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Editor's Corner

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We are happy to report that the Deep Space Climate Observatory (DSCOVR[1]) spacecraft was successfully inserted into its orbit at the first Earth-Sun Lagrange point (L1)—about 1.5 million kilometers (930,000 miles) from Earth—on June 7, 2015. At this time, all instruments are undergoing test and in-flight calibrations during the commissioning phase. While NOAA has responsibility for the mission's three space weather instruments, DSCOVR includes two NASA Earth-observing instruments: the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR). EPIC has obtained an initial series of Earth images in all 10 narrow band filter positions (wavelength range from 317 to 780 nm). Tests currently are being performed to determine optimum exposure times. The first lunar calibration test was performed on July 2, 2015, corresponding to a full moon as seen from Earth. EPIC's observations provide a unique perspective for science, with products being developed to provide ozone, sulfur dioxide, aerosol, cloud height and vegetation properties. In addition to the science products, a full disk true color "Blue Marble" image from sunrise to sunset will be produced about every two hours. EPIC and NISTAR data will be available from NASA's Langley Research Center's Atmospheric Sciences Data Center archive after the raw data have been calibrated and officially released by the project. Congratulations to the entire DSCOVR team and best wishes for this ground-breaking mission.

[1] The DSCOVR mission is a partnership between NASA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Air Force.

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On July 16, 2015, NASA's Earth Polychromatic Imaging Camera (EPIC) onboard DSCOVR returned its first view of the entire sunlit side of Earth. The image shows the effects of sunlight scattered by air molecules, giving the image a characteristic bluish tint. **Image credit:** NASA

In This Issue

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

In recent issues of *The Earth Observer*, we have been following the progress of five new missions that launched within a year—between February 2014 and January 2015: the GPM Core Observatory, OCO-2, ISS-CATS, ISS-RapidScat, and SMAP. The first four missions continue to operate well as of this writing. However, on July 7, at about 2:16 PM PDT, the SMAP radar halted its transmissions. All other components of the spacecraft continue to operate normally—including the radiometer instrument that continues to collect science data. An anomaly team has been convened at NASA JPL and is reviewing observatory and instrument telemetry and science data.

In the meantime, *beta* versions of the SMAP Level-1 instrument data (i.e., microwave brightness temperature and radar backscatter) will be released to NASA's Distributed Active Archive Centers (DAACs) and will be publicly available on August 3, 2015. *Beta* versions of the SMAP higher-level products (i.e., soil moisture and freeze/thaw state) will be released to the public at the beginning of November.

It is unfortunate to have to report that the SAC-D observatory that carried NASA's Aquarius instrument experienced a significant hardware failure and ceased operation on June 8, 2015. Aquarius/SAC-D is a partnership between CONAE [the Argentine space agency], which provided the spacecraft bus (SAC-D) as well as several instruments, and NASA, which provided the primary instrument, Aquarius. On June 7, failure of the Remote Terminal Unit (RTU) that provided power to the spacecraft attitude control system caused a loss of control and communication with the spacecraft. Aquarius itself was functioning well and, in fact, operated without significant issues since being turned on August 25, 2011.

Aquarius was a pathfinder mission demonstrating that scientifically significant measurements of sea surface salinity could be made from space—see top image on the next page. Ocean salinity data are important for improving our understanding of ocean dynamics and the global water cycle. Successfully completing its primary three-year mission in November 2014, Aquarius achieved all of its science requirements. In addition to the science, among the pioneering aspects of Aquarius was the design of the radiometer, the inclusion of a radar to correct for surface roughness, a polarimetric radiometer channel to measure Faraday rotation, and rapid sampling to mitigate the effects of radio frequency interference (RFI).

Aquarius leaves almost four years of high quality data that will continue to provide new science for years to come. For example, Aquarius has already begun to provide data about the dynamics of the salinity field and insight into interannual changes including coupling to events such as El Niño, freshwater plumes from large rivers, and even hurricanes. Aquarius data were also integral to the Salinity Processes in the Upper Ocean Regional Study (SPURS), a yearlong international field study of the oceanographic processes that sustain the maximum surface salinities in the central subtropical North Atlantic and influence global ocean circulation. Beyond ocean salinity, data from Aquarius have been used to produce global maps of soil moisture and RFI—see bottom images below.

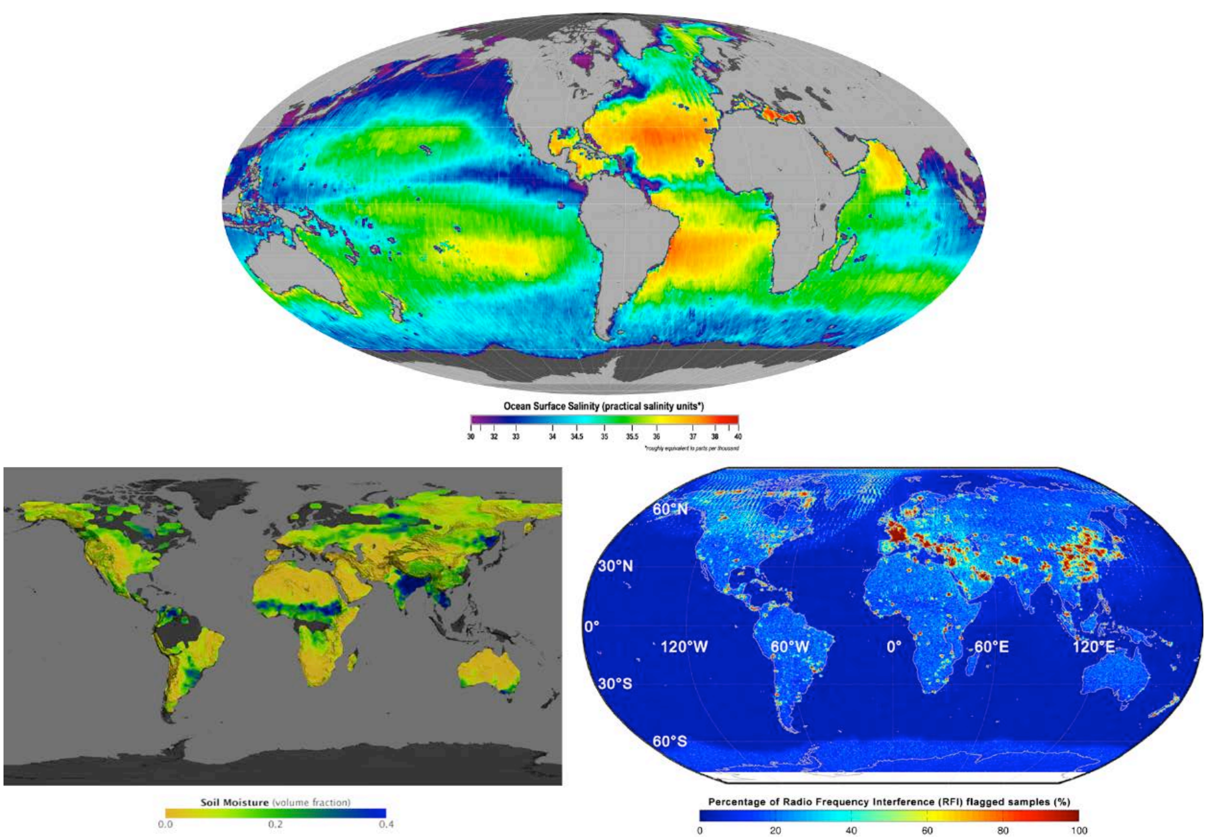
"The Aquarius sensor collected three years and nine months of valuable data," said **Gary Lagerloef** [Earth & Space Research—*Aquarius Principal Investigator*]. "It was truly a pioneering effort to determine how accurately we could measure ocean salinity from space and for the first time study large and small-scale interactions of the global water cycle."

To learn more about Aquarius, visit *www.nasa.gov/press-release/international-spacecraft-carrying-nasa-s-aquarius-instrument-ends-operations* and also *www.aquarius.umaine.edu.*

Finally, it is with great sadness that we inform you about the loss of Angelita "Angie" Castro Kelly, the first woman to become a NASA Mission Operations Manager, who passed away in June 2015. Among many accomplishments, Angie is known for her active role in guiding the Afternoon Constellation, or A-Train, from concept to reality. To learn more about Angie's career, turn to page 16. ■

Undefined Acronyms Used in the Editorial and Article Titles

ISS-CATS	International Space Station Cloud–Aerosol Transport System
CONAE	Comisión Nacional de Actividades Espaciales
GPM	Global Precipitation Measurement
ISS-RapidScat	International Space Station–Rapid Scatterometer
NOAA	National Oceanic and Atmospheric Administration
OCO-2	Second Orbiting Carbon Observatory
SAC-D	Satelite de Aplicaciones Cientificas-D
SMAP	Soil Moisture Active/Passive



This montage shows some sample data from Aquarius including: a global map of sea surface salinity, which was Aquarius' prime mission [*top*]; a global map of soil moisture [*bottom left*]; and a global map of radio frequency interference (RFI) at L-band [*bottom right*]. Additional examples of these and other products are available at *www.aquarius.umaine.edu*. **Image credit**: Aquarius Science and Project Team

NASA Sets the PACE for Advanced Studies of Earth's Changing Climate

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PACE provides a strategic climate continuity mission that will collect many global measurements essential for understanding marine and terrestrial biology, biogeochemistry, ecology, and cloud and aerosol dynamics.

Introduction

Spend any amount of time observing Earth's oceans and one thing becomes readily apparent: Ocean water is anything but clear; its color varies immensely, depending on exactly where one is looking (e.g., coastal waters are very different than the open ocean) and what happens to be dissolved or suspended in the water beneath its surface at that location. Such variations provide the basis for ocean color science. Many particulate and dissolved constituents of the near-surface water column absorb and scatter light differently in the ultraviolet (UV) and visible (VIS) regions of the electromagnetic spectrum. So at its most fundamental level, ocean color science is about relating the spectral variations in the UV-VIS marine light field (i.e., differences in the ocean's color) to the concentrations of the various constituents residing in the sunlit, near-surface water column—see *How Ocean Color Measurements Are Made* on the next page.

