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Editor's Corner

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While NASA's Earth Science Division is well-known for its Earth-observing missions, remote sensing and *in situ* suborbital measurements are critical complements to satellite observations. Airborne instruments can simulate current and future satellite measurements and products, as well as directly validate remotely sensed atmospheric parameter retrievals. Ground-based measurements are used for both atmospheric and surface parameter validation. Regardless of the motivation, suborbital instruments provide unique scientific measurements in their own right, helping to provide a more comprehensive understanding of Earth system processes and climate.

The Network for the Detection of Atmospheric Composition Change (NDACC) has been a significant contributor of *in situ* and ground-based observations of the upper troposphere and stratosphere for the past quarter-century. It is an international research and measurement program composed of more than 70 high-quality, remote-sensing research stations. NDACC provides long-term measurements for observing and understanding the physical and chemical state of the stratosphere and upper troposphere, and for assessing the impact of stratospheric changes on the underlying troposphere and global climate. The discovery of the Antarctic "ozone hole" in 1985 provided the impetus for the development of an observational network—which was originally known

continued on page 2

Image courtesy: NASA/JPL

Image credit: Patrick Cullis [NOAA]

Image credit: Thomas Blumenstock [IMK*]

Image credit: Aldona Wiacek [University of Toronto]

Shown here are 4 out of the more than 70 stations that make up the Network for the Detection of Atmospheric Composition Change (NDACC): an aerial view of NASA's Table Mountain Research Facility near Wrightwood, CA [*top left*]; a balloon launch taking place at the NOAA South Pole station in Antarctica [*top right*]; an assortment of ground-based instruments in operation at the Optical Facility of the Swedish Institute of Space Physics [Institutet för rymdfysik (IRF)] in Kiruna, Sweden [*bottom left*]; and a Fourier-Transform Infrared Spectrometer in Toronto, Canada [*bottom right*]. *IMK, used in the Image credits, stands for Das Institut für Meteorologie und Klimaforschung.

the earth observer

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In This Issue

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as the Network for Detection of Stratospheric Change (NDSC) and began operating in 1991. As the network broadened its focus beyond the stratosphere, the Steering Committee adopted a new name in 1995 intended to reflect the expanded focus of the network while at the same time emphasizing that NDACC was not designed to be a climate monitoring network, but rather an observational network that provided a broad suite of atmospheric data that contributed to understanding the interrelationship between changing atmospheric composition and climate. That mission continues to the present day. To learn more about NDACC's history, its current configuration, some of the key results it has achieved, and plans for the future please see the feature article on page 4 of this issue.

In addition, NDACC results will be highlighted in a special interjournal commemorative issue of *Earth System Science Data*, *Atmospheric Chemistry and Physics*, and *Atmospheric Measurement Techniques*, as well as in oral and poster presentations during session A017 on Atmospheric Trace Species at the Fall 2016 Meeting of the American Geophysical Union (AGU). Additional information about NDACC as it is presently configured can be found at *http://www.ndacc.org*.

Meanwhile, NASA's Land-Cover, Land-Use Change (LCLUC) Science Team has been focusing its attention on Earth's ever-changing land surface for the past 20 years. The spring LCLUC Science Team Meeting (STM) was an opportunity to celebrate this achievement with **Garik Gutman** [NASA Headquarters—*LCLUC Program Manager*] and **Chris Justice** [University of Maryland], sharing their perspectives as people that have been part of the team since its inception in 1997. Since then, the team has supported over 250 projects focusing on one or more of the program's nine science themes to advance land cover and land use science, leading to numerous peer-reviewed publications, development of land cover products, regional collaborations, and outreach activities. Please turn to page 24 of this issue to learn more about the latest LCLUC STM.

Progress also continues on new Earth-observing missions. The Total and Spectral Solar Irradiance Sensor (TSIS)-1 passed its Key Decision Point C on June 6, 2016, another milestone on its way toward launch to the ISS, currently manifested for September 2017 (although the recent Space-X launch-pad accident may impact this schedule). TSIS-1 will continue the crucial 34-year climate data record of total solar irradiance (TSI) and the record of solar spectral irradiance (SSI) begun by the Solar Radiation and Climate Experiment (SORCE) that was launched in 2003 and is still collecting good science data while carefully managing its remaining battery life. Meanwhile, the Total Solar Irradiance Calibration Transfer Experiment (TCTE[1]) launched in 2013 onboard the U.S. Air Force's Space Test Program spacecraft (STPSat-3) and carries a Total Solar Irradiance Monitor (TIM) instrument that is very similar to the one flying on SORCE. TCTE would provide a "bridge" in measurements—of TSI only—should SORCE cease operations before TSIS-1 is in place.

Two additional missions in development are covered in this issue of *The Earth Observer*. The CLARREO Pathfinder (CPF), in effect an Earth-analog of TSIS, is an Earth System Science Pathfinder (ESSP) mission intended to demonstrate essential measurement technologies that will be required to implement the full CLARREO mission. CLARREO was identified as a *Tier 1* (top priority) mission in the 2007 Earth Science Decadal Survey[2], but was delayed indefinitely in 2011 and has remained in *Pre-Phase A* status since. The allocated CPF funds support the flight of a Reflected Solar (RS) spectrometer that will be installed on the ExPRESS logistics carrier (ELC-1) of the International Space Station (ISS) in the 2020 timeframe. The improved accuracy of the RS spectrometer on CLARREO will provide reference intercalibration for other on-orbit assets (e.g., CERES on Aqua and Terra, VIIRS on Suomi NPP and the upcoming JPSS missions) and sets the stage to dramatically reduce time-to-detection of climate trends. The goals of CPF are to demonstrate improved accuracy of spectral reflectance measurements beyond current capabilities and to demonstrate the ability to improve the accuracy of other sensors through intercalibration.

The CPF is a *Class D* mission with one year of operations on orbit and one year for analysis of acquired data. To learn more about the details of CPF please turn to page 30 of this issue, which summarizes the latest CLARREO Science Definition Team Meeting.

The SWOT mission, identified as a *Tier 2* mission in the 2007 Earth Science Decadal Survey, has progressed to *Phase C* of its development. The mission is now working on final design and fabrication. The top priorities during this phase include the completion of the plans for the mission's calibration and validation and the development of science algorithms. In hydrology, the key objectives are to develop river discharge models, the effects of layover, and the wetland data product definition. The key oceanographic objectives include the effects of internal gravity waves and surface gravity waves on sea surface height observations, the development of tide models, and the utilization of high-resolution ocean models for developing science investigation plans.

SWOT brings together two international communities whose focus is on better understanding Earth's ocean and surface waters and the interplay between them. U.S. and French oceanographers and hydrologists and other international partners have joined forces to develop this new space-based mission to make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how water bodies change height over time. The SWOT Science Team held its first meeting in June; turn to page 18 to read a summary of this meeting.

Finally, I'd like to mention a new NASA–AGU collaboration on a visualization and storytelling competition. The competition is open to all two- and four-year undergraduate and graduate students who are U.S. citizens. A total of 10 winners will be chosen. Five "Runner Up" winners will receive a travel grant and complementary registration to attend the Fall AGU meeting in San Francisco, CA. Five "Grand Prize" winners will also receive several other awards including the chance to present their "story" on the Hyperwall at NASA's Fall AGU exhibit—see Advertisement on page 39 of this issue. More details about the competition can be found at *https://education.agu.org/grants/data-visualization-storytelling-competition/award-information*. ■

[1] TCTE was created to deal with the potential gap in the 34-year TSI record created by the launch failure of NASA's Glory mission in 2011.

[2] National Research Council, Earth Science and Applications from Space: *National Imperatives for the Next Decade and Beyond*. National Academies Press, Washington, DC, p. 426, 2007.

Undefined Acronyms Used in Editorial and Table of Contents

CERES	Clouds and the Earth's Radiant Energy System
CLARREO	Climate Absolute Radiance and Refractivity Observatory
ISS	International Space Station
JPSS	Joint Polar Satellite System
NPP	National Polar-orbiting Partnership
SWOT	Surface Water and Ocean Topography
VIIRS	Visible Infrared Imaging Radiometer Suite

feature articles

The Network for the Detection of Atmospheric Composition Change: 25 Years Old and Going Strong

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The year 2016 marks 25 years of successful operations for NDACC, enabling and enhancing global atmospheric research.

Introduction

The Network for the Detection of Atmospheric Composition Change (NDACC) is an international research and measurement program composed of more than 70 high-quality, remote-sensing research stations—as shown in **Figure 1.** The Network conducts long-term measurements for observing and understanding the physical and chemical state of the stratosphere and upper troposphere and for assessing the impact of stratosphere changes on the underlying troposphere and on global climate. The year 2016 marks 25 years of successful operations for NDACC, enabling and enhancing global atmospheric research through:

- analysis of long-term datasets from which trends and changes in atmospheric composition have been determined for international ozone and climate assessments;
- provision of ground-truth and correlative measurements for international satellite investigations;
- scientific collaboration in airborne and balloon campaigns for investigating stratospheric and upper tropospheric processes; and
- validation and development of atmospheric models.

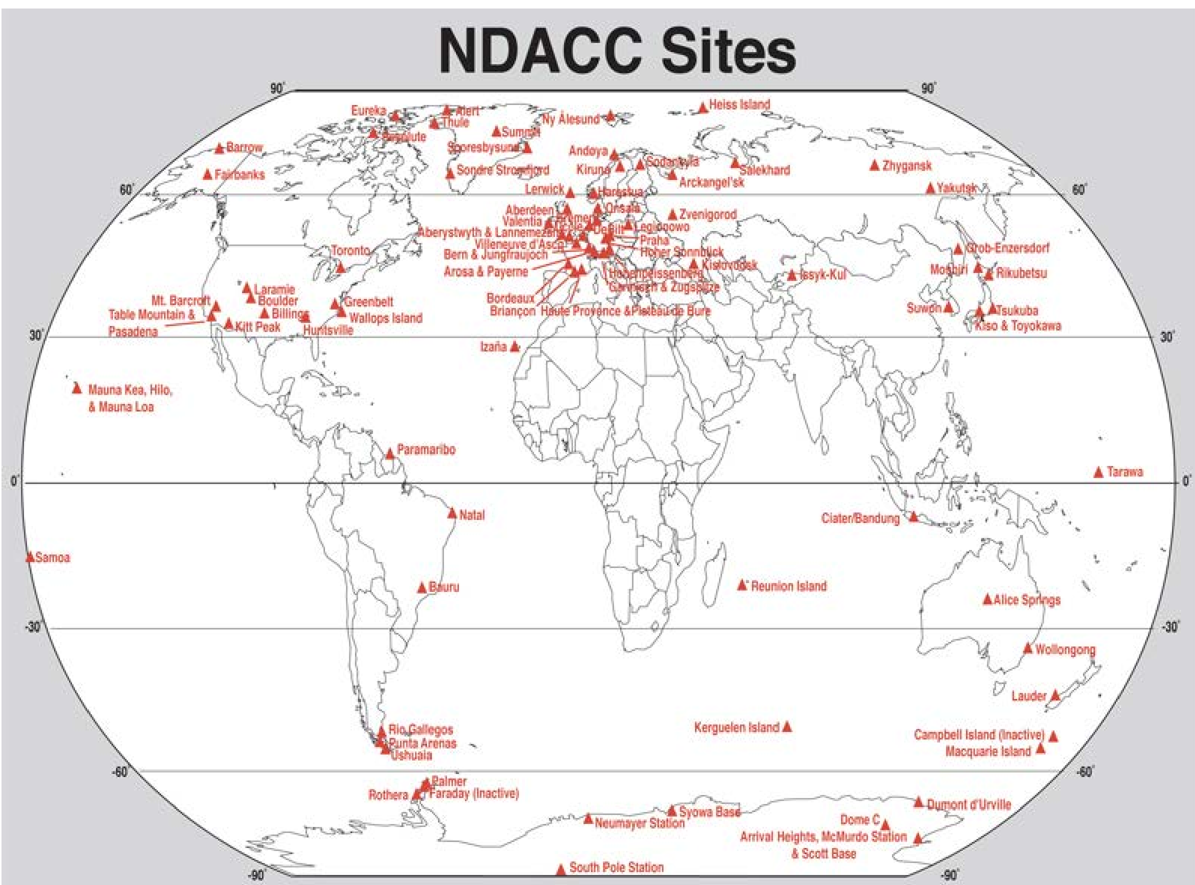

Figure 1. Global distribution of NDACC Measurement Stations **Image credit:** Geir Braathen [World Meteorological Organization]

This historic milestone provides an excellent opportunity to reflect on NDACC's history, assess where it is today, and to look to its future[1]. More-detailed information on the Network may be found at *http://www.ndacc.org*.

Historical Context for the Development of the NDACC[2]

As a result of a variety of factors, by the early-to-mid-1970s, the welfare of biological systems on our home planet became a common concern beyond the scientific community. NASA contributed to promoting this new interest in the environment by way of a series of photographs of Earth from its geosynchronous satellites and by astronauts on the Apollo missions, which provided the first global views of Earth in the late 1960s. Meanwhile, for the first time, scientists were reaching consensus that human beings now had the capacity to alter their global environment[3].

NASA's interest in focused studies of Earth's atmosphere came about through research conducted under the Department of Transportation's (DOT) Climatic Impact Assessment Program (CIAP). CIAP was initiated in 1971 to address the scientific controversy over the potential adverse impact that exhaust emissions from the proposed supersonic transport fleet, which contained oxides of nitrogen (NO_x), could have on stratospheric ozone. Additional concerns were raised shortly thereafter regarding the catalytic destruction of ozone by chlorine released from several sources, including solid rocket propellants and industrial chlorofluorocarbons. Though CIAP fell under DOT's authority, from early on, the U.S. Congress made it clear that "figuring out the ozone mess was NASA's job[4]". This led to the establishment of a stratospheric ozone research program at NASA.

NASA contributed to promoting this new interest in the environment by way of a series of photographs of Earth from its geosynchronous satellites and by astronauts on the Apollo missions, which provided the first global views of Earth in the late 1960s.

The Upper Atmosphere Research Program

NASA's 1976 authorization bill officially handed the agency the responsibility of understanding stratospheric ozone chemistry in the form of a mandate to perform research concerned with the possible depletion of the ozone layer by "conducting a comprehensive program of research, technology, and monitoring of the phenomena of the upper atmosphere." This led to NASA's establishment of the Upper Atmosphere Research Program (UARP). This mandate was further amplified through the Clean Air Act Amendments of 1990, which directed both NASA and the National Oceanic and Atmospheric Administration (NOAA) to "monitor stratospheric ozone and ozone-depleting substances (ODSs) and submit a report to Congress on the current average tropospheric concentrations of chlorine and bromine and on the level of stratospheric ozone depletion." Since then, UARP has sponsored and continues to sponsor a wide range of investigations including field measurements, laboratory kinetics and spectroscopy, modeling, and data analysis[5].

[1] The results of many past and present measurements, analysis, and exploitation activities will be highlighted in a special interjournal commemorative issue of *Earth System Science Data, Atmospheric Chemistry and Physics*, and *Atmospheric Measurement Techniques,* as well as in oral and poster presentations during session A017 on Atmospheric Trace Species at the Fall 2016 Meeting of the American Geophysical Union. Additional information about NDACC as it is presently configured can be found at the NDACC website located at *http://www.ndacc.org*.

[2] Much of the historic context summarized in the first few paragraphs is drawn from Conway, Eric, 2008: NASA Atmospheric Research in Transition. *Atmospheric Science at NASA: A History.* The Johns Hopkins University Press, pp. 122-141.

[3] This was the consensus of a July 1970 workshop held at Massachusetts Institute of Technology (MIT) that was organized to provide input for a 1972 United Nations Conference on the Human Environment. The report from that workshop, "Man's Impact on the Global Environment: Report of the Study of Critical Environmental Problems," is considered a scientific classic.

[4] This was how Eric Conway summarized the content of a letter from Senator Clinton Andersen [D, NM—*Chairman of Senate Committee on Aeronautics and Space Sciences*] to NASA Administrator James Fletcher in June 1971—several months prior to enactment of the legislation that created CIAP. To learn more, see *Atmospheric Science at NASA: A History*, p. 133.

[5] The major results and advancements in understanding from the first decade of effort were summarized in World Meteorological Organization (WMO) Report No. 16, *Atmospheric Ozone 1985: Assessment of our Understanding of the Processes Controlling Its Present Distribution and Change*; NASA RP 1162, (1986), *Present State of Knowledge of the Upper Atmosphere: Processes that Control Ozone and other Climatically Important Gases*; and *WMO Scientific Assessment of Stratospheric Ozone: 1989*, Global Ozone Research and Monitoring Report No. 20.

Enter the Network for the Detection of Stratospheric Change

The discovery of the so-called "ozone hole[6]" made it clear that more detailed stratospheric observations were needed to help determine its origins. Such observations would require a measurement and analysis network specifically designed to provide the earliest possible detection of changes in the composition and structure of the stratosphere and—more important—the means to understand the causes of those changes. The development of new technologies—made possible in part because of UARP—made implementation of the network increasingly feasible.

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In March 1986 NASA, NOAA, and the Chemical Manufacturers' Association (CMA) convened an international workshop in Boulder, CO, to evaluate the possibility of establishing such an observational network and to begin specifying its goals, measurement priorities and rationale, and operational requirements (i.e., instrument types and measurement locations). Workshop attendees agreed that the major goal of such a network would be focused, long-term observations. However, it also became clear that over the shorter term the proposed network would yield valuable scientific returns for other activities, including:

- studying the temporal (diurnal, monthly, seasonal, and annual) and spatial (latitudinal) variability of atmospheric composition and structure;
- providing the basis for ground truth and complementary measurements for satellite systems such as NASA's Upper Atmosphere Research Satellite (UARS), which was scheduled for launch in the fall of 1991; and
- critically testing multidimensional stratospheric models and providing the broad database required for improved model development.

Long-term measurement stability and quality assurance as well as comprehensive measurement and data intercomparisons among various measurement systems (including those onboard satellites) were paramount in the construction of such a network. The idea that emerged from the Boulder meeting was that initial funding for such activities would come from NASA, NOAA, and CMA. However, participants quickly realized that in order to fully implement the network, international scientific, managerial, and financial collaboration among the numerous cosponsors would be needed, with monitoring complemented by other World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) activities. Thus, follow-on meetings were held to better define the international composition of the network. In particular, several European stations where many of the required facilities already existed were identified as potential network sites.

Finally, in 1991, following five years of planning, instrument design and development, and implementation, the Network for the Detection of Stratospheric Change (NDSC)—see *NDSC Organization* on page 7—began official operations endorsed by UNEP, the Global Atmosphere Watch (GAW) Programme of the WMO, and the International Ozone Commission (IO_3C) of the International Association of Meteorology and Atmospheric Sciences. This rapid implementation of NDSC benefitted from several years of instrument development under UARP and international sponsors. Addressing NASA's congressional mandate has required a full complement of measurements in the troposphere and stratosphere conducted from the ground, balloons, aircraft, and satellites, with NDSC providing vital observational continuity, as discussed in the next section.

[6] In 1985 a group of scientists from the British Antarctic Survey made atmospheric science history when they reported a large seasonally recurring depletion of stratospheric ozone over the Antarctic region that has now become known as the *Antarctic ozone hole*. Shortly thereafter, NASA released the first satellite representation of the Antarctic ozone hole, which showed that the extent of the phenomenon was about the size of the continent itself.

NDSC: An Assessment after Ten Years of Operation

During its first decade of operations the NDSC had grown to include participation by more than 20 countries. The network celebrated its tenth anniversary with a symposium in Arcachon, France. The Symposium Report from that meeting lists several measurement and analysis results from the Symposium sessions, and can be found at *http://www.ndsc.ncep.noaa.gov/news/ndsc_01sym.html*.

