for the product. Once registered, the DOI remains unchanged and the product can still be located using the DOI even if the product's online location changes. Because DOIs have become so prevalent in the realm of NASA's Earth

[1] To learn more about EOSDIS and ESDIS, see "Earth Science Data Operations: Acquiring, Distributing, and Delivering NASA Data for the Benefit of Society" in the March–April 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 2**, pp. 4-18].

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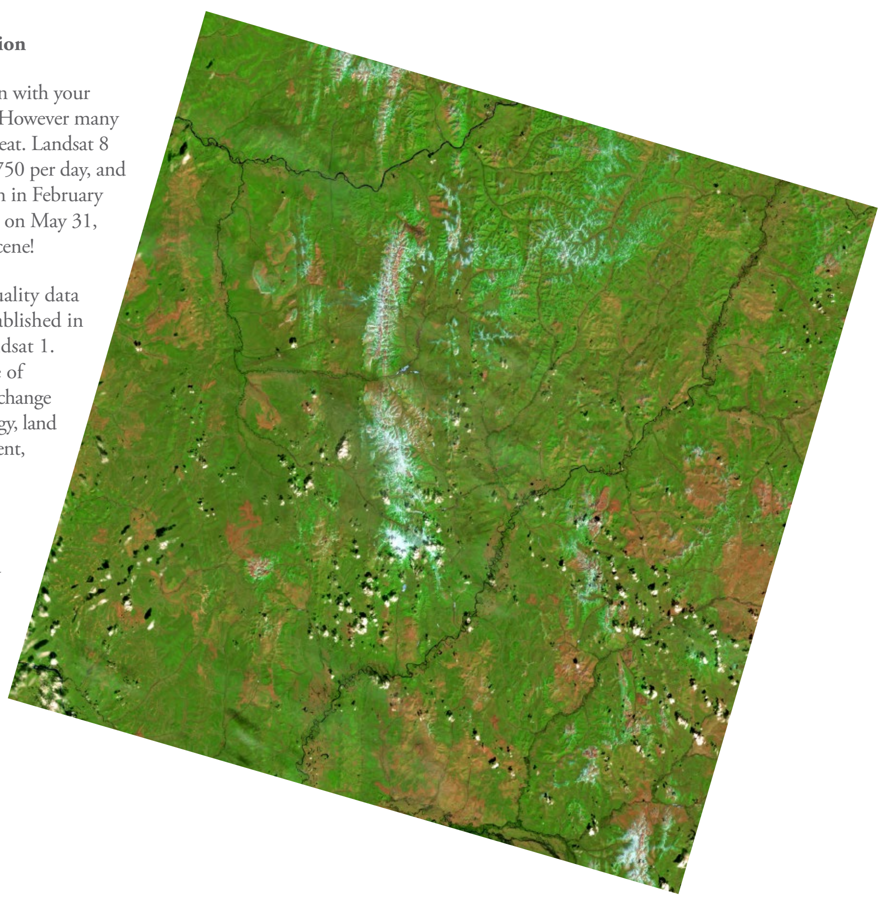
Landsat 8 Scenes Top One Million

How many pictures have you taken with your smartphone? Too many to count? However many it is, Landsat 8 probably has you beat. Landsat 8 acquires images at a rate of about 750 per day, and just a little over 4 years after launch in February 2013, the Earth-observing satellite on May 31, 2017, acquired its one millionth scene!

Landsat 8 provides the highest quality data since the Landsat archive was established in July 1972 with the launch of Landsat 1. Landsat data support a vast range of applications in areas such as global change research, agriculture, forestry, geology, land cover mapping, resource management, water, and coastal studies.



This Landsat 8 scene is located northwest of the Sea of Okhotsk, Russia, and was acquired on May 31, 2017. It is one of the first almost cloud-free acquisitions after the one millionth scene was made available for download. **Image credit:** USGS-NASA

In This Issue

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

Science data and information, an update to an earlier article in *The Earth Observer*, which described initial efforts to assign DOIs to EOSDIS data, seemed appropriate.[2] The new article (see page 4 of this issue) reviews the basic DOI structure and discusses the assignment of DOIs to EOSDIS data products.

The last two issues reported on the progress of NASA's Cyclone Global Navigation Satellite System (CYGNSS)[3]—a constellation of eight microsatellites that will provide detailed surface windspeeds in the region of tropical cyclone cores. CYGNSS launched in December 2016, and has been going through its On-Orbit Commissioning phases. On March 23, 2017, CYGNSS moved into the Science Operations phase. The spacecraft began delivering initial science data to the Physical Oceanography Distributed Active Archive Center (PO.DAAC) on May 22—just in time for the start of the 2017 Atlantic hurricane season on June 1.

Over the past several decades, forecasters have improved hurricane path prediction significantly, but their ability to predict the intensity of storms has lagged. CYGNSS will make frequent measurements of ocean surface winds in and near a hurricane's inner core—an area that up until now has proven impossible to probe accurately from space. Scientists hope these new data will lead to a better understanding of the physical mechanisms that control hurricane intensification, leading to improved models of hurricanes, and, in turn, improved intensity forecasts. Turn to page 33 to learn more about CYGNSS as it begins Science Operations, and to view some initial data collected from Tropical Cyclone Enawo.

May 4, 2017 marked the fifteenth anniversary of the launch of the EOS Aqua[4] mission. Aqua, named for its significant observations of the Earth's water cycle, far exceeded its original six year prime mission and is now entering its tenth year of extended operations. Four of its six instruments are still functioning nominally and continue to send back high-quality science data: AIRS, AMSU, CERES, and MODIS. AMSR-E suffered a major anomaly in October 2011 and was turned off until December 2012, when it was restarted but at a much slower rotation rate (2 rpm) than its original 40 rpm. With the slower rotation rate, it no longer produced high quality science data but did produce important data for cross-calibration with the AMSR2 instrument on GCOM-W1 that flies with Aqua in the international Afternoon Constellation (a.k.a., the A-Train). AMSR-E was powered off and ended its mission in March 2016. The sixth Aqua instrument, HSB,

[2] See "Digital Object Identifiers for NASA's Earth Observing System" in the September-October 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 5**, pp. 10-15].

[3] To learn more, see the Editorials of the January–February 2017 and March–April 2017 issues of *The Earth Observer* [**Volume 29**, **Issues 1** and **2**].

[4] The mission was originally named PM-1, signifying its afternoon equatorial crossing time (1:30 PM/1:30 AM), to distinguish it from AM-1 (later changed to *Terra*), which has a morning equatorial crossing time (10:30 AM/10:30 PM). The "1" distinction was because early plans for EOS called for a series of identical AM and PM spacecraft, one launching every five years, so there might have been a PM-2, and so on.

collected approximately nine months of data but failed in February 2003. The science achievements of Aqua have been described in many scientific journal articles, outreach exhibits and articles,[5] websites, and so forth, over the years—too numerous to summarize here. The list continues to grow. Congratulations to the entire Aqua team–past and present–on reaching this milestone! To learn more about Aqua, visit *https://aqua.nasa.gov*. On a related note, please see the Aqua AIRS instrument News story on page 34 of this issue.

Aqua was the first mission launched into what became the A-Train. It was joined by Aura (2004), Cloudsat and CALIPSO (2006), the CNES PARASOL mission (2004–2013), the JAXA GCOM-W1 mission (2012), and finally OCO-2 (2014). Formation flying enables the missions to operate collectively as a virtual platform having near coincident science measurements. This concept lowers total mission risk, increases the overall science return, and adds flexibility to mission evolution plans. The Third A-Train Symposium was held April 19-21, 2017, in Pasadena, CA, and was an opportunity to reflect on the remarkable scientific achievements of the constellation. *The Earth Observer* plans a full report on the symposium in its July–August 2017 issue.[6]

Another venerable mission is the joint NASA–USGS Landsat 7 mission, which continues to age gracefully as it enters its eighteenth year of operations—collecting about 430 scenes a day. Because of fuel limitations, by the fall of 2020 Landsat 7's orbit will degrade to an orbital mean local time of between 9:15 and 9:30 AM, so plans are underway for the inevitable end of mission. The Landsat Science Team is making every effort to maintain eight-day coordinated imaging with Landsat 8 and the USGS is working to extend the Landsat 7 mission until the launch of Landsat 9—currently planned for 2020.

Meanwhile, Landsat 8 has been in orbit for more than four years, and continues to operate nominally—with up to 740 scenes acquired each day—see front cover image for example. The performance of the Operational Land Imager (OLI) continues to exceed requirements, and the alternate operations concept developed for the Thermal Infrared Spectrometer (TIRS) established after the 2015 scene-select mirror encoder issue is providing useful thermal imagery.

Progress is also being made toward the next member of the Landsat series: Landsat 9. Ball Aerospace and Technologies Corporation in Boulder, CO, is moving forward with detector-module testing, focal-plane assembly construction, and other fabrication activities for OLI-2. Meanwhile, GSFC is working to develop TIRS-2 and has redesigned the telescope to include baffles that mitigate the stray-light issues that impacted Landsat 8's TIRS. Orbital ATK in Gilbert, AZ, was awarded the Landsat 9 spacecraft contract; initial reviews have already been held. Launch vehicle procurement is expected this summer (2017). The Landsat 9 ground-system requirements review took place recently, with approval to proceed to the Preliminary Design Review stage. Please turn to page 21 to learn more about the current status of Landsat 7 and 8, plans for Landsat 9, and the overall plans for the future of U.S. land imaging.

The joint NASA–JAXA Global Precipitation Measurement (GPM) Core Observatory has now been in orbit well over three years, and its GPM Microwave Imager and Dual-frequency Precipitation Radar instruments continue to perform well. The GPM mission released Version 05 of its data products in May 2017, and is well poised to successfully pass its End-of-Prime Review scheduled for late June 2017. The GPM mission consists of the Core Observatory and an international ten-member satellite constellation of microwave radiometers. The combined measurements from all the satellites are providing unprecedented retrievals of rain and falling snow characteristics—every three hours—and thereby increasing our knowledge of Earth's water and energy cycles. GPM is a science mission with integrated applications goals. Data from the GPM mission have been used for a broad range of applications across different societal benefit areas, including water resource management, disaster response, public health, ecological monitoring, and weather forecasting.

As an example of the applications focus of GPM, on March 22, NASA and the World Bank convened a workshop on GPM Applications in Washington, DC. Twenty-seven participants from the World Bank, primarily from the Environment and Natural Resources Global Practice group, as well as six representatives from NASA participated in this three-hour workshop, which the World Bank hosted. The workshop was organized to engage the water management community at the World Bank and increase awareness of NASA's water resources data—specifically focusing on precipitation. Additional goals were to promote a dialogue on the challenges to using these data on the World Bank side as well as the client/user level, and discuss opportunities for increasing capacity to utilize remote sensing products for improved situational awareness and decision making at the practitioner level. Please turn to page 13 to learn more about the workshop. ■

[5] See for example "Aqua 10 Years After Launch" in the November–December 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 6**, pp. 4-17].

[6] Learn more about the A-Train at *https://atrain.gsfc.nasa.gov*.

See page 38 for list of undefined acronyms used in the editorial and table of contents.

Enhancing the Discoverability of NASA Earth Science Data Through Digital Object Identifiers (DOIs)

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Introduction

NASA's Earth Observing System Data and Information System (EOSDIS) currently is responsible for almost 22 petabytes (PB) of archived data and more than 10,000 unique research products, which are managed by NASA's Earth Science Data and Information System (ESDIS) Project.[1] The volume of data in this vast archive is expected to grow significantly over the next several years, and may be almost 247 PB in size by 2025, according to estimates by NASA's Earth Science Data Systems Program. A prime responsibility of EOSDIS and the ESDIS Project is ensuring that these data can be discovered easily and cited accurately by data users. A key response to addressing these needs is the addition of *Digital Object Identifiers* (DOIs) to EOSDIS data products.

Since DOIs are becoming so prevalent in the realm of NASA's Earth Science data and information, it seems fitting to examine some of the "nuts and bolts" of their usage in the specific context of the Earth Observing System.

DOIs were developed in the 1990s as a means for managing the identification and location of content over digital networks, and are internationally standardized through the International Organization for Standardization (ISO) publication 26324:2012.[2] Two important attributes of DOIs are their permanence and their uniqueness, which are essential for facilitating the discoverability of DOI-assigned EOSDIS data products, as will be shown later in this article.

Of particular interest for readers of *The Earth Observer* is the adoption of DOIs for data products produced, archived, and distributed by the EOSDIS. These DOIs enable data users not only to rapidly locate specific EOSDIS data products for their research and applications, but also to easily provide valid citations for these products.[3]

Once registered, a DOI can never be changed or deleted. This means that even if the Internet location of the object changes, the DOI remains unchanged and the object can still be located using the DOI. DOIs also serve as unique identifiers of objects in that they identify a specific object without ambiguity. In addition, DOIs enable data users to provide valid citations for the data they use in research since anyone using or replicating the research can use the DOI to locate the exact data and data products cited.

The ESDIS Project began assigning DOIs in 2010, and a formal process for assigning and registering DOIs was implemented in 2012.[4] The more than 10,000 unique EOSDIS research products available to data users include not only standard products with the processing required for scientific research, but also near-real-time (NRT) products that are generally available within three hours after the raw data are collected. As of May 2017, a total of 5161 EOSDIS data products have registered DOIs, and many more are on the way.

Since DOIs are becoming so prevalent in the realm of NASA's Earth Science data and information, it seems fitting to examine some of the "nuts and bolts" of their usage in

[1] To learn more about EOSDIS, the ESDIS Project, and other elements discussed in this article see "Earth Science Data Operations: Acquiring, Distributing, and Delivering NASA Data for the Benefit of Society" in the March-April 2017 issue of *The Earth Observer* [**Volume 29, Issue 2**, pp. 4-18].

[2] ISO 26324:2012 contains information and documentation on the DOI system, which can be found at *https://www.iso.org/standard/43506.html.*

[3] Initial work on assigning DOIs to EOSDIS data has been detailed previously in "Digital Object Identifiers for NASA's Earth Observing System" in the September-October 2012 issue of *The Earth Observer* [**Volume 24, Issue 5**, pp. 10-15].

[4] More technical information about EOSDIS DOI efforts can be found in the article recently published by Wanchoo, L., N. James, and H. Ramapriyan, 2017. "NASA EOSDIS Data Identifiers: Approach and System." *Data Science Journal,* 16, p. 15, doi:10.5334/dsj-2017-015. [*Note the use of a DOI in this context—Ed.*]

this specific context. We begin with a review of the basic DOI structure and then proceed to specific details about assigning DOIs to EOSDIS data products.

Prefixes, Suffixes, and More—Understanding DOI "Grammar"

An object's DOI has two parts: a prefix and a suffix. The prefix begins with the number 10 (which is called a *handle* and identifies the string of numbers and letters after the *10* as being part of a DOI) followed by a number identifying the organization or agency registering the DOI, called the *registration agent*.[5] For example, the ESDIS Project has been assigned the registration agent number 5067. This means that all DOIs for EOSDIS data products start with *10.5067.* The DOI suffix (which is separated from the prefix by a forward slash) uniquely identifies the object, and its format is assigned and managed by the body or organization submitting the DOI for formal registration, such as the ESDIS Project. (Please see page 7 for specific details for *Assigning DOIs to NASA's EOS Data*.)

A suffix is either *opaque*, i.e., a string of seemingly random numbers and letters, or *structured*, i.e., the suffix has some meaningful content that follows a specified format. As is explained in the previously referenced *Data Science Journal* article by Wanchoo, *et al.*, one reason for data providers to use a structured DOI is that this may increase the ability of automated searches to identify articles citing specific mission, instrument, or program datasets. It is important to note that even if the DOI suffix is structured, the DOI is permanent and cannot be changed if the meaning of the suffix changes in the future. For example, a structured suffix might be written to contain the name of the specific data center originally responsible for the data product, but the data product could be moved to another data center. The use of content such as data center names or data locations in a DOI suffix is discouraged for this reason.

...one reason for data providers to use a structured DOI is that this may increase the ability of automated searches to identify articles citing specific mission, instrument, or program datasets.

Both opaque and structured suffixes are used in DOIs for EOSDIS data products. The choice of using an opaque suffix or a structured suffix (along with the structured suffix model used) depends on the preference of the EOSDIS Distributed Active Archive Center (DAAC)[6] providing the information for registering the data product DOI. The ESDIS Project recommends that a suffix be kept simple and short for ease of use, and suggests several suffix models that may be used, such as:

- [name of mission]/[name of instrument]/data[m][n]
- [name of campaign]/[name of platform]/data[m][n]
- [name of program]/[name of measurement group]/data[n]

where [m] denotes the processing level of the data product (e.g., Level-1, Level-2, etc.) and [n] indicates a sequence number.

A specific example can help demonstrate the naming convention and the value of a DOI:

The structured DOI assigned to the MODIS/Terra Land Surface Temperature and Emissivity Monthly Level-3 Global 6 km Grid SIN Version 6 product at NASA's Land Processes DAAC (LP DAAC) is *10.5067/MODIS/MOD11B3.006*. The prefix *10.5067* indicates that this is an EOSDIS data product. The suffix *MODIS/MOD11B3.006* indicates that this is a MODIS product, the product name is MOD11B3, and this is MODIS Version 6 data.

While a data user could use the Uniform Resource Locator (URL) for the LP DAAC landing page (*lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod11b3_v006*) to accesses this dataset, this URL could change or the data could be moved,

[5] Detailed information about the DOI numbering system is available through the International DOI Federation's *DOI Handbook*, Chapter 2, Numbering (*www.doi.org/doi_handbook/2_Numbering.html*).

[6] Information about EOSDIS DAACs and their datasets is available through the NASA Earthdata website at *earthdata.nasa.gov/about/daacs*.