To continue a multidecade record of ocean color measurements, NASA recently approved the Pre-Aerosols, Clouds, and ocean Ecosystems (PACE) mission to enter *Pre-Phase A*—mission preformulation and conceptual studies. First presented in the 2010 NASA plan, *Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space*[1], PACE provides a strategic climate continuity mission that will collect many global measurements essential for understanding marine and terrestrial biology, biogeochemistry, ecology, and cloud and aerosol dynamics.

PACE, the primary sensor for which is currently called the Ocean Color Instrument (OCI), is an ocean color mission but, as its name implies, it will also be used to study important aspects of atmospheric science. Since the mission's primary focus is ocean color, this article begins with some background on that topic. The origins of the mission, its objectives and scientific questions, its organizational structure, and benefits to society are also addressed.

In the coming months, *pace.gsfc.nasa.gov* will be developed and populated with news, updates, educational materials, and oceanic and atmospheric information for interested community members.

Contributions to Ocean Color

In addition to dissolved and inorganic material such as salts, ocean water contains a variety of microscopic living organisms, each with their own unique impact on the optical properties of water. In fact, one of the most important components found in ocean water are phytoplankton. These microscopic marine algae form the base of the marine food chain and produce over half of the oxygen we breathe. Phytoplankton also play an important role in converting inorganic carbon in carbon dioxide (CO_2) to organic compounds, fueling global ocean ecosystems and driving the oceanic biogeochemical cycles through grazing (i.e., they provide a food source for zooplankton) and through their degradation products and the *microbial loop*—where bacteria reintroduce dissolved organic carbon (DOC) and nutrients to the trophic system, effectively recycling both back into the food chain. Phytoplankton are therefore a critical part of the ocean's biological carbon pump, whereby atmospheric CO_2 gets sequestered to the deep ocean, and are responsible for roughly half of Earth's net *primary production*—the difference

[1] To view the report, visit *science.nasa.gov/media/medialibrary/2010/07/01/Climate_Architecture_Final.pdf.*

between the rate of plant production of useful chemical energy and the rate of their use of that energy in respiration. However, phytoplankton growth is highly sensitive to variations in ocean and atmospheric physical properties, such as upper-ocean stratification and light availability within this mixed layer. Phytoplankton also vary greatly in their size, function, response to ecosystem changes or stresses, and nutritional value for species higher in the food web. Hence, measurements of phytoplankton community composition and their distributions remains essential for understanding global carbon cycles and how living marine resources are responding to Earth's changing climate. All these inorganic and organic substances combine to form the actual optical properties of the ocean, which ultimately give it its color.

How Ocean Color Measurements Are Made

In simplified terms, here's how an ocean color measurement works: An instrument in space, such as the PACE Ocean Color Instrument (OCI) described on page 8, measures the spectral radiance exiting the top of the atmosphere. Of the total amount of radiance seen by the satellite instrument, only a small portion is actually coming from the ocean; by far the dominant portion comes from the atmosphere, and this "noise" effectively hides the desired signal. To retrieve the portion of the signal exiting the water, scientists and programmers apply atmospheric correction algorithms that remove the radiance contribution from the atmosphere; what remains is the small portion passing through the ocean surface—the component of interest for ocean color measurements. That radiance is then converted to spectral remote-sensing reflectances, which are essentially the ratio of the light coming from the ocean normalized to the light from the sun entering the ocean. Once these reflectances are known, then bio-optical algorithms are used to produce estimates of geophysical and optical properties, such as the near-surface concentration of the phytoplankton pigment chlorophyll-*a* and spectral marine inherent optical properties (IOPs).

Ocean Color: An Important Climate Data Record

A key step toward helping scientists understand how the Earth has responded to its changing climate over time—and how it may respond in the future—is through the establishment of high-quality, long-term, global time series of various geophysical parameters. Given the nature of the phenomena and the timescales needed to distinguish trends, such measurements will require combining data from several missions. These climate-quality time series are called climate data records (CDRs[2]), and are being generated for a variety of geophysical parameters, including ocean color.

Beginning with the launch of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS[3]) in 1997, NASA has generated a continuous record of global ocean color measurements—although the proof-of-concept ocean color satellite observations date back to 1978—see *OCI Builds on NASA's Ocean Color Heritage* on page 7. This time series of remotely sensed quantities provides a valuable data record for studying long-term changes in ocean ecosystems. Observations of spectral marine inherent optical properties (IOPs), the spectral absorption and scattering properties of seawater, and the particulate and dissolved constituents it contains, can be used to infer the contents of the upper ocean, including phytoplankton community composition—see **Figure 1.** This information is critical for advancing our understanding of biogeochemical oceanic processes

[2] The U.S. National Research Council (NRC) defines a CDR as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.
[3] SeaWiFS flew onboard the Orbview spacecraft, and operated until 2010.

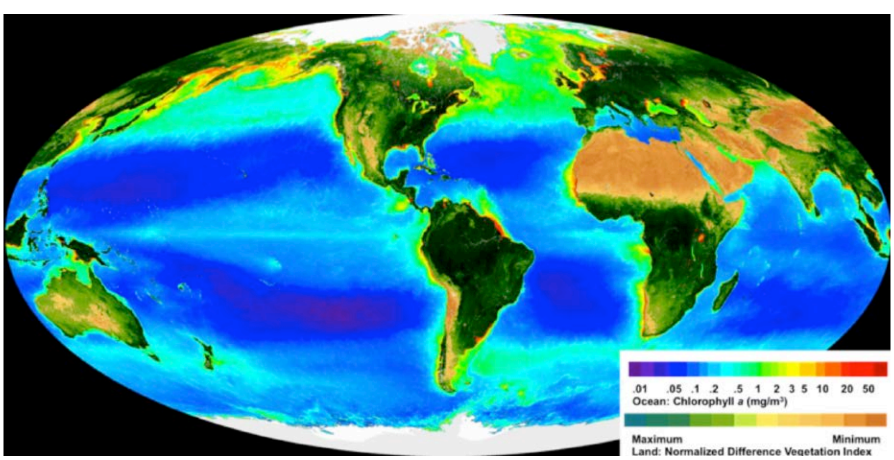


Figure 1. Global image of the Earth's biosphere as seen by SeaWiFS. For the ocean, the colors indicate the abundances of chlorophyll-*a*, with purple-blue showing low abundances and green-yellow-red showing high abundance. For land, the colors show the normalized difference vegetation index (NDVI), with brown and green indicating arid and lush regions, respectively. **Image credit:** GSFC Ocean Biology Processing Group

—e.g., carbon exchanges and fluxes, phytoplankton community dynamics, and ecosystem responses to disturbances.

PACE Science Targets

The PACE science objectives have been described in the *PACE Science Definition Team Report*[4]. They are the result of decades of experience with requirements developed by the ocean color and cloud and aerosol communities. The advanced capabilities of the PACE OCI over heritage instruments will extend the current time series of high-quality CDRs and answer the science questions listed here, grouped by topic:

The PACE science objectives...are the result of decades of experience with requirements developed by the ocean color and cloud and aerosol communities. The advanced capabilities of the PACE OCI over heritage instruments will extend the current time series of high quality CDRs.

PACE Science Questions

Global ocean ecosystems and climate

- What are the standing stocks and compositions of ocean ecosystems? How and why are they changing?
- How and why are ocean biogeochemical cycles changing? How do they influence the Earth system?
- What are the material exchanges between land and ocean? How do they influence coastal ecosystems and biogeochemistry? How are they changing?
- How do aerosols influence ocean ecosystems and biogeochemical cycles? How do ocean biological and photochemical processes affect the atmosphere?
- How do physical ocean processes affect ocean ecosystems and biogeochemistry? How do ocean biological processes influence ocean physics?
- What is the distribution of both harmful and beneficial algal blooms and how is their appearance and demise related to environmental forcings? How are these events changing?
- How do changes in critical ocean ecosystem services affect human health and welfare? How do human activities affect ocean ecosystems and the services they provide? What science-based management strategies need to be implemented to sustain our health and well being?

Coastal ocean ecosystems

- What are the distributions of habitats and ecosystems and the variability of biogeochemical parameters at moderate scales and what is the impact on coastal (e.g., estuarine, tidal wetlands, lakes) biodiversity and other coastal ecosystem services?
- What is the connectivity between coastal, shelf, and offshore environments?
- How does the export of terrestrial material affect the composition of phytoplankton communities in coastal waters, and how do these in turn affect the cycling of organic matter?
- How do moderate scale processes (e.g., sedimentation, photodegradation, respiration) affect the cycling of terrigenous organic material in the coastal environment?

Aerosols and clouds

- What are the long-term changes in aerosol and cloud properties and how are these properties correlated with inter-annual climate oscillations?
- What are the magnitudes and trends of direct aerosol radiative forcing (DARF) and the anthropogenic component of DARF?
- How do aerosols influence ocean ecosystems and biogeochemical cycles?

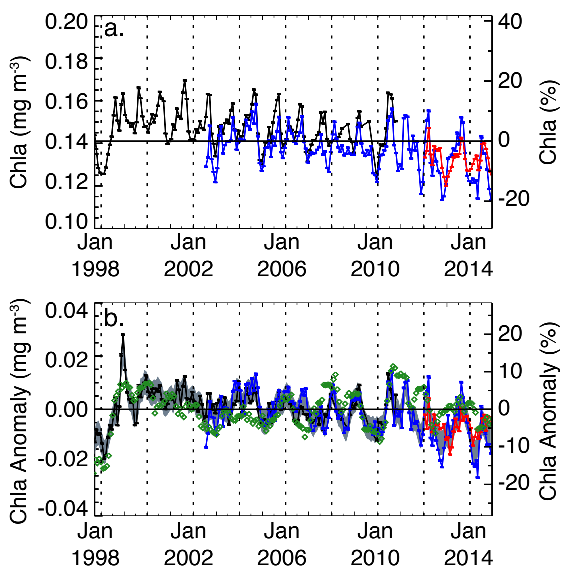
[4] To view the report, visit *decadal.gsfc.nasa.gov/PACE/PACE_SDT_Report_final.pdf.*

OCI Builds on NASA's Ocean Color Heritage

The PACE Ocean Color Instrument (OCI) builds on a firm foundation of ocean color observations at NASA that includes a 17-year continuous record of satellite ocean color observations, and many more years of experience (see graphs below). The Coastal Zone Color Scanner (CZCS), launched in 1978 onboard Nimbus-7, was the first instrument that measured ocean color from space. Intended to be a "proof-of-concept" mission, CZCS did that—and much more. CZCS observations ceased in 1986, but research continued for many years thereafter that laid the groundwork for the missions that followed*.