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Over the next several years the NDSC continued to expand in both its atmospheric measurement capabilities and its contributions to understanding a broad spectrum of atmospheric science issues. Network activities included numerous instrument validations and intercomparisons (both within the network itself and with external measurement capabilities conducted by aircraft, balloons, and satellites). Of particular note was the proactive role of the Satellite Working Group in fostering synergy with the satellite community; specific examples of the results of these interactions are given in the *Significant Contributions and Results from 25 Years of NDSC/NDACC Operations* section on page 10. Many activities contributed to placing increasing trust in the data and analyses. Indeed, more than ten years of high-quality NDSC data were now contributing significantly to the international WMO/UNEP Ozone Assessments being conducted under the provisions of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. This Protocol was the first international agreement to apply limits to the production and consumption of the main chemicals causing the destruction of the Earth's protective ozone layer. Detailed information about network achievements during this period can be found in the 2003 and 2005 NDSC Newsletters, which can be downloaded from *http://www.ndsc.ncep.noaa.gov/news/archives*.

NDSC Organization

NDSC has embodied a simple and flexible organization that has contributed to the network's longevity and successful evolution since its inception. The original, principal components of the organization are still in place 25 years later under what has become the NDACC, as described on page 5. These components are the **Steering Committee** (SC) headed by a chair and vice-chair (now two co-chairs) and comprised of representatives from the instrument and other working groups, peer-review scientists, and *ex officio* representatives from the sponsoring or partnering international agencies or institutions; and the **Science Team**, consisting of the principal investigators (PIs) from all of the network sites.

As the primary managerial body of the Network, the Steering Committee is responsible for internal operational and scientific oversight and for recommending implementation and funding actions. The Science Team acts as the actual forum for conducting network research and analysis coordinated through the Instrument Working Groups (IWGs), which are organized around the instrument types. Initially, there were four certified instrument types: Fourier transform infrared (FTIR) spectrometers—for column abundances of many chemicals; lidars—for aerosols, temperature, and ozone (O_3); microwave radiometers—for chlorine monoxide (ClO), O_3, and water vapor; and ultraviolet (UV)/visible spectrometers—for column O_3 and nitrogen dioxide (NO_2) measurements. Three more instrument types were subsequently added: Dobson/Brewer spectrophotometers for column O_3, O_3 and aerosol sondes, and UV spectroradiometers. Each of the IWGs has the responsibility of setting actions to maximize internal consistency among the network data, which are archived at a dedicated Data Host Facility (DHF), hosted and supported by NOAA. A Theory and Analysis Working Group and a Satellite Working Group were also established to promote and enhance interactions with the modeling and satellite communities, respectively.

Measurement sites, at which a majority of the aforementioned NDSC-certified instrument types operated, were designated as Primary Stations. Sites equipped with a subset of such instruments and/or operating less regularly than the Primary Stations were designated as Complementary Stations and contributed to the global coverage of the network. These sites also provided substantial support during coordinated campaigns targeted at special process studies, at calibration and validation phases of space-based sensors, and at studying more regional and potentially subtle atmospheric characteristics. In the early 1990s NASA and NOAA provided support for more than a dozen U.S. investigator teams as well as for the operation of the Primary Station at Mauna Loa, HI, and the Complementary Station at Table Mountain, CA—shown in photo on front cover.

Evolution to the Network for the Detection of Atmospheric Composition Change

To better reflect the combined free tropospheric and stratospheric coverage of network measurement, analysis, and modeling activities as well as to convey the linkage to climate change, in 1995 the Steering Committee voted to change the name of the network to the Network for the Detection of Atmospheric Composition Change (NDACC). The committee intended the new name to reflect the expanded focus of the network while at the same time emphasizing that NDACC was not designed to be a climate-monitoring network, but rather an observational network that provided a broad suite of atmospheric data that contributed to understanding the interrelationship between changing atmospheric composition and climate. The set of objectives expanded to reflect the broadened scope of NDACC observations. These objectives included:

To better reflect the combined free tropospheric and stratospheric coverage of network measurement, analysis, and modeling activities as well as to convey the linkage to climate change, in 1995 the Steering Committee voted to change the name of the network to the Network for the Detection of Atmospheric Composition Change (NDACC).

- establishing long-term databases for detecting changes and trends in atmospheric composition and understanding their impacts on the stratosphere and troposphere;
- establishing scientific links and feedbacks between climate change and atmospheric composition;
- calibrating and validating atmospheric measurements from satellites and gap-filling critical satellite datasets;
- providing collaborative support to scientific field campaigns and to other chemistry and climate observing networks; and
- providing validation and development support for atmospheric models.

In addition, the labeling of NDACC measurement sites as "primary" or "complementary" was dropped and all sites became designated simply as NDACC Stations.

Continuing Evolution: NDACC Creates Cooperating Network Affiliation

With the expansion of its focus and the transition from NDSC to NDACC, the incorporation of new measurement capabilities and collaboration with existing capabilities whose heritage was developed external to the network became increasingly important. As the network entered its second decade of operations, increased scientific cooperation between NDACC and independently operating regional, hemispheric, or global networks of instruments became critical. These other networks typically had comparable quality assurance guidelines, operational requirements, and data-archiving policies, and independent national or international recognition. Thus, NDACC formalized a Cooperating Network affiliation—see **Table**—to foster the desired collaborative measurement and analysis activities, and developed a Cooperating Networks Protocol to cover the various aspects of such affiliations. Representatives from the Cooperating Network serve on the NDACC Steering Committee, where they work to promote internetwork scientific collaboration. Further details can be found in the Cooperating Network Section at the NDACC website at *http://www.ndsc.ncep.noaa.gov/coop*.

Table. The eight currently operating NDACC Cooperating Networks.

Cooperating Network	Website
AErosol RObotic NETwork (AERONET)	*http://aeronet.gsfc.nasa.gov*
Advanced Global Atmospheric Gases Experiment (AGAGE)	*http://agage.eas.gatech.edu/index.htm*
Baseline Surface Radiation Network (BSRN)	*http://www.bsrn.awi.de*
GCOS Reference Upper-Air Network (GRUAN)	*http://www.gruan.org*
Halocarbons and other Trace Species (HATS)	*http://www.esrl.noaa.gov/gmd/hats*

Table. (*cont*). The eight currently operating NDACC Cooperating Networks.

Cooperating Network	Website
NASA's Micro-Pulse Lidar Network (MPLNET)	*http://mplnet.gsfc.nasa.gov*
Southern Hemisphere Additional Ozonesondes (SHADOZ)	*http://croc.gsfc.nasa.gov/shadoz*
Total Carbon Column Observing Network (TCCON1)	*http://www.tccon.caltech.edu*

Moving Beyond the First 10 Years

As the network continued to mature, its intercomparison campaigns became more comprehensive, with the involvement of multiple instrument types in order to better understand measurement synergies. In addition, the capabilities of FTIR and UV/visible instruments expanded so that data for the first time would have some vertical resolution. Current NDACC observational capabilities are depicted in **Figure 2**.

With the increased recognition that NDACC was a source of long-term, high-quality data for multiple species and parameters of atmospheric interest, network data-based literature citations in subsequent WMO/UNEP Ozone Assessments increased significantly. Long-term UV data records were now available for the Polar Regions, where appreciable stratospheric ozone depletion was observed, and NDACC data were now being used extensively in the evaluation of Chemistry–Climate Models (CCMs). In addition, the now-extensive database (accessible by anonymous *ftp* at *ftp.cpc.ncep.noaa.gov/ndacc*) was gaining increased recognition by space agencies around the world (e.g., NASA, European Space Agency, Japan Aerospace Exploration Agency) and by the European Union as an important resource for satellite validation. Some of the network's contributions in these areas can be found in the *Significant Contributions and Results from 25 Years of NDSC/NDACC Operations* section on page 10.

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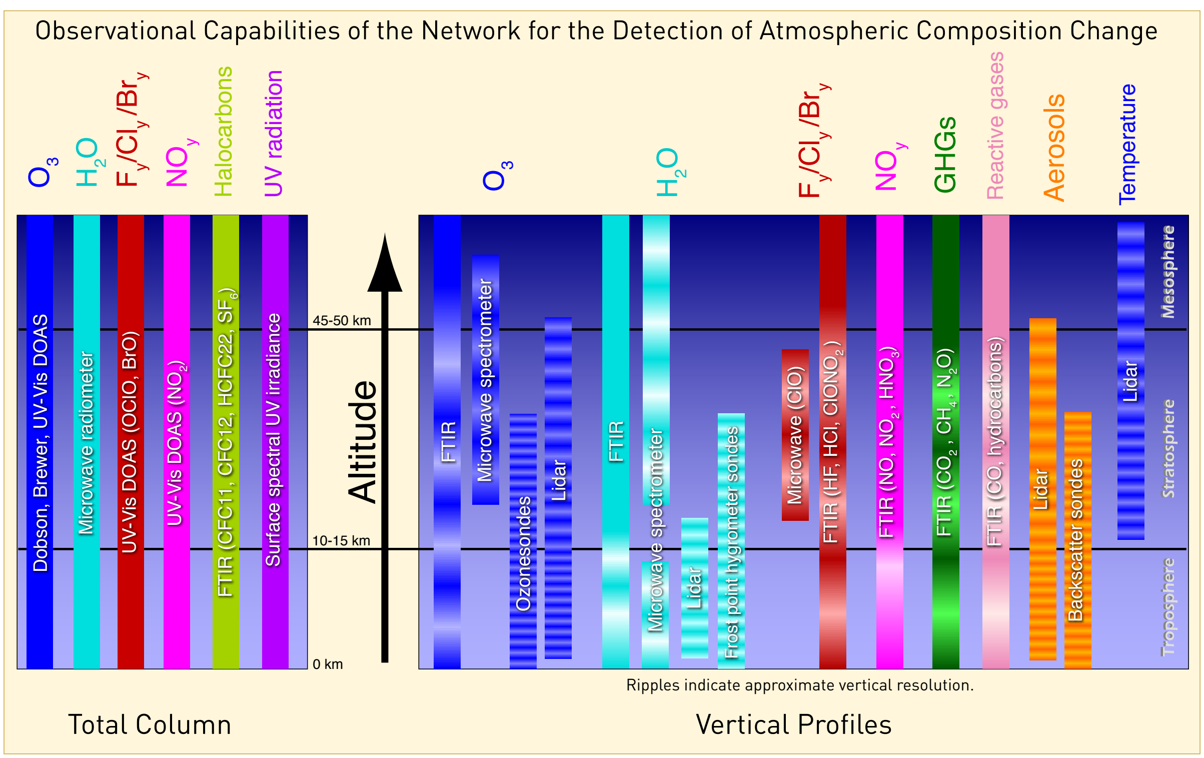

Figure 2. Summary of NDACC's measurement capabilities, including the species and parameters measured, the instrumental measurement techniques, and each measurement's approximate vertical resolution. Measurements are archived in the NDACC Data Host Facility. **Image credit:** Geir Braathen [WMO]

On the international stage, NDACC had become an important contributor to many initiatives. Of particular note is the recent use of NDSC/NDACC data in the SPARC/IO$_3$C/IGACO-O3/NDACC[7] Initiative on Past Changes in the Vertical Distribution of Ozone (SI^{2}N), which was undertaken to study and document those long-term changes and possibly enable attribution for observed ozone layer recovery.

Revisions to the network website paralleled this advancement, with links to "Hot News" articles, Working Group websites, and archives of the complete series of network *Newsletters*.

Twentieth Anniversary

In November 2011 a 20-Year Anniversary Symposium in Saint Paul, Île de la Réunion (an island NDACC Station east of Madagascar in the Indian Ocean), served as the forum for commemorating NDACC's first decade of scientific successes and two decades of combined NDSC/NDACC contributions to atmospheric science. This four-day symposium featured more than 125 oral and poster presentations, the details of which can be found at *http://ndacc2011.univ-reunion.fr*.

In November 2011 a 20-Year Anniversary Symposium in Saint Paul, Île de la Réunion (an island NDACC Station east of Madagascar in the Indian Ocean), served as the forum for commemorating NDACC's first decade of scientific successes and two decades of combined NDSC/NDACC contributions to atmospheric science.

Significant Contributions and Results from 25 Years of NDSC/NDACC Operations

The large number and broad scope of NDSC/NDACC contributions to-date that enable and enhance global atmospheric research make it difficult to single out individual results, not to mention those having the greatest impact. However, with help from the cochairs of the current NDACC Working Groups and from NDACC Station Representatives (a list of whom may be found at *http://www.ndsc.ncep.noaa.gov/organize/committee*) we have compiled the following list of achievements that exemplify the use of the high-quality data obtained from consistent, standardized, long-term measurements supported by the Network.

High-quality ozone datasets. High-quality ozone datasets from more than two decades of measurements by NDSC/NDACC Dobson/Brewer spectrometers, ozonesondes, lidars, microwave radiometers, and FTIR spectrometers have been instrumental in identifying the first two of the three stages of the predicted stratospheric ozone recovery resulting from the elimination of ODS mandated by the Montreal Protocol and Amendments, namely the slowing of ozone decline and the onset of increases. (Stage 3 would be "full recovery" to 1980 benchmark levels, projected to occur by midcentury in midlatitudes and in the Arctic and somewhat later for the Antarctic ozone hole.) Thus, NDSC/NDACC measurements, together with those from satellites, are critically important in verifying the successful implementation of the protocol requirements. **Figure 3** shows an example of some of those results.

Long-term dataset on ozone vertical profiles. The long-term NDSC/NDACC dataset on ozone vertical profiles has been used extensively in the SI^{2}N initiative aimed at better quantifying the past changes in the vertical distribution of ozone. This initiative demonstrated that stable, well-calibrated, ground-based measurements could be used to complement satellite observations and resulted in the production of a *merged* (i.e., combined satellite and ground-based data) ozone profile dataset. These latest datasets are being used in an attempt to differentiate between ozone increases due to declining ODS abundances and those attributable to changing climate.

Long-term monitoring of the vertical distribution of temperature and aerosols in the stratosphere. NDSC/NDACC lidars provide a unique capability for long-term monitoring of the vertical distribution of temperature and aerosols in the stratosphere, and thereby have provided independent verification and quantification of recent stratospheric cooling due to increasing greenhouse gases. Aerosol lidar data have quantified

[7] SPARC is the Stratosphere-troposphere Processes And their Role in Climate project of the World Climate Research Program (WCRP). IGACO-O3 is the Integrated Global Atmospheric Chemistry Observations for Ozone and UV Radiation, an international project.

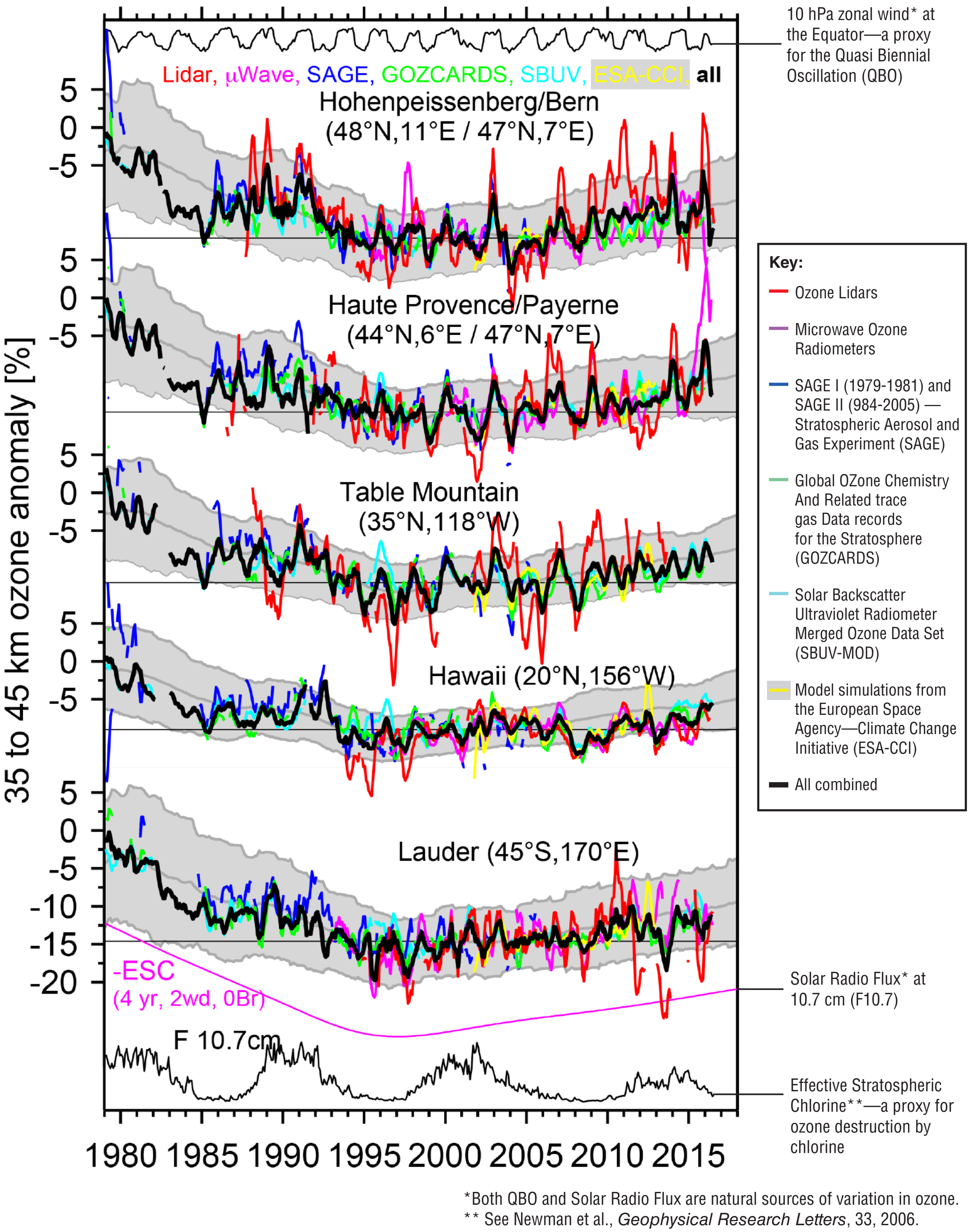

Figure 3. These graphs show ozone anomalies—departures from the mean value measured between 1998 and 2008—in the upper stratosphere, for selected ground-based instruments and satellite-based datasets at several different NDACC stations. Annual cycle signal contributions have been removed. Such data lead to the conclusion that ozone in this region of the atmosphere is recovering from chemical destruction by stratospheric chlorine. **Image credit:** Adapted from Wolfgang Steinbrecht [German Weather Office, Deutscher Wetterdienst (DWD)].

stratospheric aerosol loading and its consequences after major volcanic eruptions (e.g., Mt. Pinatubo in 1991) as well as minor ones, and have provided up-to-the minute warnings on regional conditions and risks to air-traffic safety.

NDACC data are now contributing to validation activities for the coming Joint Polar Satellite System era with the Suomi National Polar-orbiting Partnership satellite, launched in 2011.

Correlative measurement campaigns. Beginning with NDSC and continuing through NDACC, the lidars, microwave radiometers, FTIR spectrometers, UV/Vis spectrometers, and sondes have participated extensively in correlative measurement campaigns for instruments on NASA's UARS and Aura platforms as well as for the NASA Total Ozone Mapping Spectrometer (TOMS) and Stratospheric Aerosol and Gas Experiment (SAGE) instruments. Similar activities have been conducted for international instruments, such as those onboard the Canadian Space Agency's SCISAT-1 and ESA's Envisat and MetOp satellites, and the multinational Odin satellite. NDACC data are now contributing to validation activities for the coming Joint Polar Satellite System era with the Suomi National Polar-orbiting Partnership satellite, launched in 2011. Through such validation and stability assessment activities, the network has become recognized as providing fiducial reference measurements to characterize satellite observations.

Limiting the range of uncertainties in ozone absorption cross-sections. NDACC instrument scientists have helped to study, evaluate, and recommend the most suitable ozone absorption cross-section laboratory data to be used in atmospheric ozone measurements. Comparisons of NDACC ozone products generated by different instrument types have helped to determine the range of uncertainties associated with the stratospheric temperature dependence of the instrument-specific absorption cross-sections that are used operationally in deriving these data products, critical to supporting recommended spectroscopic standards.