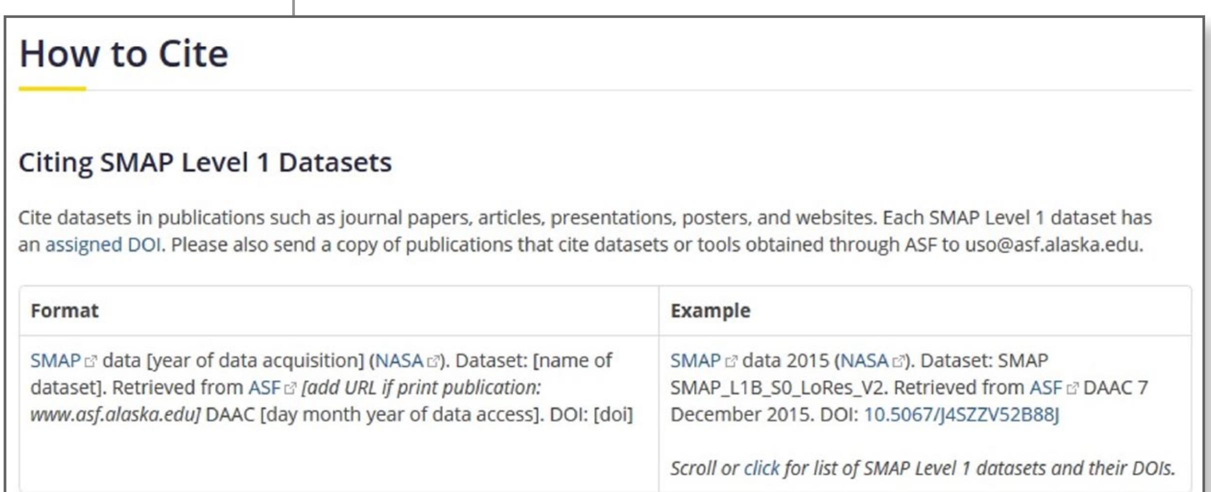
Using DOIs in data citations helps data become more discoverable. This, in turn, helps increase data distribution and, through this, fosters new and additional research using the data.

resulting in the dreaded *404: Page Not Found* error. However, by using the dataset's DOI (*dx.doi.org/10.5067/MODIS/MOD11B3.006*) a data user always will be directed to this specific dataset—regardless of where it exists on the Internet—since a valid URL is required by the ESDIS Project as part of the DOI registration process. To further ensure the accuracy of URLs associated with EOSDIS data products, the ESDIS Project periodically checks the validity of URLs for registered DOIs and receives monthly broken-links reports listing DOIs with *404: Page Not Found* errors. The ESDIS Project requests updated URLs from the DAACs for links that are not resolved.

A DOI is an integral component of a data product's *metadata*, which are data about the data, that help describe or identify them (e.g., when the data were collected or the instrument used to collect them). Metadata also make it easy to find information about the creation and history of a data product, which is called the data's *provenance*. EOSDIS DAACs are responsible for providing the ESDIS Project with data product metadata.

A DOI also has metadata associated with it, which are necessary for registering an EOSDIS data product DOI. One of the metadata elements required for DOI registration is the URL that provides the location of the data product's landing page. One benefit of having the URL as part of a data product's DOI metadata is that this enables the ESDIS Project to quickly and easily update a particular data product's URL when necessary. Along with the URL for the landing page, additional metadata required by the ESDIS Project for registering a data product DOI are the DOI name, data product title or name, the data product creator, the name of the DAAC distributing the data product, the data product publication year, the type of digital object being registered (e.g., dataset, text, services, or software), the type of DOI (i.e., new or update), and whether the DOI is ready for registration (yes or no).

As noted earlier, DOIs also make it easy to properly cite data used for research.[7] Since a DOI is assigned to a specific data product, there is no confusion about which data product or which version of the data product is being cited. The ESDIS Project requires DAACs to publicize citation policies on their websites and in communications accompanying data, including the proper use of DOIs in data citations—see **Figure 1**. Using DOIs in data citations helps data become more discoverable. This, in turn, helps increase data distribution and, through this, fosters new and additional research using the data.


How to Cite

Citing SMAP Level 1 Datasets

Cite datasets in publications such as journal papers, articles, presentations, posters, and websites. Each SMAP Level 1 dataset has an assigned DOI. Please also send a copy of publications that cite datasets or tools obtained through ASF to uso@asf.alaska.edu.

Format	Example
SMAP data [year of data acquisition] (NASA). Dataset: [name of dataset]. Retrieved from ASF *[add URL if print publication: www.asf.alaska.edu]* DAAC [day month year of data access]. DOI: [doi]	SMAP data 2015 (NASA). Dataset: SMAP SMAP_L1B_S0_LoRes_V2. Retrieved from ASF DAAC 7 December 2015. DOI: 10.5067/J4SZZV52B88J *Scroll or click for list of SMAP Level 1 datasets and their DOIs.*

Figure 1. The ESDIS Project requires DAACs to publicize citation policies, including the proper use of DOIs. This example shows a portion of the Soil Moisture Active Passive (SMAP) citation guidelines page at NASA's Alaska Satellite Facility (ASF) DAAC—*https://www.asf.alaska.edu/smap/how-to-cite*. Notice the explanation of how DOIs should be noted when citing SMAP Level-1 data. Note also that the suffix for the DOI cited in the example [*right box*] is opaque. **Credit:** NASA's ASF DAAC

[7] For the EOSDIS position on the importance of proper data citations, read "Open Data and the Importance of Data Citations: The NASA EOSDIS Perspective," available online at *https://earthdata.nasa.gov/open-data-and-the-importance-of-data-citations-the-nasa-eosdis-perspective.*

Assigning DOIs to EOSDIS Data[8]

The criteria used by the ESDIS Project to identify EOSDIS data products and supporting documents that are to receive a DOI are straightforward:

1. Is the product in question a standard data product, a NRT data product, or documentation related to a data product?
2. Is the data product planned as part of a mission or is the product already being generated, archived, and/or distributed?
3. Is the product supported by NASA's Earth Science Division?

If the answer to all of the above questions is yes, then a DOI is assigned. The end-to-end EOSDIS DOI assignment process involves three organizations:

- *the ESDIS Project* is responsible for managing DOIs as they are created and providing guidance to the DAACs in developing DOI suffixes, ensuring the completeness of DOI names and associated metadata, and reserving, registering, and updating DOIs;
- *the DAACs* are responsible for providing the ESDIS Project with data product metadata, developing data product landing pages, and providing changes in product metadata or landing page Internet locations; and
- *the California Digital Library EZID system*[9] registers EOSDIS DOIs and provides 24/7 access to the DOI handling system that enables the ESDIS Project to manage DOIs.

As stated previously, as of May 1, 2017, DOIs for 5161 data products have been registered—see **Table**.[10] An additional 458 DOIs have been created by the ESDIS Project and are reserved, but not yet registered. Unlike a registered DOI, which is permanently assigned to a specific data product, a reserved DOI can be changed or even deleted. A DAAC may wish to reserve a DOI for a data product that is not yet publicly available or for which a landing page has not been completed.

Unlike a registered DOI, which is permanently assigned to a specific data product, a reserved DOI can be changed or even deleted. A DAAC may wish to reserve a DOI for a data product that is not yet publicly available or for which a landing page has not been completed.

	Registered DOIs	Reserved DOIs	Total
ESDIS	3620	458	4078
ORNL	1267	0	1267
SEDAC	274	0	274
Total	5161	458	5619

Table. Registered and reserved EOSDIS DOIs as of May 1, 2017. All 12 EOSDIS DAACs are part of EOSDIS DOI efforts. The Oak Ridge National Laboratory (ORNL) DAAC and the Socioeconomic Data and Applications Center (SEDAC) are listed separately since they already were assigning DOIs to their data products before the EOSDIS effort began. ORNL and SEDAC continue to register DOIs for their own products directly with EZID. **Credit**: NASA's ESDIS Project

Along with the DAACs, six additional NASA entities that are involved in the processing of ESDIS Project science data are part of EOSDIS DOI efforts. These are the Land, Atmosphere, Near real-time Capability for EOS (LANCE)[11] Fire Information for Resource Management System (FIRMS);[12] NRT data from the Advanced Microwave Scanning Radiometer 2 (AMSR2), which are available through LANCE;

[8] More detailed information about the EOSDIS DOI process is available at *wiki.earthdata.nasa.gov/display/DOIsforEOSDIS/Digital+Object+Identifiers+%28DOIs%29+for+EOSDIS.*
[9] To learn more about the EZID system, visit *https://ezid.cdlib.org.*
[10] For the most current EOSDIS DOI metrics, please see the EOSDIS DOI Status and Listing page at *wiki.earthdata.nasa.gov/display/DOIsforEOSDIS/EOSDIS+DOIs+Status+and+Listing.*
[11] To learn more about LANCE, visit *earthdata.nasa.gov/earth-observation-data/near-real-time.*
[12] For information about FIRMS, visit *earthdata.nasa.gov/earth-observation-data/near-real-time/firms.*

NRT data from the Moderate Resolution Imaging Spectroradiometer (MODIS), which are available through LANCE; the Land Product Validation Subgroup (LPVS);[13] the Ozone Product Evaluation and Test Element (PEATE);[14] and the Precipitation Processing System (PPS).[15]

The DOI assignment process developed by the ESDIS Project is now largely automated.

The DOI assignment process developed by the ESDIS Project and currently in use is largely automated—see **Figure 2**. After a data product is identified by a DAAC as needing a DOI, product metadata required for DOI registration is generated by the DAAC responsible for the data. The product metadata and data landing page are checked for completeness and any updates are incorporated. DOI information is then processed automatically and final DOI information is automatically sent to EZID for registration.

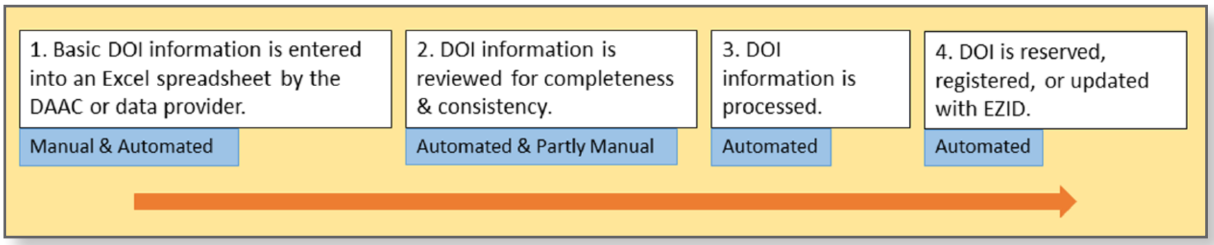


Figure 2. Programs written by the ESDIS Project (in the Perl programming language) handle automated processes, including reviewing and validating DOI metadata and checking for DOI name uniqueness within the ESDIS Project database and with EZID. An Oracle database is used to store DOI information along with some processing-related metadata (e.g., the dates of DOI submission, registration, and updates). **Credit:** NASA's EOSDIS

An upgraded system to fully automate this process is being tested at selected DAACs and will be operational for all DAACs in the next few weeks. This upgraded system features web-based submission of DOI metadata files, replacing the current approach of submitting a DOI metadata spreadsheet via email. Through this web-based submission upgrade, single or bulk DOI requests are processed in minutes with immediate email responses notifying the DAAC providing the information of any errors. The upgraded system also places a 72-hour hold on all new DOI requests before automatically registering a DOI for public use.

Summary and Conclusions

Since the implementation of the formal EOSDIS DOI process in 2012, approximately 50% of EOSDIS data products have registered DOIs. The establishment of an automated system to handle a majority of the processes for evaluating, registering, and updating DOIs has greatly sped up this effort and provides a system for organizing these data products that will become ever more important as the volume of data managed by the ESDIS Project continues to grow. ■

[13] To learn more about the LPVS, visit *lpvs.gsfc.nasa.gov*.
[14] The Ozone PEATE is now the Suomi National Polar-orbiting Partnership (NPP) Ozone Science Investigator-led Processing System (SIPS), but is still listed as Ozone PEATE on the EOSDIS DOI Status and Listing page for consistency with previous records.
[15] For more information about the PPS, visit *pps.gsfc.nasa.gov*.

April Showers of Outreach Lead to a Flowering of Public Awareness of NASA's Science Activities

Heather Hanson, NASA's Goddard Space Flight Center, heather.h.hanson@nasa.gov

Introduction

The old adage that *April showers bring May flowers* may be true, but two recent outreach activities in Washington, DC, which NASA's Science Communications Support Office (SCSO) supported, offered "showers" of a different sort. Those who participated in these events were offered the opportunity to soak up information about how NASA uses the vantage point of space to achieve a "flowering" of scientific discovery, leading to deeper understanding of: the workings of our home planet; the sun and its effects on the solar system, other planets and solar system bodies; the interplanetary environment; and the universe beyond our solar system.

Earth Day

The first line of "April showers" passed through Washington, DC's Union Station on Thursday, April 20. The SCSO organized and supported a large public Earth Day event that ran from 9:00 AM to 5:00 PM. The SCSO has supported several Earth Day celebrations in our Nation's capital, usually on the National Mall, dating back to 1994. Since 2013, however, NASA has picked Union Station to host the event. This central transportation hub attracts some 25,000 to 30,000 individuals a day, allowing NASA potential to reach a larger cohort of citizens who were not already planning to attend the event.

To kick off the event, **Michael Freilich** [NASA Headquarters—*Director of the Earth Science Division*], **William Werkheiser** [U.S. Geological Survey (USGS)—*Acting Director*], and **Beverley Swaim-Staley** [Union Station Redevelopment Corporation—*President and CEO*] took turns providing opening remarks and welcoming attendees to the celebration—see **Photo 1**.

With participation from the U.S. Department of State (DOS) and USGS, NASA offered a full schedule of Science Stories on the Hyperwall,[1] 20 hands-on activities (see **Table 1**), and a special appearance by **Former NASA Astronaut Scott Altman**, who presented exciting information in front of the Hyperwall and held a one-hour autograph-signing session—see **Photos 2-4**. There were 22 Hyperwall Science Stories told by individual scientists and outreach personnel throughout the day. Each story lasted about 15 minutes, covering a variety of Earth-science topics, the August 2017 solar eclipse, planetary exploration, and the universe.

[1] NASA's Hyperwall is a video wall capable of displaying multiple high-definition data visualizations and/or images simultaneously across an arrangement of screens. Functioning as a key component at many NASA exhibits, the Hyperwall is used to help explain phenomena, ideas, or examples of world change.

Photo 1. Participants gathered in front of NASA's Hyperwall for a special kickoff celebration. **Michael Freilich** provided opening remarks, explaining that Earth is a complex system and in order to understand it we need to continuously observe a variety of parameters on a global scale, and that NASA's Earth-observing fleet has been designed to do just that. **Photo credit:** NASA

Photo 2. Lawrence Friedl [NASA Headquarters—*Director of the Applied Sciences Program, Earth Science Division*] interacted with student participants and described ways the public uses NASA data to make informed decisions. **Photo credit:** NASA

Photo 3. Tim Newman [USGS—*Land Remote Sensing Program Coordinator*] talked about the USGS–NASA Landsat Program. **Photo credit:** NASA

Photo 4. Former NASA Astronaut **Scott Altman** signed autographs and took photos with the general public. **Photo credit:** NASA

Prior to the event, NASA arranged for more than 300 middle- and high-school students, teachers, and chaperones to attend, extending the reach of the event to New Jersey, Maryland, Virginia, and Georgia. The students were divided into small groups that followed a rotation schedule. Each group completed several hands-on activities and listened to a variety of science stories, including a talk titled "Reach for the Stars," given by Scott Altman, where all 300 participants gathered in front of the Hyperwall—see **Photos 5-7**.

In addition to the pre-arranged student visitors, approximately 1000 general-public participants completed at least 6 hands-on activities to earn a special NASA take-home kit—see **Photo 8**—while several hundred others listened to Hyperwall stories, including a reporter who interviewed Scott Altman after his talk. Approximately 20,000 individuals who passed through Union Station witnessed the event.

Photo 5. While making a pin-hole projector, these Girl Scouts learned about the total solar eclipse that is going to take place across the contiguous U.S. on Monday, August 21, 2017. **Photo credit:** NASA

Photo 6. Participants used a model of the water cycle to learn about the processes the Global Precipitation Measurement mission studies. **Photo credit:** NASA

Photo 7. All school groups gathered in front of the Hyperwall to hear **Scott Altman's** story about being a NASA Astronaut, titled "Reach for the Stars." **Photo credit:** NASA

Photo 8. General-public participants enjoyed completing several hands-on activities to earn a NASA take-home kit. **Photo credit:** NASA

Table 1. Hands-on Activities at Earth Day 2017

Activity	Description
Digital Photo Booth	A NASA representative took attendees' pictures—and they could take away personal keepsakes and cool science images from NASA.
B-Line to Space	Visitors learned how NASA balloons are used to understand the dynamics of Earth's systems.
Dynamic Planet	A touchscreen interface allowed users to drive a spherical display that showed a variety of remote-sensing satellite datasets.
Puzzling Changes in the Land	Visitors arranged a time series of Landsat images and pieced together a Landsat scene to reveal Earth's changing landscape.

Table 1. Hands-on Activities at Earth Day 2017. (*cont.*)

Matching Our World to Spectral Measurements	Visitors discovered how NASA satellites sense the amount of light reflected from and absorbed by the surface of our planet.
What Color is the Ocean?	Visitors measured the visible light spectrum through different-colored water samples and learned how NASA satellites use this principle to detect *chlorophyll*—the green pigment in phytoplankton.
Ultraviolet Beads	NASA keeps a close eye on the sun's ultraviolet (UV) radiation. To understand how, visitors became "UV detectives," equipped with specially designed UV-sensitive beads; they walked away with their own UV-detection bracelet.
What's up with Precipitation?	Visitors learned the nuts and bolts about how and why NASA satellites are measuring precipitation from space.
Show Me the Solar Eclipse	On Monday, August 21, 2017, a total solar eclipse will be visible in a narrow path from Oregon to South Carolina. Every American state will have a view of at least a partial eclipse. NASA scientists are planning to observe Earth, the sun, and moon during this unique opportunity from several vantage points. Visitors learned how a solar eclipse occurs and how to make a pin-hole projector to view the event.
Spandex Spacetime	Visitors were asked to imagine spacetime as a Spandex® tarp, noting that when a massive ball is on the tarp, it stretches. When a smaller ball rolls toward the larger, it "orbits" the center, mimicking two bodies interacting gravitationally. Astrophysicists explained and answered questions about this demonstration.
ICESat-2 Height Matters	Attendees followed the adventures of *Pho the Photon* in a new animated short called "Photon Jump," produced by NASA's second Ice, Cloud, and land Elevation Satellite (ICESat-2) mission. Visitors learned about how this new satellite will use lasers to take measurements of Earth's elevation through a fun bouncy-ball activity.
Clouds: In a Bottle and in the Sky	Participants helped create a cloud in a bottle and learned about the important role clouds play in our atmosphere. They also learned how to submit cloud observations to NASA straight from their mobile phone.
Exploring Earth's Neighbor: The Moon	Earth's Moon is a stunning and beautiful place! Visitors explored how it's similar to—and different from—Earth.
The Earth and Titan: Greenhouse Cousins	Saturn's moon Titan has many similarities to Earth, including the presence of an atmosphere with weather phenomena like clouds and rain. This activity demonstrated how the greenhouse effect on both worlds acts like a blanket to warm the planets' surfaces.
NASA Visualization Explorer	Visitors experienced the NASA Visualization Explorer (*NASA Viz*), which is a free iPhone, iPad, and iPod app that provides access to visualizations of current NASA research in Earth and planetary science, heliophysics, and astrophysics. For more information, visit *https://nasaviz.gsfc.nasa.gov*.
IR Imager: Seeing the World in a Different Light	Visitors learned how infrared cameras allow humans to "see" the heat that our bodies and other objects emit.
Where in the Air?	Visitors learned about properties of the layers of Earth's atmosphere by locating where objects such as commercial aircraft, hot air balloons, and birds fly in the atmosphere, along with what is needed for human survival in those locations.
Eyes on the Earth 3D: Come Fly with NASA	This activity immersed visitors in a three-dimensional (3D) visualization experience that lets them "fly along" with NASA's fleet of Earth Science missions and observe climate data from a global perspective and in real time. To experience this at home, interested parties can visit *https://eyes.nasa.gov*.
View your World with NASA Worldview	Visitors interactively browsed and visualized global Earth Science data and viewed natural hazard events with the NASA *Worldview* web interface. For more information, visit *https://worldview.earthdata.nasa.gov*.
U.S. Department of State: We Use Science Too!	Visitors learned about the environment and science diplomacy programs at the U.S. Department of State.