While some climate data records (CDRs) (e.g., ozone) are continuous from the Nimbus era to the present, such is not the case with ocean color. There was an 11-year gap between the end of CZCS observations and the next NASA ocean color mission**: the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), launched in 1997 onboard the SeaStar (later renamed Orbview-2) satellite. Despite a challenging start—SeaStar was initially deployed upside down!—SeaWiFS proved itself resilient and went on to provide quality global ocean-color observations for over a decade.

Ocean color measurements continued into the NASA Earth Observing System (EOS) era. Two of the flagship EOS missions carried the Moderate Resolution Imaging Spectroradiometer (MODIS): Terra, launched in 1999, and Aqua, launched in 2002. More recently, the Visible Infrared Imaging Radiometer Suite (VIIRS), launched in 2012 onboard the Suomi National Polar-orbiting Partnership (NPP), also obtains ocean-color measurements. VIIRS will also fly on upcoming Joint Polar Satellite System missions, the first of which (JPSS-1) is scheduled for launch in late 2016.



These graphs illustrate the seventeen-year, multimission record of chlorophyll-*a* averaged globally for the latitudinal band 40° S to 40° N for SeaWiFS (black), MODIS onboard Aqua (blue), and VIIRS (red). The top graph plots the independent record from each mission, with the multi-mission mean chlorophyll-*a* concentration for the region (horizontal black line). The bottom graph plots monthly anomalies after subtraction of the monthly climatological mean (SeaWiFS relative to the SeaWiFS climatology, and MODIS and VIIRS relative to their respective climatologies), with the average difference between SeaWiFS and MODIS-Aqua over the common mission lifetime (grey). The multivariate El Niño Southern Oscillation index is inverted and scaled (green diamonds) to match the range of the chlorophyll-*a* anomalies. **Image credit**: Bryan Franz, NASA's Goddard Space Flight Center

* To learn more about the ocean-color instruments that followed, click on the Missions & Sensors tab on the left menu bar at *oceancolor.gsfc.nasa.gov.*

**This story is told in Chapter 5 of *The Color of the Atmosphere with the Ocean Below: A History of NASA's Ocean Color Missions,* by Jim Acker. The book provides a summary of the development of NASA's ocean color missions with many references to "source" material.

PACE Mission Requirements

Responding to mission objectives and finding ways to answer the scientific questions is what drives mission requirements. NASA will incorporate many of the features and "lessons learned" from heritage spectrometers flown by NASA as well as those flown by international partners[5] into the OCI instrument design. A lesson learned from the

While some climate data records (CDRs) (e.g., ozone) are continuous from the Nimbus era to the present, such is not the case with ocean color.

[5] Examples would include the European Space Agency's Medium Resolution Imaging Spectrometer (MERIS) instrument that flew onboard Envisat and the Japanese Aerospace Exploration Agency's Ocean Color and Temperature Scanner (OCTS), and Global Imager (GLI) instruments that flew onboard the Advanced Earth Observation Satellite (ADEOS) and ADEOS II, respectively.

SeaWiFS era, for example, is the benefit of an ocean color instrument that can view the full Moon each month from its Earth view port. The reflectance of the Moon can be accurately modeled, providing an invaluable temporal calibration source for the ocean color instrument. As of this early stage in the project, the key minimum threshold mission and OCI instrument characteristics and capabilities are:

- Earth surface spatial resolution at nadir of 1 km^2 (~0.4 mi^2) for all science bands.
- Sun-synchronous polar orbit with an equatorial crossing time near local noon (1100-1300).
- Two-day global coverage of science measurements to a solar zenith angle of 75° and sensor view zenith angles not exceeding 60°—with mitigation of sun glint.
- A spectral range from 350 to 800 nm at 5-nm resolution, plus near-infrared bands at 865 and 940 nm and four or more shortwave infrared bands spanning 1240, 1378, 1640, 1880, 2130, and/or 2250 nm.
- Downlink and storage of the complete 5-nm resolution data from spacecraft to ground.
- Monthly characterization of instrument detector and optical component changes using lunar observations through the Earth-viewing port that illuminate all science detector elements.

Organizational Requirements and Responsibilities

PACE is being implemented as a NASA *Class C*[6] mission with a notional launch date in the 2022–2023 timeframe and minimum mission duration of three years, with orbit maintenance capabilities for 10 years. PACE is designated as a design-to-cost mission, meaning that it has a fixed budget cap of $805 million. Under this funding framework, science returns from the mission will need to be optimized through a series of trade and feasibility studies that encompass the OCI, a potential polarimeter (see PACE: Measuring More than Ocean Color below), the spacecraft and launch vehicle, the ground and science data processing segments, pre- and post-launch, science and calibration/validation programs, and all other components of system integration and mission management.

Full responsibility for the PACE mission was directed to NASA's Goddard Space Flight Center (GSFC) in December 2014. GSFC will design and build the OCI, as well as maintain responsibility for project management, safety and mission assurance, mission operations and ground systems, launch vehicle/spacecraft/instrument payload integration and testing, and OCI calibration, validation, and science data processing.

While PACE is predominantly an "ocean color" mission, it will also have secondary objectives—and possibly a secondary instrument. An additional overarching goal for the mission is to help determine the roles of the ocean and atmosphere in global biogeochemical cycling and how perturbations to Earth's energy balance both affect and are affected by rising atmospheric CO_2 levels and Earth's changing climate.

PACE: Measuring More than Ocean Color

While PACE is predominantly an "ocean color" mission, it will also have secondary objectives—and possibly a secondary instrument. An additional overarching goal for the mission is to help determine the roles of the ocean and atmosphere in global biogeochemical cycling and how perturbations to Earth's energy balance both affect and are affected by rising atmospheric CO_2 levels and Earth's changing climate.

The PACE mission will contribute to the continuation of atmospheric CDRs as well as those for ocean color. The OCI will allow continuation of "heritage" aerosol measurements made using the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua and the Ozone Monitoring Instrument (OMI) onboard Aura. It will also provide additional

[6] To learn more about the classifications used to categorize NASA missions, see *Appendix B* of "NASA Procedural Requirements (NPR) 8705.4," which can be found at *nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_0004_/N_PR_8705_0004_.pdf.*

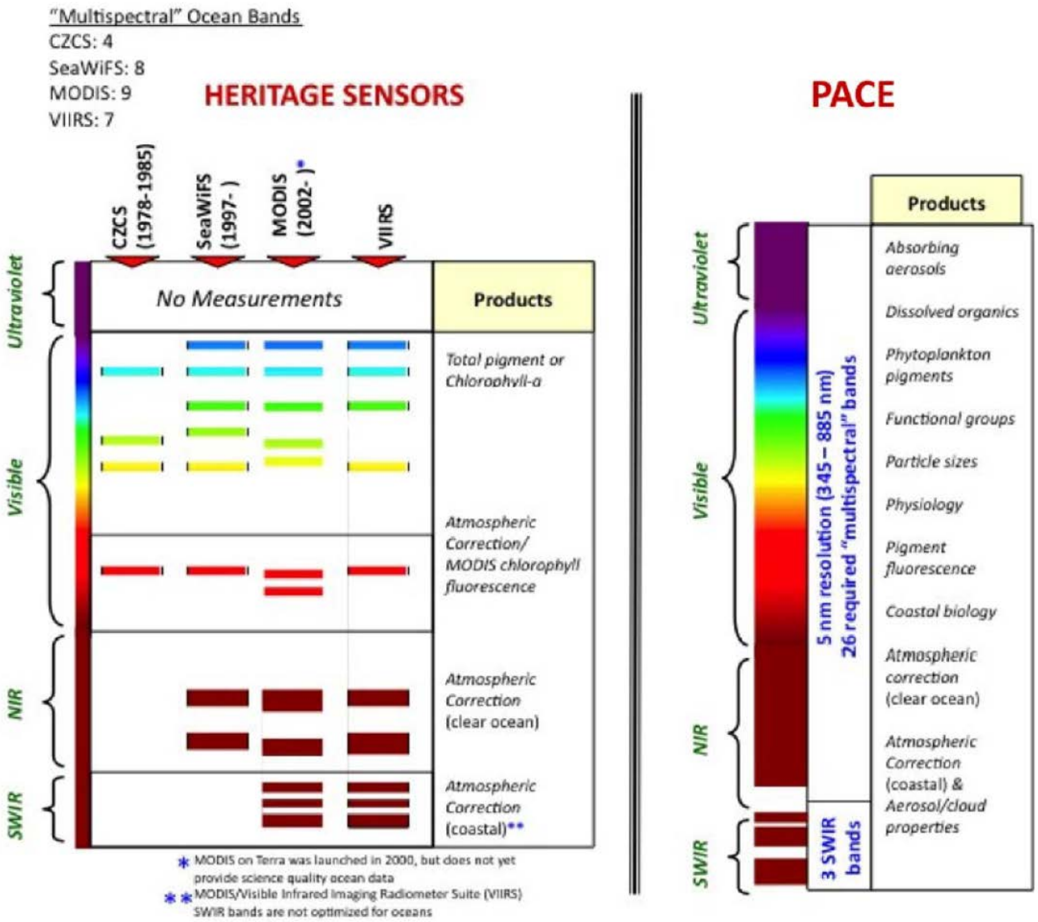


Figure 2. Comparison of PACE spectral coverage with heritage U.S. ocean color sensors. The PACE instrument will provide continuous high-spectral-resolution observations (5 nm) from the UV to NIR (350 – 800 nm), plus several short-wave infrared (SWIR) bands to support cloud and aerosol science and ocean color atmospheric correction. **Image credit**: PACE Science Definition Team Report (*see Footnote 4 for access information)*

characterization of aerosol particles because its spectral range will include short-wave infrared wavelengths—see **Figure 2**. This will enable continuation of MODIS-like and OMI-like characterization of aerosol properties, and MODIS-like measurements of water vapor and retrievals of cloud optical properties. These are the key atmospheric components affecting our ability to predict climate change as they contribute the largest uncertainties in our understanding of climate forcings and cloud feedbacks for an increasingly warmer planet. The interactions between these species are key to such understanding, as aerosols, water vapor, and clouds remain intertwined within the hydrologic cycle because most cloud droplets are seeded by small aerosol particles called cloud condensation nuclei. Changes in the amount, type, and distribution of aerosols, therefore, can alter the micro- and macro-physical characteristics of clouds. Furthermore, natural and anthropogenic changes to the aerosol system may affect clouds and precipitation, which can alter where, when, and how much precipitation may fall.