Providing precise documentation of the multidecadal trends of many tropospheric and stratospheric constituents. High-resolution solar absorption spectra regularly recorded by NDACC FTIR spectrometers under cloud-free conditions provide precise documentation of the multidecadal trends of many tropospheric and stratospheric constituents. For example, the data records for hydrogen chloride (HCl) and chlorine nitrate ($ClONO_2$) are shown in **Figure 4**. These two substances are the primary reservoir compounds for stratospheric chlorine and these data help to confirm our understanding of the reaction cycles associated with the chemical destruction of stratospheric ozone.

Providing significant contributions to understanding atmospheric water vapor behavior. NDACC measurements have made significant contributions to understanding atmospheric water vapor behavior. Since 1996 millimeter-wave spectrometers have

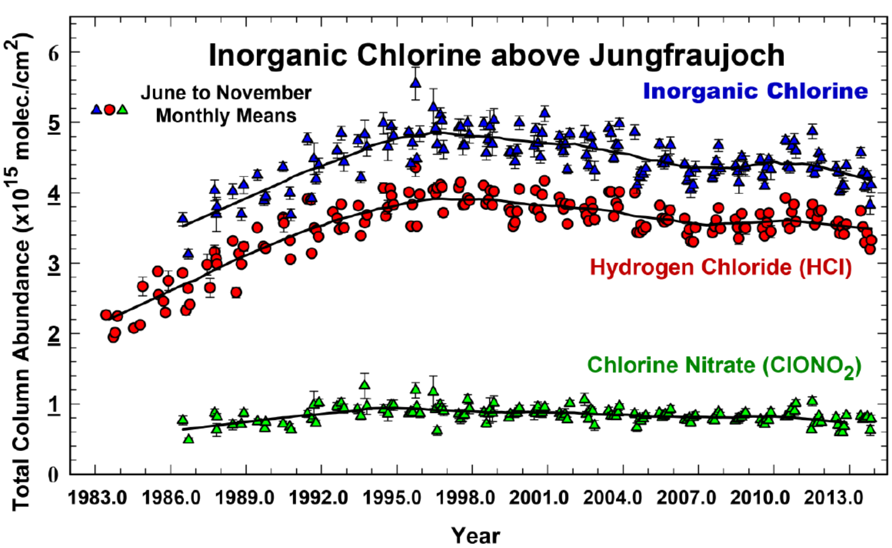

Figure 4. The graph shows a time series (from 1983 to 2012) of monthly-mean total column hydrogen chloride (HCl, red circles) and chlorine nitrate ($ClONO_2$, green triangles) concentrations, measured above the Jungfraujoch, Switzerland station (46.5° N). Total column inorganic chlorine (Cl_y, blue triangles) amounts were obtained by summing the corresponding HCl and $ClONO_2$ data points. **Image credit:** Emmanuel Mahieu, University of Liege, Belgium

measured significant interannual variations in water vapor, but only a small overall increase near the stratopause. Meanwhile, the FTIR long-term dataset on the variability in isotopic ratios of water has become an important tool for investigating different water cycle processes that are important in Earth's climate system.

Making major contributions to assessing atmospheric water vapor measurement techniques. The NDACC Working Group on Water Vapor participated extensively in an assessment conducted by the International Space Science Institute Working Group on Atmospheric Water Vapor of *in situ* and remote sensing techniques presently used to monitor the distribution of atmospheric water vapor. NDACC measurement and analysis experience played major roles in several sections of the report.

Bounding causative factors in latitudinal UV variation. Latitudinal variations in annual doses of UV-B and UV-A radiation have recently been assessed using data from NDACC UV spectroradiometers. Large differences between corresponding latitudes in the Northern and Southern Hemispheres have been attributed to differences in total ozone, cloudiness, aerosol loading, and sun–Earth separation. NDACC spectral UV measurements have also been used to compare surface UV levels derived from satellite observations, specifically from the Ozone Monitoring Instrument (OMI) on Aura and the Global Ozone Monitoring Experiment (GOME)-2 instrument on MetOp-A. However, the hemispheric differences have yet to be reproduced in satellite retrievals.

Evaluating coupled chemistry-climate models. NDACC data have been extensively used in the evaluating coupled Chemistry–Climate Models (CCMs) under the CCMVal activity conducted by the SPARC project of the World Climate Research Program (WCRP), in which the radiative, dynamical, transport, and chemical processes in the models were analyzed in unprecedented detail. In particular, the long time series of NDACC observations were crucial for evaluating the past trends produced by the models.

The Path Forward

Given the clear importance of the NDACC not only to its component organizations, but also to those working in other organizations whose activities are intimately dependent on the Network's results, moving forward in three specific areas becomes key: organizational flexibility, data access improvements, and data quality assurance.

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Organizational Flexibility

Continued successful contributions to worldwide atmospheric research have required constant evolution of the Network, the current configuration of which is summarized in **Figure 5**. Given the complexities of the topic areas and the organizational imperatives, oversight of such growth has been and continues to be a major responsibility of the NDACC Steering Committee. There is enough flexibility built into the structure of the organization to allow for near "on-the-fly" changes. For example, while the nine permanent NDACC Working Groups (see Figure 5) were organized around seven specific instrument types and two other relevant activities (Satellites and Theory and Analysis) as described earlier, the Steering Committee identified the need for new Theme Groups (three of which are shown in Figure 5). These can be of more limited duration and are organized around specific foci, with attendant flexibility in organizational response. Representatives from each Theme Group also serve on the NDACC Steering Committee.

Of particular note is the Water Vapor Measurement Strategy Theme Group that has been tasked with developing a network-wide measurement plan for atmospheric water vapor. The strategy includes all current NDACC water vapor measurements (i.e., lidar, microwave, FTIR, and frost-point sondes); its development is critical for NDACC to fulfill its objective of establishing the scientific links and feedbacks between climate change and atmospheric composition. Implementation of the strategy will likely enhance the relationship between NDACC and climate-focused networks such as GRUAN.

Figure 5. NDACC's current organizational structure is summarized here. Many of the elements are mentioned in this article including the Steering Committee, Working and Theme Groups, Quality Assurance Protocols, Cooperating Networks (detailed in Table), Data Host Facility, Website, and Newsletter. The Station Network map is a smaller version of the representation in Figure 1. **Image credit:** Geir Braathen [WMO]

Data Access Improvements

Timely access to data is a key factor for scientific endeavors, and the NDACC's holdings are no different. While the time scale for archiving verifiable network data at the DHF and for their public release is now one year, most PIs approve release of their data upon submission to the database. These data are available at *ftp.cpc.ncep.noaa.gov/ndacc/station*. In continuing efforts to make data not just available, but also trustworthy, the DHF itself is undergoing improvements to provide greater clarity for the data users. For example, more comprehensive information will be provided to reflect any changes in the data files themselves and the versions of the algorithms used in the data processing. The DHF manager will implement more thorough data-quality checks to ascertain formatting and gridding and to verify completeness of the metadata files. In addition, a dedicated directory has been established for submission of and access to Rapid Delivery Data, i.e., data that may be revised before entry in the full database.

In an effort to provide a clearer and more direct path to access NDACC data, the NDACC web page is being redesigned. Inclusion of a new "data search" page will guide users to their desired level of data query (species, measurement site or latitude range, instrument type, time period, etc.). Model output generated by the Theory and Analysis Working Group are also now available at the website. These model-generated data will help provide a better understanding of station data variability and representativeness (i.e., a bridge between individual stations and the global perspective) and a context for interpreting station observations. Model simulations produced by the group can be used to help set priorities for network expansion and/or instrument relocation. The model data—categorized by instrument type—may be accessed at *ftp://ftp.cpc.ncep.noaa.gov/ndacc/gmi_model_data*.

Data Quality Assurance

Each of the Instrument Working Groups is engaged in data reprocessing and enhancing data consistency and stability by homogenizing and possibly centralizing data-processing procedures, based on instrument type. The IWGs are also participating in several European projects to ensure measurement traceability, harmonize and quantify measurement uncertainties, and harmonize and document the traceability of retrieval methods. Such long-term quality assurance and up-to-date data archiving and availability are critical for continued international network recognition and data use. These groups also emphasize NDACC's utility in providing fiducial reference measurements for characterizing satellite observations—necessary conditions for a more complete understanding of our home planet's complex systems and the interactions between them.

Conclusion

As a major component of the international atmospheric research effort, NDACC stands as a shining example of what can be achieved through international cooperation and from continuity and quality assurance in measurements and their analyses. The critical roles of ground-based networks such as NDACC have been emphasized in the *Report of the Ninth Meeting of Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer* [WMO Global Research and Monitoring Project Report No. 54 (2014)]. For example, NDACC could become a singular resource for research and monitoring the chemistry of the upper atmosphere when NASA's Aura mission ends.

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This article has described NDSC/NDACC's many successes over the last 25 years, but the network is not resting on its laurels. As it has done for the past quarter-century, in order to remain a viable, international atmospheric-research effort in an era of more constrained budgets, the network must continue to refine its focus—and, as needed, evolve its measurement capabilities. NDACC is one of several networks that currently bring unique capabilities to the global observing system, and as a result there are instances where NDACC's activities and capabilities overlap with these other networks, thereby resulting in some duplication of effort. Some of this overlap is essential for quality assurance, but for optimum resource utilization it is also imperative for each network to "find its niche" and identify the degree to which it can and should take on a specific responsibility and to develop a long-term operational strategy for doing so. The NDACC Theme Group on Measurement Strategies and Emphases was established for this very purpose. With such responsiveness and the flexible structure that has been described herein, the NDACC Steering Committee and Science Team are confident that they can meet the challenges facing them, and look forward to continuing the network's important role for many years to come. ■

NASA's Science Program Support Office Partners with the U.S. Department of State on Outreach

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NASA's Science Program Support Office (SPSO) recently represented NASA at the 2016 International Union for Conservation of Nature (IUCN) World Conservation Congress and the 2016 Our Ocean Conference, hosted by the Honorable John F. Kerry, Secretary of State of the United States.

In anticipation of the IUCN World Conservation Congress and to underscore the importance of the deliberations, on August 31, U.S. **President Barack Obama** made remarks to the IUCN delegates (and the Pacific Island Conference of Leaders), during which he discussed connections between conservation and climate change and his administrations' commitment to protect the environment and prevent worsening impacts of climate change. Over 10,000 attended the Congress, which was held September 1-7 in Honolulu, HI.

At the request of the U.S. Department of State, the NASA Hyperwall was featured prominently in the U.S. Pavilion, where NASA also had a table with hands-on activities for attendees.

2016 IUCN World Conservation Congress

At the request of the U.S. Department of State, the NASA Hyperwall was featured prominently in the U.S. Pavilion, where NASA also had a table with hands-on activities for attendees. NASA-funded scientists and SPSO personnel gave four Hyperwall talks per day, addressing such topics as: A Space Based View of Earth's Biodiversity; Climate Change in Yellowstone; Near Real-Time Monitoring of Alert Systems for Improved Forest Management in the Tropics; Observing Wildfires from Space; Global Land Cover Monitoring and Mapping with Landsat Data; Monitoring of Chimpanzee Habitat Health from Space; and Drones that See through Waves, and new Technologies for Ocean Conservation. A total of 21 Hyperwall presentations were given to a variety of audiences, including hundreds of students—see **Photo 1**.

A major activity for the NASA representatives was an hour-long panel discussion, *Satellite Remote Sensing for Conservation Actions: A Jane Goodall Institute Case Study*, which drew over 100 attendees to the exhibit. **Allison Leidner** [NASA Headquarters (HQ)—*Research Scientist*] moderated the panel. **Jane Goodall** (the world's foremost expert on chimpanzees) highlighted the importance of new technologies in related areas—including remote sensing for conservation—see **Photo 2**. She then participated as a panelist in the ensuing discussion. Other panelists included **Lilian Pintea** [The Jane Goodall Institute—*Vice President for Conservation Science*], who described

Photo 1. Students visited the U.S. Pavilion at the IUCN World Conservation Congress and completed hands-on activities offered by NASA. **Photo credit:** NASA

Photo 2. Jane Goodall [*speaker, right*] spoke at the NASA Hyperwall at the IUCN World Conservation Congress. She also participated in an hour-long panel discussion along with [*left to right*] **Lilian Pintea**, **Woody Turner**, and **Allison Leidner**. **Photo credit:** NASA

Photo 3. [*Left to right*] **NASA Administrator Charles Bolden**, **Deputy Administrator Dava Newman**, **Winnie Humberson** [GSFC—*SPSO Lead*], **Paula Bontempi**, **Michael Freilich**, and **Steve Graham** [GSFC—*Senior Outreach Specialist*] stand in front of the Hyperwall at the 2016 Our Ocean conference. **Photo credit:** NASA

Photo 4. Miguel Roman [*left*] shows **Secretary of State John Kerry** [*third from right, front*] how he uses images from the Suomi National Polar-orbiting Partnership (NPP) satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) day-night band to track illegal fishing in the South China Sea. **Photo credit:** NASA

how he uses satellite remote sensing to advance chimpanzee conservation efforts, and **Woody Turner** [NASA HQ—*Program Scientist for Biological Diversity and Program Manager for Ecological Forecasting*], who provided an overview of NASA and the agency's contributions to conservation.

The Hyperwall also served **Kathy Sullivan** [National Oceanic and Atmospheric Administration (NOAA)—*Administrator*] who used it to present information on the U.S. Marine Biodiversity Observation Network.

While not part of NASA's exhibit, the agency's Biological Diversity, Ecological Forecasting, and Applied Remote Sensing Training (ARSET) programs were also on the Congress program: a roundtable discussion, during which feedback from the conservation community on remotely sensed essential biodiversity variables was solicited, and a half-day workshop on an introduction to remote sensing. (NASA co-led the later event with Conservation International—a nongovernmental organization that addresses conservation efforts across a wide range of topics in several locations around the globe).

The SPSO also supported the NASA Hyperwall exhibit at the 2016 Our Ocean Conference, held at the U.S. Department of State in Washington, DC, September 15-16, hosting over 1000 attendees. Five Hyperwall presentations were given over the two-day event.

2016 Our Ocean Conference

The SPSO also supported the NASA Hyperwall exhibit at the 2016 Our Ocean Conference, held at the U.S. Department of State in Washington, DC, September 15-16, hosting over 1000 attendees. Five Hyperwall presentations were given over the two-day event. Presenters included: **Ellen Stofan** [NASA HQ—*Chief Scientist*]; **Michael Freilich** [NASA HQ—*Earth Science Division Director*]; **Paula Bontempi** [NASA HQ—*Ocean Biology and Biogeochemistry Program Manager*]; **Miguel Roman** [NASA's Goddard Space Flight Center—*Physical Scientist*]; and **Laura Lorenzoni** [NASA HQ—*Ocean Biology and Biogeochemistry Program Scientist*]. **NASA Administrator Charles Bolden** and **Deputy Administrator Dava Newman** were also at the NASA booth—see **Photo 3**. One highlight from the event was a 10-minute visit to the Hyperwall by **Secretary of State John Kerry**. **Miguel Roman** used the Hyperwall to show Secretary Kerry how he uses images from the Suomi National Polar-orbiting Partnership (NPP) satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) day-night band to track illegal fishing in the South China Sea—see **Photo 4**. Secretary Kerry was keenly interested in hearing about this unique application of NASA satellite data. Other notable visitors included **Teresa Heinz Kerry** (the Secretary's wife) and Norway's Foreign Minister, **Borge Brende**. During nonpresentation times the Hyperwall displayed a loop of 60 NASA-provided ocean-related visualizations.

To view more photos from these and other events that the SPSO supports, visit *https://www.flickr.com/photos/eospso/albums/with/72157672964571852*. ■

Surface Water and Ocean Topography Science Team Meeting

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Introduction

The Surface Water and Ocean Topography (SWOT) mission brings together two international communities whose focus is on better understanding Earth's ocean and surface waters and the interplay between them. U.S. and French oceanographers and hydrologists and other international partners have joined forces to develop this new space-based mission to make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topography, and measure how the height of water bodies change over time.

The first SWOT Science Team Meeting was held in Pasadena, CA, June 13-15, 2016. The meeting was immediately followed on June 16 by parallel sessions of the SWOT Ocean Calibration/Validation Workshop and Hydrology High-Level Data Products Workshop.

SWOT was identified as a "Tier 2" mission in the National Research Council's 2007 Earth Science Decadal Survey, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*[1], which provided the basis for the future direction of NASA's space-based Earth observation system. SWOT is now scheduled for launch in 2020.

The primary objectives of the SWOT Science Team Meeting were to:

- describe the SWOT mission, its organization, status, and anticipated products;
- introduce the science investigation teams, grouped by synergistic efforts; and
- plan future activity within working groups focused on hydrology, oceanography, and interdisciplinary topics.

The meeting lasted three days to accommodate the contributions of 153 participants across 85 oral presentations, and over 50 posters. A summary, along with all of the presentations from the plenary, splinter, and poster sessions, are available on the SWOT website at http://*swot.jpl.nasa.gov*.

Opening Session

Eric Lindstrom [NASA Headquarters—*Physical Oceanography Program Scientist*] opened the meeting with a status overview of SWOT. He welcomed the new SWOT Science Team members and encouraged them to "grow the SWOT community" through research activities and discussion.

Parag Vaze [NASA/Jet Propulsion Laboratory (JPL)—*SWOT Project Manager*] summarized changes associated with the transition from mission Phase B ("preliminary design") to Phase C ("final design and fabrication"). Together, Lindstrom and Vaze emphasized the importance of ongoing science team involvement as the project strives to maximize science return while balancing mission risk.

Mission Description Session

Presenters in this session shared detailed descriptions of the planned science payload, orbit configuration, data processing, calibration/validation (cal/val) plan, data simulators, and applications.

The SWOT mission is being jointly developed by NASA and the Centre National d'Études Spatiales (CNES) with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency (UKSA). **Image credit:** NASA/JPL

Brian Pollard [JPL] provided an overview of the SWOT payload, which is driven by the need for interferometric precision, stability, and continuous data coverage—see **Figure 1**. He provided an overview and status update on the K_a-band Radar Interferometer (KaRIn), nadir altimeter, cross-track Advanced Microwave Radiometer, X-band telecommunications, and instruments for orbit determination—e.g., Détermination d'Orbite et Radiopositionnement Intégré par Satellite (DORIS). Pollard stated that the SWOT payload team has made progress in developing engineering model hardware and expects to have a prototype by the end of 2016.

[1] The report can be downloaded from *www.nap.edu/catalog/11820/earth-science-and-applications-from-space-nationalimperatives-for-the.*

Lee-Lueng Fu [JPL—*SWOT Oceanography Science Lead and Project Scientist*] addressed SWOT's mission design, including differences between the post-launch *fast sampling* orbit and subsequent *science-data-collection orbit*—see **Figure 2**. He stated that during the one-day repeat phase, about three months will be spent focusing on achieving cal/val objectives and studying rapidly changing phenomena. The subsequent 21-day repeat orbit (nominally lasting three years) has been chosen to balance global coverage and frequent sampling. SWOT's orbit, with an inclination between 74° and 80°, will be non-sun-synchronous to minimize tidal aliasing and ensure coverage of major water bodies on land. SWOT's 120-km-wide (~75-mi-wide) swath will result in overlapping measurements over most of the globe, with an average revisit time of 11 days.