National Math Festival

The second band of "April showers" came two days later, on Saturday, April 22, when NASA offered three hands-on activities at the National Math Festival, which was held at the Walter E. Washington Convention Center in Washington, DC, from 10:00 AM to 7:00 PM. The crowd size was estimated to be 20,000. While it is not likely that all 20,000 attendees visited the NASA activities, at any given time there were approximately 30-60 attendees participating in NASA's three activities—the *Dynamic Planet*, *What Color is the Ocean?*, and *Precipitation Towers*.

NASA's *Dynamic Planet* is a 32-inch illuminated spherical visualization platform that provides a unique and vibrant global perspective of Earth, our sun, various planetary bodies in our solar system, and the universe, to increase and improve scientific understanding of these and related topics. The touchscreen interface allows users to navigate several datasets, each with their own descriptive storytelling text—see **Photo 9-10**.

The activity called *What Color Is the Ocean?* explained how the color of an object results from the color of the light reflected by the object while all other colors are absorbed. Participants used an inexpensive, simple spectrophotometer to test how light at different visible wavelengths (e.g., blue, green, red) is transmitted or absorbed through four different-colored water samples—see **Photo 11**.

Photo 9. *Dynamic Planet* allowed users to navigate several global datasets. **Photo credit:** NASA

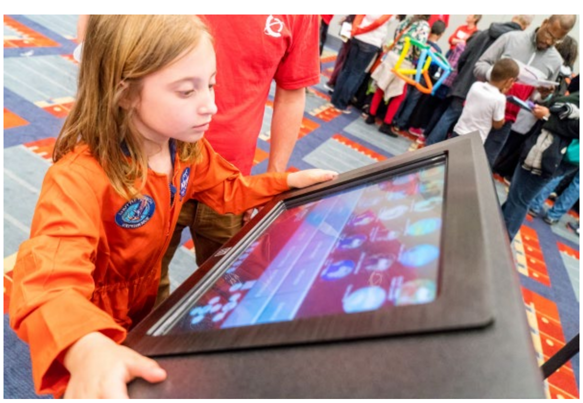


Photo 10. Participants used the *Dynamic Planet* touchscreen interface to navigate the globe. **Photo credit:** NASA

Photo 11. Participants gathered around the *What Color Is the Ocean?* activity for group demonstrations. **Photo credit:** NASA

Photo 12. *Precipitation Towers* included a Lego® model showing the three-dimensional structure of rainfall in a hurricane. **Photo credit:** NASA

In the activity called *Precipitation Towers*, participants learned how rainfall and snowfall can be measured from the ground and also from satellites. Hands-on graphs showed monthly average precipitation amounts in various locations around the world. With these phenomena as background, participants were then asked to think about the different factors that affect the amount of rain and snow in different regions of Earth—see **Photo 12**.

Summary

Indeed, while it rained in Washington during the Earth Day event and the National Math Festival, the many interactions between participants and the NASA staff gave NASA representatives the opportunity to additionally "shower" the public with unforgettable stories and examples of science and math in a friendly, attractive environment that led to curiosity and the means to satisfy it. To view more photos from these and other events supported by the SCSO, visit *https://www.flickr.com/photos/eospso/albums/with/72157681039942371*. ■

NASA-World Bank Workshop on Global Precipitation Measurement Applications

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Introduction

NASA and the World Bank convened a workshop on Global Precipitation Measurement (GPM) Applications on March 22, 2017, at the School of Public Health at George Washington University, in Washington, DC. Twenty-seven participants from the World Bank, primarily from the Environment and Natural Resources Global Practice group, as well as six representatives from NASA, participated in this three-hour workshop, which the World Bank hosted. The workshop was organized to engage the water-management community at the World Bank and increase awareness of NASA's water resources data—specifically focusing on precipitation. Other goals of the workshop were to promote a dialogue on the barriers or challenges to using these data on the World Bank side as well as at the client/user level, and to discuss the opportunities for increasing capacity to utilize remote sensing products for improved situational awareness and decision making at the practitioner level.

Following a brief introduction to the GPM mission and the reason for its implementation, the results of this workshop and discussion are summarized below.

GPM Overview

The GPM mission[1] is a joint venture between NASA and the Japan Aerospace Exploration Agency (JAXA). It is currently comprised of a constellation of nine satellites, with instruments that measure rain and falling snow characteristics at each location every three hours, and to provide information on Earth's water and energy cycles. GPM is a science mission with integrated applications goals. Data from the GPM mission have been used for a broad range of applications across different societal benefit areas, including water resource management, disaster response, public health, ecological monitoring, and weather forecasting. The applications activities have focused on engaging user groups through user workshops,[2] webinars and in person trainings,[3] and publications (e.g., a 2017 article in the *Bulletin of the American Meteorological Society*[4]), all of which have the goal of advancing the use of GPM and its predecessor Tropical Rainfall Measurement Mission (TRMM) data to support decision making and improve situational awareness across different sectors at local-to-global scales.

Workshop Executive Summary

The NASA-World Bank GPM Applications Workshop focused on the topic of water resources and how NASA data and products may be utilized within projects relevant to the participants. The agenda featured presentations from NASA and the World Bank, where a new NASA–World Bank developed e-book was introduced. There was then an hour-and-a-half long discussion session where World Bank and NASA representatives had lively breakout discussions focusing on a few key questions. All of the workshop participants classified themselves as novice or intermediate users of remote sensing data, but were highly engaged in discussing potential opportunities for building the capacity of using such data at the client level. There was a continued thread of discussion on how to best "train the trainers" at the end-user/practitioner level, with the goal of demystifying the use of remote sensing data for users through focused trainings. Results of this workshop and discussion follow.

Photo. Brad Dorn [NASA Headquarters (HQ)—*Program Manager for Water Resources*] presented an overview of NASA's remote sensing data products that are being used in applications related to water resources. **Photo credit:** Dalia Kirschbaum

Brad Doorn [NASA Headquarters (HQ)—*Program Manager for Water Resources*] began the workshop with a *NASA Remote Sensing for Water Resources Applications Overview*—see **Photo**.

[1] For more on the GPM Mission and its payload, visit *https://pmm.nasa.gov/gpm* and *https://www.nasa.gov/mission_pages/GPM/spacecraft/index.html.*

[2] To learn about previous GPM Applications Workshops, see "Measuring Rain for Society's Gain: A GPM Applications Workshop" in the January–February 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 1**, pp. 26-35] and "Summary of the Second GPM Applications Workshop" in the September–October 2015 issue [**Volume 27**, **Issue 5**, pp. 4-11].

[3] For information on upcoming training opportunities, visit *https://pmm.nasa.gov/training.*

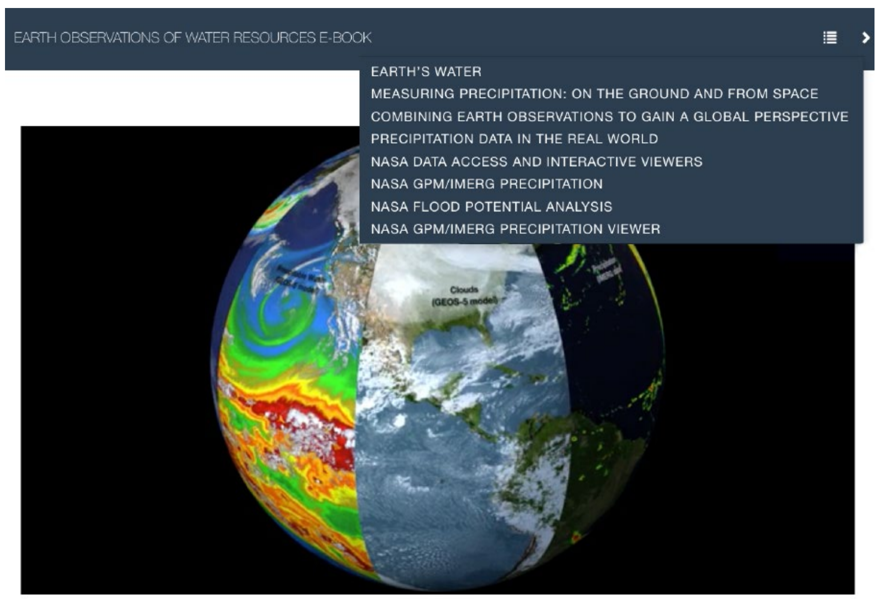
[4] Kirschbaum, D. B., *et al.* (2017), NASA's Remotely-sensed Precipitation: A Reservoir for Applications Users, *Bulletin of the American Meteorological Society*, doi:10.1175/BAMS-D-15-00296.1.

Nagaraja "Harsh" Rao Harshadeep [World Bank—*Global Lead of the Environment and Natural Resources Global Practice*] then gave attendees a perspective from the World Bank, providing additional information about resources that are already available, and outlined potential opportunities for both collaboration and future utilization of data products.

Dalia Kirschbaum [NASA's Goddard Space Flight Center (GSFC)—*GPM Deputy Project Scientist for Applications*] described GPM data and applications, followed by **Dorian Janney** [GSFC—*GPM Outreach Specialist*], who provided an overview of the *Earth Observations of Water Resources* E-book (*http://www.appsolutelydigital.com/Nasa*), a recent publication on Earth observations in water resources co-produced by NASA and the World Bank—see **Figure 1**.

Amita Mehta [University of Maryland, Baltimore County, Joint Center for Earth Systems Technology] discussed GPM data access, and the tools that could be used by participants to analyze or extract precipitation and other water resource product information.

After these presentations, there were breakout group discussions on water resources data needs, followed by reports to the plenary session from each breakout group and a group discussion. After the reports and discussion, the participants were surveyed to generate information on the nature of the participants' work areas—see **Figure 2**—their level of knowledge in Earth science areas—see **Figure 3**—



WORLD BANK GROUP Environment & Natural Resources

Figure 1. Screenshot of the *Earth Observations of Water Resources* E-book. **Credit:** Dalia Kirschbaum

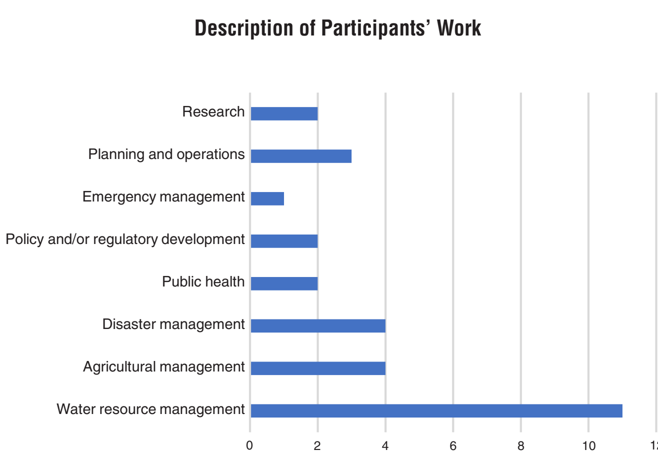


Figure 2. Description of participants' work areas and discipline foci. **Credit:** Dalia Kirschbaum

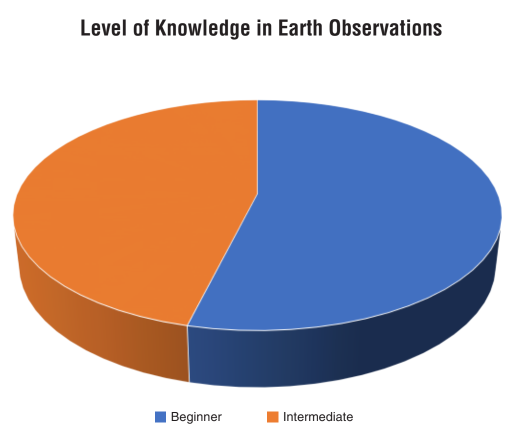


Figure 3. Level of participants' knowledge in Earth observations. **Credit:** Dalia Kirschbaum

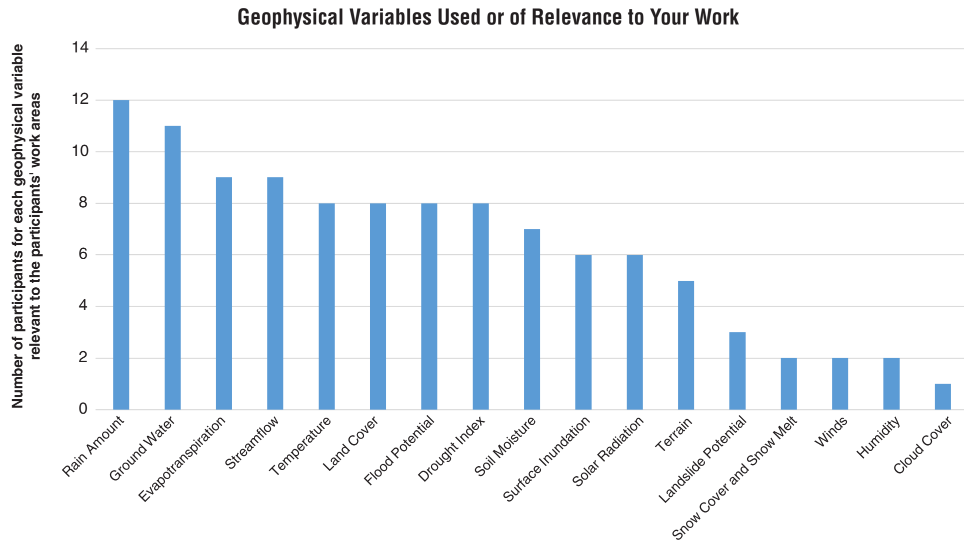


Figure 4. Geophysical variables used by (or relevant to) participants' work areas. **Credit:** Dalia Kirschbaum

and the geophysical variables they use for work—see **Figure 4**.

Discussion Summary

For the discussion section of the workshop training, participants were divided into four groups, each led by a NASA or World Bank representative and in most cases a rapporteur. The discussion questions posed to the group were:

1. What information do you and/or the end users with whom you will share this information typically use to make decisions? Are any of the resources that you/they rely on based on remotely sensed data? What types of decisions do you and/or the end-users make? What is the process that is followed when making decisions?

2. What are some challenges that you foresee in using these data and resources? How might some of these challenges be addressed to remove some of the potential barriers?

3. What are the new opportunities that you see after being introduced to the resources we shared today? How might these data or products be useful in your/their work?

Responses from all groups are summarized in the next three subsections.

Information Utility for Decision-Making

Of those participants who have used remote sensing data, the data usage included precipitation data products (e.g., TRMM, CHIRPS[5]), vegetation indices [e.g., the normalized difference vegetation index (NDVI)], evapotranspiration (ET) databases, and flood information (e.g., from the Dartmouth Flood Observatory). Participants understood that more-sophisticated data [e.g., data from the Gravity Recovery and Climate Experiment (GRACE)] were also available, but that more training is often required to use such data.

The participants also articulated data needs based on the type of issue being addressed—particularly for those less familiar with remote sensing products. The discussion allowed World Bank participants to highlight specific thematic areas and decisions that may be enhanced with remote sensing data and allowed NASA participants to highlight potential data sources that may be useful. For example, there was discussion about the impact of installing a dam on a river, which can lead to changes in water storage, land cover, and water temperature (i.e., before versus after installation). The dam's presence also has an impact on fisheries, vegetation, and the overall ecosystem in its vicinity. Also within this topic came a discussion about how reservoir operations (e.g., when to release stored water to make room for water from extreme rainfall versus when to store water for drought) would benefit from precipitation information, soil moisture, and seasonal forecasts.

Another topic of discussion centered on decisions about water usage for populations and agricultural activities. This included the need for determining freshwater quality (e.g., mineral composition) and availability for drinking water purposes, dissolved oxygen content in water bodies, rain frequency during planting periods, and hydrological forecasting. There is also a need to consider water resources awareness and management in rural areas, which impact decisions related to basin planning and water allocation, providing appropriately framed uncertainty estimates, and crop mapping (i.e., what types of crops are using how much water and where are they are located).

[5] CHIRPS stands for Climate Hazards Group InfraRed Precipitation with Station data; it is a 30+ year, quasi-global rainfall dataset. Spanning 50° S-50° N latitudes (and all longitudes), CHIRPS incorporates 0.05° resolution satellite imagery with *in situ* station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

Challenges in Using Data and Resources, and How to Overcome Barriers to Data Usage

While there is a large repository of Earth observation data relevant to addressing the decision making needs previously mentioned in this article, there are many potential barriers to utilizing these data that cross several boundaries, ranging from lack of baseline data to having useful, accessible tools to use the data.

Participants mentioned a number of specific barriers including: lack of access to data of all types, providing location-specific baseline data to support decisions; limitations in interagency coordination; lack of capacity—or even the language—to use the data; questions about data validity or applicability; limitations in the availability or understanding of tools to use satellite data for specific decision making purposes; ineffective spatial and/or temporal data resolution; relative cost benefits or trust of *in situ* vs. remotely sensed data—and relative costs of acquiring both; and lack of integration in forecasting systems between ground and satellite data. Other barriers to remote sensing data applications for decision support include differences in regional/local language, culture, and return on investment—a key metric—to learn new information systems or data products; and—perhaps key to all these things—physical and cost-based limitations on Internet access.

Opportunities and Utility

Despite the many practical and organizational barriers to applying Earth observation data to specific projects, the participants were enthusiastic in generating ideas for how to address and overcome those barriers, and ways to further enhance the utility of available data.

Participants discussed a number of ideas including: "marketing" the availability of data and tools by involving stakeholders at all levels; making World Bank consultants more aware of appropriate tools—especially at the local (town) to regional (municipality, district) scale; leveraging academia as an intermediate technical layer between decision- and policy-makers, particularly within the country in which the project is ongoing; increasing World Bank capacity to synthesize data products across datasets; and training appropriate parties who could then communicate findings and approaches to others in their countries or regions.