A number of possible enhancements to the base PACE mission have been proposed. While all of these enhancements would make the mission more scientifically robust, they come with possible technical tradeoffs...

Possible Enhancements to OCI

A number of possible enhancements to the base PACE mission have been proposed. While all of these enhancements would make the mission more scientifically robust, they come with possible technical tradeoffs: Enhancements might result in delays in launch schedule; decreasing the mission's technology readiness level[7] (which implies more risk of failure); increased payload mass leading to increased power requirements;

[7] Technology readiness levels are a means to classify how "ready" a given system component or instrument is. For more on how the Earth Science Technology Office defines them in the context of NASA missions, see *esto.nasa.gov/technologists_trl.html.*

changes in data rates, data volume, signal-to-noise ratios, spectral resolution, and/or spatial resolution; higher probability of image artifacts (e.g., striping); and more extensive pre- and post-launch calibration efforts. All of these might have an impact on the cost of the mission.

OCI Upgrades

The possible enhancements to the PACE OCI that are under consideration would push beyond the minimum mission requirements and enable the mission to address some of the more advanced science questions. Possibilities include reducing ground spatial resolution of OCI to 50, 100, or 250 m (~164, 328, or 820 ft, respectively) to enable fine-scale coastal and inland water retrievals; extending the spectral range of the instrument down to 300 nm to better discriminate between color contributions from dissolved organic matter and absorbing aerosols; and, reducing spectral resolution to less than 5 nm and/or enabling spectral subsampling between 1 and 2 nm in particular regions of the spectrum (e.g., over the chlorophyll fluorescence peak to reveal additional information on phytoplankton physiology and health).

PACE may optionally carry a multi-angle polarimeter as a secondary instrument, which would add significant capabilities to the atmospheric science components of the mission. While still in the exploratory stages, early results suggest that polarimetry has the potential to make significant contributions to the retrieval of atmospheric characteristics and selection of aerosols as part of ocean-color atmospheric correction.

Polarimeter Options

PACE may optionally carry a multiangle polarimeter as a secondary instrument, which would add significant capabilities to the atmospheric science components of the mission. While still in the exploratory stages, early results suggest that polarimetry has the potential to make significant contributions to the retrieval of atmospheric characteristics and selection of aerosols as part of ocean-color atmospheric correction.

With regards to retrieving atmospheric characteristics, a polarimeter allows quantitative retrieval of aerosol scattering optical properties, absorption, size, and particle shape, in addition to the MODIS-OMI heritage of aerosol optical depth, and a less exact measure of size and absorption. For clouds, polarimetry provides a more exact measure of cloud droplet size distributions, including the width of the distribution. Retrievals of cloud top height and ice cloud phase function are also possible with appropriate choices of wavelength bands and angular sampling.

The second area that the addition of a polarimeter would help feeds into the mission's primary objective: ocean color. A PACE polarimeter would provide an unprecedented opportunity to develop novel joint ocean-atmosphere retrievals that may improve upon or enhance traditional ocean color atmospheric correction and provide information on ocean biologic and atmospheric components from a simultaneous inversion. Furthermore, polarimetric measurements of the ocean surface may enable estimation of the angular distribution of the underwater light field, which could additionally shed light on the optical properties of near-surface marine particles.

Several polarimeter options exist as of this writing: no polarimeter; a polarimeter development directed to the NASA/Jet Propulsion Laboratory (JPL); and an open-competed (or contributed) polarimeter, with GSFC excluded. Under these options, the Project is exploring several measurement concepts—temporal modulation, spectral modulation, amplitude splitting, and sequential measurement strategies can all be used to provide imaging of both the total and polarized intensity of light. Assuming that a polarimeter is added to PACE, it will certainly constitute a significant enhancement to the base mission—but it will also increase the technical complexity of the mission.

PACE Mission Organization

Successful implementation of any mission requires close coordination at several organizational levels, and PACE is no different. The main responsibility at the project level is the responsibility of the PACE Project Science Team (listed in sidebar on page 11), with scientific and other responsibilities allocated to the Science Team, the Calibration and Validation Team, and the Science Data Processing Team.

PACE Science Team

The first competed PACE Science Team was awarded and assembled in July 2014[8]. This science team will serve three years and is led by **Emmanuel Boss** [University of Maine—*PACE Science Team Lead*] and **Lorraine Remer** [University of Maryland, Baltimore County—*Deputy PACE Science Team Lead*]. Team members received funding to complete a variety of individual science inquiries. Team members have also been working collaboratively in a variety of subgroups to address the science of IOPs and their retrieval from space and of atmospheric characterization as it pertains to PACE, including ocean color atmospheric correction.

The specific goals of the PACE Science Team are to achieve consensus and develop community-endorsed paths forward for the PACE instrument(s) for the full spectrum of IOP and atmospheric measurements, algorithms and retrievals; and to identify gaps in knowledge, research, and technologies that should be filled (such that they could be addressed in future ROSES calls). PACE Science Team members have been conducting new and novel studies and evaluating previous studies to assess the merits associated with various radiometer and polarimeter features. In addition, the PACE Science Team has provided input on radiometer and polarimeter specifications. For example, the Science Team hosted a series of webinars where community experts described new and available technologies, their attributes, and the science they will facilitate.

PACE Calibration and Validation Team

Under a separate solicitation, three proposals were funded in the same time frame to develop prototype, advanced hyperspectral radiometer systems to perform vicarious calibration for PACE. This post-launch, on-orbit calibration removes any remaining absolute bias in the instrument (and, atmospheric correction algorithm, in the case of ocean color). Vicarious calibration remains a critical component of every ocean color mission as no satellite radiometer system can be sufficiently well characterized on Earth to provide the accuracy required to derive geophysical products from measured radiances once on orbit.

PACE Science Data Processing Team

Building on a legacy of ocean color data processing spanning decades, the Ocean Biology Processing Group within the GSFC Ocean Ecology Laboratory (*oceancolor.gsfc.nasa.gov*) will maintain responsibility for all science data processing of ocean color data products, and their distribution and storage. Similar support for atmospheric science data products from the OCI and potential polarimeter will be determined pending the development of an acquisition strategy for the polarimeter.

Societal Benefits

Science for its own sake is not enough to provide the needed support to perform such activities. Particularly in a resource-limited environment, benefits to society at large—most commonly through applications of the data—must be demonstrated, and PACE will amply address this requirement. Specifically, the advanced capabilities of the PACE OCI over heritage instruments will enable improvement in the following categories of science applications:

Climate: PACE will allow improved mapping, assessment, and understanding of climate-relevant biogeochemical concentrations and fluxes; enhanced climate model skill and forecasting capabilities; improved support for policy analyses and

PACE Project Science Team

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Brian Cairns [Goddard Institute for Space Studies—*PACE Deputy Project Scientist – Atmospheres*]

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Hal Maring [NASA HQ—*PACE Deputy Program Scientist – Atmospheres*]

Woody Turner [NASA HQ—*PACE Applied Sciences*]

[8] The team resulted from a NASA Research Announcement (NRA), titled *Research Opportunities in Space and Earth Sciences (ROSES)–2013*, implemented by the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES).

assessments; and refined design of planning adaptation and response approaches to impacts of climate change.

Oceans, coasts, Great Lakes: PACE will support enhanced fisheries and ecosystem management; improved monitoring of water quality, hypoxic conditions, eutrophication, and oil spills/seeps; refined detection of harmful algal blooms (HABs); improved models of abundances of toxic pollutants, pathogens, and bacteria that affect human and ecosystem health; refined monitoring of sea ice extent and passages; and enhanced mapping of ocean currents with relevance to fuel economy strategies for the shipping industry.

Ecological forecasting: PACE will support improved models for forecasting and early warning detection of HABs, identification of endangered species, and assessment of biodiversity; and refined data assimilation into ocean models to improve model skill and forecasting capabilities.

With the PACE mission now moving forward, NASA anticipates extending its ocean color data record into a third decade with continuous measurements of biogeochemical and cloud and aerosol properties from specialized space-borne radiometers such as OCI.

Water resources: PACE will allow improved assessment of water quality and management of water resources in lakes, estuaries, coastal areas, and over the open ocean.

Disasters: PACE will enable refined detection, tracking, and assessment of the effects of hurricanes, oil spills and seeps, volcanic ash plumes, and fires, and improve evaluation of the impact of these disasters on marine and terrestrial ecosystems and human health.

Human health and air quality: PACE will support improved air quality monitoring, forecasting, and management, and refined assessment of climate change impacts on air quality and public health.

Looking Forward

With the PACE mission now moving forward, NASA anticipates extending its ocean color data record into a third decade with continuous measurements of biogeochemical and cloud and aerosol properties from specialized spaceborne radiometers such as OCI. These data records will enable the continued development of CDRs of oceanic and atmospheric properties that will further our scientific understanding of Earth's responses to its changing climate and the subsequent impacts of these responses on living marine resources. Furthermore, the large-scale views of the biosphere and atmosphere that PACE provides will help reveal the roles of the ocean and atmosphere in global biogeochemical cycling and how Earth's changing energy balance both affect and are affected by rising atmospheric CO_2 levels and changing climate. The PACE mission will also complement two additional missions recommended in the 2007 decadal survey,[9] that will support ocean color, land, and cloud and aerosols science: the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission, which will maintain a geostationary orbit that provides continuous views of the Earth's Western Hemisphere, and the Hyperspectral Infrared Imager (HyspIRI) mission, a polar orbiter like PACE, but with very small ground pixel sizes (60 m) and reduced temporal coverage for studying land-ocean ecosystems. For more information about GEO-CAPE and HyspIRI, visit *geo-cape.larc.nasa.gov* and *hyspiri.jpl.nasa.gov*, respectively. ■

[9] To learn more about NASA's decadal survey, visit *science.nasa.gov/earth-science/decadal-surveys*.