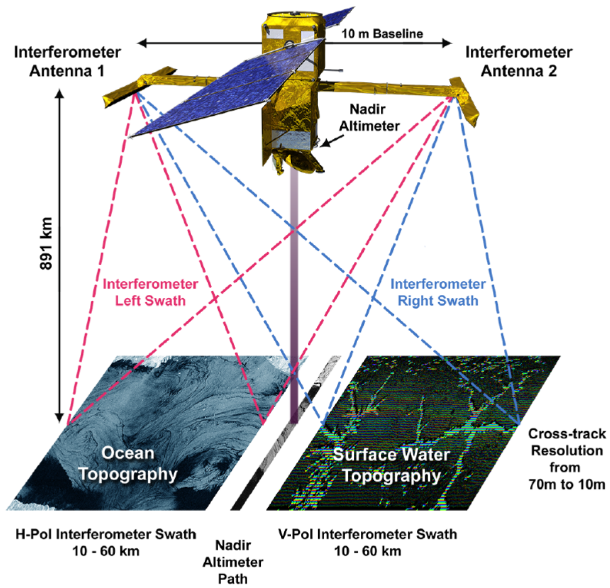

Figure 1. SWOT's K_a-band Radar Interferometer (KaRIn) will have two swaths to determine ocean and surface water topography. A Jason-class altimeter beam will be located between these swaths. **Image credit:** NASA/JPL

The next few presentations described SWOT data processing issues. **Sylvain Biancamaria** [Centre National de la Recherche Scientifique/Laboratoire d'Études en Géophysique et Océanographie Spatiales (CNRS/LEGOS), France] summarized how SWOT's data High Rate (HR) mode, 10-60 m (~33-197 ft) in range by 5 m (16 ft) in azimuth, cannot sample all continental surfaces because of onboard storage capacity. As a result, the SWOT Science Definition Team formed a working group to define a HR land mask[2] compliant with mission constraints. The HR mask covers 86% of continental surfaces between 78° N and 78° S latitude—excluding Antarctica. **Eva Peral** [JPL] described SWOT's highly flexible onboard processing approach, including individual objectives for each of the algorithms (ocean, land, calibration, and Doppler centroid estimation) that KaRIn will perform. **Daniel Esteban-Fernandez** [JPL] presented SWOT's measurement performance studies, which demonstrate that the system meets mission requirements with an adequate level of margin. He noted, however, that efforts to advance understanding of key phenomenology will continue, and will include examining available datasets, modeling, and simulation efforts.

Phil Callahan [JPL] gave an overview of how JPL, Centre National d'Études Spatiales (CNES; the French Space Agency), and the SWOT Science Team are jointly defining the content of science data products, developing algorithms and their theoretical bases, providing working code and test cases, developing or gathering auxiliary data [e.g., digital elevation models (DEMs)], and supporting independent reviews of algorithms. Callahan outlined key science data products for public distribution, including Low Rate (LR) mode ocean interferograms [average resolution of 500 m^2 (5382 ft^2)] and HR single-look complex radar hydrology products.

Roger Fjørtoft [CNES] gave a complementary presentation to Callahan's, providing details on how raw (i.e., Level-0) synthetic aperture radar (SAR) data from KaRIN will be processed into sets of Level-1 interferograms (i.e., amplitude, phase, coherence). Fjørtoft explained that LR-mode data will be processed onboard the spacecraft while HR-mode data will be downloaded and processed

[2] The SWOT HR mask can be accessed at *http://west.rssoffice.com/SWOT/hrmask.jsp*.

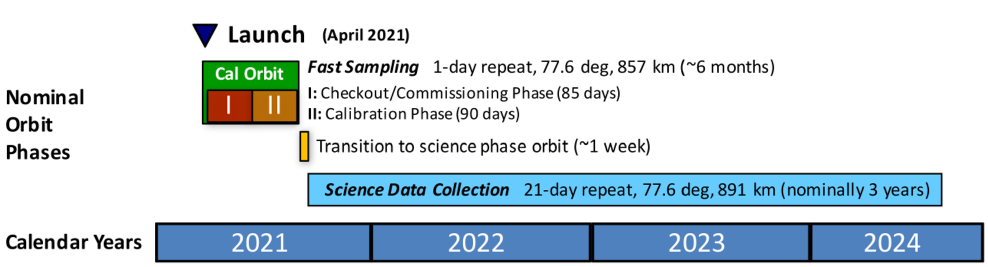

Figure 2. After SWOT's launch (currently scheduled for 2021), there will be an initial *checkout/commissioning phase* lasting about 85 days, followed by a roughly 3-month *calibration phase*. During these initial phases, the mission conducts *fast sampling*, meaning that it will operate on a one-day repeat cycle and focus on achieving cal/val objectives and studying rapidly changing phenomena. Once these two phases are complete (approximately six months after launch) the satellite will be moved to a slightly higher altitude where it will stay for the remainder of the mission (nominally three years). It will take about a week to transition SWOT to *science data collection phase*; data collection will occur on a 21-day repeat cycle designed to balance global coverage and frequent sampling. **Image credit:** NASA/JPL

on the ground. SWOT data will undergo a series of corrections—such as amplitude, signal-to-noise ratio, phase bias, tropospheric delay, and ionospheric and tidal effects. Geophysical factors, including significant wave height, wind, rain, ice, electromagnetic bias, and the potential for *layover*[3] must be estimated and/or flagged.

Ernesto Rodriguez [JPL] presented SWOT's cal/val approach. He stated that a relatively small number (10 – 20) of "Tier 1" sites will be designated as the focus of project-funded cal/val activities for hydrology, augmented by approximately 100 "Tier 2" sites to characterize SWOT spatial variability (e.g., U.S. Geological Survey water level gauges). All Tier 1 sites for hydrology are currently located in North America and France. An existing instrument site in the Gulf Stream will be used for oceanographic validation; this location will be covered by SWOT-orbit crossovers during the fast sampling orbit phase described earlier. Rodriguez pointed out that ocean calibration of sea surface height (SSH) is a major challenge; however, three approaches have been identified to validate the high-frequency spectrum over the ocean: AirSWOT[4], Modular Aerial Sensing System lidar, and *in situ* instrumentation (e.g., moorings, drifters, gliders).

Clement Ubelmann [Collecte Localisation Satellites (CLS), France] and **Ernesto Rodriguez** provided an overview of SWOT's ocean and hydrology simulators, respectively. Ubelmann explained that the ocean simulator was developed in collaboration with SWOT's Science Definition Team and was principally designed for scientists to investigate SWOT downstream applications using realistic data. Available online[5], it relies on spectral-error budget specifications and has been used to explore various science applications for SWOT. The *SWOT Hydrology Simulator* generates radar interferograms, detects pixels that represent water, and geolocates to a pixel cloud. It is accompanied by *RiverObs*, which takes in the pixel-cloud output from the *SWOT Hydrology Simulator* to estimate key parameters (e.g., width, height, slope) over river segments.

Margaret Srinivasan [JPL] concluded the session with an overview of SWOT's applications efforts, which are being implemented at the project level with support from NASA, CNES, and the Science Team. She explained that the SWOT Applications Working Group (SAWG) provides feedback on data-product development with respect to applications (and vice versa) and helps to disseminate information about SWOT applications-relevant data to broad communities. Srinivasan stated that SAWG team members have authored key documents (e.g., the *SWOT Applications Plan, Applications Traceability Matrix,* and various journal articles), administered a user needs survey, and implemented an "Early Adopters" program for stakeholders who can demonstrate the utility and/or social value of SWOT data using resources obtained outside of NASA's Applications programs.

Highlights from Science Team Topical Area Presentations

To kick off the meeting's second day, members of the SWOT Science Team gave presentations grouped by topic; lead presenters provided a high-level summary of the group's collective work. These introductions oriented the audience to the posters being presented that afternoon, many of which can be accessed online at *http://swot.oceansciences.org/meetings_posters.htm*. Each of the topics listed below encompasses the work of several investigators. One presenter represented the work of all the investigators in each topical area.

Oceanography topical areas included:

Meso- and Sub-Mesoscale Processes and Modeling: Projects will employ a range of inversion techniques of varying complexity to infer lateral and vertical exchanges from SWOT data.

Meso- and Sub-Mesoscale Processes and Observation System Simulation Experiments: Projects will use model and *in situ* data to demonstrate SWOT's potential contributions to understanding links among ocean physics, biogeochemistry, and ecology.

Techniques for Reconstruction and Assimilation of SWOT Ocean Observations: Projects will use data from multiple sources (e.g., sea surface temperature, nadir altimetry, elephant seals equipped with temperature and salinity sensors) in conjunction with dynamics to determine ocean state with the longer-term goal of informing how to process gridded SWOT map fields.

Tides, Waves, and High-frequency Processes: Projects will support the SWOT mission by developing tide models (i.e., barotropic, baroclinic), modeling internal wave signals and their predictability, and characterizing global internal tides at high horizontal resolution.

SWOT Oceanography Cal/Val: The overall goal of these projects is to establish a network of calibration sites geographically distributed for more robust characterization of existing and future radar altimeter system instrument biases and their drifts over ocean and inland waters. In addition, the group is involved in developing high-resolution models (i.e., tides, dynamic atmospheric correction).

[3] *Layover* in SAR data occurs when, due to topography or vegetation, returns from separate areas on the ground reach the sensor at the same time.

[4] AirSWOT is the airborne cal/val and science support instrument for the SWOT mission. To learn more, visit *http://swot.jpl.nasa.gov/airswot*.

[5] The open-source SWOT Simulator for Ocean Science can be accessed at *http://sourceforge.net/projects/swotsimulatorforoceanscience*.

Coastal and Estuarine Processes: These projects will augment previous studies that demonstrated SWOT's ability to reproduce coastal hydrodynamics across a broader range of environments with different tidal contexts (i.e., macro-, meso-, and micro-tidal), diverse morphologies (i.e., estuary, delta, bay, sandy beach, cliff, and shelf), and in various climates (i.e., temperate, Mediterranean, tropical, and Arctic).

Hydrology topical areas included:

Global Hydrologic Modeling: These global-scale efforts will interact through a multiyear, multiphase, intercomparison project with shared methodology development, providing a multimodel vision of global hydrologic processes and potential SWOT impact.

River Algorithms, Models, and Data Assimilation: Projects include developing global assimilation and modeling frameworks for SWOT data products, river and assimilation-based discharge algorithms, hydrologic and hydrodynamic modeling in South America, and synergies between SWOT and the Global Precipitation Measurement (GPM) mission.

Lake, River, and Wetland Processes and Science: These projects, whose study sites span six continents, generally use radar altimeter data to characterize water surface extents while addressing lake, river, and wetland dynamics.

SWOT Hydrology Cal/Val: Projects are largely focused on validation during the fast sampling (i.e., one-day repeat) phase of the mission, studying hydrologic parameters and phenomenology in North and South America.

Synergistic Science: These diverse projects will use SWOT data to improve the resolution and accuracy of the global marine gravity field for seafloor mapping and tectonic investigations; understand polar ice sheet dynamics; monitor ice-covered polar oceans in terms of SSH, sea ice freeboard, and thickness; and a United Kingdom-based effort focused on open-ocean and coastal oceanography, along with sea-ice and atmospheric effects on instrument performance.

Applications: Wide-ranging projects include performing outreach to open broad access to information about the SWOT mission and its applications; integrating lateral contributions and longitudinal controls along river segments to improve discharge estimates for flood hazards, risks, insurance, etc.; and preparing SWOT for "ground-truthing," discharge product development, and water-management applications in Asian river systems.

Themes and Challenges for SWOT

After (and as a result of) the second day's presentations and deliberations, Science Team members summarized key themes and challenges for SWOT moving forward. They are listed here by topical area, or theme:

Oceanography Challenges

- Understanding the two-dimensional SSH signal;
- analyzing high-frequency dynamics for SWOT (i.e., tides, internal waves, surface waves);
- characterizing coastal zones (including estuaries and deltas);
- understanding the two-dimensional SSH error budget over the SWOT swath;
- projecting fine-scale SWOT observations horizontally and vertically; and
- developing data products and applications.

Hydrology Challenges

- Improving stand-alone SWOT discharge algorithms;
- developing and testing robust, global assimilation schemes in hydrologic and hydrodynamic models;
- developing more datasets to test algorithms (e.g., models, simulator, AirSWOT);
- identifying optimal ways to leverage existing *in situ* and satellite datasets to improve SWOT discharge estimates;
- figuring out how to robustly estimate and incorporate layover;
- developing robust global models and assimilation schemes;
- assessing how assimilation of SWOT data will improve water-cycle representation;
- developing assimilation schemes to leverage SWOT data in one- and two-dimensional hydrodynamic models; and
- applying model results to improve SWOT algorithms.

Highlights from the Working Group Reports

The last day of the SWOT Science Team Meeting began with reports from working groups and other teams. These Working Group reports set the stage for issues to be discussed in more detail during the subsequent splinter sessions.

Ernesto Rodriguez discussed the structure of the Algorithm Team, key areas of concern, and the need to broaden the representation of science team members and disciplines on the algorithm team (e.g., sea ice, continental ice sheets, ocean bathymetry/gravity). He followed with a report from the Cal/Val Steering group outlining the team's organization, workflow, and "hot topics" (e.g., mix of airborne and *in situ* data, integration of efforts among cal/val sites, pre-launch activities).

Richard Ray [NASA's Goddard Space Flight Center] represented the Tides Working Group. He stated that the group's focus is on assessing the accuracy of coherent internal tide models and correcting/flagging incoherent internal tides. They are also developing an atlas for local high-resolution models for barotropic tides in coastal and shallow sea areas, along with improving tidal models at high latitudes.

Patrice Klein [Institut français de recherche pour l'exploitation de la mer (Ifremer)] presented results from three years of analysis of high-resolution [1-4 km (0.6-2.5 mi)] ocean general circulation models. This effort has revealed some new impacts of small-scale phenomena [10-50 km (~6-31 mi)] at larger scales, leading to two specific recommendations: revisit existing satellite and *in situ* data to confirm new results; and continue to increase simulation resolution.

Colin Gleason [University of Massachusetts Amherst] described the activities of the Discharge Algorithm Working Group (DAWG), which is tasked with generating river discharge estimations from SWOT measurements. The DAWG's principle activity, also known as the *Pepsi Challenge*, is testing discharge results from different inversion algorithms, all of which use the same assumptions and 19-river hydraulic model dataset (width, height, slope).

Margaret Srinivasan concluded the plenary session with a report from the SWOT Applications Working Group including key publications, presentations, and SWOT Applications user needs survey results. She also discussed broad issues related to funding, interactions with operational agencies, participation of private industries, and synergies with other NASA missions.

Splinter Sessions

The majority of day three was spent in splinter sessions. **Rosemary Morrow** [CNRS/LEGOS] and **Lee-Lueng Fu** [JPL] chaired the Oceanography session, while **Tamlin Pavelsky** [University of North Carolina (UNC)] and **Jean-Francois Cretaux** [CNRS/LEGOS] both chaired the Hydrology splinter session.

Oceanography

The oceanography splinter session began with presentations related to the effects of various ocean phenomena on SSH signals at length scales of 15-150 km (9-93 mi). **Raffaele Ferrari** [Massachusetts Institute of Technology], **Brian Arbic** [University of Michigan, and **Edward Zaron** [Portland State University] focused on the effects of internal waves, internal tides, gravity waves, and nonstationary tides on SSH signals.

The next series of presentations addressed the effects of surface waves on SSH signals, during which **Ernesto Rodriguez** and **Ken Melville** [Scripps Institution of Oceanography] discussed AirSWOT and airborne lidar measurements, pointing out the utility of these intercomparisons for SWOT science and cal/val activities. **Fabrice Ardhuin** [Ifremer] gave an overview of the effects of surface waves on SSH based on theories and models (e.g., sea-state biases caused by uneven power returns from horizontal facets at the surface).

The next focus was on estimates of upper-ocean circulation, where **Clement Ubelmann** [CLS], **Dudley Chelton** [Oregon State University], **Bo Qiu** [University of Hawaii at Manoa], and **Jim McWilliams** [University of California, Los Angeles] presented their work, which ranged from exploration of dynamic interpolation methods, estimation of surface velocity and vorticity based on data at SWOT resolution and reconstruction of vertical velocities in the ocean, to addressing the limits of geostrophic dynamics at the ocean surface at various scales.

Nathalie Steunou [CNES] concluded the session with a report on SWOT's LR Level-2 (gridded, mapped) data products. She outlined the steps that will be taken to convert nine beam interferograms to 1 km^2 (0.4 mi^2) SSH products. She reviewed the origin and geometry of the KaRIn beams: 9 beams, spread out in the along-track direction, which yield 9 separate images [500 m x 500 m (1640 ft x 1640 ft) pixels] that are shifted by approximately 200 m (~656 ft) each. This results in center beams being more reliable and thus weighted higher during processing—see **Figure 3**. She provided a table of SWOT's Level-2 products, along with information on the expected LR data volume (per day and per half-orbit) for various product types.

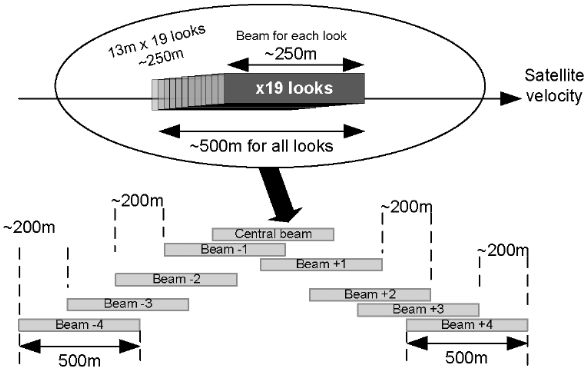

Figure 3. Diagram of the KaRIN beam configuration.
Image credit: CNES, NASA/JPL

Hydrology

The Hydrology splinter session opened with a simulator tutorial by **Brent Williams** [JPL] featuring two primary packages: *SWOT Hydrology Simulator* and *RiverObs*. The *SWOT Hydrology Simulator* directly generates interferograms with appropriate statistics for SWOT geometry. *RiverObs* is a proof-of-concept vector product that reads *SWOT Hydrology Simulator* data.

Tamlin Pavelsky [UNC] then provided an overview of AirSWOT and data from its hydrology campaigns (e.g., Willamette River, OR; Sacramento River, CA; Wax Lake Delta, LA; Tanana River, AK). While there have been good results in measuring river height and slope, preliminary findings generally demonstrate the need for future work such as collecting additional data, addressing errors, and reprocessing some existing data.

Pierre-André Garambois [Institut National des Sciences Appliquées (ICube)] then addressed how best to use SWOT data to infer river discharge at the global scale and provided an overview of data from DAWG's *Pepsi Challenge*, as described earlier in this article. This topic prompted a group discussion about organizing SWOT model intercomparisons for data assimilation purposes.

Stéphane Calmant [LEGOS] shared the benefits of leveraging international partnerships such as engagement in SWOT cal/val. He outlined specific activities that have already begun with partners in South America (i.e., Brazil, Chile, Paraguay, Uruguay). **Alain Pietroniro** [Environment Canada] provided background on activities in Canada including identification of potential river-based SWOT cal/val sites and plans to use SWOT hydrology simulators.

The Hydrology Splinter Session ended with the discussion of several interesting potential appplications for SWOT data.

Brent Williams [JPL] addressed the use of SWOT interferograms for land-based water detection. **Jean-Francois Cretaux** [CNRS/LEGOS] noted the need for a prelaunch *a priori* focused on lakes database. **Renato Frasson** [Ohio State University] using SWOT data to establish *reach boundaries* for features such as tributaries, confluences, dams, and waterfalls. **Clement Ubelmann** [CLS] discussed using SWOT's ocean coverage—especially at swath cross-over points—and inland interpolation to correct hydrology measurements.

Closing Session

The meeting concluded with two science presentations and summaries of future plans from the oceanography and hydrology leads.

Benoit Laignel [University of Rouen] addressed issues and questions in coastal-estuary-river continuums, areas that are significantly impacted by human activity and climate change. SWOT's high spatial resolution and global coverage could be used to improve knowledge of the complexity of physical processes (e.g., floods, tides, storm surges) and its data could help calibrate and validate models. He suggested investigating how SWOT science products could be designed to meet the needs of stakeholders in these regions.