The participants were clear that the potential to use the kind of remote sensing data as discussed at this Workshop was extremely high, particularly for projects supported by the World Bank. The World Bank could help by providing mechanisms to store and access data that would be most relevant to their stakeholder communities, and levy requirements that appropriate data be placed in the public domain.

The participants also opined that communications at several levels must be facilitated—and that it was important to establish a two-way conversation between the scientists who provide relevant data and the decision makers who could use them. Other communication-related possibilities include the formation of virtual spaces to support webinars, access to success stories, and case studies; promoting best practices; and formation of workshops—such as this one—to further demonstrate data availability and utility.

Take-Away Messages

The group reconvened after the discussion period and summarized some overarching themes that emerged from the small group discussions. Overall, three main messages were articulated:

- *Awareness of remote sensing products and knowledge in how to use them for decision making*. This is generally at a beginner or intermediate level for World Bank water/agricultural managers; however, there is a large interest in continuing a two-way dialogue to determine how best to present, utilize, and access this information for their clients via trainings, additional resources, tools, etc.

- *Significant barriers exist to using remote sensing data*. Such barriers exist owing to limited capacity of using data on the client side, reluctance to change from existing data usage to new products (due to lack of time or infrastructure to process the data), and language, cultural, or knowledge barriers at the local-to-regional levels.

- *There is great opportunity to build capacity for use of remote sensing data.* This may be done by providing skills for practitioners to use the information and bring together different sectors to interface. This would create a domino effect for increased use and start to build coherent interfaces among agencies and increased trust of remote sensing data.

Conclusion

Workshop participants were enthusiastic about the level of engagement in this training and were keen to continue these discussions through routine online meetings or future trainings. This workshop was held during the World Bank water week. It was deemed by some to be the most successful training during that period. The success owed primarily to the small number of attendees and the ability to have a two-sided discussion where the participants could give their perspective and feedback and receive real-time information about potentially relevant products for their specific applications. Future GPM applications workshops will be scheduled focusing on other thematic areas, including the agriculture and energy sectors. For more information on these and future trainings, visit *https://pmm.nasa.gov/meetings/gpm-applications-workshops*. ■

Arctic–Boreal Variability Experiment (ABoVE) Science Team Summary

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Introduction

Climate change appears to be making itself felt in the Arctic and boreal regions of Earth faster than anywhere else on the planet. The Arctic-Boreal Vulnerability Experiment (ABoVE), organized under the auspices of the NASA Terrestrial Ecology Program, is the latest in a series of campaigns to study this region, tracing back to the BOREAS experiment,[1] which took place in part of the ABoVE study domain—see **Figure**. ABoVE is a 3-phase, 9-to-10-year duration field campaign in Alaska and Western Canada to explore environmental changes and their implications for social and ecological systems. For details about ABoVE, visit *https://above.nasa.gov*.

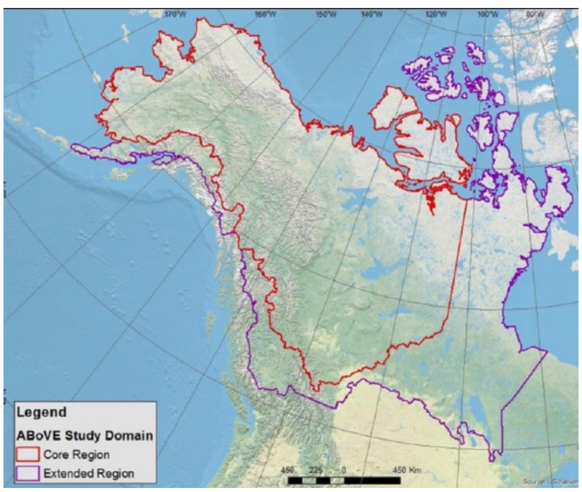

Figure. This map shows the ABoVE Study Domain. The core region is outlined in red; the extended region is outlined in purple. Studies are being carried out over a range of spatial scales within different terrestrial ecoregions spanning a range of climatic and environmental gradients. To see a map of current ABoVE projects, visit *https://above.nasa.gov/APPUT/MandS_P.html*. **Image credit:** NASA

The ABoVE Science Team met in Boulder, CO, January 18–20, 2017, with nearly 100 people in attendance. Meeting participants included both newly funded and current investigators, representatives from partner organizations and affiliated projects, support and logistics staff from the Carbon Cycle and Ecosystems (CCE) Office at NASA's Goddard Space Flight Center (GSFC), as well as **Hank Margolis** [NASA Headquarters (HQ)—*ABoVE Program Manager*] and **Eric Kasischke** [NASA HQ—*Program Scientist*]. A detailed agenda with links to presentations can be found at *https://above.nasa.gov/meeting_jan2017/agenda.html*.

[1] BOREAS took place in 1993, 1994, and 1996. It was a large-scale experiment that investigated interactions between the boreal forest biome and the atmosphere. To learn more, read "Reflections on FIFE and BOREAS: Historical Perspective and Meeting Summary" in the January–February 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 1**, pp. 6-23] or visit *https://daac.ornl.gov/BOREAS*.

Immediately prior to the Science Team meeting, many of the participants gathered for an Airborne Planning Meeting at the same location, that took place from January 17 through the morning of January 18. To learn more see *The View from ABoVE: Airborne Planning Session* on page 19.

Science Team Meeting

Scott Goetz [Northern Arizona University (NAU)—*ABoVE Science Lead*] and **Chip Miller** [NASA/Jet Propulsion Laboratory (JPL)—*ABoVE Deputy Science Lead*] convened the Science Team meeting, with reflections on the Airborne Planning Session that had taken place over the preceding day and a half. Both Goetz and Miller emphasized the relevance of the airborne planning efforts for the entire Science Team.

Interdisciplinary Working Group Reports

Each of the ABoVE Science Team interdisciplinary working groups reported on their recent activities and outcomes from the prior year, while highlighting areas of synergistic activity and potential for collaboration on synthesis projects. The working groups and their chairs are listed in the **Table** on page 18. Copies of the working group presentations can be found at *https://above.nasa.gov/meeting_jan2017/agenda.html#thurs*.

Partner Presentations

ABoVE has several important partners, collaborating on research and logistics both in Alaska and Canada. A representative of each of these partners gave short presentations on their research interests and activities in the ABoVE Study Domain. Brief descriptions appear below. Refer to the full presentations at the URL given in the Introduction for more information.

Mike Gill [Polar Knowledge Canada (POLAR)] gave a presentation on the research that POLAR has funded in the ABoVE study domain, as well as the monitoring they are conducting in their Experimental Research Area outside of Cambridge Bay, Nunavut.

Table. ABoVE Science Team interdisciplinary working groups and chairpersons.

Working Group	Chair(s) [Affiliation(s)]
Hydrology and Permafrost	**John Kimball** [University of Montana]
Vegetation Dynamics	**Bruce Cook** [GSFC] and **Mike Goulden** [University of California, Irvine]
Fire Disturbance	**Michelle Mack** [Northern Arizona University]
Carbon Dynamics	**Sue Natali** [Woods Hole Research Center]
Wildlife and Ecosystem Services	**Natalie Boelman** [Columbia University, NY, Lamont–Doherty Earth Observatory]
Modeling Framework and Comparisons	**Joshua Fisher** [NASA/Jet Propulsion Laboratory]
Digital Elevation Models	**Chris Neigh** [NASA's Goddard Space Flight Center (GSFC)]
Geospatial Products and Standards	**Tatiana Loboda** [University of Maryland, College Park] and **Liz Hoy** [GSFC]
Core Variables and Standards	**Peter Griffith** [GSFC]

Jason Edwards [Natural Resources Canada, Canadian Forest Service] discussed Canadian Forest Service participation in ABoVE through participating in working groups, collaborating with individual investigators, and contributing data and analyses from activities such as their Forest Inventory and Monitoring program.

Chris Derksen [Environment and Climate Change Canada (ECCC)] described ECCC activities that are related to ABoVE research themes. While no resources are dedicated to ABoVE participation, there are several research and monitoring efforts that can make contributions to ABoVE, such as their *in situ* monitoring network for carbon dioxide and methane.

Ridha Touzi [Natural Resources Canada, Canada Centre for Mapping and Earth Observation (CCMEO)] gave a presentation about CCMEO's data analysis activities, especially those using synthetic aperture radar (both airborne and satellite-based) approaches to characterizing peatland ecosystems.

Aynslie Ogden [Government of Yukon] reviewed the science priorities of the Government of Yukon, which is committed to research, monitoring, and capacity building in the territory. She also highlighted a few projects directly related to ABoVE science.

Andrew Applejohn [Government of Northwest Territories (GNWT)] presented GNWT's research priorities and monitoring activities, particularly focusing on climate change and traditional knowledge. Many of the research topics intersect with ABoVE science themes.

Stan Wullschleger [U.S. Department of Energy's Next Generation Ecosystem Experiment-Arctic (NGEE-Arctic)] outlined the research approach NGEE-Arctic has conducted at field sites outside Barrow and Nome, AK.

In addition to the partner reports, **Merritt Turetsky** [University of Guelph] provided some perspective from Canadian academic institutions. **Michelle Mack** [Northern Arizona University] and **Natalie Boelman** [Columbia University, NY, Lamont–Doherty Earth Observatory] gave updates on synergistic activities being conducted at the Bonanza Creek and Arctic Long Term Ecological Research (LTER) stations, respectively. **Sarah Elmendorf** and **Rommel Zulueta** [both at the National Science Foundation's National Ecological Observatory Network (NSF NEON)] described the activities of their organization.

Interesting Results from the ABoVE Projects

A number of ABoVE studies have focused on the impacts of changes to *shoulder season*[2] snow and ice cover on wildlife and native subsistence activities. For example, research results reveal that the snow-free date strongly affects the ratio between lambs and ewes in Dall sheep populations. However, the researchers studying relationships between snow and wildlife subsistence activities determined that the standard snow-cover products derived from MODIS[3] data do not have the needed spatial resolution for landscape-scale analyses of the impacts of snow cover on wildlife habitat.

Other studies focused on understanding processes controlling hydrologic processes in permafrost terrain. The contributions of Canadian researchers have strengthened ABoVE in this area. Hydrologic studies are ongoing at a number of the the ABoVE study regions. Studies provide a strong foundation for the flights that will be carried out during the ABoVE Airborne Campaign in 2017 (e.g., UAVSAR, AirMOSS, AirSWOT[4]). Numerous studies focus on understanding vegetation dynamics in a number of different landscape settings, including post-fire regeneration tundra-taiga transition in Denali National Park, in forest and peatlands in the Northwest Territories, and in boreal

[2] In ecological studies, *shoulder season* refers to the times between peak activity and minimum activity.
[3] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms.
[4] UAVSAR stands for Uninhabited Aerial Vehicle Synthetic Aperture Radar; AirMOSS stands for Airborne Microwave Observatory of Subcanopy and Subsurface; AirSWOT stands for Air Surface Water and Ocean Topography.

The View from ABoVE: Airborne Planning Session

Chip Miller [NASA/Jet Propulsion Laboratory (JPL)—*ABoVE Deputy Science Lead*] convened the airborne science planning session on the afternoon of January 17, 2017, with more than 65 participants in attendance. Representatives from each of the nine newly selected airborne projects gave brief presentations on their projects, detailing the planned sensors and platform combinations. The projects address a range of scientific topics including permafrost and hydrology, vegetation structure and function, carbon cycle dynamics, and forecasting and modeling.*

A significant portion of the session was dedicated to adjusting flight plans to accommodate logistical and financial constraints. Project teams and partners from Alaska and Canada (as described in the article's main text) worked to identify key locations for data collection that have the substantial historical data and/or scientific importance. While not every desired flight location can be accommodated, the resultant compromises yield a scientifically robust final plan for the airborne campaign. The Foundational Airborne measurements include L-band and P-band radars (UAVSAR and AirMOSS)** and a vegetation lidar (LVIS) and a narrow-band spectroradiometer (AVIRIS-NG). Other airborne instruments from selected airborne science teams include the Canopy Fluorescence Imaging Spectrometer (CFIS) and a K_a-band radar (AirSWOT).

* Details on the nine projects selected can be found at *https://above.nasa.gov/cgi-bin/above/pi_list.pl?subset=2*.

** All undefined acronyms in this sidebar refer to specific aircraft instruments. LVIS stands for Land, Vegetation, and Ice Sensor (a.k.a., the Laser Vegetation Imaging Sensor); AVIRIS-NG stands for Airborne Visual Imaging Infrared Spectrometer–Next Generation. All others are defined in the article's main text.

forests in northern Alberta; shrub expansion in tundra (i.e., Inuvik, Seward Peninsula); altitudinal treeline (i.e., Wolf Creek, Kluane Lake, and across Alaska); southern boreal forest dynamics; and forest dynamics at the northern treeline.

Several projects have developed new satellite remote sensing data products or demonstrated new uses for remote sensing data. These include:

- mapping permafrost plateaus in an ice-rich region of the Yukon-Kuskokwim Delta.
- using lidar tree height measurements to study northern treeline dynamics;[5]
- using time series of MODIS and Landsat data to study complex land cover changes in Yukon–Kuskokwim Delta;
- using Landsat data to study post-fire succession;
- developing new vegetation indices from MODIS using water band 11 to study phenology and to scale flux-tower measurements;
- integrating airborne lidar data with Landsat data to produce improved percent forest cover maps for the North American boreal forest region and to produce new maps of aboveground forest biomass in Tanana River Valley, AK;
- developing a lichen-shrub cover mapping for Alaska's North Slope based on integrating Landsat data with fine-resolution Digital Globe[6] data; and
- developing new datasets for mapping burned area and severity.

Additionally, extensive field-based observations of biomass consumption during wildland fires have been made in tundra regions, in forests and peatlands in the Northwest Territories, and in the southern boreal forest.

Science Team modeling activities include:

- integrating field observations and new remote sensing products into models that estimate carbon consumption and greenhouse gas emissions during fires;
- large-scale modeling of the carbon cycle;
- developing a new framework for data integration using field observations and remote sensing data;
- modeling permafrost dynamics in Alaska (using remote sensing data as inputs and using AirMOSS products for validation); and
- modeling forest growth and forest dynamics, where Goddard-Lidar Hyperspectral Thermal (G-LiHT) lidar data were used for model calibration and validation.

[5] There is a strong correlation between tree height and tree age, so researchers can use airborne lidar data to study the spatial and temporal dynamics of northward tree migration.

[6] DigitalGlobe is a private company that owns and operates the most agile and sophisticated constellation of high-resolution commercial Earth-imaging satellites. Including WorldView-1, GeoEye-1, WorldView-2, WorldView-3, and WorldView-4. Learn more at *https://www.digitalglobe.com*.

Affiliated Projects

In addition to the first round of 25 "Phase 1" ABoVE core projects and the 9 new Airborne Science projects, there are also some 30 projects directly affiliated with ABoVE. Affiliated projects are funded by NASA or other sources and are selected based on submissions to the ABoVE leadership group. About a dozen of the recently added projects presented "speed talks" on their research goals and relevance to the overall ABoVE effort.

Infrastructure and Logistics

The CCE Office at GSFC has assigned **Dan Hodkinson, Leanne Kendig,** and **Sarah Sackett** to focus exclusively on infrastructure, safety, and logistics for the ABoVE campaign. They gave an overview of logistics support for ABoVE, including information about permitting; obtaining field vehicles, equipment, and technicians; safety training and planning; and the Fairbanks (AK) and Yellowknife (NWT) logistics hubs. Throughout the meeting the staff met with individual researchers to review their respective logistics and safety needs.

ABoVE Science Cloud

CCE Office staff member **Liz Hoy** gave an update on the ABoVE Science Cloud, including information on data holdings and high-resolution imagery. The NASA Center for Climate Simulation High Performance Computing hosts the Cloud. In addition to offering data storage, the ABoVE Science Cloud has virtual machines for cloud computing, greatly decreasing processing time. Greater than two petabytes of data have already been staged on the system, including contributions from Landsat, MODIS, MERRA-GEOS-5,[7] and DigitalGlobe Imagery. The CCE Office has also been working to develop tasking requests for both DigitalGlobe and Radarsat-2 data.

Collaborations and Engagement

Active engagement with local community representatives, land managers, and other stakeholders is a priority for the ABoVE Science Team. Collaborators and relevant decision-makers have participated in prior Science Team meetings to facilitate knowledge sharing and project development and planning. CCE Office staff member **Libby Larson** reported on a CCE Office pilot activity to further enhance connections with potential stakeholders. ABoVE projects will assess the *applications readiness level* (ARL) for each product the project will produce. ARLs range from 1 (basic research) to 9 (sustained operational use). Because the NASA Terrestrial Ecology Program, a basic research program, funds most of the ABoVE projects, many of the products will fall within the lower range of the ARL scale (i.e., they are focused on research and are not necessarily applications-oriented). However, the process of self-evaluation of the progress and intended uses of products will enable identification of additional potential stakeholders and possible future applications research. **Chalita Forgotsen** has been hired as an additional staff member to help the ABoVE projects determine ARLs for their products.

Citizen Science and Communications

Peter Griffith [GSFC—*Director of the CCE Office*] presented the citizen science and communications activities of both the CCE Office and the Science Team. ABoVE has partnered with Earth to Sky (ETS[8]), an interagency partnership that conducts a variety of professional development efforts in science and science communication for informal educators and interpreters (principally those in national parks, wildlife refuges, and similar public lands). ETS also maintains and nurtures an expanding community of practice comprised of ETS course alumni who, in turn, reach millions of people annually with content derived from their courses and resources. Last year, ABoVE and ETS offered a climate science and communication minicourse in Fairbanks, hosting participants from several national parks, Alaska state agencies, museums, nongovernmental organizations, and university and academic programs. A regional course on the same topic is planned for April 2017 in Yellowknife, Northwest Territories, Canada. ABoVE is also working with GLOBE Observer (*https://observer.globe.gov*), a citizen science program that creates protocols to allow individuals to collect environmental data locally on their smartphones for use in more-formal scientific endeavors.

Conclusion

The January 2017 ABoVE Science Team Meeting focused on planning for the 2017 airborne campaign, introducing newly funded and affiliated projects to the Science Team, and developing synthesis activities by the thematic working groups. The Science Team worked closely with partners and instrument and aircraft managers to refine the flight plans within mission parameters, while maintaining the highest possible scientific merit. Important progress was made in identifying key areas of historic and/or current data collections as well as land-management interest. The second half of the meeting was devoted to reports from thematic working groups, an array of partner and affiliated projects, and other business and logistics matters. As ABoVE continues to mature, the opportunities for collaboration and synthesis will continue to emerge. The Science Team is poised to take advantage of them through the coordinated activities of the interdisciplinary working groups.