DEVELOP Project Uses Satellite Data to Help Control Malaria in Zanzibar

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Introduction

According to a 2013 study published by the World Health Organization (WHO[1]), across the globe malaria is considered endemic in 104 countries and territories, with some 3.4 billion people—and children, especially—at risk of the disease.

Given these facts, there is increasing consensus that the practical policy option for dealing with malaria is to pursue a global policy of progressive elimination and aggressive control in high-burden areas, potentially leading to its eventual eradication. Some African countries have chosen this path and are already developing malaria control and elimination strategies along with *aid delivery roadmaps*, plans to effectively target and distribute resources and to prevent malaria from being reintroduced into regions where control strategies have been successful.

New strategies to eradicate malaria require understanding how interventions affect the transmission of the disease across different geographic areas, in varying climates, and where detailed land-surface processes affect vector[2] population dynamics and behavior. Climate variability and change at multiple spatial and temporal scales are among the most important factors in the transmission of malaria. A key problem in collecting appropriate data is that, owing to a lack of much needed resources, and consequently the infrastructure necessary to acquire and process such data, it is often difficult to collect the *in situ* meteorological and ecological data needed to establish links between environmental factors and the spread of vector-borne diseases.

Some of these problems can be overcome by using Earth-observing satellite data to fill these "data voids." The remainder of this article describes a project conducted under the auspices of NASA's DEVELOP Program[3] in which data from the International Space Station (ISS) SERVIR[4] Environmental Research and Visualization system (ISERV) camera are being compared with data from the Landsat 5 satellite to determine which data product produced the best results for classifying land cover on the island of Zanzibar. The results will be applied to help predict the occurrence of and/or track the spread of future malaria outbreaks in this area.

Study Area: Zanzibar

Zanzibar is located off the coast of Tanzania, in Southeast Africa. The island contains numerous lush forests and mangroves housing a plethora of rare species of flora and fauna. Its picturesque beaches and striking landscapes have propelled tourism to be a major economic driver in the country. Unfortunately, some of those eye-catching landscapes can provide fertile breeding grounds for mosquitoes; therefore, periodic outbreaks of malaria have been problematic for Zanzibar.

Currently, Zanzibar employs several malaria control methods, such as insecticide-treated nets, indoor-residual spraying, and a *combination therapy* based on the use of artemisinin (derived from the sweet wormwood plant) along with some other treatment modality. The combination approach is necessary because malarial parasites in this area appear to be becoming drug-resistant and WHO has explicitly discouraged *monotherapy*—i.e., using artemisinin alone.

Important Satellite Data: Landsat and ISERV

Since a key factor in predicting where malaria outbreaks are likely to happen is knowledge of the land surface, land imagery from satellite remote sensing can be a valuable tool. In this study, a series of images taken by the ISERV camera system were used in concert with a single image from the Thematic Mapper (TM) onboard Landsat 5 to identify which product better classified land cover for Zanzibar, where malaria transmission is still present.

Landsat Image

The Landsat image chosen for the classification was a Landsat 5 image from July 1, 2009, obtained from

[1] The WHO *World malaria report 2013* is available for download at *www.who.int/malaria/publications/world_malaria_report_2013/report/en.*

[2] A *vector* is any agent that carries and transmits pathogens to another organism.

[3] The NASA DEVELOP National Program fosters an interdisciplinary research environment where applied science research projects are conducted under the guidance of NASA and partner science advisors. For more information, visit *develop.larc.nasa.gov/about.html.*

[4] SERVIR is a joint NASA and U.S. Agency for International Development effort that provides analyses and applications from space-based, remotely sensed information to help developing nations in decision-making processes that address natural disasters, climate change, and other environmental threats. SERVIR is an acronym meaning "to serve" in Spanish.

the 2010 Global Land Survey—shown on the left in **Figure 1**. This particular image was chosen because it was the only image from Landsat 5, 7, or 8 that did not have cloud cover over the island. Unfortunately, because the image was obtained from Landsat 5, panchromatic sharpening could not be used (since the panchromatic band was not available until Landsat 7) to enhance the resolution of the image for classification purposes. Despite this limitation, however, the resolution of the Landsat image was an eminently useful 30 m (~98 ft).

ISERV Images

The ISERV images chosen for the classification comparison were acquired from NASA's Global Hydrology Resource Center[5]. Unlike the Landsat image, the ISERV images were only able to cover the northern portion of the island due to the camera's smaller viewing area, but they had a higher spatial resolution of approximately 3 m (~10 ft). Despite the reduced aerial coverage, the area covered in the ISERV images contained various land cover types, so it was still a viable candidate for the comparative analysis. As explained in the next section, the image on the right in Figure 1 shows the area covered by all of the mosaicked ISERV images that were used in this study.

Classifying and Reclassifying the Data

The land-cover determination for the Landsat data was done using an *Iso-Cluster analysis*—an unsupervised classification tool in the *ArcMap* geographic information system (GIS). To complete the classification, the ISERV scenes were mosaicked in *ENVI*, a commercial platform for advanced image processing and geospatial analysis. After that, another unsupervised classification was performed, this time, to classify the mosaicked scene. Both the Landsat image and the mosaicked ISERV images were classified with many different parameters such as the number of classes, minimum class size, and differing sample intervals for the classes. The ideal classifications were selected by visually comparing the results of the classifications with a ground-truth map and *in situ* photos.

After the various classifications were performed on the images, the maps with the classifications that were most similar to the ground-truth map were chosen and then reclassified based on the ground-truth map. Certain land cover types (e.g., forest) in the reclassified images were originally spread over numerous classes and were subsequently combined to match the ground truth map as best as was practicable.

As shown in Figure 1, the Landsat 5 image outperformed the ISERV images in differentiating between the various land cover classes. The Landsat classification was able to adequately classify brush and shrub areas, forest, urban areas, mangrove swamps, and sugarcane and rice fields. One of the limitations found when using the Landsat 5 classification was that it would sometimes incorporate high-reflectance areas (such as coastlines) into the same class as urban areas.

[5] For more on the Center, visit *earthdata.nasa.gov/about/daacs/global-hydrology-resource-center-ghrc-daac*.

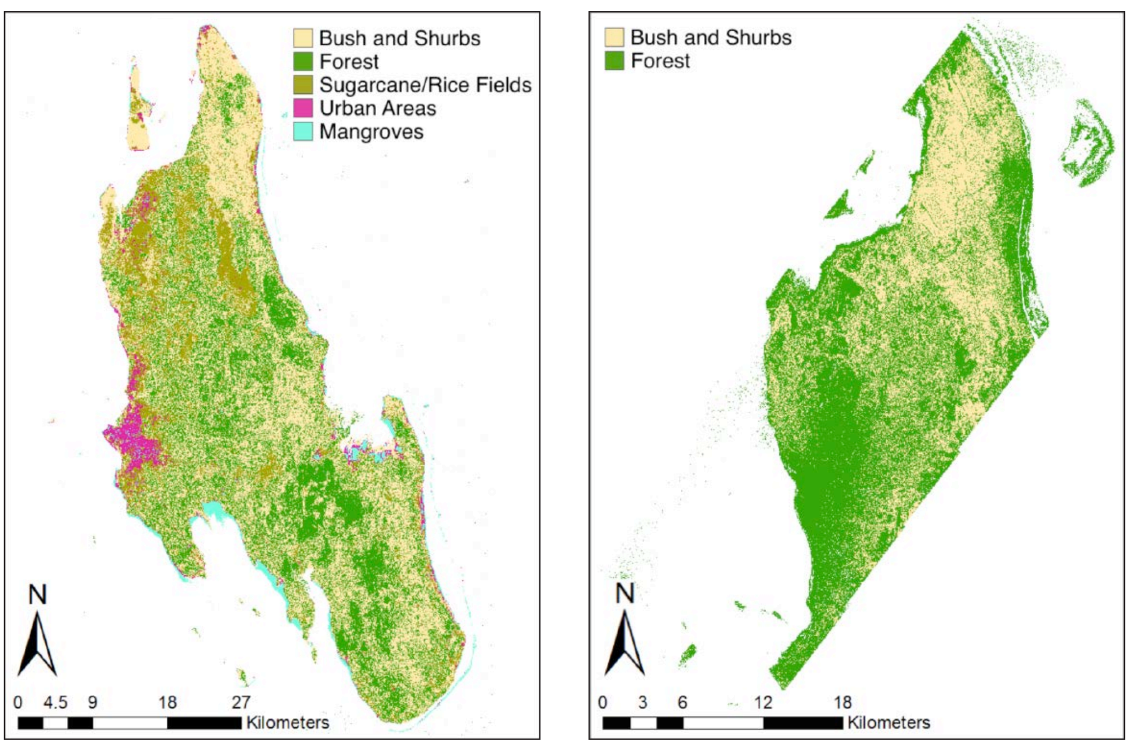


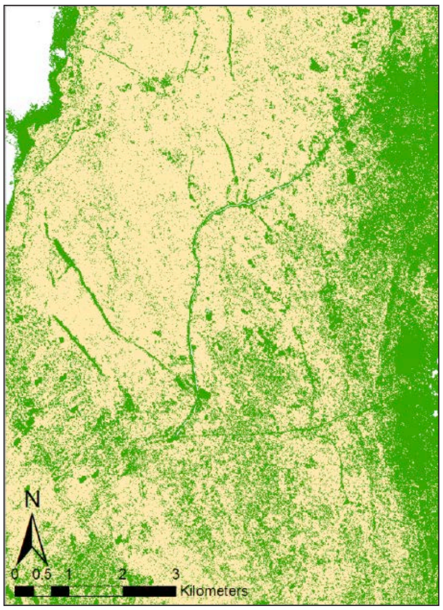
Figure 1. Finalized classification maps using an Iso-cluster unsupervised classification analysis on a Landsat 5 Thematic Mapper image [*left*] and on a set of mosaicked ISERV images [*right*]. Note the scales of these maps are different; the ISERV images only covered the northern portion of the island but had much greater spatial resolution than Landsat 5. **Image credit**: Jerrod Lessel

The ISERV images generally were not able to differentiate between the various land-cover classes. The image classes had a tendency to overlap after reclassification; consequently, distinct regions were not apparent. The only classes that could be viewed as similar to the ground-truth map were the brush/shrubs class and the forest class, and these classes tended to overextend into other classes (such as urban areas and sugarcane/rice fields). A beneficial result from the ISERV classification was that it was able to identify some high-spatial-resolution features such as roads—as shown in **Figure 2**.