Jerome Monnier [L'Institut National des Sciences Appliquées de Toulouse] reported on the potential for SWOT to contribute to the understanding of polar ice sheet dynamics and a fully integrated data assimilation system. For example, data from SWOT may be helpful for measuring *grounding lines*—where ice sheets contact the ocean and the ice mass starts to float by buoyancy—or inferring bed topography beneath ice caps, ice flows, and other related phenomena.

Tamlin Pavelsky [UNC] summed up the key points from the Hydrology presentations and discussions, including the desirability of establishing continental hydrologic model and geoid working groups, along with increased involvement of Science Team members with SWOT algorithm development and cal/val efforts. He also mentioned ongoing analyses of AirSWOT data and future development of mapped, gridded, and model output products.

Lee-Lueng Fu [JPL] provided a summary of the Oceanography session, including the formation of working groups for surface waves, tides/internal waves, HR modeling, reconstruction (i.e., handling geostrophic and ageostrophic SSH components and errors), and coastal/estuarine studies. He mentioned upcoming meetings and the development of a "Mission Science Investigation Plan," which will include summaries from each investigation team.

Conclusion

The meeting fulfilled all its objectives. It provided a forum for new Science Team members to become familiar with the SWOT mission and each other's work. The meeting set the stage for important tasks to be completed during Phase C of the mission. The top priorities include completing the plans for the mission's calibration and validation and the development of science algorithms. In hydrology, the key objectives are to develop river discharge models, characterize the effects of layover, and wetland data product definition. The key oceanographic objectives include understanding the effects of internal gravity waves and surface gravity waves on sea surface height observations, developing tide models, and using high-resolution ocean models to develop science investigation plans. Various working groups have been formed to address these priority tasks. The next SWOT Science Team meeting will take place during June 2017 in France. ■

Summary of the Spring 2016 NASA Land-Cover Land-Use Change Science Team Meeting

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The Spring 2016 NASA Land-Cover Land-Use Change (LCLUC) Science Team Meeting was held on April 18-19, 2016, in North Bethesda, MD. This meeting marked the twentieth anniversary of NASA's LCLUC program. On this special occasion the meeting focused on accomplishments, current issues (with discussions on future directions to advance LCLUC research), and a special session on mapping industrial forests. The two-day meeting was organized into ten sessions, with five on each day. More than 100 participants, including U.S. and international researchers from academia, government, and the private sector, attended.

Participants at the NASA LCLUC Spring 2016 Science Team Meeting. **Photo credit**: Kristofer Lasko

Day 1: Opening Session, Invited Talks, Panel Discussion, Regional Synthesis

After a welcome and formal opening of the meeting, **Garik Gutman** [NASA Headquarters (HQ)—*LCLUC Program Manager*] shared his experiences based on almost two decades with the LCLUC program and its partners. Since its inception in 1997 the program has supported over 250 projects focusing on one or more of the program's nine science themes to advance land cover and land use science, leading to many peer-reviewed publications, development of land cover products[1], regional collaborations[2], and outreach activities[3]. With a stable financial budget the program has successfully balanced funding research on "Processes of change" with "Regional land cover projects" and grown in the past 20 years by coalescing with other NASA programs.

There was an "In Memoriam" presentation to recognize the contributions to LCLUC Program of the late **Jack Estes** [University of California, Santa Barbara], **Don Deering** [NASA's Goddard Space Flight Center (GSFC)], and **Greg Leptoukh** [Goddard Earth Sciences' Data and Information Services Center (GES DISC)-Data Manager]—see *Remembering Those Who Contributed to the LCLUC Program* on page 27. Numerous studies conducted by these and other LCLUC alumni have been integral to the program's success. Over the years, the NASA LCLUC program has established itself as the leading program in land-cover and land-use science by addressing critical research areas and needs with its connections to various other land-cover programs both at the national[4] and international levels[5].

Chris Justice [University of Maryland, College Park (UMD)] went on to describe his own 20-year journey with the program, highlighting his perspective on its various accomplishments. He shared how the program had its roots in the IGBP's Land Use and Cover Change

[1] Some noteworthy products include, the Global Forest Cover Change Product, 2013; Mangrove Forest Cover Change 1990-2005; and NASA-U.S. Geological Survey (USGS) global land surveys (GLS) datasets.

[2] Examples of regional collaborations include the Large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA) and network development [e.g., the Northern Eurasian Earth Science Partnership Initiative (NEESPI), Monsoon Asia Integrated Regional Study (MAIRS), and the South/Southeast Asia Research Initiative (SARI)].

[3] Outreach activities include the NASA–Michigan State University International Association for Landscape Ecology (MSU IALE), Trans-Atlantic Training (TAT), LCLUC webinars, the LCLUC newsletter, and the LCLUC website and Facebook page.

[4] National programs include those from NASA, the U.S. Global Climate Research Program (USGCRP), U.S. Geological Survey (USGS), and the U.S. Agency for International Development (USAID).

[5] International programs include Global Observation for Forest Cover and Land Dynamics (GOFC-GOLD), Committee on Earth Observation Satellites Group on Observations (CEOS/GEO), International Geosphere-Biosphere Programme International Human Dimension Programme (IGBP-IHDP), European Association of Remote Sensing Laboratories (EARSel) Special Interest Group (SIG) on Land-Use and Land-Cover (LU/LC), the European Space Agency (ESA), and the French Centre National d'Études Spatiales/Centre d'Études Spatiales de la BIOsphêre (CNES/CESBIO).

(LUCC) Program, chaired by **David Skole** [Michigan State University] in its early years, and which was strongly supported at NASA by **Tony Janetos** [NASA HQ—*First LCLUC Program Manager*] and **Bob Harriss** [NASA HQ—*Former Earth Science Division Director*], leading to the first LCLUC Science Team meeting at Airlie House, VA, in 1997. Justice sketched the evolution of the foci of the program from its early days exploring the impacts of LCLUC on ecosystem goods and services and the processes of change, to detection and monitoring change (initially by epochs) and climate-change interactions. The present thematic and regional focus of the program is on LCLUC processes pertinent to South and Southeast Asia. Compared to previous decades, the emphasis has moved from biogeochemical impacts (which are now addressed by the NASA Carbon Program) to characterization of land use (e.g., agricultural field size, plantations), urban expansion, adaptation, and other land-use processes. He suggested future directions in which the program could expand based on: new or improved Earth observations (EO) and data continuity activities and missions[6]; greater regional collaboration in South and Southeast Asia under the SARI network; opportunities for new collaborations in South America; thematic focus on agriculture, forests, and land use to support climate agreements (e.g., The Paris Agreement); food security; and land use climate adaptations. Justice ended his presentation with an acknowledgement of the invaluable, long-term contributions of **John Townshend** [University of Maryland, College Park] to the program in the area of global land cover mapping.

LCLUC Invited Talks

Eric Lambin [Stanford University and Université catholique de Louvain, Belgium] focused on the influence of *telecoupling*[7] and land-use governance on investments in land systems and specific land use. Investment decisions beyond national boundaries often impact the expansion of nonstaple crop coverage (e.g., soy) at the expense of forests in emerging economies with weak institutions, while staple crops are grown in intensive cycles in urban areas. He discussed forest transition, offshoring deforestation trends, where sending manufacturing to other countries can have concomitant environmental impact in the country where the industry is relocated in the form of deforestation, and the role of private governance, where private companies and nongovernmental organizations (NGOs) effectively enforce forest conservation policies.

David Skole focused on the evolution of land-cover products. In the past two decades, global land-cover datasets have evolved from coarse-resolution products from the Advanced Very High Resolution Radiometer (AVHRR) to 30-m (~98-ft) Landsat products. The evolution is accompanied by a shift in focus from pattern- to process-oriented science and applications. In the post-Paris Climate Agreement environment, the importance of a closer link between science, regional culture, and development policies cannot be emphasized more highly. Suggested areas for future exploration include forest degradation, forest carbon-stock mapping, and monitoring trees outside of forests and woodlands.

Panel Discussion

Garik Gutman led a panel discussion on *Past Achievements and Future Directions of Land-Cover Land-Use Science*. Panelists included **Karen Seto** [Yale School of Forestry], **Dan Brown** [University of Michigan], **Stephen Walsh** [University of North Carolina at Chapel Hill], **Mutlu Ozdogan** [University of Wisconsin-Madison], and **Volker Radeloff** [University of Wisconsin-Madison], as shown in the photo below. The panelists agreed that technology and policy advancements have increased the availability of data sources and have enabled the community to look into land-use processes that drive land-cover patterns—something that could not be done 20 years ago. However, much more remains to be explored in terms of understanding how complex socioeconomic systems and telecoupled events impact land cover and land use at different scales in an increasingly globalized world. Addressing these questions requires availability of time-series of high-resolution remote sensing and social data

Participants in the panel on *Past Achievements and Future Directions of Land-Cover Land-Use Science*. **Photo credit**: Kristofer Lasko

[6] The international Multi-Source Land Imaging science team's missions include the ESA Sentinels, China-Brazil Earth Resources Satellite (CBERS), NASA/Indian Space Research Organization (ISRO) Synthetic Aperture Radar (NISAR), ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Global Ecosystem Dynamic Investigation Lidar (GEDI), the Joint Polar Satellite System Visible Infrared Imaging Radiometer Suite (JPSS VIIRS; an instrument), and Biomass (ESA's seventh Earth Explorer mission).

[7] Telecoupling is a conceptual framework that encompasses both socioeconomic and environmental interactions among coupled human and natural systems over distances.

with wider spatial coverage at affordable costs, and integration of the activities of social and remote sensing scientists into cohesive activities. The panel suggested that future directions to advance LCLUC research include improvements in methods, a need for validation and accuracy assessments of data products, and a deeper understanding of interconnections between climatic, socioeconomic, and land-cover systems.

LCLUC Regional Synthesis Presentations

Regional synthesis provides an opportunity for new conceptual development for land-use science, based on previous program investments in regional science.

LCLUC in Central Asia and Northern Eurasia

In Central Asia, mismanagement of water—combined with warmer and drier climate in recent times—has led to less irrigation, shrinking croplands, and decreasing vegetation. The most rapid rates of change have been observed in areas of moderate population that are undergoing development. In the Mongolian Plateau, the complex, coupled, nature-human system was found not to be driven by climate alone as most ecologists believed; however, the feedbacks between human and climate systems have yet to be studied in depth. Another study addressed the impact of different land-use scenarios on biogeochemical cycling in North Eurasia. Different land-use scenarios produce different predictions of the future of carbon in North Eurasia, ranging from an overall decrease in the terrestrial carbon sink by 74%, to net creation of a carbon source (~17 Pg of carbon) during the twenty-first century. There is large uncertainty in methane emissions due to uncertainties in the effects of complex hydrological dynamics upon permafrost thaw and net methane emissions over the region, which greatly affects total radiative forcing. Further, it was found that the dominant drivers of evapotranspiration (e.g., temperature, precipitation) are the same regardless of the input forcing datasets used (i.e., regardless of which model is used). Other work showed that during the growing season, precipitation is dominant in the regional south, while temperature is dominant in the north. In rapidly warming permafrost regions, ice-wedge degradation and the hydrological changes associated with the resulting differential ground subsidence (e.g., as exhibited in the Yamal Peninsula) are expected to expand and amplify. The highest rates of shrub expansion were found in northwestern Siberia, where active *frost boils*[8] are common.

A study in the Siberian Yamal-Nenets[9] Social-Ecological Systems showed that the combination of abundant availability of food, space for long-distance reindeer migration, and bureaucratic intervention sensitive to the needs of the herders have helped the native people adapt to a variety of pressures from oil and gas extraction in recent decades. The study also identified cultural aspects of resilience such as, intact nuclear families with high retention among youth, accepting attitudes toward climate change and industrial development, and consciousness of their role as responsible stewards of the territories. Russian institutions administering reindeer herding accommodate decision-making that is sensitive to herders' needs and timetables and smaller, privately managed herds that can better utilize available pastures have also helped them persist.

LCLUC in South and Southeast Asia

Synthesis studies in South and Southeast Asia highlighted the important role of policy in determining regional LCLUC trends. Capitalist economic policies were found to drive the transition from agrarian to industrialized systems in the less-developed nations and uplands of mainland Southeast Asia. A country-by-country analysis of the rate of LCLUC in whole of South and Southeast Asia highlighted Nepal's successful forest conservation efforts, involving community forestry programs. As mentioned earlier, more studies are expected in the program as it focuses on this region of the world.

Posters and Celebratory Reception

The first day ended with a poster session, which began with participants giving a two-minute description of their posters. That evening, Stinger Ghaffarian Technologies and Science Systems and Applications, Inc. sponsored a celebratory reception to show their appreciation for the former and current principal investigators (PIs), LCLUC alumni, and program staff.

Day 2: Presentations From LCLUC Program Partners, New Program Initiatives, Industrial Forest Mapping, and Wrap-up

GOFC-GOLD Program—Nineteen Years of Coordination Activities

GOFC-GOLD is an extragovernmental scientific organization that has been involved with the LCLUC program for 19 years. It continues to be closely associated with the program through the Land Cover and Fire Implementation Teams (IT) and the global change SysTem for Analysis, Research and Training (START) activities. To help developing countries understand and

[8] *Frost boils* (also known as mud boils, frost scars and mud circles) are upwellings of mud that occur through frost heave and cryoturbation in permafrost areas, such as arctic and alpine regions. They are typically 1-3 m (~3-10 ft) in diameter with a bare soil surface, and predominantly circular, lacking "a border of stones."

[9] The Nenets are the indigenous people of Siberia that live on the Yamal peninsula, which extends from northern Siberia to the Kara Sea—far above the Arctic Circle.

Remembering Those Who Contributed to the LCLUC Program

An "In Memoriam" presentation took place during the meeting to honor the contributions of several individuals that have played a key role in and/or made key contributions to the Land-Cover, Land-Use Change Program.

Jack Estes led the "Accuracy Assessments of the IGBP Fast-Track 1-km Land Cover Data Sets" project in the LCLUC Program. He was a pioneer of remote sensing and GIS applications in environmental sciences. He worked closely with federal agencies like NASA and USGS and was awarded the 1999 William T. Pecora Award and 2001 Distinguished Public Service Medal for his outstanding contribution to satellite based earth observations.

Don Deering founded the Northern Eurasia Earth Science Partnership Initiative (NEESPI) program. NEESPI is a regional program that LCLUC supports. A detailed description of Don Deering's role in formation of NEESPI (written by Garik Gutman) can be found at *http://neespi.org/news/Don-in_memorium.pdf*.

Gregory "Greg" Leptoukh was a member of LCLUC and supported NEESPI and the Monsoon Asia Integrated Regional Study (MAIRS) partnerships. He led the development of the Giovanni Data Portal and Giovanni NEESPI was the first application developed, which allowed analyses of more than 35 interdisciplinary parameters from multi-satellites observations and numerical models over the Northern Eurasia. The 2012 and 2014 Online Giovanni Workshops[1] were named in his honor.

[1] These two workshops were reported on in the March–April 2013 [**Volume 25**, **Issue 2**, pp. 39-40] and May–June 2015 [**Volume 27**, **Issue 3**, pp. 14-18] issues of *The Earth Observer,* respectively.

prepare their own REDD+ reports[10], the GOFC-GOLD Land Cover IT office has developed REDD+ training material. The material is posted at *http://www.gofcgold.wur.nl/redd/Training_materials.php*. They also developed Boston Education in Earth Observing Data Analysis (BEEODA), a suite of open-source software and educational materials for processing Earth-observation data. An update of the GOFC-GOLD Fire IT activities highlighted fire monitoring with the next-generation operational polar orbiters [e.g., VIIRS on the Suomi National Polar-orbiting Partnership (NPP) and JPSS-1, Sea and Land Surface Temperature Radiometer (SLSTR) on Sentinel 3, Geostationary Operational Environmental Satellite (GOES)-R]; Moderate Resolution Data Continuity [e.g., Landsat 8, Sentinel 2, ResourceSat, CBERS-4]; Regional/Global Burned Area Products from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 6 and ESA's Climate Change Initiative; Moderate-resolution (i.e., Landsat-class) derived and validated fire products; Multi-source fire data fusion and information integration [e.g., Advanced Fire Information System, MuSLI]; and Near Real-Time global daily active fire monitoring [e.g., VIIRS via NASA's Land, Atmosphere Near real-time Capability for the Earth Observing System (LANCE)]. The next GOFC Fire-IT meeting with GEO's Global Wildfire Information System (GWIS) will be held in November 2016 in Santiago, Chile.

START's work contributes to building and enhancing capacities for advancing knowledge on global environmental change in Africa and Asia-Pacific. Future directions for START include capacity building within GOFC-GOLD objectives, and more opportunities for cross-network knowledge exchange, through learning forums and collaborative research.

New Initiatives

Future Earth U.S. is an international global change research program launched in 2013. It addresses the second and fourth goals of the U.S. Global Change Research Program[11]—to inform decisions by providing the scientific basis for timely decisions on adaptation and mitigation, and to advance communication and education to broaden public understanding of global change and to develop a future scientific workforce—by being involved in building funding coalitions to support co-created science for sustainability [e.g., Ocean Knowledge-Action Network[12]], capacity building [e.g., International Institute for Applied Systems Analysis (IIASA), International Social Science Council (ISSC) in Africa], and spreading awareness about global change through the Future Earth media portal (*http://medialab.futureearth.org*) and *Anthropocene Magazine*. Future Earth in Asia focuses on the regional priorities in the Asian region: the Water, Energy, and Food

[10] REDD+ is an abbreviation meant to describe efforts to reduce deforestation and forest degradation and to support sustainability and mitigation in such areas. Additional information may be found at *https://www.forestcarbonpartnership.org*.

[11] For more on the USGCRP goals, see *http://www.globalchange.gov/about/mission-vision-strategic-plan*.

[12] For more information, visit *http://futureearth.org/knowledge-action-networks*.

(WEF) nexus. A group discussion focused on the role of the land system and the impact of land-cover and land-use changes in the WEF nexus. Population in the Asian region is expected to grow rapidly over the next few years and food, water, and energy consumption is expected to grow by 50%, 30%, and 50%, respectively. To meet the increased demands in a sustainable manner remains a regional challenge.

Regional needs of the South/Southeast Asia Research Initiative (SARI) region that were identified during the recent LCLUC meeting in Burma in January 2016[13]. The next SARI meeting is in October 2016 at Ho Chi Min City (Saigon), Vietnam. More information on SARI can be found at *http://www.sari.umd.edu*.

The final initiative discussed was the Northern Eurasia Future Initiative (NEFI), a successor of the Northern Eurasia Earth Science Partnership Initiative (NEESPI). NEFI expands on the NEESPI program to answer the question: *What will the changes in this ecosystems dynamics and interactions mean for the societal well-being, activities, health, and strategic planning?* The NEFI White Paper can be found at *http://neespi.org/NEFI-WhitePaperDraft.pdf*.

Mapping Industrial Forests

This session provided an opportunity to the PIs from NASA's Research Opportunities in Space and Earth Sciences (ROSES) 2014 call to share their results with the community. The two mapping-effort foci in this session were algorithm development and regional application. Landsat data, with its global spatial coverage and rich historic archive, was a popular choice for all of the PIs. Of the four mapping methods discussed, two focused specifically on Landsat spectral and temporal information to develop forest disturbance maps. One such effort is the North America Forest Disturbance Product (NAFD-NEX), distributed through the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC) (*https://daac.ornl.gov*). In combination with ancillary datasets, these products can be used to develop higher-level products like a pre-Landsat-era forest-disturbance map, and species-specific plantation and harvest maps. Another effort used Landsat vegetation fractional cover to develop plantation type and rotation maps for Malaysia. A time-series analysis based on these products provided insight as to the dynamic teleconnections of economy and land-use relationships in that region. The fourth study proposed a three-step method to combine the information from Landsat and radar observations to map industrial plantations—a method that was able to successfully map rubber and oil-palm plantations in China.

[13] Please see "Summary of the 2016 Land-Cover Land-Use Change Regional Science Team Meeting" in the May-June 2016 issue of *The Earth Observer* [**Volume 28, Issue 3**, pp. 24-29].