The next ABoVE Science Team Meeting has been scheduled for January 23-26, 2018, in Seattle, WA. ■

[7] MERRA stands for Modern-Era Retrospective Analysis for Research and Applications; GEOS-5 stands for Goddard Earth Observing System Model, Version 5.

[8] To learn more, visit: *http://earthtosky.org*

Landsat Science Team: 2017 Winter Meeting Summary

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Introduction

The winter meeting of the NASA-U.S. Geological Survey (USGS) Landsat Science Team (LST) was held January 10-12, 2017, at Boston University. LST co-chairs **Tom Loveland** [USGS's Earth Resources Observation and Science Center (EROS)—*Senior Scientist*], **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Deputy Director, Earth Sciences Division*], and **Curtis Woodcock** [Boston University—*Professor* and *LST Co-Leader*] welcomed the participants to the three-day meeting. The group immediately and enthusiastically recognized Woodcock's receipt of the *2016 Pecora Award*. Loveland summarized the primary meeting objectives to identify priorities for future Landsat measurements and to begin identifying next-generation Landsat products. He also discussed USGS's plans to issue a request for proposals for membership on the 2018-2023 LST (i.e., the next five-year term). Irons stressed Landsat's bipartisan support but cautioned against complacency when looking toward future capabilities. Meeting presentations are available at *https://landsat.usgs.gov/landsat-science-team-meeting-jan-10-12-2017*.

With the current LST nearing the end of its five-year term (2012-2017), **Mike Wulder** [Canadian Forest Service—*LST Member*], **David Roy** [South Dakota State University—*LST Co-Leader*], and **Curtis Woodcock** led a discussion of the major impacts of the 2012–2017 LST on relevant activities—these are summarized in *The Legacy of the Second (2012–2017) Landsat Science Team* on page 22.

Tim Newman [USGS Land Remote Sensing Program—*Program Coordinator*] and **David Jarrett** [NASA Headquarters—*Earth Science Missions Program Executive*] updated the LST on Landsat's programmatic status. Newman discussed planning for Landsat 9 and Sustainable Land Imaging (SLI) capabilities. He also reviewed Landsat's role in supporting the growing commercial imagery market, which includes developing network-cloud access to data and processing services, and multimission calibration. Jarrett then discussed the need to consider all options for Landsat configurations beyond Landsat 9.

NASA Land Cover and Multi-Source, Land-Imaging Activities

Garik Gutman [NASA Headquarters—*Land Cover and Land Use Change (LCLUC) Program Manager*] summarized the LCLUC program's vision that includes developing periodic global inventories of land use and land cover and the research projects associated with this vision. He focused his discussion on the Multi-Source Land Imaging (MuSLI) initiative to link Sentinel-2[1] and Landsat observations to map and monitor land-surface properties. **Jeff Masek** [GSFC—*Chief of the Biospheric Sciences Laboratory*] provided a detailed view of research leading to harmonized Landsat and Sentinel-2 data products. He explained that the goal is to create seamless, near-daily, 30-m (~98-ft) surface reflectance products by integrating Landsat 8 and Sentinel-2 data along with atmospheric corrections, spectral and bidirectional reflectance distribution function (BRDF) adjustments, and regridding. Preliminary products for selected areas are available for review at *https://hls.gsfc.nasa.gov*.

Tom Loveland and **Garik Gutman** concluded the session by discussing the relationship between the MuSLI and LST. Each team has a different focus for its activities: The LST seeks to ensure science-quality Landsat data while the MuSLI emphasizes synergy between Landsat and data from the European Sentinel missions. However, they overlap on two important issues: assessing data quality requirements and processing approaches. Because of these common areas of interest, the two teams plan to begin meeting with each other at least once a year.

Sentinel-2 Status

Benjamin Koetz [European Space Agency—*Sentinel-2 Exploitation Engineer*] summarized the status of Sentinel-2a and launch plans for Sentinel-2b.[2] Sentinel-2a's performance is exceeding most specifications, and absolute geolocation, multispectral registration, absolute radiometric uncertainty, and signal-to-noise ratio (SNR) measured performance are excellent. Multitemporal registration circular error is the only mission requirement not yet met, but full performance is expected once the global reference image is completed. Ten-day coverage is currently being acquired for Europe, Africa, and

[1] A series of Earth-observation missions have been or will be developed under the European Space Agency's Sentinel programme. Sentinel-2 provides high-resolution optical imaging for land services (e.g., imagery of vegetation, soil and water cover, inland waterways, and coastal areas). Sentinel-2 will also provide information for emergency services. Sentinel-2a was launched on June 23, 2015, from ESA's Spaceport in French Guiana.

[2] **UPDATE:** Sentinel-2b was successfully launched on March 7, 2017, from ESA's Spaceport in French Guiana.

The Legacy of the Second (2012–2017) Landsat Science Team

The LST is selected to serve a five-year term and provide direction, research, and scientific and technical evaluations of issues affecting the active Landsat missions and the Landsat archive. The USGS–NASA cosponsorship of the LST began in 2006, and the first team therefore served through 2011. The LST members are representatives of the Landsat user community and offer perspectives that enhance or expand Landsat applications. As explained in the article text, the third team is expected to be selected later this year, to serve from 2018–2023.

The second LST has made several contributions that have directly influenced the future of Landsat, and has played a major role in ensuring Landsat continuity. In particular, Team members produced science statements that were used to define the Sustainable Land Imaging (SLI) framework. These statements addressed Landsat continuity, Landsat 9 capabilities, and Landsat synergy with international imaging systems (e.g., European Sentinel missions, India's Resourcesat). They also provided the scientific rationale for particular sensing features the SLI Architecture Study Team has recommended, exemplified by articulation of the science value of 12-bit radiometric resolution. The second LST also established the importance of the Landsat Global Archive Consolidation (LGAC) in producing new terrestrial Essential Climate Variables that make full use of the program's spatial and temporal coverage, multidecadal continuity, metadata, instrument calibration and cross-calibration, and data access.

The second LST has also made major contributions to the success of the Landsat 7 and 8 missions. For example, Team members provided science justification for revising the Landsat 7 and 8 acquisition schedules—nearly doubling the scenes obtained per day from ~650 to ~1200, which reduces emphasis on cloud avoidance—and advocated for increased daily imaging rates. The second LST also quantified the variability of Landsat 5 local overpass time, which was used to inform Landsat 7 end-of-life scenarios, and also documented the Landsat 8 science and product vision for terrestrial global change.

The second LST made numerous contributions to improving Landsat products. Team members developed algorithms to deal with cloud/shadow detection, data tiling, and land cover change mapping, which were incorporated into USGS's Landsat operational systems. Team members provided rationale, insight, and advice to help Landsat Collections provide users with access to the most up-to-date and traceable analysis-ready data (ARD). The second LST also provided a science motivation for bringing Multispectral Scanner (MSS) data in line with those from the Thematic Mapper (TM) and later Landsat instruments, and offered options to produce reliable, continuous, measurements across all Landsat missions. Team members demonstrated the importance of absolute calibration and they evaluated and recommended improvements to Landsat surface reflectance algorithms. They also characterized Landsat image radiometry—ensuring consistency across Landsat instruments and quality of climate variables (e.g., albedo) and developed the capacity to estimate biophysical parameters.

Finally, the second LST supported the expansion of Landsat science and applications. Team members supported the global applications community in using Landsat data by providing science, enhanced understanding, and evidence of the benefits of new Landsat capabilities and products. They also articulated novel scientific applications with notable insights into water resources and cryosphere systems. In addition, the second LST demonstrated the need for thermal data and advancements to improve mapping of vegetation phenology and stress over large areas, and increase the accuracy of required cloud and shadow detection and screening algorithms. Team members also communicated the advanced information content as a result of Landsat time series availability and contributed science leadership regarding use of time series data to characterize land-cover dynamics.

Greenland, and coverage of the rest of the world alternates between 10 and 20 days.[3] Full, global, 10-day coverage is expected sometime during 2017.

Patrick Griffiths [Humboldt University of Berlin] summarized his research involving the integration of Landsat and Sentinel-2 data for interannual time series studies of crop type and land-cover mapping, and documenting cover-specific phenology variables. While Griffiths reported some confusion between some crop types, the spatial consistency of the classifications benefited from 10-day composites, and the characterization of grassland and cropland phenology was promising.

[3] For the rest of the globe, areas are imaged roughly every other overpass, but it varies depending on the particular day and situation.

Landsat 9 Development Status

Del Jenstrom [GSFC— *Landsat 9 Project Manager*] and **Jim Nelson** [USGS—*Landsat 9 Project Manager*] provided an update on the status of Landsat 9 development. Jenstrom reported that Ball Aerospace and Technologies Corporation in Boulder, CO, is making significant progress with Operational Land Imager-2 (OLI-2) detector-module testing, focal-plane assembly construction, and other fabrication activities. Meanwhile, GSFC is working to develop the Thermal Infrared Sensor-2 (TIRS-2) and has redesigned the telescope to include baffles that mitigate the *stray-light* issues that impacted Landsat 8's TIRS.[4] Orbital ATK in Gilbert, AZ, was awarded the Landsat 9 spacecraft contract; initial reviews have already been held. Launch vehicle procurement is expected this summer (2017). Nelson reported that the ground-system requirements review took place recently; at the conclusion of the review, the panel approved the Landsat 9 Ground System team to proceed to the Preliminary Design Review (PDR) stage. The Landsat 9 launch is tentatively scheduled for December 2020.

Landsat 7 and 8 and Archive Status

Brian Sauer [USGS EROS—*Landsat Sustaining Engineering Project Manager*] gave an update on Landsat 7 and 8 and the Landsat archive. Landsat 7 is performing nominally and collecting about 430 scenes per day. Now in its eighteenth mission year, end-of-life planning is underway. However, maintaining eight-day imaging with Landsat 8 is a top priority and the USGS is working to extend the mission until the launch of Landsat 9. Because of fuel limitations, by the fall of 2020 Landsat 7's orbit will degrade to an orbital mean local time between 9:15 and 9:30 AM. The NASA Restore-L mission has targeted Landsat 7 to demonstrate in-orbit refueling capabilities. Restore-L calls for a refueling mission following the end of the Landsat 7 science mission in late 2020. Landsat 7 would descend to a lower orbit, pair with the Restore-L spacecraft, and be refueled.[5] Options for a refueled Landsat 7 include de-orbiting to meet or exceed the 25-year re-entry guideline established in U.S. Space Policy, thus extending the Landsat 7 science mission and enhancing cross-calibration between Landsat 8 and 9, or extending the science mission in the event of a Landsat 9 failure.

[4] Thermal energy from outside the normal field of view (*stray light*) has affected the data collected in Landsat 8 TIRS Bands 10 and 11. This varies throughout each scene and depends upon radiance outside the instrument field of view. Band 11 is significantly more contaminated by stray light than Band 10. Details about Landsat 8 TIRS stray light can be found in Appendix A of the Landsat 8 Data User Handbook, accessible online at *https://landsat.usgs.gov/sites/default/files/documents/Landsat8DataUsersHandbook.pdf*.

[5] To learn more about Restore-L, visit *https://sspd.gsfc.nasa.gov/restore-L.html*.

Sauer also reported that Landsat 8 systems are working nominally, with up to 740 scenes acquired each day. OLI performance continues to exceed requirements, and the TIRS alternate operations concept established after the 2015 scene-select mirror encoder issue is providing useful thermal imagery.[6]

The Landsat archive has grown to more than 6.7 million scenes from Landsats 1–8, and the number of scenes distributed to users worldwide exceeded 17.4 million for Fiscal Year 2016—nearly double the number of scenes distributed in Fiscal Year 2015. The LGAC activity has added nearly 4.1 million scenes. LGAC is approximately 62% complete, with 71% of the scenes new to the archive.

Landsat Product Improvements

Dennis Helder [South Dakota State University] gave a review of research on radiometric calibration across the entire Landsat record. Historically, the USGS applied radiance-based calibration using solar exoatmospheric-irradiance values (ESUN). Different sources have defined different ESUN values for the same Landsat instrument. Enhanced Thematic Mapper Plus (ETM+) ESUN values published in a 2009 *Remote Sensing of Environment* paper by Gyanesh Chander, Brian Markham, and Dennis Helder,[7] have been used by many, but the authors advise against using those values due to differences in calculated irradiance. Helder described research on reflectance-based calibration that uses Landsat 8 OLI top-of-atmosphere (TOA) reflectance as the basis for calibrating the Landsat archive and to minimize uncertainties due to solar model differences. Ensuing discussion led to LST members endorsing the use of reflectance-based calibration, and recommending their routine implementation.

Brian Sauer gave an update on implementing Landsat data collection management. By definition, data collections have well-characterized radiometric quality, are cross-calibrated among the different Landsat sensors, and are assigned to different tiers based on data quality. Tier-1 data are suitable for time-series analysis and have root mean square error (RMSE) in georegistration accuracy of less than 12 m (~39 ft). Tier-2 and real-time data have georegistration-accuracy RMSE exceeding 12 m. Collection 1 processing of all U.S. Landsat 4–7

[6] On November 1, 2015, TIRS experienced a condition related to the instrument's ability to accurately measure the location of the Scene Select Mirror (SSM). A new approach for determining the exact position of the SSM through analysis of instrument telemetry data was implemented to provide the information needed to regularly update the line of sight model that is used for geometric correction and alignment of TIRS and OLI data.

[7] Chander, G., Markham, B.L., and Helder, D.L., 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, 113, 893-903.

data was completed in October 2016, and processing of data for the rest of the world was completed in February 2017. Landsat 8 processing is now underway, with priority given to images of the U.S.; the processing should be completed by June 2017. For Collection 1, 70% of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data and 57% of Landsat 4 and 5 Thematic Mapper (TM) data meet Tier-1 specifications.

Ron Morfitt [USGS EROS—*Landsat 8 Calibration and Validation Lead*] reviewed research on algorithms for processing Landsat Multispectral Scanner (MSS) data and Landsat TM scenes missing payload correction data (referred to as *noPCD*). MSS algorithm development includes filling missing Level-0 scans and improving reflectance calibration and image geometry. Approximately 375,000 noPCD scenes lack the attitude and ephemeris data needed to accurately georegister pixels. At this point, the development team is working toward having both MSS and noPCD processing capabilities in place later in 2017.

John Dwyer [USGS EROS—*Landsat Project Scientist*] gave an update on Landsat atmospheric correction and surface reflectance processing. New releases of Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithms, used to generate Landsat 4–7 surface reflectance products, were recently completed, using per-pixel, solar-zenith-angle corrections and quality-assurance-band pixel-quality attributes. The Landsat 8 Surface Reflectance Code (LaSRC) is also being improved to address aerosol retrievals over water, using per-pixel solar-azimuth and -zenith angles, and quality attributes. Development of Landsat 4–8 land surface temperature products for North America continues.

To end this session, **Brian Sauer** and **John Dwyer** summarized the development of Landsat analysis-ready data (ARD) products. Landsat ARD products are consistently processed to the highest scientific standards needed for direct use in applications. ARDs consist of TOA, surface reflectance, and surface temperature data that are consistently processed, gridded to a common cartographic projection, and accompanied by appropriate metadata to enable further processing while retaining traceability of data. Generation of Landsat 4–8 ARD products for the U.S. is underway and will be completed by September 2017. Landsat 4–7 data will be processed first, followed by those for Landsat 8.

Future Landsat Requirements and Capabilities Discussion

The LST is firmly committed to the idea that future Landsat missions absolutely must advance measurement capabilities while preserving continuity with earlier missions and constraining program costs. With this guiding premise in mind, the LST is working to define the science drivers and future capabilities for Landsat 10 and beyond. Five specific areas of investigation are underway: continuity issues, acquisition temporal frequency, spatial resolution and geometry, radiometric resolution and SNR, and spectral bands. Breakout groups were established to identify preliminary capabilities in each of the five areas. Each group reviewed their preliminary results and developed plans to produce a consensus recommendation. A report on recommended capabilities and the supporting science justification will be finalized at the next LST meeting.

The LST's efforts benefit from the USGS Requirements, Capabilities, and Analysis for Earth Observation (RCA-EO) project.[8] **Greg Snyder** [USGS—*RCA-EO Project Manager*] summarized the status of their effort to document user requirements for federal programs. Through interviews with federal stakeholders, the RCA-EO project is working to document environmental parameters and measurement attributes associated with a wide range of applications. The collective results are being analyzed to identify potential capabilities for future Landsat missions.

Other Reports

Frank Avila [National Geospatial Intelligence Agency—*Landsat Advisory Group (LAG) Vice Chair*] gave an update on LAG activities. LAG is part of the Department of Interior's National Geospatial Advisory Committee and contributes to the requirements, objectives, and actions of the Landsat Program. The LAG is currently investigating several topics, including the roles of smallsats in Earth observations, the feasibility and utility of temporal data cubes (e.g., ARDs) in monitoring global change and projecting future land variables, and data-continuity-mission enhancements.

Rick Lawrence [Montana State University—*Professor and AmericaView[9] Liaison*] gave an update on AmericaView's plans to survey its constituents on future Landsat requirements. They intend to use the approach developed by the RCA-EO team. Lawrence also summarized AmericaView-sponsored research on classification accuracy. While classification tree and support vector machines generally performed best, there was significant variability in results depending on the specific tests conducted.

Summary of Boston Area Remote Sensing Activities

Meeting co-hosts **Curtis Woodcock**, **Crystal Schaaf** [University of Massachusetts, Boston—*LST Member*]

[8] To learn more about RCA-EO, visit *https://remotesensing.usgs.gov/rca-eo/rcaeo*.

[9] AmericaView is a nationwide consortium for remote sensing education, research, and geospatial applications. To learn more, visit *https://americaview.org*.

Table. Summary of Landsat-related remote sensing activities in the Boston area.

Presenter [Affiliation]	**Topic**
Zhan Li [University of Massachusetts, Boston (UMass)]	Landsat/Sentinel surface albedo comparisons
Angela Erb [UMass]	Studying changes in albedo from boreal fire scars
Yan Liu [UMass]	Studying California savanna and grassland phenology
Peter Boucher [UMass]	Monitoring salt marshes
Farouk El-Baz [Boston University (BU)]	Monitoring Egypt's deserts
Eli Melaas [BU]	Studying boreal and temperate forest phenology
Damien Sulla–Menashe [BU]	Tracking boreal forest greening and browning
Jordan Graesser [BU]	Monitoring the changing scale of South American agriculture
Pontus Olofsson [BU]	SilvaCarbon* capacity building
Paulo Arevalo [BU]	Columbian Amazon change area estimates
Damien Sulla–Menashe [BU]	Monitoring deforestation with synthetic aperture radar/optical fusion
Xiaojing Tang [BU]	Near-real-time monitoring of forest change
Eric Bullock [BU]	Developing postprocessing approaches for time-series structure break detection
Stephan Estal [BU]	Conducting global assessments of protected area effectiveness

*SilvaCarbon is a U.S. technical coordination program to enhance capacity worldwide in monitoring and managing forest and terrestrial carbon. To learn more, visit *http://silvacarbon.org*.

and their student and faculty colleagues gave presentations showcasing a number of ongoing research projects where Landsat data are being used to study topics of interest to the LST—see **Table**.