The Best of Both Worlds

Each of the final maps were compared with *in situ* field photos to further verify that the classes were properly differentiated—with results as shown in **Figure 3**.

The combination of using the overall land-cover classes from Landsat alongside the higher-spatial-resolution classifications from ISERV will prove useful in tracking the spread of malaria throughout Zanzibar and better identify fertile breeding grounds for the mosquitoes that transmit the disease. The Zanzibar Malaria Control



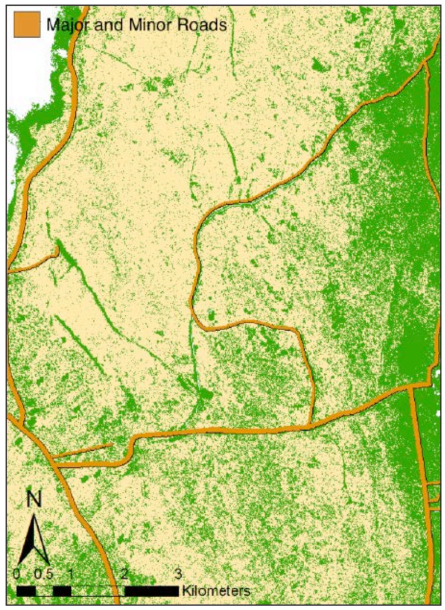
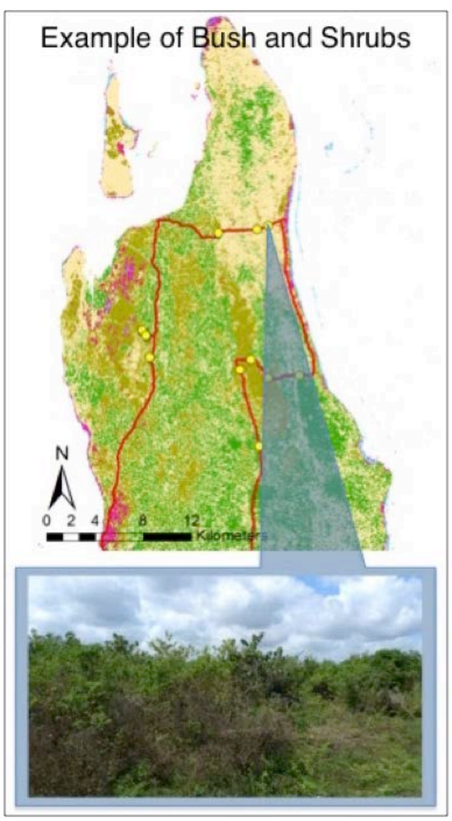


Figure 2. While ISERV in general was not as effective at classifying the land cover as Landsaat 5, the higher resolution allowed for some smaller scale features, e.g., roads, to be identified. Shown here is a zoomed-in portion of the classified ISERV image from Figure 1 [*left*] overlaid with a major and minor roads shapefile [*right*]. **Image credit**: Jerrod Lessel



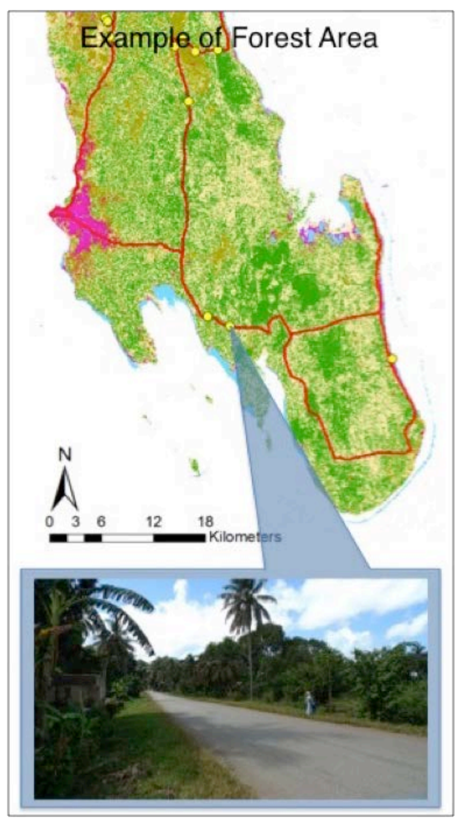


Figure 3. The final Landsat 5 classification map was validated against *in situ* field photos. Each map [*top*] shows where the photograph below it was obtained (yellow boxes). The photographs are examples of two of the land cover types used in the study (listed on Figure 1): an area classified as *brush and shrubs* [*bottom left*] and an area classified *forest* [*bottom right*]. The red line on each of the maps shows the path the researcher in the field took during his time on the island. **Photo credits:** Pietro Ceccato

Program (ZMCP) will be able to use these products and combine them with their own malaria data to help track the distribution and spread of malaria.

Conclusion

A key factor in predicting where malaria outbreaks are likely to happen is knowledge of the land surface. This article has described a NASA DEVELOP study to test the effectiveness of using land classifications from satellite remote sensing as a means to help control the spread of malaria in Zanzibar. The study used both a Landsat 5 image and a series of mosaicked ISERV images, and the results revealed benefits with respect to the classification from both types of images. The Landsat 5 image was able to accurately classify the brush/shrubs, forest, urban areas, mangroves, and sugarcane/rice fields land cover classes. While the ISERV images were not able to differentiate between the various land cover classes nearly as well, they were able to classify high spatial resolution features such as roads that the Landsat 5 image could not detect. One of the main benefits of using remotely sensed products such as the ones used in the methodology described in this study is that the maps can be updated to include additional *layers*, e.g., ecosystem conditions and urban growth change. Hence there are opportunities to expand this study in the future. Using this methodology and the maps created, the ZMCP can more accurately track how malaria responds to these changing ecosystem conditions and urban growth in an effort to eradicate malaria on Zanzibar. ■

In Memoriam

Angelita "Angie" Castro Kelly, the first woman to become a NASA Mission Operations Manager (MOM), passed away on June 7, 2015, at the age of 72.

Angie served as Earth Observing System Constellation Team Manager and played an active role in guiding the Earth science Morning and Afternoon Constellations from concept to reality. As the constellation mission manager she conducted numerous Mission Operations Working Group meetings for constellation members, where she brought together diverse groups of engineers and scientists from the U.S., the U.K., Netherlands, France, Japan, and Argentina. The continuing success of these two Earth science constellations is a testament to her leadership. In addition, Angie served as the Science Interface Manager and was the liaison between ESMO and the instrument teams for Terra, Aqua, and Aura.

She once said, "I'm the first woman MOM, so I cracked the ceiling. Before me, all the MOMs—which is kind of funny—were men[1]." Angie joined the Earth Science Data and Information System (ESDIS) team in 1990, which later became known as the Earth Science Mission Operations Office (ESMO). In her role as EOS MOM, she developed early mission operations concepts for many of the EOS missions now in orbit. Before becoming EOS MOM, Angie had a career in manned space flight. She was the project manager for the highly successful Space Shuttle/Spacelab Data Processing Facility, which she helped develop. She learned how to work with science data users to understand their requirements as she negotiated agreements with NASA's Johnson Space Center, NASA's Marshall Space Flight Center, and NASA's international partners in Germany and Japan.

Born in Isabela province in the Philippines in 1942, she grew up in Sampaloc, Manila, graduating with a bachelor's degree in Mathematics and Physics at the University of Santo Tomas (UST). She later finished her master's degree in physics at the University of Maryland. Kelly reaped numerous awards in her distinguished career, including the *NASA Exceptional Achievement* and *Exceptional Service Medals*, the *Goddard Space Flight Center Exceptional Service Award*, the *Manned Flight Program Launch Honoree Award*, the *Goddard Space Flight Center Exceptional Performance Award*, and the unique *Astronauts' Manned Flight "Snoopy" Award*.

The Earth Observer staff extends its condolences to Angie's family and her NASA colleagues as we all mourn her loss.

[1] From Kelly's interview in *The Great Ilocanos* interview series (2012) which can be viewed at *www.youtube.com/watch?v=IH-zJwhYtWc*.

Geostationary Orbit as a New Venue for Earth Science Collaboration: Eleventh CEOS Atmospheric Composition Constellation Workshop

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Introduction

The European Space Agency (ESA), the Korean Aerospace Research Institute (KARI), and NASA have embarked on a new program to share air quality observations from satellites in geostationary and polar orbits. The collaboration is being fostered by the Atmospheric Composition Constellation (ACC), an element of the Committee for Earth Observation Satellites (CEOS), whose membership consists of most of the world's space agencies—see *ceos.org* for more information. The purpose of CEOS is to coordinate Earth observations to ease access of space data by the scientific and operational communities. CEOS supports the requirements established by international bodies, such as the World Meteorological Organization (WMO), the Global Climate Observing System (GCOS), and the Group on Earth Observations (GEO). It is the primary forum for international cooperation for the acquisition and release of space-based Earth observations where informal (non-binding) agreements allow for coordination of observations while maintaining the independence of individual CEOS agency contributions.

The Virtual Constellations, described at *ceos.org/our-work/virtual-constellations*, are functional elements of CEOS where selected Earth science disciplines are expected to coordinate missions in their discipline. Their purpose is to optimize space-based, ground-based, and data delivery systems to meet a common set of requirements within the discipline. The ACC's goal is to collect and deliver data to improve monitoring, assessment, and model predictions for changes in the ozone layer, air quality, and climate forcing associated with changes in the environment through coordination of existing and future international space assets. In this light, additional candidate constellations are under examination, as described below.

CEOS ACC Workshop

The ACC conducted its Eleventh Workshop on April 28-30, 2015, at ESA's European Space Research Institute (ESRIN[1]) facility in Frascati, Italy, with about 45 attendees from the Chinese Academy of Science, ESA, Japanese Space Agency (JAXA), KARI, NASA, and other national institutions and universities. The Workshop agenda and presentations can be found at *ceos.org/meetings/acc-11*. This report summarizes the highlights of the workshop. It is organized around the three objectives of the meeting, which were to:

- further formulate an Air Quality Constellation;
- consider establishing a Green House Gas (GHG) Constellation; and
- discuss progress on establishing consistent ozone datasets from several ozone-monitoring instruments flying on different CEOS agency missions.