International Partner Programs, Education, and Capacity Building

The last working session included presentations from representatives of the international partner programs. **Ioannis Manakos** [The Centre for Research and Technology, Hellas, Greece—*European Association of Remote Sensing Laboratories (EARSeL) Special Interest Group (SIG) Land Cover Chair*] discussed the opportunities and challenges in using EO data to monitor the condition of various ecosystems in Europe. To promote collaboration between NASA and European scientists on land-cover and land-use change research, the First Joint Workshop between the EARSeL SIG on Land Use and Land Cover (LU/LC) and the NASA LCLUC program was held in Berlin 2014. Following on its success, the second EARSeL SIG LU/LC and NASA LCLUC Joint Workshop was held in Prague, Czech Republic, on May 6-7, 2016, in conjunction with the ESA Living Planet Symposium held May 9-13, 2016.

Vladimir Gershenzon [ScanEx, Russia] discussed opportunities for future collaboration with ScanEx. The company provides a suite of near-real-time remote sensing applications and services for a variety of land-cover mapping applications, ranging from fire monitoring to industrial plantation mapping. It has been involved with the NASA-USGS International Mid-Decadal Global Land Survey (MDGLS) Project since 2006. For more information on ScanEx, visit *http://www.scanex.ru/en*.

SERVIR[14]—a joint venture between NASA and the U.S. Agency for International Development (USAID)—plays an important role in facilitating the use of EO, geographic information systems (GIS), and predictive models in regional decision-making. SERVIR is present in 4 global regions covering 37 nations. The SERVIR Hubs[15] work with regional governments to incorporate satellite-based information in end-user decision-making processes. SERVIR provides tools in key application areas like water, land cover and land use, natural disasters, agriculture, and biodiversity. This helps improve the lives and livelihoods of individuals, and ensures community safety.

[14] SERVIR is an acronym standing for the Spanish words meaning Mesoamerican Regional Visualization and Monitoring System; it also means "to serve."
[15] The hubs include the International Center for Integrated Mountain Development (ICIMOD), the Himalayan hub that covers Kathmandu and Nepal; the Regional Center for Mapping of Resources for Development (RCMRD), the Eastern and Southern African Hub, covering Nairobi, Kenya, and the Asian Disaster Preparedness Center ADPC, the Mekong hub, which covers Lower Mekong countries and is located in in Bangkok, Thailand.

The NASA-Michigan State University Professional Enhancement Awards Program started in 1998 and has been supported by the LCLUC program since its inception. The objective of this program is to provide outstanding students with support to attend the annual meetings of International Association for Landscape Ecology (IALE), thereby to establish and expand their professional networks, train future generations of scientists, and nurture future leaders in areas related to NASA's mission. Since its start, the very successful program has provided awards to 382 individuals from 140 institutions in 16 countries.

The Trans-Atlantic Training (TAT) and Capacity Building Activity is a joint venture of NASA and ESA to increase awareness among East European students about EO products available from NASA and ESA, expose them to scientific research while young, educate them about use of analytical tools, and motivate them to consider careers in Earth science. The activity is being coordinated by the LCLUC partner, Charles University, in Prague.

Meeting Wrap-Up

During the closing session, participants got a "tour" of the new LCLUC website from **Kristofer Lasko** [UMD]. **Garik Gutman** and **Chris Justice** then presided over a question-and-answer session on the LCLUC program, which, with further discussion, surfaced suggestions for future directions that included integration of land cover and land use change science across different regions, studying ecological and social connections through telecoupling frameworks, integration of land-cover products generated from the LCLUC program with datasets from other fields for use in land-use modeling, synthesis with other users with an increased social component, a need for cross-program research calls, and increased involvement of computer and social scientists in the program. The meeting successfully provided a platform for long-term and recently added LCLUC members to share their research ideas and experiences, discuss current LCLUC issues, and seek future directions for program advancement. ■

Two NASA Earth Scientists Among the 2016 Class of AGU Fellows

Since the American Geophysical Union (AGU) established its Fellows Program in 1962, the organization has elected outstanding members as Union Fellows. This special honor recognizes scientific eminence in the Earth and space sciences. It acknowledges Fellows for their remarkable contributions to their research fields, exceptional knowledge, and visionary leadership. Only 0.1% of AGU membership receives this recognition in any given year.

Claire Parkinson

This year, **Claire Parkinson** and **Brent Holben** [both at NASA's Goddard Space Flight Center] are among the 60 that have been chosen as AGU Fellows. The exceptional achievements, talents, and inspirations of these individuals will be recognized in a ceremony to be held December 14 at the 2016 AGU Fall Meeting in San Francisco, CA.

Brent Holben

The Earth Observer staff extends congratulations to Claire and Brent, along with all this year's other AGU Fellows.

2016 CLARREO Science Definition Team Meeting Summary

Amber Richards, Science Systems and Applications, Inc., amber.l.richards@nasa.gov
Rosemary Baize, NASA's Langley Research Center, rosemary.r.baize@nasa.gov
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Introduction

The ninth meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at the University of Michigan in Ann Arbor, MI, May 10-12, 2016. Over 30 investigators participated in the meeting, which comprised 32 presentations. Attendees were from NASA Headquarters (HQ), NASA's Langley Research Center (LaRC), NASA's Goddard Space Flight Center (GSFC), NASA/Jet Propulsion Laboratory (JPL), University of Wisconsin, Harvard University, University of Michigan, Lawrence Berkeley National Laboratory, Science Systems and Applications, Inc., McGill University (Canada), and Imperial College London (U.K.).

Attendees at the 2016 CLARREO SDT Meeting held in Ann Arbor, MI. **Photo credit:** University of Michigan

The meeting's objectives were to discuss progress made for the CLARREO Pathfinder (CPF) Mission, which is to fly onboard the International Space Station (ISS); receive reports on science, project, and engineering progress for the Infrared (IR), Reflected Solar (RS), and Radio Occultation (RO) instruments; discuss ongoing efforts in support of the 2017 National Research Council (NRC) Decadal Survey[1]; and relay the status of international collaboration efforts for CLARREO.

A few of the highlights from the presentations given at the meeting are summarized in this article. Many of the presentations can be viewed online at *http://clarreo.larc.nasa.gov/events-STM2016-05.html*.

Meeting Highlights

CLARREO Pathfinder Mission: Project Status

Bruce Wielicki [LaRC—*CLARREO Mission Scientist*] highlighted the progress made on the CPF mission since receiving Authority to Proceed from NASA HQ on April 11, 2016. This charge resulted in the decision to have the mission's first formal NASA review, the Mission Concept Review (MCR), scheduled for August 25, 2016, hosted at LaRC. He explained the differences between the Pathfinder mission and the original Tier 1 mission—see *CPF: A Risk Reduction Approach* on page 32. The purpose of CPF is to demonstrate essential measurement technologies for the RS measurements from the full CLARREO Tier 1 Decadal Survey Mission.

Wielicki reiterated that in the NASA FY2016 President's Budget request, funds were included for CLARREO Pathfinder, a technology demonstration to be launched to the ISS that will serve as a risk-reduction effort for the full 2007 Decadal Survey-recommended CLARREO mission. The guidance in the budget request stated that the CPF was to demonstrate the capability of essential measurement technologies for the full CLARREO mission, validate the high-accuracy calibration requirements needed for climate change studies, and initiate climate benchmark measurements. Ultimately, the objective of this pathfinder mission is to reduce risk and provide confidence that the full CLARREO mission can achieve the science goals. Wielecki emphasized, however, that this is not the full CLARREO mission; rather, it is a necessary step towards a successful full CLARREO mission, which has been in Pre-Phase A following a fully successful Mission Concept Review in November 2010.

CPF will demonstrate on-orbit, high-accuracy, SI-traceable calibration[2] and the ability to transfer that calibration to other on-orbit assets. The scope of the mission includes mission formulation, implementation, launch, and operation, and analysis of measurements from an RS spectrometer that will be launched to the ISS as early as 2020 and will likely be installed on the

[1] For more information on the 2017 Decadal Survey, visit *http://science.nasa.gov/earth-science/decadal-surveys*.

[2] SI traceability is a technique used for measurements that links an instrument's measurements to internationally-recognized measurement standards. The SI in SI traceability refers to the International System of Units (Système International d'Unités, in French). For more information, visit *http://clarreo.larc.nasa.gov/about-SITrace.html*.

ISS ExPRESS Logistics Carrier-1 (ELC-1)[3] in slot 3 or slot 8—see **Figure 1**. CPF is a Category 3/Class D Mission[4], with a nominal one-year mission life plus one year of science data analysis.

The presence of the RS spectrometer on CPF is to demonstrate:

- new solar attenuator technologies for on-orbit, higher-accuracy calibration;
- new gimbal-pointing ability to match the range of instrument scanning views for instruments like the Visible Infrared Imaging Radiometer Suite (VIIRS) and Clouds and the Earth's Radiant Energy System (CERES) instruments for reference intercalibration—see **Figure 2**;
- the CLARREO solar and lunar cross-calibration approach;
- that lunar radiance measurements and select ground scenes relative to the sun and moon can be acquired, enabling links to future instruments' measurements using the sun to calibrate the spectrometer relative to SI-traceable standards; and
- the highest-accuracy radiance and reflectance measurements that have been obtained from sensors on-orbit by providing the first on-orbit, SI-traceable reflectance with uncertainty <0.5% (k=2).

The CPF will benefit a future CLARREO mission through reducing risk; demonstrating high-accuracy intercalibration approaches; proving that high accuracy SI-traceability can be transferred to orbit; and showing that high accuracy intercalibration is achievable.

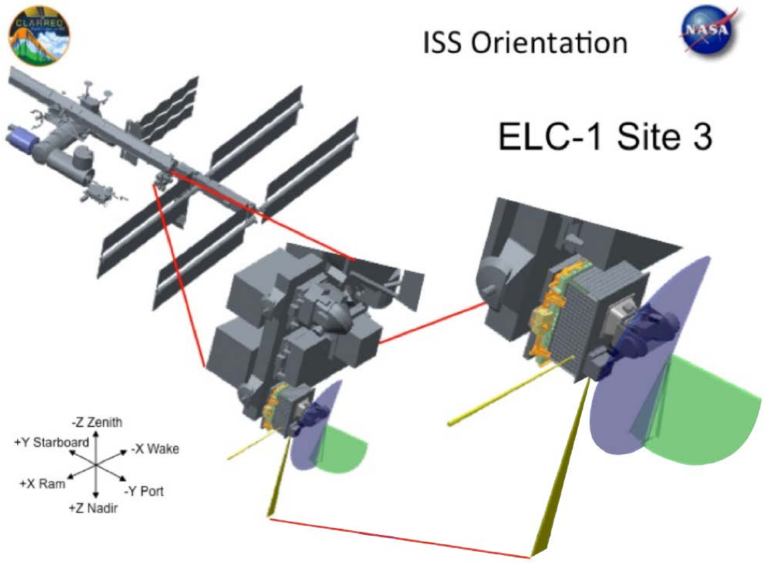

Figure 1: The CPF reflected solar (RS) spectrometer and its field of views are shown installed at Site 3 on the ISS ExPRESS Logistics Carrier-1 (ELC-1). **Image credit:** LaRC

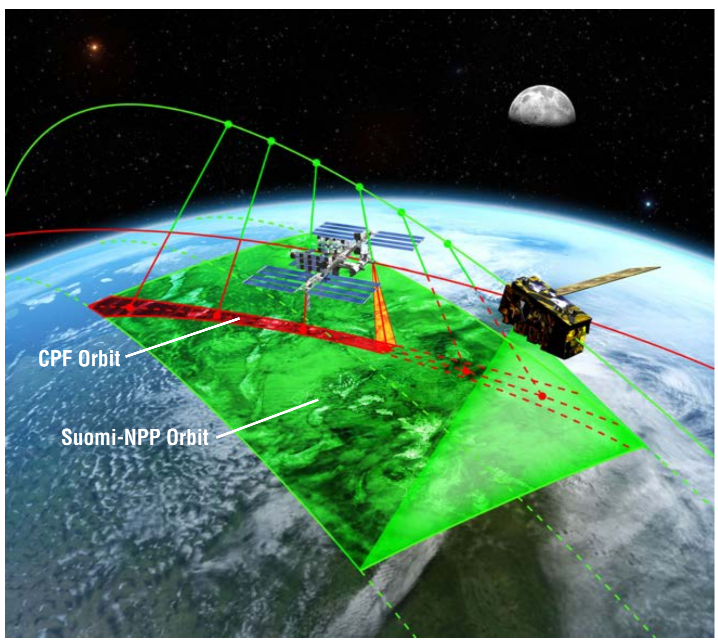

Figure 2: The CLARREO RS spectrometer onboard the ISS will conduct intercalibration of free-flyer satellites with instruments such as VIIRS and CERES onboard the Suomi National Polar-orbiting Partnership (NPP) satellite, pictured in the foreground. As the CPF orbit crosses that of a satellite such as Suomi-NPP with an operational target sensor (e.g., CERES, VIIRS), the CPF RS spectrometer collects data matched in time, space, and view angles to provide a reference inter-calibration standard for the target sensors. To match viewing angles with the target instrument, and to maximize the intercalibration sampling, the CPF RS spectrometer has a two-dimensional pointing capability with its roll-over azimuth gimbal. **Image credit**: LaRC

[3] For a more detailed discussion about this location, please refer to the March-April 2016 issue of *The Earth Observer* [**Volume 28, Issue 2**, p. 22].
[4] A *Class D* mission is considered low priority with regard to NASA's strategic plan; low-to-medium in terms of national priority; medium-to-low in complexity; with a lifetime of less than two years. Full details on risk classifications for NASA payloads can be found in *Appendix B* of the NASA Procedural Requirements (NPR) document 8795.4: *nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_0004_/N_PR_8705_0004_.pdf.*

CLARREO Pathfinder: A Risk-Reduction Approach

The purpose for the CLARREO Pathfinder (CPF) mission is to achieve risk reduction (as mentioned in the article) and to demonstrate the robustness of the calibration and verification systems, without expenditure of resources needed for a full mission. In keeping with this approach, CPF will not have an infrared instrument nor global positioning system (GPS) radio occultation (RO) [or Global Navigation Satellite System (GNSS)-RO observations[1]]. Furthermore, the short planned lifetime (one-to-two years) of the CPF will likely result in a record shorter than the five years of observations needed to begin the spectral fingerprint benchmarks expected from the CLARREO mission (i.e., Level-2 and Level-3 data products).

The CPF budget also puts limits on the data processing that will be possible. Only observations sufficient to demonstrate the calibration accuracy and intercalibration capability will be processed to Level-1, and no Level-2 or -3 processing is planned. The only Level-4 processing will be that required to demonstrate intercalibration for the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbitng Partnership (NPP) satellite and the future Joint Polar Satellite System (JPSS) missions, and the Clouds and the Earth's Radiant Energy System (CERES) instrument onboard Terra, Aqua, and Suomi NPP, and planned for JPSS-1. The threshold requirement for the CLARREO Pathfinder RS spectrometer includes intercalibration of the VIIRS and CERES instruments. The CLARREO Pathfinder will perform reference intercalibration for any of these bands for which there is a suitable signal-to-noise level and sufficient sampling of high-accuracy observations that are matched in time, space, and viewing angles to overcome the random error sources from instrument noise and imperfect data matching.

Lessons learned from CPF will produce benefits across many NASA Earth Science missions including improved laboratory calibration approaches; development and testing of innovative on-orbit SI-traceable methods; transfer calibration to sensors in operation at the time of the CPF mission; and an improved lunar irradiance standard.

[1] To clarify, there are GPS/RO measurements obtained on the ISS; however, the CPF will not obtain its own GPS/RO measurements.

Session Topic Highlights

As has been done at each of the CLARREO science team meetings held to date, members from the CLARREO Science Definition Team (SDT) gave presentations of progress made on their science studies. Provided below are summaries highlighting a few of those presentations.

Improved Radiative Transfer Code for Reflected Shortwave Spectra and Use in CLARREO Climate Model Observing System Simulation Experiments

Qiguang Yang [Science Systems and Applications, Inc.] delivered an update detailing progress on developing an ultrafast, high-accuracy Principal Component-based Radiative Transfer Model (PCRTM-SOLAR) for completing spectral calculations of multiple layers of clouds and aerosols. He discussed advances made from the previous PCRTM-SOLAR model and the earlier and much slower method of using the MODerate resolution atmospheric TRANsmission (MODTRAN) model.

Yang discussed earlier work in developing a general version of PCRTM-SOLAR for multilayer clouds and aerosols and a special version for one-layer clouds and aerosols. Although the speed of the general PCRTM-SOLAR is already hundreds of times faster than MODTRAN, even more speed is needed to simulate years of data for applications such as the CLARREO climate model observing system simulation experiments (OSSEs). The major advantage of the one-layer version is that it is orders of magnitude faster than the multiple-layer version. However, it cannot be used for multiple layers of cloud and aerosol conditions.

To develop a robust fast and high-accuracy radiative transfer model with multilayer clouds and aerosols, Yang and his team developed a new strategy to simulate the reflected solar spectrum that falls within the range of 300 to 2500 nm. The goal of this new strategy was to be able to conduct calculations much more quickly than previous PCRTM-SOLAR and MODTRAN models, as portrayed in **Table 1**. Note that the modified PCRTM-SOLAR model completes one spectrum calculation in approximately three seconds, while it takes MODTRAN some three hours to complete the same calculation. The spectral resolution in this case is one wavenumber. The method can be extended to reduce the computational burden for polarized radiative transfer models.

Table 1: Performance increases in PCRTM-SOLAR *vs.* MODTRAN processing

Method	Number of Frequencies	Speed-Up Factor
MODTRAN	259,029	1
PCRTM-SOLAR	1359	190
MODIFIED PCRTM-SOLAR	1359 (4 stream) + 35 (16 stream)	4560

HySICS Results from a High-Altitude Balloon Flight #2

Greg Kopp [Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder (LASP)] gave a summary of the performance results from the second of two high-altitude balloon flights of the Hyperspectral Imager for Climate Science (HySICS). This imaging spectrometer, which provides a potential design for the CLARREO mission, was designed and built by LASP through an Earth Science Technology Office (ESTO)-funded Instrument Incubator Project. These flights—which reached an altitude of 120,000 ft (37 km)—enabled above-the-atmosphere demonstration of the instrument's novel solar cross-calibration approach, by means of which hyperspectral images of Earth scenes can be radiometrically calibrated with SI traceability to a known spectral solar irradiance—see **Figure 3**. This approach should help achieve reflected-solar uncertainties of ~0.3% (k=2) needed by the CLARREO mission to establish climate-benchmark measurements and to intercalibrate other instruments, on orbit.

The HySICS operates over the spectral range 350 to 2300 nm with 6-nm resolution using a single focal-plane-array (FPA) to reduce instrument complexity, mass, cost, and volume. A four-mirror-anastigmat telescope images portions of the Earth, sun, or moon onto a spectrometer entrance slit defining a 10° cross-track field-of-view (FOV) with an instantaneous FOV of 0.02°. From CLARREO's nominal 600-km (~373-mi) orbit altitude, this FOV enables less than 100 km (62 mi) cross-track swath widths with along-track image-smear providing less than 0.5-km (~0.3-mi) spatial resolution from nadir-viewed ground scenes. Observations of the sun with the same optics enable the ground-scene radiances to be radiometrically calibrated from the independently known spectral solar-irradiance. These direct views of the sun and the resulting radiometric calibrations are enabled using attenuation methods providing intensity reduction of over 10^5 via a combination of precisely known geometric aperture-sizes and focal plan array integration times. During the August 2014 high-altitude balloon flight from Fort Sumner, NM, HySICS acquired bright Earth-scene reflectances with solar-weighted radiometric-uncertainties averaging as low as 0.4% (k=1) across the 500-to-1800-nm spectral range from single spatial-elements. Providing radiometric accuracies six times greater than those obtained by current on-orbit imagers, the HySICS shows promise to enable the high target accuracies from the future CLARREO reflected-solar instrument.