Finally, **Valerie Pasquarella** [University of Massachusetts, Amherst], a Boston University alumnus, presented her research on monitoring northeastern forest dynamics using Landsat time-series data, and **Zhe Zhu** [Texas Tech University—*Assistant Professor*] presented his work on classifying change agents using Landsat time series.

Conclusion

The Boston meeting gave the LST a chance to reflect on the status of the Landsat program. Landsat 7 and 8 are acquiring more imagery than ever, Landsat 9 is authorized and proceeding toward a December 2021 launch date, and planning for Landsat 10 and beyond is underway. The LGAC initiative has doubled the size of the Landsat archive and new Landsat product specifications are being implemented. With Landsat applications growing in number and impact, the value of Landsat continues to grow. The attendees all agreed that this is an unprecedented time in Landsat's long history.

The next Landsat Science Team meeting will be held July 11-13 2017 at the USGS EROS Science Center in Sioux Falls, SD. ■

2016 HyspIRI Symposium Summary

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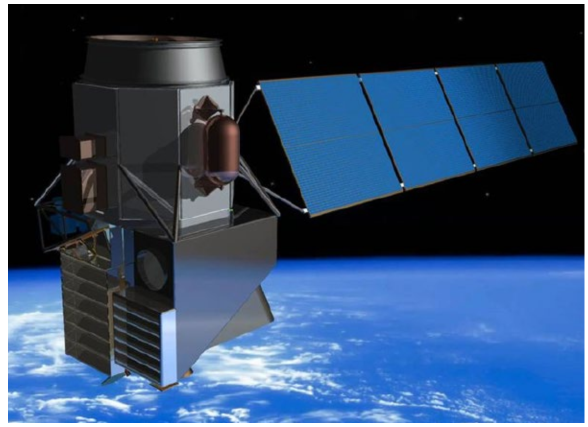
Introduction

The Hyperspectral Infrared Imager (HyspIRI) satellite will be a global-coverage mission operating in low Earth orbit. It will include two instruments: an imaging spectrometer that will take measurements from visible to shortwave infrared (VSWIR) wavelengths in contiguous 10-nm bands between 380 and 2500 nm, and a multispectral imager that will take measurements in the mid- and thermal-infrared (TIR) regions of the spectrum between 3 and 12 µm. The VSWIR and TIR instruments both have a spatial resolution of 60 m (~197 ft) at nadir. The VSWIR spectrometer will provide global coverage every 19 days; the TIR instrument will provide global coverage every 5 days, due to its larger swath width.



Artist's rendering of HyspIRI spacecraft. **Image credit:** NASA

HyspIRI will study the world's ecosystems and provide information on natural disasters such as volcanoes, wildfires, and drought. The mission will provide a benchmark on the state of the world's ecosystems, against which future changes can be assessed. The mission will also characterize the pre-eruptive behavior of volcanoes and the likelihood of future eruptions, and measure the levels and distribution of carbon-containing and other gases released from wildfires. HyspIRI also includes an Intelligent Payload Module (IPM), which will enable onboard processing and direct (real-time) broadcast of a subset of the data for immediate application, such as for disaster aid. The HyspIRI mission was recommended as a *Tier 2* priority in the 2007 National Research Council's (NRC) Decadal Survey, which NASA requested, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS).[1] Additional information on the mission may be found at *https://hyspiri.jpl.nasa.gov*.

Meeting Overview

The sixth Annual HyspIRI Product Symposium was held June 1-3, 2016, at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. This year's theme was "Evolving the HyspIRI Mission and Products," with the objective of developing "HyspIRI Strategies to Meet Sustainable Land and Aquatic Imaging Needs." In all, there were 115 participants at the three-day symposium, with 91 onsite participants and 24 more attending via Webex. Some participants were from other government agencies and academic institutions.

[1] The 2007 report is called "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" and can be downloaded from *https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*. To learn details about the 2017 survey visit *http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm*.

HyspIRI science team meeting participants. **Photo credit**: David Landis [GSFC]

There were a total of 11 symposium sessions covering a variety of topics including: HyspIRI Mission Update; Terrestrial Ecosystem Priorities; Calibration/Validation Activities; five sessions addressing various aspects of HyspIRI Science Preparatory Activities: Applications, New Technologies and Products, Airborne Campaigns, Carbon and Water Science, and Other Activities; and one Addressing International Space Station Related Mission Activities. The Fourth Annual HyspIRI Aquatic Studies Forum was held at the end of the symposium to allow discussion of topics on hyperspectral coastal and inland water remote sensing applications. The final two sessions were part of the forum, and report on the activities of the HyspIRI Aquatic Study Group (HASG). They focus on Aquatic Airborne Campaigns and Aquatic Missions respectively.

The symposium and forum covered a total of 49 presentations, 46 speakers, 9 chair persons, 5 posters presentations, a Webex Tutorial on EcoSys Spectral Library presented by **Phil Townsend** [University of Wisconsin], and a keynote presentation by **Susan Ustin** [University of California, Davis (UC Davis)].

This article gives a brief summary of the content of each session. The presentations provided a thorough background on the HyspIRI mission by addressing new approaches and products of land imaging. The HyspIRI Symposium presentations are available on the HyspIRI website provided in the Introduction.

Day One

The first day of the meeting featured five technical sessions, including the symposium keynote address during Session Two.

Session One: HyspIRI Mission Update

The opening session started with **Betsy Middleton** [GSFC—*GSFC HyspIRI Lead Scientist*], who served as session chair, giving an overview of the symposium. Then **Woody Turner** [NASA Headquarters (HQ)—*Program Scientist for Biological Diversity and Ecological Forecasting*] presented a HyspIRI mission update and overview of current activities, which included:

- continuing HyspIRI data product generation and benchmarking with airborne and satellite data;
- continuing instrument mission trade studies, including pursuing opportunities for SmallSat and International Space Station (ISS) missions, and IPM for throughput/low-latency products;
- ensuring the HyspIRI VSWIR and TIR instruments meet the Sustainable Land Imaging (SLI)[2] measurement requirements, including compatibility with heritage data product resolutions, and inter-sensor band synthesis;
- utilizing the ECOSTRESS[3] mission development for HyspIRI risk reduction; and
- preparing materials to update the NRC 2017 Decadal Survey on the status and value of HyspIRI, and providing NRC with options for accomplishing the mission.

Rob Green [NASA/Jet Propulsion Laboratory (JPL)] described the ways in which HyspIRI scientists are providing input for the upcoming 2017 Decadal Survey, and referenced a key article on HyspIRI in *Remote Sensing of Environment* (*https://www.sciencedirect.com/science/journal/00344257/167*).

Miguel Román [GSFC] discussed the Terrestrial Observation Panel for Climate (TOPC), which was set up by the Global Climate Observing System and the World Climate Research Programme to develop a balanced and integrated system of *in situ*, air- and space-based observations of the terrestrial ecosystem. The panel focuses on: identifying terrestrial observation requirements, assisting the establishment of climate-observing networks, providing guidance on observation standards and norms, facilitating access to Essential Climate Variables (ECV) data, and promoting climate studies and assessments. At the end of the session, the meeting participants agreed that HyspIRI should do well in the upcoming Decadal Survey, hopefully moving up to Tier 1 status.

Session Two: Terrestrial Ecosystem Priorities

Susan Ustin [UC Davis] first provided the symposium keynote lecture, laying out "The Case for a Global Biodiversity Observatory." She talked about significant and largely irreversible changes to species diversity and how HyspIRI's detailed land-cover maps could be used to catalog these changes. **Rob Green** [JPL] then presented a history of imaging spectrometers and the science benefits of spectroscopy—including advances that provide finer detail in vegetation species maps and improved water and ice imagery. **Andreas Müller** [Deutsches Zentrum für Luft- und Raumfahrt (DLR)][4] Earth Observation Center, Potsdam, Germany] described the "Applications of Hyperspectral Imaging for Terrestrial Environmental Monitoring." He discussed using hyperspectral imaging to monitor plant functional diversity from space and showed results from

[2] SLI is a NASA-U.S. Geological Survey (USGS) partnership to develop, launch, and operate a spaceborne system that will provide researchers and other users with continuous, high-quality, and global land-imaging measurements.

[3] ECOSTRESS stands for ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station; the mission is scheduled to launch to the ISS in 2018, and will mount a HyspIRI-like TIR instrument on the ISS to measure the temperature of terrestrial vegetation and use that information to better understand how much water plants require and how they respond to stress.

[4] DLR is the German Aerospace Center.

a series of case studies, including iron oxide dust monitoring, lake phytoplankton detection, and monitoring of the 2010 Gulf Oil Spill. **Neus Sabater** [University of Valencia] presented material on the upcoming Fluorescence Explorer Space Mission (FLEX),[5] the first space mission dedicated to mapping solar-induced chlorophyll fluorescence (SIF) of terrestrial vegetation. To wrap up the session, **Woody Turner**, who served as session chair, led a group discussion on "Steps Toward Achieving the Next NASA Spectrometer in Space." This discussion led to enthusiastic support among participants for a proposal that Landsat 10 should have a spectrometer as its main instrument.

Session Three: Calibration/Validation Activities

Bruce Cook [GSFC] gave an update on the Sustainable Land Imaging program, and efforts to combine Landsat 8 and Sentinel-2 products to improve time-series coverage and create new multisource imagery.[6] **Guoqing Sun** [University of Maryland, Earth System Science Interdisciplinary Center (ESSIC)] described his work to create Landsat-like multispectral band-like responses using data from the Earth Observing-1 (EO-1)[7] spacecraft's Hyperion instrument (which had much broader, continuous hyperspectral coverage than Landsat's narrow, isolated multispectral bands), and how this technique could be applied to create Landsat-like HyspIRI products. Session chair **Chris Neigh** [GSFC] discussed the calibration/validation efforts of EO-1's Hyperion instrument using Pseudo Invariant Calibration Sites (PICS), especially the Libya-4 desert calibration site.[8] These efforts show how stable the Hyperion instrument was and how a similar design could be useful to the HyspIRI mission. **Bo-Cai Gao** [Naval Research Laboratory] gave a detailed description of the spectrum-matching techniques used for atmospheric correction and how this could be applied to the development of HyspIRI and other instruments. **Fred Huemmrich** [University of Maryland, Baltimore County (UMBC)] described the FUSION[9] instrument, a GSFC prototype for calibration and validation of field-based spectroscopy.

Session Four: HyspIRI Science Preparatory Activities—Applications

Lawrence Friedl [NASA HQ—*Director of the Applied Sciences Program,Earth Science Division*] presented an overview of the activities of NASA's Applied Sciences Program, describing specific interagency activities relating to societal and economic applications, mission planning, and future capacity development. Session chair **Jeff Luvall** [NASA's Marshall Space Flight Center (MSFC)] then focused on the HyspIRI Applications Program, discussing potential applications of the hyperspectral data (e.g., tracking infectious diseases outbreaks from space and spotting harmful algal blooms). **Stuart Frye** [Stinger Ghaffarian Technologies (SGT)] discussed how SensorWeb[10] networks have been used to trigger EO-1 image targeting for disaster support, and how this technology could be applied to other satellite programs, including HyspIRI.

Session Five: HyspIRI Science Preparatory Activities—New Technologies and Products

Dan Mandl [GSFC], the session chair, described the proposed Hyperspectral Cubesat Constellation (HCC), a collection of tiny cube-shaped satellites (10 x 20 x 30 cm [~4 x 8 x 12 in]) fitted for hyperspectral imaging. Next, **Petya Campbell** [UMBC] described efforts to deploy a new hyperspectral instrument, called Nano-Hyperspec,[11] on unpiloted aerial vehicles (UAVs) for ecosystem monitoring. **David Thompson** [JPL] discussed atmospheric correction using the Bayesian Empirical Line instead of the Classical Empirical Line.[12] **Pat Cappelaere** [Vightel Corporation] described the development of low-latency co-registered products onboard the EO-1 satellite, and how these techniques could be applied to HyspIRI. **Shannon Franks** [SGT] described his study on the changing illumination (due to orbital precession) of the EO-1 Hyperion and Advanced Land Imager (ALI) image collections. He explained that the earlier overpass times have not significantly impacted the image quality. **Zbynek Malenovsky** [GSFC] ended the session with a discussion of the use of hyperspectral unmanned airborne systems (UAS) to map vegetation stress in the Antarctic.

[5] FLEX is a European Space Agency mission. To learn more, visit *https://earth.esa.int/web/guest/missions/esa-future-missions/flex*.
[6] The combining of images from Landsat and Sentinel-2 is also discussed in the "2017 Winter Landsat Science Team Meeting Summary" that appears on page 21 of this issue.
[7] The EO-1 mission was decommissioned on March 30, 2017. EO-1 carried three instruments: the Advanced Land Imager (ALI), the Hyperspectral Imager (Hyperion), and the Linear Etalon Imaging Spectrometer Array (LEISA) Atmospheric Corrector [LAC].
[8] fAPARchl is the fraction of photosynthetically active radiation absorbed by chlorophyll, a measure of plant GPP.
[9] Learn more about FUSION by downloading a presentation available at *https://hyspiri.jpl.nasa.gov/downloads/2016_Symposium/day1/III-5_Fusion_prototype_4_Field_Spectroscopy_Huemmrich.pdf*. Note that FUSION is not an acronym.
[10] In the context of NASA a sensor web refers to an interoperable environment for a diverse set of satellite sensors via the use of software and the Internet. This capability can be used to better understand physical phenomena, such as volcanic eruptions, fires and floods. To learn more, visit *https://sensorweb.nasa.gov*.
[11] To learn more about Nano-Hyperspec, visit *http://www.headwallphotonics.com/spectral-imaging/hyperspectral/nano-hyperspec*.
[12] Classical methods for atmospheric correction rely upon physic-based methods using radiative transfer models or empirical methods using *in situ* measurements. The Bayesian Empirical Line is a more general probabilistic approach that unifies the two classical approaches and allows for combined solutions. To learn more, visit *https://www.researchgate.net/publication/292186697_Atmospheric_correction_with_the_Bayesian_empirical_line*.

Day Two

There were four sessions on the second day, as described here.

Session Six: HyspIRI Science Preparatory Activities—Airborne Campaigns

Jack Kaye [NASA HQ—*Associate Director of Research for the Earth Science Division*] opened the first session of the second day of the symposium with a discussion on the NASA HQ perspective on airborne campaigns; **Simon Hook** [JPL] served as session chair. **Rob Green** [JPL] gave an overview of the HyspIRI Campaigns, stating that during 2013, 2014, and 2015, NASA flew the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Moderate Resolution Imaging Spectroradiometer (MODIS)/Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Airborne Simulator [MASTER] instruments on a NASA ER-2 aircraft to collect precursor datasets in advance of the HyspIRI mission. Many of these missions were paired with coincident images from EO-1/Hyperion. **Lyle Mars** [USGS] described efforts using the HyspIRI Preparatory Datasets (AVIRIS-classic and AVIRIS-next generation data) to create mineral maps of the Salton Sea area in California. **Susan Ustin** discussed the ground-measurement support campaigns used to validate the HyspIRI Airborne Campaigns in California. **Wendy Calvin** [University of Nevada] described how AVIRIS data have been used to monitor water quality and surface minerology at the Leviathan Mine in California. **Jan van Aardt** [Rochester Institute of Technology] described spectral-structural interactions at small scales (e.g., leaf area index and canopy structure), including the impact of subpixel vegetation structure on imaging spectroscopy, and how this might impact the development of HyspIRI. **Dongdong Wang** [University of Maryland, College Park] discussed surface radiation- and energy-budget measurements from AVIRIS and observations. **Vince Realmuto** [JPL] discussed how several different types of data acquired from airborne instruments (e.g., UAVs, AVIRIS, and MASTER) are being used to study volcanoes in Hawaii. **Paul Moorcroft** [Harvard University] described efforts to link ecosystem models with imaging spectrometry measurements; he specifically discussed using AVIRIS data from the HyspIRI Preparatory Mission and how this could be applied to future HyspIRI data.

Session Seven: Addressing International Space Station Related Mission Activities

The presentations given during this session all focused on missions or research onboard the ISS. **Bryan Blair** [GSFC] discussed the Global Ecosystems Dynamics Investigation (GEDI)[13] mission, which will be a lidar instrument installed on the ISS to generate canopy height and biomass data. **Fred Huemmrich** described the use of time-series data from Hyperspectral Imager for the Coastal Ocean (HICO)[14] mission to compute gross ecosystem production (GEP). **Steve Ungar** [Universities Space Research Association (USRA)], the session chair, discussed how EO-1's precession to earlier overpass times showed that satellite data can be collected in degrading orbits without serious impacts on science results. **Ray Perkins** [Teledyne Brown Engineering] discussed the new DLR Earth Sensing Imaging Spectrometer (DESIS) that will be will be integrated in the Multiple User System for Earth Sensing (MUSES) platform on the ISS in 2017. **Simon Hook** [JPL] gave an update on the ECOSTRESS mission, referenced previously. He then led a group discussion on the "Synergies Among Orbital Assets" to close out the session. The focus of the discussion was on combining the data products from a variety of compatible satellite platforms (such as Landsat 8 and

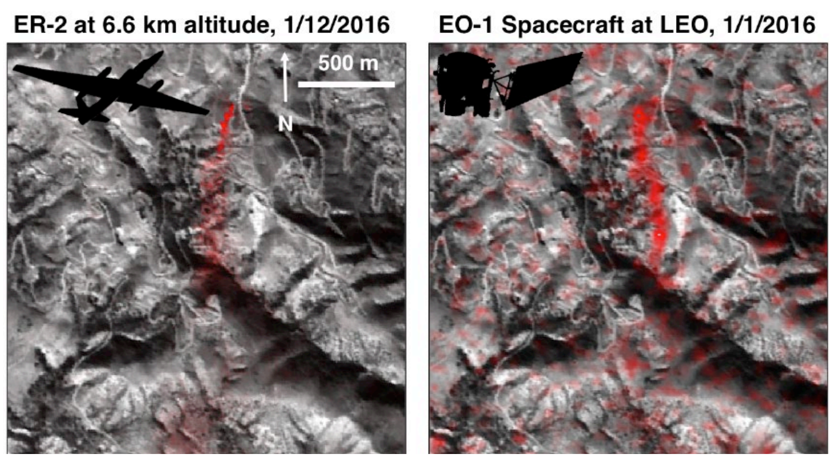


Figure. The methane gas spewing from the Aliso Canyon (California) natural gas leak [*white circles*] was invisible to human eyes but these two images show that the plume [*shown in black*] was clearly detected by two different hyperspectral imagers. The right image was obtained by Hyperion on the EO-1 satellite from low Earth orbit on January 1, 2016. The left image was obtained by AVIRIS on the NASA's high-altitude ER-2 aircraft flying at 6.6 km (~4.1 mi) almost two weeks later, on January 12, 2016. **Image credit:** Dave Thompson [JPL]

[13] To learn more about GEDI, see "Summary of the Second GEDI Science Team Meeting" in the November–December 2016 issue of *The Earth Observer* [**Volume 28, Issue 6**, pp. 31-37], or visit *https://science.nasa.gov/missions/gedi*.