Maurice Borgeaud [ESA, Directorate of Earth Observation Programmes—*Head of Science, Applications, and Future Technologies*] welcomed the workshop attendees and provided an overview of ESA's in-orbit and planned Earth science missions and their schedules. ESA's three distinct Earth Observation mission programs fall under the categories of Meteorological (in collaboration with the European Organisation for the Exploitation of Meteorological Satellites, or EUMETSAT), Sentinels (in collaboration with the European Union), and Explorers (part of ESA's Earth science program)[2]. In preparation for the three-day workshop, Borgeaud also recapped the goals of the meeting and their relevance to ESA.

The Air Quality Constellation

The U.S. National Research Council's 2007 Decadal Survey[3] recommended the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) as a *Tier 2* priority mission that would observe changes in ocean color and air quality over much of North America from geostationary orbit (GEO). Its purpose is to measure air pollution's key components and short-term evolution during the course of a day on a regular basis. In addition, simultaneous measurements were planned for key water quality, ocean chemistry, and ecological indicators in coastal waters, including their responses to environmental change. As planning begins for the second Earth Science Decadal Survey, flying a GEO-CAPE mission remains uncertain. However, in the interim the world science community (NASA in particular) has been considering alternatives that would at least allow parts of the GEO-CAPE (e.g., air quality observations) to

[1] This organization is also known as the European Space Agency's Centre for Earth Observations.

[2] These missions were described in "An Overview of Europe's Expanding Earth-Observation Capabilities" in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15].

[3] The 2007 National Research Council (NRC) Decadal Survey report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, provides the basis for the future direction of NASA's space-based Earth observation system.

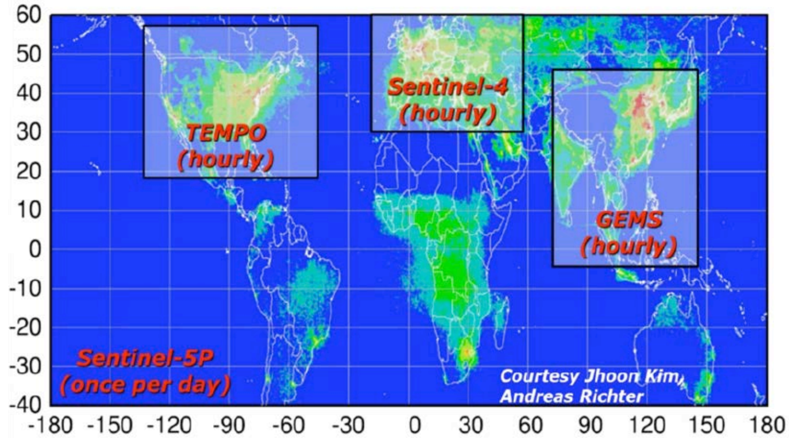


Figure 1. The Atmospheric Composition Constellation consists of three GEO satellites that hover over the Earth's major industrial regions. Several polar-orbiting satellites that cover nearly the entire Earth will link the GEO satellites. Sentinel-5P, in polar LEO, will focus on air quality. Other polar-orbiting satellites, such as Aura, MetOp, and Suomi NPP will make complementary measurements. **Image credit**: Jhoon Kim [Yonsei University], Andreas Richter [University of Bremen]

be obtained in the more immediate future. Furthermore, as detailed below, CEOS ACC has come up with the concept of an Air Quality Constellation, which would extend the observations to cover most of the globe.

Missions

The air quality requirements of GEO-CAPE will mostly be fulfilled by the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission that was selected as the first instrument under the first Earth Venture Class Instrument program. TEMPO will be flown as a hosted payload in the 2019 timeframe[4].

A single geostationary satellite views only one sector of the globe, and limits the ability to observe sources of pollution outside the instrument field of regard. To overcome this limitation, TEMPO will be part of a constellation. KARI and ESA are also developing their own GEO satellite missions that will have instruments onboard for air quality monitoring[5]—namely, the Geostationary Environment Monitoring Spectrometer (GEMS) and the Sentinel-4/Ultraviolet/Visible/Near-Infrared (UVN) sounder, respectively, that will also measure air quality and will be in orbit around the same time as TEMPO—planned for launches somewhere between 2018 and 2022. Both of these instruments will have science objectives and measurement capabilities similar to TEMPO.

In addition to these three GEO missions, ESA is planning two polar, low-Earth orbiting (LEO) satellites: Sentinel 5 Precursor (to be launched in 2016) and Sentinel 5 (to be launched in 2021). These two missions will have capabilities similar to the GEO missions for measuring air quality—but will view the entire Earth in a single day. The combination of the three GEO satellites positioned to focus on Europe (UVN), East Asia (GEMS), and North America (TEMPO), respectively, with the two polar-orbiting Sentinel missions will provide daily global and diurnal (about once-per-hour) coverage over Earth's major industrial regions—see **Figure 1**. This portion of the workshop reviewed the ongoing and upcoming areas of collaboration among the agencies participating in the Air Quality Constellation.

Measurements

The science requirements for observations of air quality are fairly mature and have subsequently evolved to instrument performance requirements—e.g., wavelength range, spatial resolution, and scan sequences. The presentations on the respective instrument specifications indicated that the five instruments will have similar capabilities. This commonality allows instrument calibrations, algorithms, and data formats to be consistent across the instruments. Algorithms for the new instruments will evolve from those employed for heritage instruments such as the Ozone Monitoring Instrument (OMI) onboard Aura, and the Global Ozone Monitoring Experiment-2 (GOME-2) and Infrared Atmospheric Sounding Interferometer (IASI) onboard the EUMETSAT's MetOp series[6].

There are some challenges unique to operations in GEO that still need to be addressed. These include: developing calibration procedures to account for instrument diurnal thermal cycles in orbit so that true atmospheric diurnal cycles can be detected; dynamic range improvements to account for the large range in latitude and longitude; algorithm advancement to enable retrievals in the troposphere's boundary layer; and establishing improved validation systems for cross-calibrating all the constellation's instruments. Finally, new challenges in data processing and analysis will have to be overcome—since the new instruments will have spatial resolutions roughly 50 times better than existing air quality instruments in LEO, which will require much larger data processing capabilities.

Prelaunch Activities

With all of the Air Quality Constellation Missions scheduled to launch between 2018 and 2022, instrument development is already underway. Therefore this session focused on discussions of prelaunch activities for

[4] This mission was described in "NASA Ups the TEMPO on Monitoring Air Pollution" in the March-April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10-15].

[5] The missions are the GEO-KOMPSAT 2B and Sentinel-4 respectively.

[6] MetOp-A and -B are in orbit now and operating in parallel. MetOp-C is due to launch in 2018.

TEMPO, Sentinel 4, GEMS, and Sentinel 5 Precursor. For TEMPO, a series of instrument performance characteristics were presented, along with information on how some of them would be tested. Since TEMPO will be hosted on a commercial (likely, communications) satellite where instrument data acquisition and downlink are the responsibility of the host, the data processing and flow is less straightforward than with traditional NASA-launched missions, so it was described in some detail during the meeting. Once the data are received on the ground they will be transferred to the Smithsonian Astronomical Observatory—the principal investigator's (PI's) institution—and processed there as they are through any other NASA Science Investigators Processing System (SIPS). Processed data (i.e., Level-1, -2, and -3 products) will then be transferred to NASA's Distributed Active Archive Centers (DAACs).

The Sentinel 4 presentation outlined the pre-launch activities, including the Level-0 (L0) performance parameters and an overview of the calibration procedures. These tests include actual sky-view measurements, which provide end-to-end tests of instrument performance using the real atmosphere.

ESA is managing the development of the Sentinel 5 Precursor instrument, which is an advanced follow-on to OMI, and will follow its heritage calibration principles and L0 processing with close involvement of the OMI PI team. The addition of a near infrared (IR) spectrometer to measure carbon monoxide (CO), methane (CH_4), and aerosol profile and layer height is an upgrade over OMI's capabilities.

Simulations Help Satellite Retrievals

There was more discussion of the role of complimentary LEO instruments during this session. The two main features these add to the constellation are cross-calibration of the geostationary instruments and filling in gaps in coverage, particularly over the oceans, to track pollutants and their precursors as they are lofted and transported by transcontinental winds.

To simulate this scenario, there were four presentations about Observing System Simulation Experiments (OSSE) studies[7] to assess the impact of hypothetical observations from the Air Quality Constellation on retrievals, analysis models, and forecasts, and also to provide a means to explain conclusions of case studies particularly calculated for the constellation. Existing satellite air-quality data, e.g., Aura's CO measurements, provide a strong constraint for constellation OSSEs. These studies can also predict the effects of cloud cover on the GEO component of the constellation. The Goddard Earth Observing System Model, *Version 5 (*GEOS-5) will provide a *Nature Run* that includes aerosols, CO, carbon dioxide (CO_2), and sulfur dioxide (SO_2) at 7-km (~4-mi) resolution. The system is scheduled to be available in late 2015.

In Europe, OSSEs are being performed to study the impact of Sentinel 4 (GEO) and Sentinel 5 (LEO) on air quality forecasts. These simulations will also study the impact of cloudiness, aerosol, surface albedo, and uncertainty in dynamical fields (i.e., vertical transport) on model and forecast skill. Studies also show the importance of resolving the troposphere at three levels to distinguish between local and nonlocal sources of pollution.

As data are being modeled for the future Air Quality Constellation, air quality measurements from instruments on NASA's Aura and Suomi National Polar-orbiting Partnership (NPP) and EUMETSAT's MetOp missions is ongoing. For example, measurements of CO and ammonia (NH_3), the latter of which is an important aerosol precursor, have been measured from the Aura satellite. The major industrial and agricultural burning regions clearly stand out as sources of these gases. Other data show increasing pollution over Asia, while pollution is decreasing over North America and Europe.

Validation Is Always a Priority

Although aerosol retrievals from the Geostationary Operational Environmental Satellite (GOES) have been in place for several years, air quality measurements from GEO are still relatively new, and therefore validation is a priority. Although there are plans to maintain consistency of L1 and L2 data products amongst the instruments in the Air Quality Constellation, there are several unique challenges to account for the slightly different measurement techniques and algorithms developed for each individual mission. These include: algorithm refinements to account for large changes in solar zenith and viewing angles with time of day and latitude; matching space and ground measurements because of higher spatial and altitude resolution; and careful intercomparison of these systems—since there are different validation systems dedicated to each GEO mission. As with all remotely sensed activities, calibration baselines for both ground and space measurements will be essential. Programmatically, advanced instruments and infrastructure will be needed, as will continued support for maintaining existing validation capabilities.