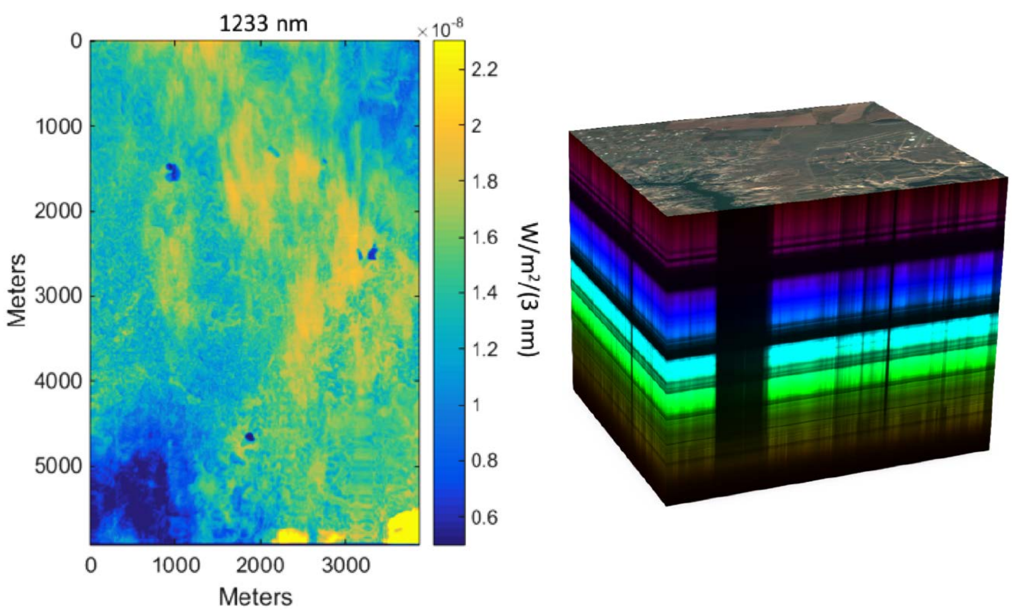

Figure 3: This HySICS-acquired image of the New Mexico desert [*left*] at 1233 nm has reflectances that are radiometrically referenced with SI traceability to the spectral solar irradiance *via* the instrument's novel solar cross-calibration techniques, as demonstrated on two high-altitude balloon flights. The color bar scale refers to reflected irradiance in the 1233 nm spectral band. The yellow values indicate that there is more reflected irradiance (more energy reflected) than over the blue areas in the figure. A full data cube [*right*] from another Earth scene shows the type of hyperspectral spatial (horizontal plane) and spectral (vertical direction) imagery such as HySICS provides. **Image credit:** LASP

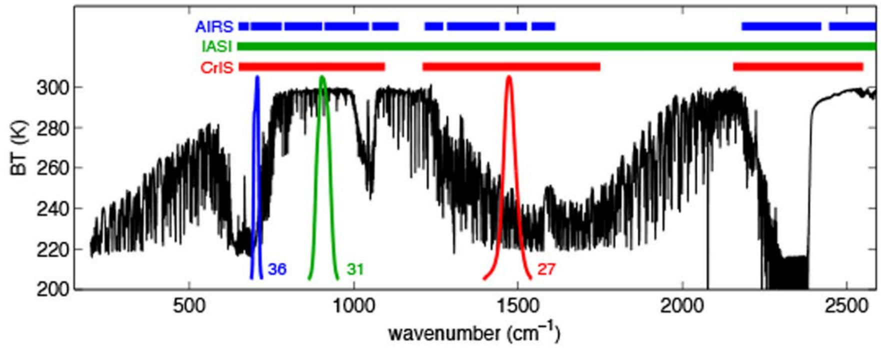

Figure 4: An example CLARREO brightness temperature spectrum (black) overlaid with spectral response functions of MODIS bands 27, 31, and 36. The spectral coverage of the Atmospheric Infrared Sounder (AIRS) is shown in blue, Infrared Atmospheric Sounding Interferometer (IASI) is shown in medium green, and Cross-track Infrared Sounder (CrIS) is shown in red. **Image credit:** UW Space Science and Engineering Center

Characterization of CLARREO's Ability to Serve as an Infrared Satellite Intercalibration Reference

Dave Tobin [University of Wisconsin (UW)-Space Science and Engineering Center] discussed the results of his recent paper published in *Journal of Geophysical Research–Atmospheres*[5] that describes the characterization of the CLARREO IR spectrometer and its ability to serve as a satellite intercalibration reference. UW's Absolute Radiance Interferometer (ARI) prototype has demonstrated better than 0.1 K 3σ accuracy, at least three-to-five times better than current IR sounders. This is significant because providing a highly accurate intercalibration reference (for both IR and RS sensors) is a primary objective of the CLARREO mission and ARI has demonstrated accuracy sufficient to meet this objective. Tobin described a study that simulates intercalibration sampling errors using Moderate Resolution Imaging Spectroradiometer (MODIS) images from bands 36 (14.2 micron CO_2), 31 (11 micron window), and 27 (6.7 micron water vapor)—as shown in **Figure 4**.

Tobin's results present a new infrared intercalibration methodology that minimizes the intercalibration uncertainties and provides uncertainty estimates resulting from the scene variability and instrument noise. The results are encouraging and suggest that biases between CLARREO and sounder observations can be determined with low uncertainty and with high time frequency during a CLARREO mission. Of particular note is that the three-sigma intercalibration uncertainty is less than 0.1 K for channels at infrared window wavelengths using two months of accumulated overpass data, and for more-absorbing channels with less scene variability, the uncertainties are less than 50 mK.

Next Steps and Moving Forward

The meeting concluded with a discussion of the next steps that the CLARREO SDT needs to take to continue moving forward with the full CLARREO mission (IR plus RS instruments) and with the CPF mission (RS only). For the full CLARREO mission, the group discussed the need for a continued effort to advance relevant science by: publishing key journal papers on CLARREO orbit sampling; conducting IR and RS intercalibration sampling; using calibration methods and accuracy levels developed in the Instrument Incubator Program and Calibration Demonstration System; and assessing the economic value of higher accuracy climate observation missions—most notably, CLARREO. At the close of the meeting the group declared that they would like to host discussions with members of the observation and climate modeling communities to discuss strategic planning efforts for observations needed to improve climate models.

The next CLARREO SDT Meeting is scheduled to take place November 29 through December 1 at the National Institute of Aerospace in Hampton, VA. ■

[5] To access the paper, visit *http://onlinelibrary.wiley.com/doi/10.1002/2016JD024770/abstract*.

NASA Releases First Map of Thawed Areas under Greenland's Ice Sheet

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

NASA researchers have helped produce the first map showing what parts of the bottom of the massive Greenland Ice Sheet are thawed—key information in better predicting how the ice sheet will react to a warming climate.

Greenland's thick ice sheet insulates the bedrock below from the cold temperatures at the surface. Because the ice bottom is slowly warmed by heat coming from the depths of the Earth, the bottom of the ice sheet is often tens of degrees warmer than at the top. Knowing whether Greenland's ice lies on wet, slippery ground or is anchored to dry, frozen bedrock is essential for predicting how this ice will flow in the future, but scientists have very few direct observations of the thermal conditions beneath the ice sheet, obtained through fewer than two dozen boreholes that have reached the bottom of the sheet. Now, a new study synthesizes several methods to infer the Greenland Ice Sheet's *basal thermal state*—whether the bottom of the ice is melted or not—leading to the first map that identifies frozen and thawed areas across the whole ice sheet.

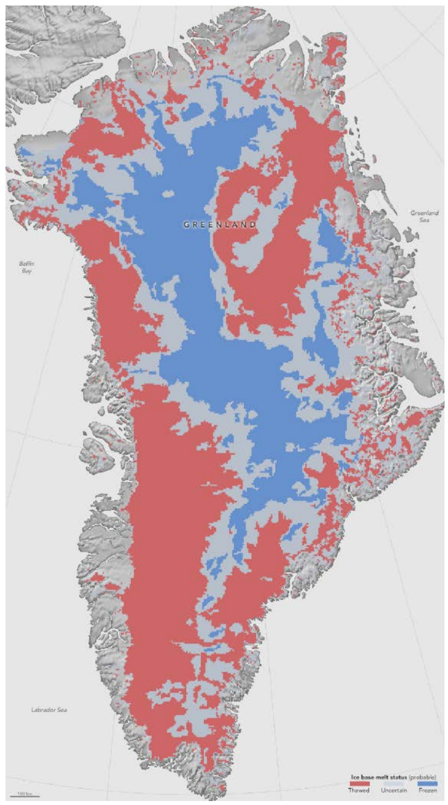

Figure. This first-of-a-kind map, showing which parts of the bottom of the Greenland Ice Sheet are likely thawed (red), frozen (blue) or still uncertain (gray), will help scientists better predict how the ice will flow in a warming climate. **Image credit:** Jesse Allen [NASA's Earth Observatory]

"We're ultimately interested in understanding how the ice sheet flows and how it will behave in the future," said the study's lead author, **Joe MacGregor** [NASA's Goddard Space Flight Center—*Glaciologist*]. "If the ice at its bottom is at the melting point temperature, or thawed, then there could be enough liquid water there for the ice to flow faster and affect how quickly it responds to climate change."

For this study, published in July 2016 in the *Journal of Geophysical Research—Earth Surface*, MacGregor's team combined four different approaches to investigate the basal thermal state. First, they examined results from eight recent computer models of the ice sheet, which predict bottom temperatures. Second, they studied the layers that compose the ice sheet itself, which are detected by radars onboard NASA's Operation IceBridge aircraft, and indicate where the bottom of the ice is melting rapidly. Third, they looked at where the ice surface speed measured by satellites exceeds its "speed limit," the maximum velocity at which the ice could flow and still be frozen to the rock beneath it. Fourth, they studied imagery from the Moderate Resolution Imaging Spectroradiometers on NASA's Terra and Aqua satellites, looking for rugged surface terrain that is usually indicative of ice sliding over a thawed bed.

"Each of these methods has strengths and weaknesses. Considering just one isn't enough. By combining them, we produced the first large-scale assessment of Greenland's basal thermal state," MacGregor said.

For each method, MacGregor's team looked for areas where the technique confidently inferred that the bed of Greenland's ice sheet was thawed or frozen. They then looked at the places where these methods agreed and classified them as likely thawed or likely frozen. The zones where there was insufficient data or the methods disagreed, they classified as uncertain.

From this synthesis, MacGregor and his colleagues determined that the bed is likely thawed under Greenland's southwestern and northeastern ice drainages, while it's frozen in the interior and west of the ice sheet's central ice divide. For a third of the Greenland ice sheet, there are not enough data available to determine its basal thermal state.

MacGregor said the team's map—see **Figure**—is just one step in fully assessing the thermal state of the bottom of Greenland's ice sheet.

"I call this the 'piñata,' because it's a first assessment that is bound to get beat up by other groups as techniques improve or new data are introduced. But that still makes our effort essential, because prior to our study, we had little to pick on," MacGregor said. ■

NASA Flies to Africa to Study Climate Effects of Smoke on Clouds

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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.

As of this writing, a group of NASA scientists and two research aircraft were among the individuals and instrumentation deployed in a unique "natural laboratory" off the Atlantic coast of southwest Africa to study a major unknown in climate projection. NASA's Observations of Aerosols Above Clouds and their Interactions (ORACLES) is a collaborative research effort that involves more than 100 scientists from 5 NASA centers, 5 national laboratories, 10 U.S. universities, and 5 African research institutions. It's a multiyear NASA Earth Venture suborbital investigation[1] to probe Earth system processes that are not completely understood. These flights from Namibia are the first of several planned field campaigns for the mission.

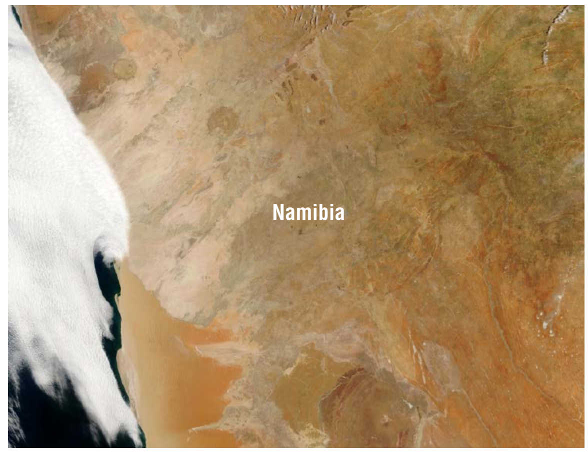
The coast of Namibia is one of three places on Earth with persistent low-level clouds, and the only such location with a steady supply of tiny aerosol particles in the form of smoke from inland fires that mix with the clouds—see **Figure 1**. ORACLES will observe and measure how these particles interact with clouds and change their ability to warm or cool the planet.

"This is the perfect natural laboratory to study aerosol-cloud interactions, which are some of the largest uncertainties in the prediction of future climate," said **Jens Redemann** [NASA's Ames Research Center (ARC)—*ORACLES Principal Investigator (PI)*].

Some aerosols, such as dust and sea salt, have a natural origin. But others, such as soot and smoke released by set fires and industrial activities, are the result of human activities. Once aerosols enter the atmosphere, they can cause either a warming or cooling effect.

"Human activities currently are estimated to be responsible for perhaps half of all the aerosol particles in the atmosphere," said **Robert Wood** [University of Washington in Seattle—*ORACLES Deputy PI*]. "Smoke particles both reflect sunlight back to space, thus cooling the Earth, and absorb sunlight, which has the opposite effect of warming the Earth. When aerosols encounter clouds, they also change the properties of the clouds they are ingested into."

[1] ORACLES was one of the missions selected on the EVS-2 Announcement of Opportunity. The others are listed at *http://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder*. Links to each individual mission can be found there.



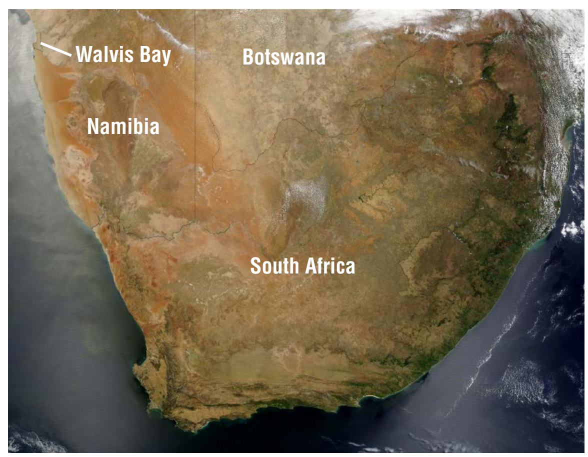


Figure 1. The Namibian coast of southwest Africa is a unique "natural laboratory" with both persistent low-level clouds and a steady supply of tiny aerosol particles in the form of smoke from inland fires that mix with the clouds—see clouds off Namibia's coast [*left*] in the top image. NASA's ORACLES airborne science campaign is operating from Walvis Bay, Namibia, located in the top left corner of bottom image. **Image credit:** NASA

Understanding which effect is dominant, and under what conditions, is essential for improving the regional and global computer models that predict what may occur with future climate change. Changes in the properties of the cloud layer caused by aerosols could also have an effect on regional coastal fisheries by altering the amount of sunlight reaching the ocean surface, which drives currents and ocean upwelling.

The initially separate cloud and aerosol layers off the Namibian coast are relatively stable. As the cloud

Figure 3. NASA's high-altitude ER-2 aircraft will make flights during ORACLES at 65,000 feet (~20 km) with instruments that make measurements similar to those acquired from satellites. **Image credit:** NASA

layers thicken away from shore like a wedge, it gradually mixes with the aerosol layer. The result is a range of steadily changing conditions that allow the ORACLES science team to probe several different types of cloud-aerosol interactions.

The ORACLES field campaign is based out of Walvis Bay, Namibia (see Figure 1), where faculty and students from Namibian universities will be working alongside the ORACLES team. The project team has built new relationships with their African colleagues, in particular, the Namibia University of Science and Technology in Windhoek. University personnel provide support logistics for ORACLES field work and will collaborate in data analysis and modeling. The Gobabeb Research and Training Centre in the Namib Desert, which previously has worked with NASA using the desert as an analog for the surface of other planets, is providing ground-based remote sensing of the atmosphere.

"Science is a great unifier," said **Bernadette Squire Luna** [ARC—*ORACLES Project Manager*]. "We are building relationships with Namibian scientists that will outlast this project and will lead to yet more science and more interactions. We're connecting our countries in a very grassroots way."

NASA's P-3 aircraft, managed by NASA's Wallops Flight Facility, carries five remote sensing instruments and flies through the cloud and aerosol layers at up to 20,000 ft (~6 km) to gather direct measurements from more than a dozen cloud and aerosol probes attached to the wings and inlets on the windows. NASA's ER-2 aircraft (shown in **Figure 3**), managed by NASA's Armstrong Flight Research Center in Edwards, CA, will fly at 65,000 ft (~20 km) with instruments that make measurements similar to those acquired from satellites.

ORACLES flights will complement and validate current satellite observations of aerosols and clouds, and test instruments that may fly on future satellites, by making detailed observations that are impossible to make from space with current capabilities.

Unlike a satellite, which generally gets one pass per day over a certain location, both aircraft will be able to sample clouds and aerosols throughout the day over the entire study area to see how they evolve. Together, data from the two aircraft will provide a comprehensive picture of how aerosols behave in the presence of clouds—and how aerosols directly or indirectly change how clouds behave. ■

in the news

Arctic Sea Ice Annual Minimum Ties Second Lowest on Record

Maria-José Viñas, NASA's Goddard Space Flight Center, maria-jose.vinasgarcia@nasa.gov

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

Arctic sea ice appeared to have reached its annual lowest extent on September 10, 2016, reports NASA and the NASA-supported National Snow and Ice Data Center (NSIDC) at the University of Colorado at Boulder.

An analysis of satellite data showed that at 1.60 million mi^2 (4.14 million km^2), the 2016 Arctic sea ice minimum extent is effectively tied with 2007 for the second lowest yearly minimum in the satellite record. Since satellites began monitoring sea ice in 1978, researchers have observed a steep decline in the average extent of Arctic sea ice for every month of the year.

The sea ice cover of the Arctic Ocean and surrounding seas helps regulate the planet's temperature, influences the circulation of the atmosphere and ocean, and impacts Arctic communities and ecosystems. Arctic sea ice shrinks every year during Northern Hemisphere spring and summer months until it reaches its minimum yearly extent. Sea ice regrows during the frigid fall and winter months, when the sun is below the horizon in the Arctic.

In summer 2016, the melt of Arctic sea ice surprised scientists by changing pace several times. The melt season began with a record low yearly maximum extent in March and a rapid ice loss through May. But in June and July, low atmospheric pressures and cloudy skies slowed down the melt. Then, after two large storms went across the Arctic basin in August, sea ice melt picked up speed through early September.

"It's pretty remarkable that this year's sea ice minimum extent ended up the second lowest, after how the melt progressed in June and July," said **Walt Meier**, [NASA's Goddard Space Flight Center (GSFC)—*Sea Ice Scientist*]. "June and July are usually key months for melt because that's when you have 24 hours a day of sunlight—and this year we lost melt momentum during those two months."

But in August, two very strong cyclones crossed the Arctic Ocean along the Siberian coast. These storms didn't have as much of an immediate impact on the sea ice as the great cyclone of 2012, but in late August and early September there was "a pretty fast ice loss in the Chukchi and Beaufort seas that might be a delayed effect from the storms," Meier said.

Meier also said that decades ago, the melt season would slow down by the middle of August, when the sun starts setting in the Arctic.