[14] HICO was mounted on ISS in 2009 and ceased operations in 2014. To learn more, visit *http://hico.coas.oregonstate.edu*.

Sentinel-2), and upcoming synergistic opportunities with new and planned satellites.

Session Eight: HyspIRI Science Preparatory Activities—Carbon and Water Science

Martha Anderson [U.S. Department of Agriculture, Agriculture Research Service] described agricultural applications for high-spatiotemporal-resolution evapotranspiration datasets. **David Thompson** [JPL] discussed EO-1 Hyperion detection and characterization of the California methane event of 2015,[15] the first time an event like this was detected from space. **Glynn Hulley** [JPL] described use of the Hyperspectral Thermal Emission Spectrometer (HyTES)[16] aircraft instrument to measure methane and other trace gases. **Tian Yao** [USRA] presented a summary of efforts to improve global primary production (GPP) estimations in Climate Limited-Area Models (CLM) using the MODIS *fAPARchl* product. **Qingyuan Zhang** [USRA] discussed the uncertainties in various estimates of fAPAR for determining photosynthesis. **Petya Campbell** [UMBC], who served as session chair, discussed using the EO-1 Hyperion spectral time series to compute GPP and access ecosystem function at various flux sites around the world.

Session Nine: HyspIRI Science Preparatory Activities—Other Activities

The HyspIRI Science Preparatory Activities session featured additional presentations on preparations for science expected to result from HyspIRI. **Fred Huemmrich** served as session chair. **Amit Angal** [SSAI] discussed the cross-calibration of MODIS and Landsat using EO-1 Hyperion and the USGS's Libya-4 ground-calibration site.[17] **Chris Crawford** [ESSIC] described a cryosphere study that was conducted on Great Lakes ice cover using Landsat and EO-1 Hyperion data. **Jeff Luvall** [MSFC] described planned urban applications for HyspIRI data, including assessing and characterizing human health, disease vectors, heat and air quality, urban heat island effects, land cover/land use change, and regional climate impacts. **Amanda Armstrong** [USRA] discussed improvements to forest modeling (e.g., the SIBerian BOReal forest simulator (SIBBORK) Model, a new spatially explicit gap model for simulation of boreal forest dynamics) using EO-1 Hyperion data. Finally, **Joe Ortiz** [Kent State University] discussed observations of *Microcystis*—a genus of freshwater cyanobacteria that cause harmful algal blooms—in Lake Erie. He also described the use of *white reference atmospheric correction,* where a series of on-site floating concave mirrors were set up on the lake to bounce a dispersed version of the solar radiance back to the airborne or orbiting sensor and allow for better atmospheric correction and glint removal over water.

Day Three

On day three, the symposium shifted gears for two final sessions, focusing on the activities of the HyspIRI Aquatic Study Group (HASG).

Session Ten: Aquatic Airborne Campaigns

Kevin Turpie [UMBC], the session chair, presented an overview and update on the activities of the HASG. **Sindy Sterckx** [VITO] gave an overview of the Airborne Portable Remote Imaging Spectrometer (PRISM)[18] EXperiment [APEX], which collected hyperspectral data over European coasts. **Rob Green** discussed the COral Reef Airborne Laboratory (CORAL)[19] and the HyspIRI Airborne Campaigns in Hawaii, which are being conducted to asess coral health. **David Lagomasino** [USRA] discussed GSFC's LiDAR, Hyperspectral and Thermal Imager (G-LiHT)[20] aircraft flights over mangrove forests in southern Florida, which seek to predict peatland collapse. **John** and **Tiffany Moisan** [both from NASA's Wallops Flight Facility] described the AIRborne Sensors for Hyperspectral Reflectance Imaging of Marine Pigments (AirSHRIMP) campaign, imaging marine pigments using UAVs and light aircraft carrying small hyperspectral sensors from Ocean Optics, Inc. **Jeremy Werdell** [GSFC] described the Cyanobacteria Assessment Network (CYAN), which uses data from Landsat 7 and 8 to track bacterial blooms in water bodies. **Larry Liou** [NASA's Glenn Research Center] discussed the airborne hyperspectral observation of harmful algal blooms in the Great Lakes region. **Heidi Dierssen** [University of Connecticut] described efforts to use hyperspectral imagery from the PRISM instrument to assess seagrass ecosystems of Denmark and California. **Raphe Kudela** [University of California, Santa Cruz] described water quality and cyanobacterial bloom observations of San Francisco Bay using AVIRIS, Landsat 8, and Sentinel-2—to use data from HyspIRI to do the same thing.

[15] On October 23, 2015, a massive natural gas leak was discovered at a storage well near Los Angeles (Aliso Canyon). Before the well was plugged on February 11, 2016, it is estimated that 100,000 tons of methane escaped into the atmosphere—the largest methane release in U.S. history—which had the same 20-year climate impact as burning nearly a billion gallons of gasoline.

[16] To learn about HyTES, visit *https://airbornescience.jpl.nasa.gov/instruments/hytes*.

[17] Libya-4 is one of 47 radiometric calibration sites the USGS maintains around the world. (There are also 4 thermal calibration sites.) Learn more about these sites at *https://calval.cr.usgs.gov/rst-resources/sites_catalog/radiometric-sites*.

[18] PRISM is JPL's Portable Remote Imaging Spectrometer. To learn more, visit *https://prism.jpl.nasa.gov.*

[19] CORAL is a broad effort to conduct an airborne study of coral reef health using PRISM mounted on a Gulfstream-IV aircraft. To learn more, visit *https://coral.jpl.nasa.gov/about-coral*.

[20] To learn about G-LiHT, visit *https://gliht.gsfc.nasa.gov*.

continued on page 35

New Night Lights Maps Open Up Possible Real-Time Applications

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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 scientists have released new global maps of Earth at night, providing the clearest yet composite view of the patterns of human settlement across our planet.

Satellite images of Earth at night—often referred to as *night lights*— have been a gee-whiz curiosity for the public and a tool for fundamental research for nearly 25 years. They have provided a broad, beautiful picture, showing how humans have shaped the planet and lit up the darkness. Produced every decade or so, such maps have spawned hundreds of pop-culture uses and dozens of economic, social science, and environmental research projects.

But what would happen if night-lights imagery could be updated yearly, monthly, or even daily? A research team led by Earth scientist **Miguel Román** [NASA's Goddard Space Flight Center] plans to find out this year.

In the years since the 2011 launch of the NASA-National Oceanic and Atmospheric Administration's (NOAA) Suomi National Polar-orbiting Partnership (NPP) satellite, Román and his colleagues have been analyzing night-lights data and developing new software and algorithms to make night-lights imagery clearer, more accurate, and readily available—see **Figures 1** and **2** for examples. They are now on the verge of providing daily, high-definition views of Earth at night, and are targeting the release of such data to the science community later this year.

Since colleagues from NOAA and NASA released a new Earth at night map in 2012, Román and teammates at NASA's Earth Observing Satellite Data and Information System (EOSDIS) have been working to integrate nighttime data into NASA's Global Imagery Browse Services (GIBS) and Worldview mapping tools. Freely available to the science community and the public via the Web, GIBS and Worldview allow users to see natural- and false-color images of Earth within hours of satellite acquisition.

They have released a new global composite map of night lights as observed in 2016, as well as a revised version of the 2012 map. The NASA group has examined the different ways that light is radiated, scattered, and reflected by land, atmospheric, and ocean surfaces. The principal challenge in nighttime satellite imaging is accounting for the phases of the moon, which constantly varies the amount of light shining on Earth—though in predictable ways. Likewise, seasonal vegetation, clouds, aerosols, snow and ice cover, and even faint atmospheric emissions (such as airglow and auroras) change the way light is observed in different parts of the world. The new maps were produced with data from all months of each year. The team wrote code that picked the clearest night views each month, ultimately combining moonlight-free and moonlight-corrected data.

Román and colleagues have been building remote sensing techniques to filter out these sources of extraneous light, gathering a better and more consistent signal of how human-driven patterns and processes are changing. The improved processing moves Suomi NPP closer to its full potential of observing dim light—down to the scale of an isolated highway lamp or a fishing boat. The satellite's workhorse instrument is the Visible Infrared Imaging Radiometer Suite (VIIRS), which detects photons of light reflected from Earth's surface and atmosphere in 22 different wavelengths. VIIRS is the first satellite instrument to make quantitative measurements of light emissions and reflections, which allows

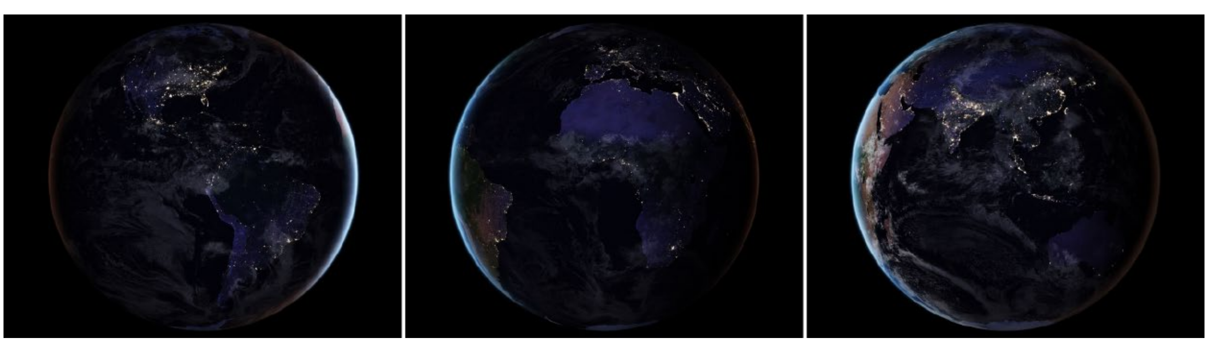

Figure 1. These three composite images, created using data from the Suomi National Polar-orbiting Partnership (NPP) satellite, provide full-hemisphere views of Earth at night. The clouds and sun glint—added here for aesthetic effect—are derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument's land surface and cloud cover products. **Image credit:** NASA's Earth Observatory, NASA's Goddard Space Flight Center

Figure 2. Composite image of continental U.S. at night—using data collecting during 2016. **Image credit:** NASA Earth Observatory, NASA's Goddard Space Flight Center

researchers to distinguish the intensity, types, and the sources of night lights over several years.

Suomi NPP observes nearly every location on Earth at roughly 1:30 PM and 1:30 AM (local time) each day, observing the planet in vertical 3000-km (~1865-mi) strips from pole to pole. VIIRS includes a special *day-night band*, a low-light sensor that can distinguish night lights with six times better spatial resolution and 250 times better resolution of lighting levels (dynamic range) than previous night-observing satellites. And because Suomi NPP is a civilian science satellite, the data are freely available to scientists within minutes to hours of acquisition.

Armed with more accurate nighttime environmental products, the NASA team is now automating the processing so that users will be able to view nighttime imagery within hours of acquisition. This has the potential to aid short-term weather forecasting and disaster response.

"Thanks to VIIRS, we can now monitor short-term changes caused by disturbances in power delivery, such as conflict, storms, earthquakes, and brownouts," said Román. "We can monitor cyclical changes driven by reoccurring human activities such as holiday lighting and seasonal migrations. We can also monitor gradual changes driven by urbanization, out-migration, economic changes, and electrification. The fact that we can track all these different aspects at the heart of what defines a city is simply mind-boggling."

For instance, VIIRS detected power outages in the wake of Hurricane Matthew, a major storm that struck the northeastern Caribbean and the southeastern U.S. in late September 2016. NASA's Disasters Response team provided the data to colleagues at the Federal Emergency Management Agency (FEMA). In the future, NASA, FEMA, and the Department of Energy hope to develop power outage maps and integrate the information into recovery efforts by first responders.

The NASA team envisions many other potential uses by research, meteorological, and civic groups. For instance, daily nighttime imagery could be used to help monitor unregulated or unreported fishing. It could also contribute to efforts to track sea ice movements and concentrations. Researchers in Puerto Rico intend to use the dataset to reduce light pollution and help protect tropical forests and coastal areas that support fragile ecosystems. And a team at the United Nations has already used night lights data to monitor the effects of war on electric power and the movement of displaced populations in war-torn Syria.

In a separate, long-term project, Román is working with colleagues from around the world to improve global and regional estimates of carbon dioxide emissions. The team at NASA's Global Modeling and Assimilation Office (GMAO) is combining night lights, urban land use data, and statistical and model projections of anthropogenic emissions in ways that should make estimates of sources much more precise.

The full version of this feature includes several regional images of Earth at night. To view the full story, visit *https://www.nasa.gov/feature/goddard/2017/new-night-lights-maps-open-up-possible-real-time-applications*.

To download the 2016 "Earth at Night" map, visit *https://earthobservatory.nasa.gov/Features/NightLights/page3.php*.

To navigate through the Earth at Night map online using Worldview, visit *https://go.nasa.gov/2qnWN1V*. ■

NASA's CYGNSS Satellite Constellation Begins Public Data Release

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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.

On May 22, 2017, NASA's Cyclone Global Navigation Satellite System (CYGNSS) began regular production of its science data products—measurements of ocean surface wind speed and roughness—with public release of these data facilitated by the Physical Oceanography Distributed Active Archive Center (PO.DAAC). The production and distribution was timed to coincide with the beginning of the Atlantic hurricane season on June 1.

CYGNSS—a constellation of eight microsatellite spacecraft launched into low inclination, low-Earth orbit over the tropics on December 15, 2016—will make frequent measurements of ocean surface winds in the tropics, with a primary objective of monitoring the location, intensity, size, and development of tropical cyclones.

The ability of the CYGNSS constellation to track the development of surface winds in a major storm is demonstrated by preliminary measurements made during its flyover of Tropical Cyclone Enawo on March 6, 2017, as the system approached Madagascar with surface winds in excess of 100 mph (~161 km/hr)—see **Figure**.

"Successive spacecraft in the constellation observed Enawo over a period of several hours just before it made landfall on Madagascar," explained **Chris Ruf** [University of Michigan—*CYGNSS Principal Investigator*]. "During the flyover, four of our eight spacecraft were operating in science mode and we managed to capture important elements of the size and structure of the storm." According to Ruf, the other four spacecraft were still undergoing engineering commissioning activities. "Those activities are now largely complete and, as we enter the Atlantic hurricane season, we expect to have all eight of them available for science observations. This will effectively double our sampling and coverage."

The CYGNSS mission is led by the University of Michigan. The Southwest Research Institute led the engineering development and manages the operation of the constellation. The University of Michigan Climate and Space Sciences and Engineering department leads the science investigation, and the Earth Science Division of NASA's Science Mission Directorate oversees the mission.

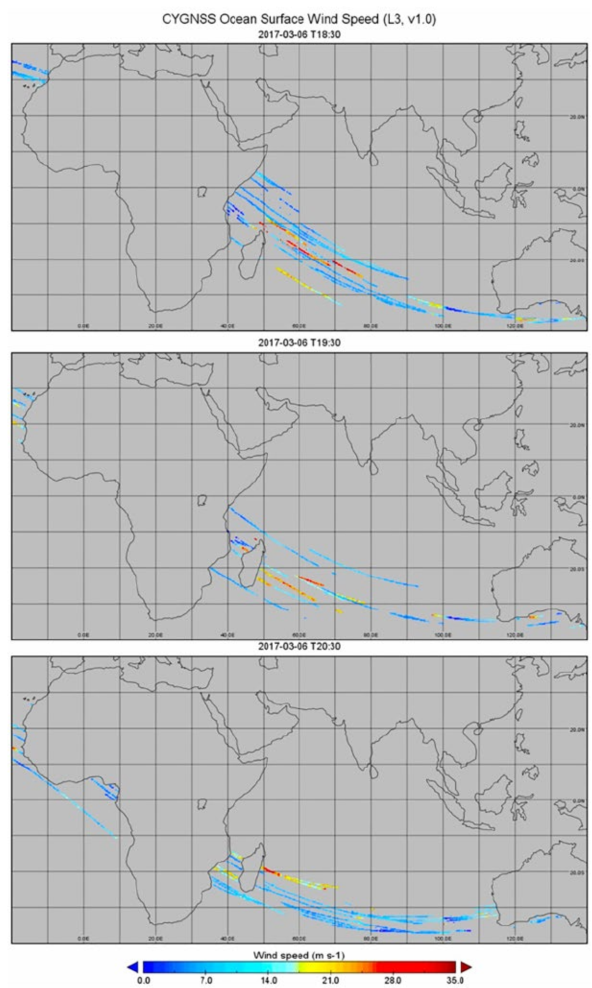

Figure. These maps show measurements of ocean surface wind speeds made by four of the eight CYGNSS spacecraft on March 6, 2017, as Tropical Cyclone Enawo approached landfall on Madagascar. The times of the measurements are, from top to bottom: 1830, 1930, and 2030 UTC (1:30 PM, 2:30 PM, and 3:30 PM EST, respectively). The other four instruments were still undergoing engineering commissioning activities on March 6, but those activities are now complete, and all eight satellites are ready for science observations just in time for the start of the Atlantic Hurricane season—which began on June 1. **Image credit:** NASA

For more information about CYGNSS, visit *http://www.nasa.gov/cygnss*. ■

AIRS: 15 Years of Seeing What's in the Air

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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.

Accurate weather forecasts save lives. NASA's Atmospheric Infrared Sounder (AIRS) instrument, launched on May 4, 2002, on NASA's Aqua satellite, significantly increased weather forecasting accuracy within a couple of years by providing extraordinary three-dimensional maps of clouds, air temperature, and water vapor throughout the atmosphere's weather-making layer. Fifteen years later, AIRS continues to be a valuable asset for forecasters worldwide, sending seven billion observations streaming into forecasting centers every day.