"In the past, we had this remaining sea ice pack that was mostly thick, old ice. But now everything is more jumbled up, which makes it less resistant to melt, so

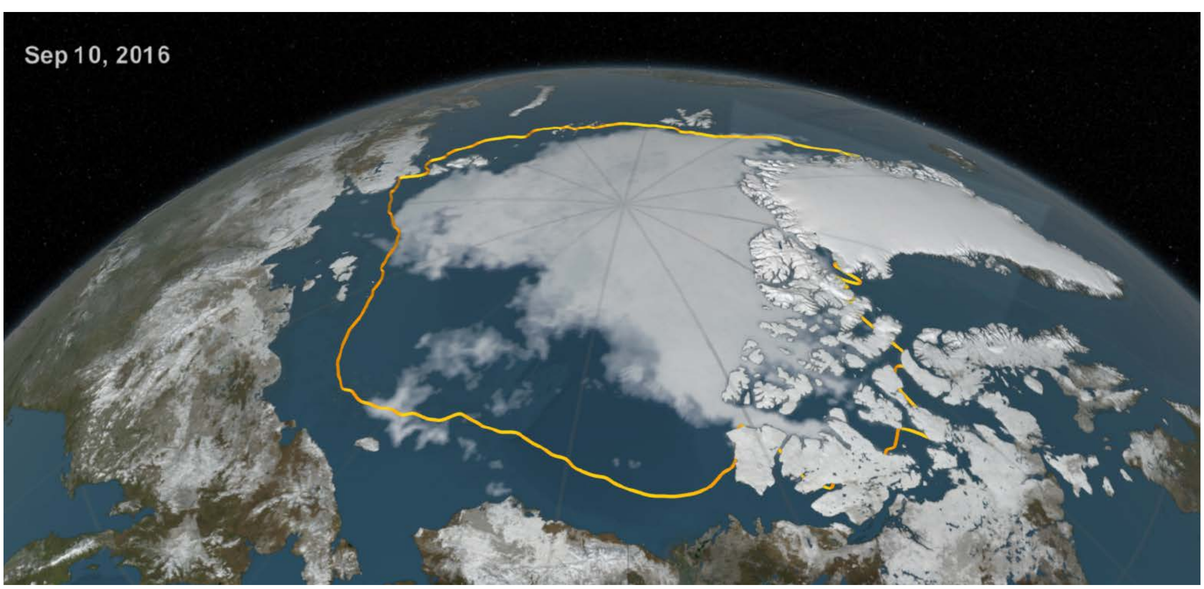


Figure. The 2016 Arctic sea ice summertime minimum, reached on September 10, is 911,000 mi^2 below the 1981-2010 average minimum sea ice extent, shown here as a thin line. **Image credit:** NASA's Goddard Space Flight Center, Scientific Visualization Studio.

even late in the season you can get weather conditions that give it a final kick," Meier said.

Arctic sea ice cover has not fared well during other months of the year either. A recently published study that ranked 37 years of monthly sea ice extents in the Arctic and Antarctic found that there has not been a record high in Arctic sea ice extents in any month since 1986. During that same time period, there have been 75 new record lows.

"When you think of the temperature records, it's common to hear the statement that even when temperatures are increasing, you do expect a record cold here or there every once in a while," said **Claire Parkinson** [GSFC—*Senior Climate Scientist*], main author of the study. "To think that in this record of Arctic sea ice that goes back to the late 1970s, since 1986 there hasn't been a single record high in any month of the year, and yet, over that same period, there have been 75 record lows, it's just an incredible contrast."

"It is definitely not just September that's losing sea ice. The record makes it clear that the ice is not rebounding to where it used to be, even in the midst of the winter," Parkinson said.

Parkinson's analysis, which spans from 1979 to 2015, found that in the Antarctic, where the trends are toward more rather than less sea ice, there have only been six record monthly record lows after 1986, and 45 record highs.

"The Antarctic numbers are pretty amazing, except when you compare them with the Arctic numbers, which are much more amazing," Parkinson said. ■

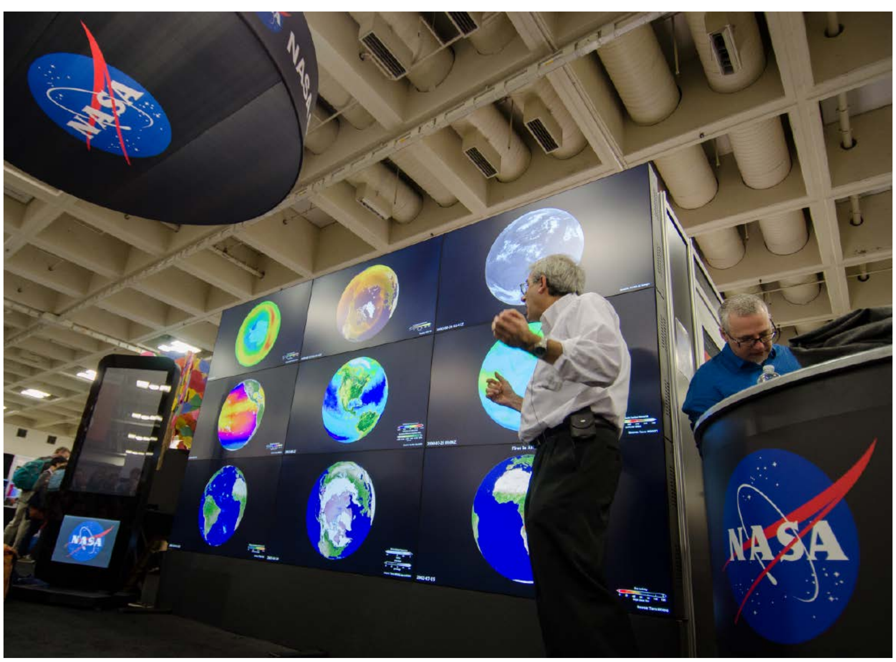
Storytelling and More: NASA Science at the 2016 AGU Fall Meeting

Please plan to visit the NASA booth (# 535) during the American Geophysical Union's (AGU) forty-ninth annual Fall Meeting! This year's exhibit hall will open on Monday, December 12, and will continue through Friday, December 16.

NASA Science has a story to tell and, at AGU, you can be part of it. Visit our nine-screen Hyperwall, where scientists will cover a diverse range of topics including Earth science, planetary science, and heliophysics. The exhibit will also feature a wide range of science demonstrations, printed material, and tutorials on various data tools and services.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*http://eospso.nasa.gov*—in early December.

We hope to see you in San Francisco!



Michael Freilich [NASA Headquarters—*Earth Science Division Director*] delivers a NASA Earth Science presentation using the dynamic Hyperwall display during the 2015 AGU Fall Meeting. **Image credit:** NASA

NASA Earth Science in the News

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

NOAA, NASA Support Flood Response with Data, August 22, *gcn.com*. A government response to a flood that affects populations typically involves operational assistance from the Federal Emergency Management Agency (FEMA) and the National Guard. But as data streams become faster and more efficient, research agencies like NASA and the National Oceanic and Atmospheric Administration (NOAA) are also supporting those operations—with real-time data and analysis. NASA has created a rapid-response team that provides data and analysis to organizations like FEMA; for example, it has responded with satellite mapping of the recent Nepalese earthquake and data on rainfall for the recent deadly flooding in Louisiana. **Dalia Kirschbaum** [NASA's Goddard Space Flight Center (GSFC)—*Disaster Response Coordinator*] said the rapid response team has only been in existence for about a year, and it is still trying to determine its role in disasters such as the Louisiana flood. This means talking to FEMA every day during an event that both organizations are responding to; these conversations give responders a better understanding of the data and products that NASA can provide. Much of what NASA offers during a flooding event is inundation data: *How much rain fell? Where did it fall?* Key to productively using the data in a timely manner is that it be provided in an accessible format, Kirschbaum said, which can mean combining the data with geospatial information or other models.

How Hot Was July? Hotter than Ever, August 22, *nytimes.com*. Continuing a string of global heat records, July 2016 was the hottest July since adequate record-keeping began in 1880, NASA said. But the agency added a wrinkle: This July was the hottest of *any* month ever recorded. The recent El Niño event, in which sea surface temperatures rise in the eastern equatorial Pacific, contributed to the record, as did overall warming linked to greenhouse gas emissions. As the recent El Niño has now ended, forecasters wonder if there will be a transition to La Niña conditions, in which sea surface temperatures fall below normal. If that happens, while next year may still be hot, temperatures may stay below this year's records.

Melting Arctic Ice Is the "New Normal," NASA says, August 23, *cbsnews.com*. It is by now a familiar headline—the Arctic sea ice is melting at increasingly rapid rates. While this year's melt season started at an alarming pace, with a record low maximum ice extent in March, the melt slowed down by June. Although this summer won't be setting a melt record, NASA scientists now say we have to consider this kind of melt the new normal. "A decade ago, this year's sea ice extent would have set a new record low and by a fair amount. Now, we're kind of used to these low levels of sea ice—it's the 'new normal'," **Walt Meier** [GSFC—*Sea Ice Scientist*] said in a press release. Meier stressed that while we won't be seeing a record low for the year, "the sea ice is not showing any kind of recovery." The melt was not as extreme this year because the Arctic weather conditions overall were not as extreme as they have been in recent years.

NASA Showcasing the National Park Service from Space in Honor of Its 100th Birthday, August 26, *scienceworldreport.com*. The U.S. National Park Service (NPS) celebrated its 100th birthday on August 25. In honor of its centennial, NASA unveiled heretofore unseen views of some National Parks—from an off-planet perspective! The NPS was founded in 1916 to preserve the unimpaired natural and cultural resources and values of the National Park System for the education, enjoyment, and inspiration of people not only from the U.S., but visitors from all across the globe. To view the collection of images—featured by NASA's Earth Observatory—visit *http://earthobservatory.nasa.gov/Features/NationalParks*.

Surface Water Shifting around Earth, August 25, *bbc.com*. Scientists have used satellite images to study how the water on Earth's surface has changed over the past 30 years. They found that 115,000 km^2 (~44,000 mi^2) of land is now covered in water and 173,000 km^2 (~67,000 mi^2) of water has now become land. The largest increase in water has been on the Tibetan Plateau, while the Aral Sea has been the biggest conversion of water to land, although many coastal areas have also changed significantly. The research, carried out by the Deltares Research Institute in the Netherlands, is published in the journal *Nature Climate Change*. The researchers analyzed satellite images recorded by Landsat satellites, which have observed Earth for decades. They were able to monitor changes in Earth's surface at a resolution of 30 m (~98 ft).

NASA Is Studying Alaska's Creepy Bubbling Lakes from Space, August 28, *motherboard.vice.com*. Every month of 2016 has been the hottest on record, respectively, and this uptick in temperature is sure to have wide-ranging consequences, globally. One of the weirdest and least understood of these climate-related side effects is that Arctic boreal lakes are boiling with methane bubbles. Indeed, some of these areas are such rich producers of methane that scientists can ignite plumes of the lake's escaped gas. These gassy lakes are created by thawing *permafrost*—soil that normally remains frozen all year. But warmer temperatures have caused more permafrost to melt, causing the ground around it to collapse into water-filled sinkholes called *thermokarst lakes*. Carbon that has been stored in the permafrost for millennia is released in this process, and is then metabolized by the microbial community in the lakebeds. The byproduct is methane, which bubbles to the surface. As lakes freeze again in the winter, these methane bubbles accumulate underneath the surface ice, only to be released as seasonal temperatures rise. Scientists have been studying this phenomenon on the ground for years, but now NASA is pioneering some from-space views with the Arctic Boreal Vulnerability Experiment (ABoVE). The idea is to scale up the measurements made by ground crews with more-focused satellite observations of Alaska's changing permafrost landscape. "We're trying to establish the amount of methane that's released from these lakes," said **Prajna Lindgren** [University of Alaska, Fairbanks—*Postdoctoral Researcher*] in a NASA project blog post.

NASA: Earth Is Warming at a Pace 'Unprecedented in 1000 Years', August 30, *theguardian.com*. The planet is warming at a pace not experienced within the past 1000 years, making it "very unlikely" that the world will stay within a temperature limit agreed by nations just last year as being critical for the health of existing biosystems, according to NASA's top climate scientist. This year has already seen scorching heat around the world, with the average global temperature peaking at 1.38 °C (~2.5 °F) above levels experienced in the nineteenth century, perilously close to the "healthy" 1.5 °C (2.7 °F) limit agreed to in the recent landmark Paris climate accord. July was the warmest month since modern record keeping began in 1880, with each month since October 2015 setting a new high mark for temperature—see **Figure**. But NASA said that records of temperature that go back far further, taken via analysis of ice cores and sediments, suggest that the warming of recent decades is out of step with any period over the past millennium. "In the last 30 years we've really moved into exceptional territory," **Gavin Schmidt** [NASA's Goddard Institute for Space Studies (GISS)—*Director*] said. "It's unprecedented in 1,000 years. There's no period that has the trend seen in the twentieth century in terms of the inclination (of temperatures)." He continued, saying, "Maintaining temperatures below the 1.5 °C guardrail requires significant and very rapid cuts in carbon dioxide emissions or coordinated geo-engineering. That is very unlikely. We are not even yet making emissions cuts commensurate with keeping warming below 2 °C (3.6 °F)." Schmidt repeated his previous prediction that there is a 99% chance that 2016 will be the warmest year on record, with around 20% of the heat attributed to a strong El Niño climatic event. The year 2015 is currently the warmest year on record, beating the earlier landmark set in 2014.

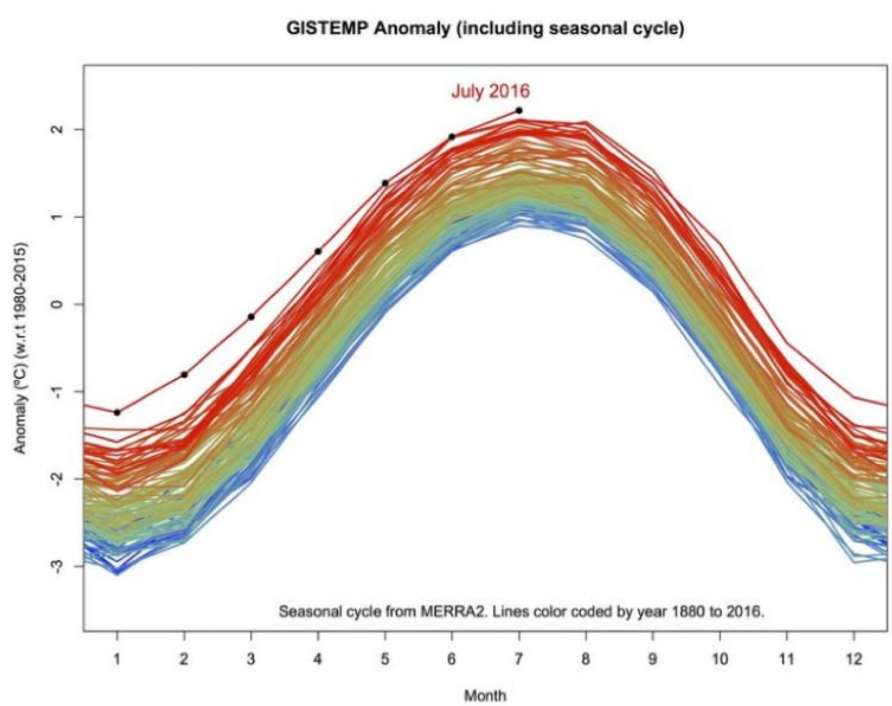


Figure. The monthly analysis by the GISS team is assembled from publicly available data acquired by about 6300 meteorological stations around the world, ship- and buoy-based instruments measuring sea surface temperature, and Antarctic research stations. The modern global temperature record begins around 1880 because previous observations didn't cover enough of the planet. **Image credit:** Gavin Schmidt [GISS]

*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

These items were obtained from *http://www.nasa.gov/audience/foreducators*. While in some cases the information has been modified to match the style of The Earth Observer, the intent is to reprint it with its original form largely intact.

GLOBE Observer: New Citizen Science Opportunity

Want to be a citizen Earth scientist and directly contribute to studies of our home planet? All you need is a smartphone, access to the outdoors, and the new *GLOBE Observer* app.

Now available for Apple and Android phones, the app is an initiative of the Global Learning and Observations to Benefit the Environment (GLOBE) program, a science and education effort that—for over two decades—has enabled schools and students in more than 110 countries to investigate their local environment and put their observations in a global context.

The initial release of the app allows users to collect observations of clouds, which are critical parts of the global climate system. Additional types of observations are planned for GLOBE Observer, with topics ranging from exploring land cover types and uses to identifying mosquito larvae—important in understanding the spread of disease. The observations encourage the public to be more keenly observant of their outdoor environment and perform their own scientific field investigations.

Here's an example of how it works for cloud investigations: The GLOBE Observer team challenges citizen scientists to collect cloud observations that coincide with a cloud-observing satellite passing over their location—which they will be told about through the GLOBE Observer app. Users can also view daily maps of the satellite's path by following GLOBE Observer on Facebook or Twitter.

An Internet connection is not needed while making GLOBE Observer cloud observations—but will be needed later—as data can be stored in the phone and then later submitted when an Internet connection is available. All photo submissions are reviewed before being displayed on the GLOBE site.

For more information on GLOBE Observer and how to download it, visit *http://observer.globe.gov*.

Sign Up for NASA Education 'Science WOW!' Weekly Email Newsletter

Are you a science educator or interested in science education? Sign up for the NASA Education *Science WOW!* mailing list. Receive an email with NASA's latest science education offerings, delivered "Weekly on Wednesdays," or "*WOW!*"

Just as scientific activities start with a question, so too does Science WOW! Each week's item kicks off with a science question and a link to where you can find the answer. Science WOW! also highlights a particularly interesting science education tool each week. These featured resources include NASA apps, interactive games, three-dimensional (3-D) printing templates, and more!

But that's not all: Science WOW! delivers—right to your inbox—the latest science education opportunities offered by NASA. It's an easy way to keep up with the latest in professional development webinars, student contests, workshops, lectures, and other relevant activities.

To be added to the distribution list, register your email address at *http://www.nasa.gov/education/sciencewow*.

Call for Submissions—NASA Announcement for High Impact/Broad Implementation STEM Education Partnerships

The NASA Headquarters Office of Education, in cooperation with the agency's four mission directorates, nine center education offices, and the Jet Propulsion Laboratory education office, announces this competition to improve science, technology, engineering, and mathematics (STEM) education.

NASA Education seeks to partner with eligible domestic or international organizations on a no-exchange-of-funds basis to reach wider and more diverse audiences and to achieve mutually beneficial objectives. The announcement places a priority on collaborations involving the following: digital learning, engaging underrepresented groups in STEM activities, NASA-themed STEM challenges, and youth-serving organizations. NASA also is receptive to other creative ideas including, for example, investigations in or application of science, technology, engineering, arts, mathematics and design ("STEAMD"), or activities culturally relevant to or focused on populations underrepresented in STEM careers, such as women, ethnic minorities, and persons with disabilities.

Submission deadline: December 31, 2017

For more information about this opportunity, visit NSPIRES at *http://go.nasa.gov/1RZwWCi*. Responses must be submitted electronically at *http://nspires.nasaprs.com*. ■

EOS Science Calendar

October 18–21, 2016
CERES Science Team Meeting,
Reading, U.K.
http://ceres.larc.nasa.gov

October 31–November 4, 2016
Ocean Surface Topography Science Team Meeting,
La Rochelle, France.

November 29–December 1, 2016
CLARREO Science Definition Team Meeting,
Hampton, VA

Global Change Calendar

October 18–21, 2016
Earth Radiation Budget Workshop,
Reading, U.K. [Convened by GERB, ScaRaB Megha-Tropiques, and CERES STMs]
http://www.ecmwf.int/en/learning/workshops-and-seminars/earth-radiation-budget-workshop

November 7–18, 2016
22nd Session of the Conference of the Parties (COP 22),
Marrakesh, Morocco.
http://climate-l.iisd.org/events/unfccc-cop-22

December 12–16, 2016
American Geophysical Union Fall Meeting,
San Francisco, CA.
http://fallmeeting.agu.org/2016

April 18–21, 2017
A-Train Symposium,
Pasadena, CA.
https://espo.nasa.gov/a-train_2017/content/A-Train_2017

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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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