Besides contributing to better forecasts, the AIRS instrument maps greenhouse gases, tracks volcanic emissions and smoke from wildfires, measures noxious compounds like ammonia, and indicates regions that may be entering drought conditions. Have you been wondering how the ozone hole over Antarctica is healing? AIRS observes that too.

These benefits come because AIRS "sees" many more wavelengths of infrared radiation in the atmosphere, and makes vastly more observations per day, than the observing systems that were previously available. Before AIRS launched, weather balloons provided the most significant weather observations. Previous infrared satellite instruments made observations using about two dozen broad "channels" that averaged many wavelengths together. This reduced their ability to detect important vertical structure. Traditional weather balloons produce only a few thousand *soundings*—atmospheric vertical profiles—of temperature and water vapor a day, almost entirely over land. AIRS observes 100 times more wavelengths than the earlier instruments and produces close to 3 million soundings a day, covering 85% of the globe.

AIRS observes 2378 wavelengths of heat radiation in the air below the satellite. "Having more wavelengths allows us to get finer vertical structure, and that gives us a much sharper picture of the atmosphere," explained **Eric Fetzer** [NASA/Jet Propulsion Laboratory—*AIRS Project Scientist*]. Weather occurs in the troposphere, 7 to 12 mi (11 to 19 km) high. Most of the infrared radiation observed by AIRS also originates in the troposphere.

AIRS was widely recognized as a great advance very quickly. Only three years after its launch, former National Oceanic and Atmospheric Administration (NOAA) Administrator **Conrad Lautenbacher** said AIRS provided "the most significant increase in forecast improvement [in our time] of any single instrument."

In the Beginning

AIRS was the brainchild of NASA scientist **Moustafa Chahine**. In the 1960s, Chahine and colleagues at JPL first conceived the idea of improving weather forecasting by using a *hyperspectral instrument*—one that breaks infrared and visible radiation into hundreds or thousands of wavelength bands. He flew some experimental prototypes as early as the 1970s, but AIRS did not come to fruition until advances in miniaturization made it possible to build an instrument with the needed capability that wasn't too heavy and bulky to launch. Chahine, who died in 2011, became the first AIRS Science Team leader.

The instrument was built by BAE Systems, now located in Nashua, NH, under the direction of JPL. It is one of six instruments flying on the Aqua satellite in the Afternoon "A-Train" satellite constellation. With a planned mission life of 5 years, AIRS is still going strong at 15 and is expected to last until Aqua's fuel supply is reduced to a level requiring it to exit the A-Train, which is expected to occur in 2022.

The value of AIRS to weather forecasting was quantified in several experiments by forecasting centers worldwide. In particular, the European Centre for Medium Range Weather Forecasts (ECMWF) has investigated in detail the impact on forecasts of different observational systems. "ECMWF studies have shown that in many circumstances, AIRS is responsible for reducing forecast errors by more than 10%. This is the largest forecast improvement of any single satellite instrument of the 2000s," said **Joao Teixeira** [JPL—*AIRS Science Team Leader*].

Seeing More than Weather

Scientists always knew that measurements from AIRS contained information beyond what meteorologists need for weather forecasting. The spectral wavelengths it sees include parts of the electromagnetic spectrum that are important for studying climate. Carbon dioxide (CO_2) and other atmospheric trace gases leave their signatures in the measurements. Chahine once commented, "The information is all there in the spectra. We just had to figure out how to extract it."

In the mid to late 2000s, the AIRS project team turned to that challenge. In 2008, under Chahine's leadership, they published the first-ever global satellite maps of CO_2

in the mid-troposphere. These measurements showed for the first time that the most important human-produced greenhouse gas was not evenly mixed throughout the global atmosphere, as researchers had thought, but varied by as much as 1% (2 to 4 molecules of CO_2 out of every million molecules of the atmosphere).

Since then, more and more information has been extracted from the AIRS spectra. The team now also produces datasets for methane, carbon monoxide, ozone, sulfur dioxide, and dust, which has an important influence on how much radiation reaches Earth from the sun and how much escapes from Earth to space. Researchers have used these new datasets, and also the original AIRS temperature, cloud, and water datasets, for many discoveries. To name a few recent findings:

- A 2015 study showed that measurements of relative humidity near Earth's surface obtained by AIRS show promise in detecting the onset of drought almost two months ahead of other indicators.
- In 2013, researchers used the AIRS data record to find 18 global hot spots for *atmospheric gravity waves*—up-and-down ripples that may form in the atmosphere above something that disturbs air flow, such as a thunderstorm updraft or a mountain range. This new record of where and when disturbances regularly create gravity waves is valuable for improving weather and climate forecasts.
- Global warming increases the amount of water vapor in the atmosphere, which in turn warms the atmosphere even further. This kind of self-feeding process is called a *positive feedback loop*. Climate scientists had long theorized that this feedback might double the warming from increases in CO_2. Temperature and humidity data from AIRS allowed them to confirm this hypothesis for the first time.

AIRS' Legacy

Due to its resounding success, AIRS is no longer one of a kind. "The mission has demonstrated a measurement approach that will be used by operational agencies for the foreseeable future," said **Tom Pagano** [JPL—*AIRS Project Manager*]. Already, there are three other hyperspectral sounders in orbit: the Cross-track Infrared Sounder (CrIS) on the NASA/NOAA Suomi National Polar-orbiting Partnership (NPP) satellite, and two Infrared Atmospheric Sounding Interferometer (IASI) instruments on the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Metop-A and -B satellites. Additional sounders are planned for launch into the 2030s.

Together, these hyperspectral instruments will create a record of highly accurate measurements of our atmosphere that will be many decades long. That will add one more benefit to the legacy of AIRS: the potential for improving understanding of the climate of today and the future.

To view the online version of this feature, including a short video about AIRS and its accomplishments, visit *https://www.nasa.gov/feature/jpl/airs-15-years-of-seeing-whats-in-the-air*. ■

2016 HyspIRI Symposium Summary

continued from page 30

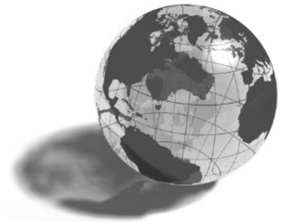
Session Eleven: Aquatic Missions

Antonio Mannino [GSFC] presented an update on the GEOstationary Coastal and Air Pollution Events (GeoCAPE)[21] mission, and new ocean color product fields for tracking ocean color features such as coastal mesoscale plumes and blooms. **Jeremy Werdell** presented an update on the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission and the new Ocean Color Instrument (OCI) that will fly on PACE. **Glynn Hulley** [JPL] and **Simon Hook** discussed the potential usages of HyspIRI water temperature measurements and prototyping that with MASTER data. To end the session (and the symposium), **Kevin Turpie**, who served as session chair, led a discussion titled "Types of Data Needed for Coastal and Inland Data Product Development." This discussion concluded that, in addition to the need for widely accessible hyperspectral imagery and corresponding surface data, there is a need for a centralized repository linked to the imagery servers. Also, more data from high-altitude aircraft are needed to test atmospheric correction in coastal regions and to determine the impacts observed at high-spatial-resolution by phenomena such as cloud shadows and adjacency effects.

Summary

The HyspIRI community covered various aspects of the symposium theme "Evolving the HyspIRI Mission and Products." There were presentations highlighting new potential sustainable land imaging products and other uses for HyspIRI data, with a focus on the HyspIRI Airborne Campaign (using the NASA ER-2 and AVIRIS). This work is important and could move HyspIRI a step closer to ascension into the list of fully-funded *Tier 1* missions in the 2017 Decadal Survey. ■

[21] GEO-CAPE was identified as a Tier-2 mission in the 2007 Decadal Survey. To learn more, visit *https://eospso.nasa.gov/missions/geostationary-coastal-and-air-pollution-events*.



NASA Earth Science in the News

Samson Reiny, NASA's Earth Science News Team, samson.k.reiny@nasa.gov

Glacier National Park Once Had 150 Glaciers, But Only 26 Remain, May 11, *businessinsider.com*. The era of the glacier will end in the U.S. within decades, according to researchers who worked on a major new study of glacial health in Montana. A report released by the U.S. Geological Survey follows 39 *glaciers* in Montana—37 of them in Glacier National Park—from 1966 to 2015. During that period of significant warming around the world, those 39 glaciers—lumbering, ancient bodies of ice that still move through high altitudes—shrank by an average of 39%—with some shrinking by as much as 85%. At the beginning of the twentieth century, there were as many as 150 glaciers in the region. But in the time studied, 13 of the 39 glaciers shrank to less than 25 acres (~0.1 km^2), the minimum size to be considered a glacier. That leaves just 26. The shrinking Montana glaciers are part of a larger story. Humans are now the leading driver of glacial melt on Earth, since climate change has led to warmer winters that carry more rain into frigid glacial zones. NASA estimates that around the world, glaciers have lost, on average, 400 billion tons of ice per year since 1994. That's about 67,000 Great Pyramid of Giza's worth of landlocked water melting into streams and the ocean.

The 48 states in the continental U.S. have a significant but rapidly declining glacier population distributed across Montana, Colorado, Washington, Wyoming, California, Oregon, Idaho, Nevada, and Utah. In Colorado, a 1000-year-old glacier is expected to disappear within 25 years.

'We All Knew This Was Coming:' Alaska's Thawing Soils Are Now Pouring Carbon Dioxide Into The Air, May 8, *washingtonpost.com*. A study published in the *Proceedings of the National Academy of Sciences* suggests that frozen northern soils—often called *permafrost*—are unleashing an increasing amount of CO_2 into the air as they thaw in summer or subsequently fail to refreeze as they once did, particularly in late fall and early winter. The research was published by 19 authors from a variety of institutions, including NASA's Jet Propulsion Laboratory and the National Oceanic and Atmospheric Administration. The study, based on aircraft measurements of CO_2 and methane, and tower measurements from Barrow, AK, found that from 2012 through 2014, the state emitted the equivalent of 220 million tons of carbon dioxide gas into the atmosphere from biological sources (the figure excludes fossil fuel burning and wildfires). That's an amount comparable to all the emissions from the U.S. commercial sector in a single year. The chief reason for the greater CO_2 release was that as Alaska has warmed up, emissions from once frozen tundra in winter are increasing—presumably because the ground is not refreezing as quickly.

A New Crack In One Of Greenland's Largest Glaciers Has Scientists' Attention, April 18, *cnn.com*. Something caught Stef Lhermitte's [Delft University of Technology in the Netherlands—*Assistant Professor*] eye one day in early April as he pored over satellite images of Northwest Greenland's Petermann Glacier, one of the largest glaciers in Greenland. "I saw a small line and thought 'that seems new,'" said Lhermitte as he was working with data from the European Space Agency's Sentinel-1 satellite. Lhermitte took his findings directly to *Twitter*, tweeting several images of the crack and searching for help determining its significance. His tweets caught the attention of **Tom Wagner** [NASA Headquarters—*Program Scientist for the Cryosphere*], who directs NASA's polar research. Wagner pointed them out to a member of his team, **Joe MacGregor** [NASA's Goddard Space Flight Center—*Research Scientist*]. MacGregor was in Greenland leading a unique research campaign called Operation IceBridge, which makes low-level flights over Greenland and Antarctica's ice sheets to create 3-D views of the ice with the intent of understanding its rapid changes. The Operation IceBridge flight confirmed the existence of the crack and scientists were able to map the area in detail using sophisticated onboard equipment. (The **Figure** on page 37 shows an image of the crack taken by the Operational Land Imager on Landsat 8.)

Sierra Snowpack Bigger Than Last Four Years Combined, Says NASA, April 18, *cnbc.com*. California's snowpack level is near a record high. New data from NASA show that this past winter's snowpack levels in California's Tuolumne River Basin, located in the Sierra Nevada mountain range, are higher than they were in the last four years combined. Melting snow along the Tuolomne is an important source of water for both California's Central Valley—the heart of California's agricultural sector, and the crowded San Francisco area. On April 1, NASA's Airborne Snow Observatory measured the Tuolumne Basin snowpack at 1.2 million acre-feet, which NASA says is enough snow to fill the Rose Bowl in Pasadena, CA, nearly 1600 times. The snowpack is twice the volume of last year's, and it is 21 times larger than 2015's level—which was the lowest on record.

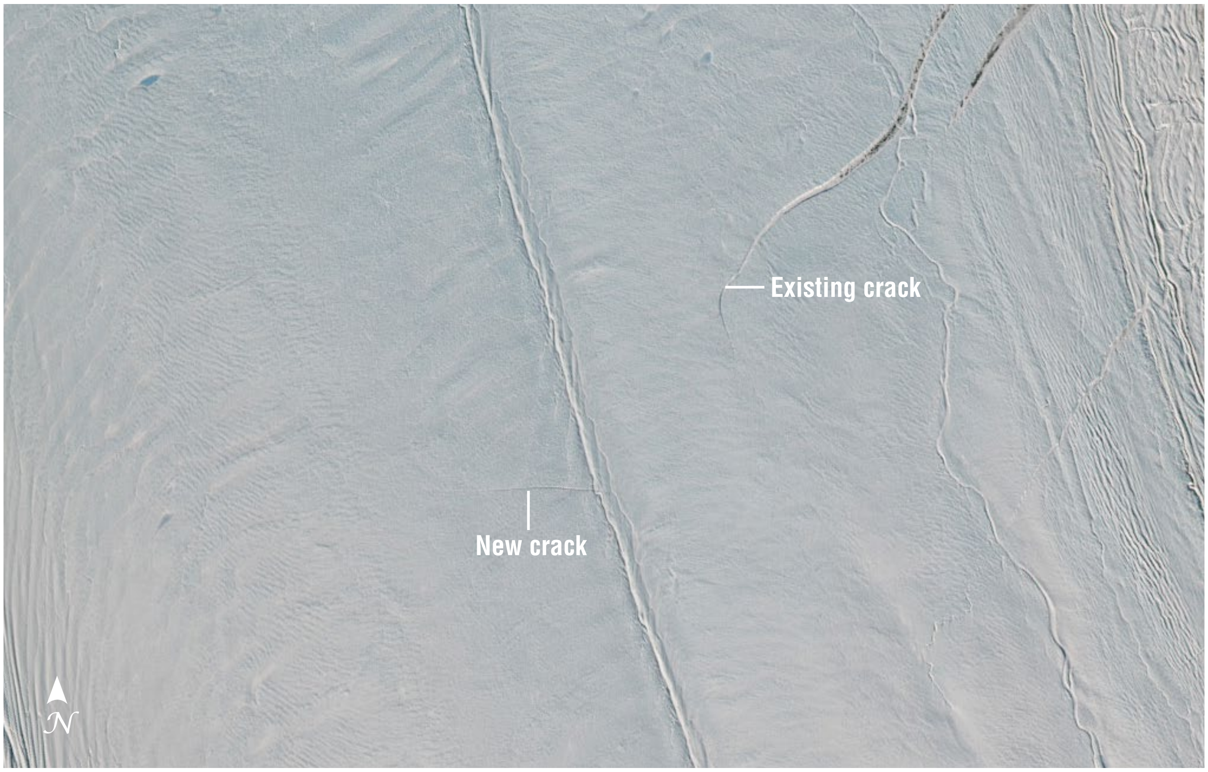


Figure. While poring over some Sentinel-1 images of Northwest Greenland's Petermann Glacier, **Stef Lhermitte** [Delft University of Technology in the Netherlands] discovered a new crack in the ice. The new *rift* is visible in this image acquired on April 15, 2017, with the Operational Land Imager (OLI) on Landsat 8. **Image credit:** NASA's Earth Observatory

***NASA Releases Stunning New Images of Earth As Seen From Space At Night,** April 13, *cbsnews.com*. For the first time since 2012, NASA has released a global map of Earth at night—and the results are breathtaking. NASA has examined the different ways that light is radiated, scattered, and reflected by land, atmospheric, and ocean surfaces. The principal challenge in nighttime satellite imaging is accounting for the phases of the moon, which constantly varies the amount of light shining on Earth. NASA has dubbed the new image "Black Marble"—a play on the original "Blue Marble" image of Earth taken by the Apollo 17 crew on December 7, 1972. Armed with more accurate nighttime environmental products, the NASA team is automating the processing so that the public will be able to view nighttime imagery within hours of acquisition. As a result, this has the potential to aid short-term weather forecasting and disaster response.

*See News Story in this issue.

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

NASA Science Mission Directorate – Science Education and Public Outreach Update

EDITOR'S NOTE: As of this issue, we are discontinuing the *NASA Science Mission Directorate—Science Education and Public Outreach Update*. The column has been rendered obsolete by online sources. To subscribe to weekly emails highlighting NASA education opportunities, visit *https://www.nasa.gov/audience/foreducators/Express_Landing.html*. *The Earth Observer* staff wishes to thank all who have made contributions to this column over the years.

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Undefined Acronyms Used in Editorial and Table of Contents

AIRS	Atmospheric Infrared Sounder
AMSR-E	Advanced Microwave Scanning Radiometer for the Earth Observing System
AMSU-A	Advanced Microwave Sounding Unit-A
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CERES	Clouds and the Earth's Radiant Energy System
CNES	Centre National d'Études Spatiales [French Space Agency]
GCOM-W1	Global Change Observation Mission–Water
JAXA	Japan Aerospace Exploration Agency
HSB	Humidity Sounder for Brazil
MODIS	Moderate Resolution Imaging Spectroradiometer
OCO-2	Orbiting Carbon Observatory-2
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar
USGS	U.S. Geological Survey

EOS Science Calendar

July 11–13, 2017
Landsat Science Team Meeting,
Sioux Falls, SD

September 12–14, 2017
OMI Science Team Meeting,
Greenbelt, MD.

October 3–4, 2017
DSCOVR EPIC/NISTAR Science Team Meeting,
Greenbelt, MD.

October 10–12, 2017
GRACE Science Team Meeting,
Austin, TX.

October 23–27, 2017
Ocean Surface Topography Science Team Meeting,
Miami, FL.

January 23–26, 2018
ABovE Science Team Meeting, Seattle, WA
https://above.nasa.gov/meetings.html?

March 19–23, 2018
2018 Sun-Climate Symposium,
Lake Arrowhead, CA.
http://lasp.colorado.edu/home/sorce/news-events/meetings/2018-scs

Global Change Calendar

July 23–28, 2017
IEEE International Geoscience and Remote Sensing Symposium, Fort Worth, TX.
http://www.igarss2017.org

August 6–11, 2017
Annual Meeting Asia Oceania Geosciences Society,
Singapore.
http://www.asiaoceania.org/aogs2017/public.asp?page=home.htm

December 11–15, 2017
AGU Fall Meeting, New Orleans, LA.
http://fallmeeting.agu.org/2016/2017-fall-meeting-new-orleans

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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 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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