Both NASA and ESA have fairly broad validation experience from existing missions, in particular for air quality measurements, e.g., Aura and MetOp. This experience includes routine ground-based measurementts and the use of multifaceted field campaigns employing aircraft, balloon, and ground-based instruments (both *in situ* and remote sensing) that target industrial areas. The value of campaigns such as NASA's DISCOVER-AQ[8]

[7] These experiments have historically been used by the numerical weather prediction community to develop and optimize meteorological satellite instruments, and are now increasingly being used in other Earth-observation disciplines.

[8] DISCOVER-AQ stands for Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality.

in the U.S. and ESA's AROMAT[9] was discussed. These campaigns drew scientists from several government agencies and academic institutions on both sides of the Atlantic to carefully analyze air quality data over areas known to experience regular pollution events. These campaigns also provide platforms to test new airborne systems for validating future satellite air-quality measurements. Follow-up campaigns are planned as components of the Air Quality Constellation go into orbit.

The Korean National Institute for Environmental Research and NASA presented plans for the joint Korea-U.S. Air Quality Study (KORUS-AQ) campaign, a cooperative, intensive airborne, ground, and satellite field study planned for a six-week period from April through June 2016. The target area will be the Korean peninsula and adjacent waters. The participating elements will be NASA's DC-8 with its complement of *in situ* and remote sensing instruments, and a Korean B-200 partner aircraft, as well as ground sites, including the Korean Air Quality network and research supersites. The advantages of conducting an air quality field study in Korea relate to the distribution of emission sources within the country and their location along the Asian Pacific Rim. The joint campaign offers opportunities for collaborative research in air quality monitoring, ground-based measurements, satellite data analysis, modeling, and forecasting.

This session of the meeting concluded with a broad range of action items and recommendations for implementing the Air Quality Constellation. Among these include harmonization of calibration procedures, data products and their distribution, and completion of a comprehensive validation requirements document.

The Green House Gas Constellation

Several international space agencies have launched or are currently planning to launch satellites between 2015 and 2025, to measure GHGs. As a single satellite cannot fulfill established GHG user requirements, CEOS has established a need for a GHG Constellation. The ACC, based on experience with the Air Quality Constellation, was directed to coordinate detailed planning and preparation for a constellation of passive and active remote sensing instruments that will measure CO_2 and CH_4 from LEO and GEO. Emphasis should be on homogenizing the various elements of the constellation, such as by way of calibration, validation, data production and release, and encouraging international scientific collaboration.

GHG Data – Some Results

This session began with presentations on the status and interpretation of recent GHG data collected by NASA and JAXA. For the U.S., NASA's Orbiting Carbon Observatory-2 (OCO-2) has now been in orbit for almost a year. Operations in the A-Train and instrument performance are nominal in both the nadir and glint modes[10]. Preliminary global maps show the expected "hot spots" over industrialized regions—see **Figure 2**. Validation is ongoing using the Total Carbon Column Observing Network (TCCON)[11].

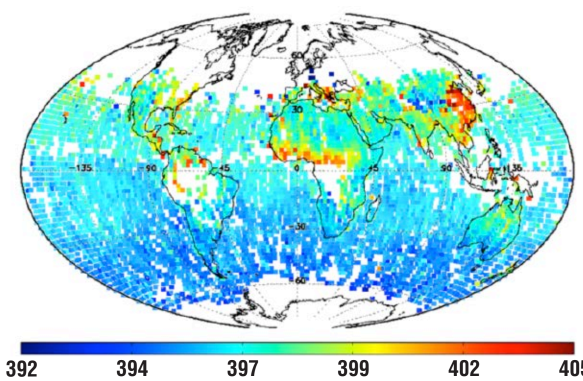


Figure 2. Global map of CO_2 measured by OCO-2. The CO_2 abundance is expressed in terms of the *column-averaged CO_2 dry air mole fraction*, denoted by XCO_2, and is defined as the ratio of the total column abundance of CO_2 to the column abundance of dry air. The scale is in units of parts-per-million (ppm). The data shown here include an ensemble of both nadir (land only) and glint (land and oceans) observations collected between November 21 and December 29, 2014. The largest XCO_2 values appear over heavily industrialized regions, including large cities, and biomass burning regions. **Image credit**: David Crisp [NASA/Jet Propulsion Laboratory]

A report on JAXA's Greenhouse Gases Observing Satellite (GOSAT) included an overview of the instrument and spacecraft performance, in-flight calibration, and validation. Results presented included monthly averages of global column amounts of CO_2 and CH_4 for the years 2009 to 2013. Additional maps illustrated GOSAT's capability to measure CO_2 and CH_4 profiles. Further analysis yielded flux estimates for these gases for both summer and winter months. Uncertainties in the preliminary data were high, but improvements are on their way through improved calibrations and algorithms. An interesting byproduct of GOSAT measurements was column ozone. Data on seasonal variation of ozone over the northern and southern poles were shown, as well as sample maps of tropospheric ozone.

The French Space Agency [Centre National d'Études Spatiale (CNES)] contributed IASI (as mentioned earlier) to MetOp. IASI is the EUMETSAT operational sounder, but has been collecting GHG data since 2007. Its sensitivity is primarily in the mid-troposphere and not at ground level—therefore CO_2 fluxes must be inferred. Nevertheless, the data from IASI clearly show increasing CO_2 trends and CH_4 trends that have a latitudinal dependence. IASI's maps of CH_4 show strong emissions over Asian rice paddies in summer—emissions

[9] AROMAT stands for European Airborne ROmanian Measurements of Aerosols and Trace gases

[10] This mission was described in "Orbiting Carbon Observatory-2: Observing CO2 from Space," in the July-August 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 4**, pp. 4-11].

[11] The network was described in "Integrating Carbon from the Ground Up: TCCON Turns Ten," in the July-August 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 4**, pp. 13-17].

that are then uplifted by monsoon convection and subsequently transported southward to Indonesia. Overall, there is good agreement with GOSAT data.

To round out the session, there was discussion of ESA's project called Greenhouse Gas-Climate Change Initiative. Data from GOSAT and from the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), which flew onboard ESA's now defunct ENVISAT satellite, were used to estimate carbon fluxes over Europe. The results indicate that carbon uptake is about twice as much than was previously estimated without satellite data. Over eastern Asia, the data show increasing emissions but smaller levels of oxides of nitrogen (NO_x) per CO_2, which implies a trend toward the use of cleaner fossil-fuel-burning technology. Other data from SCIAMACHY show that *fugitive*[12] CH_4 emissions from fracking over several large oil and gas fields in the U.S. exceed the amount of the supposed "climate benefit" threshold from switching from coal to natural gas, i.e., the benefit of burning the cleaner-burning (meaning fewer CO_2 emissions) natural gas is offset by the methane leakage resulting from extracting the gas from the ground.

Planned and Proposed Missions

TanSat (CarbonSat) is a Chinese minisatellite mission, funded by the Ministry of Science and Technology, scheduled for launch in mid-2016. Among its various capabilities, TanSat will monitor CO_2 by observing nadir (land) and sun-glint (ocean) scenes, making targeted observations for validation. The spectrometer has three bands for CO_2, an oxygen-A band, and a cloud and aerosol polarization imager. The satellite will fly in a sun-synchronous orbit with a local afternoon (1:30 PM) equator crossing time and a revisit period shorter than 16 days. Validation sites will be established throughout China, some using Fourier transform spectrometers (FTS).

The second part of the JAXA GOSAT presentation described plans for GOSAT-2, which is scheduled for launch in 2018. The instrument onboard is a FTS, which is an improvement over GOSAT with regard to radiometric sensitivity, spatial resolution, and coverage. Aerosols will be measured directly, which will improve retrievals and can be correlated with GHG emissions. The satellite will also fly in a sun-synchronous orbit.

A second CNES presentation described the development of an advanced instrument to fly on follow-on MetOp missions called IASI-Next Generation (NG), planned for launch in 2021, that will have the same spectral range as the heritage instrument, but better spectral resolution and an improved signal-to-noise ratio. Ground resolution will be 12 km (~7 mi). Therefore CO_2 measurements from IASI-NG will penetrate further into the troposphere than IASI.

In addition, CNES, in collaboration with the German Space Agency [Deutschen Zentrum für Luft- und Raumfahrt (DLR)], is building the Methane Remote Sensing Mission (MERLIN), a minisatellite climate mission with a planned launch date of 2019. The objective is to obtain spatial and temporal gradients of atmospheric CH_4 columns, with high precision and accuracy on a global scale. Germany (*via* DLR) is developing the methane lidar instrument, while France (*via* CNES) is providing the satellite platform. Joint data processing and science activities will be established in both countries.

CNES's planned MicroCarb[13] mission seeks to measure CO_2 concentrations at very high precision (about 1 ppm, or 0.3%). The mission will fly on a CNES minisatellite, and will employ a small spectrometer with three spectral bands. The mission could be ready for launch as early as 2020.

DLR is also funding a study for a Geostationary Emission Explorer for Europe (G3E). The mission's goals are to measure CO_2 and CH_4 column-average concentrations across Europe from geostationary orbit with spatial and temporal resolution of a few kilometers and a few hours, respectively. This dense spatial and temporal imaging of the GHG fields above Europe is expected to improve the ability to disentangle anthropogenic emissions from natural sources and sinks, and to impose constraints on quantifying surface flux.

The University of Bremen and DLR are collaborating on CarbonSat, that aims to quantify natural and anthropogenic CO_2 and CH_4 fluxes and their changes through measurements of global atmospheric column amounts of CO_2 and CH_4 observations. Strong localized and emission areas (known as "hotspots") will also be imaged. In addition, several secondary products will be delivered, such as high-quality, solar-induced chlorophyll fluorescence, which is linked to photosynthetic efficiency. This is a proposal being considered for the ESA Explorer 8 mission, which has a User Consultation Meeting scheduled for September 2015, a step in ESA's selection process.

Two future NASA GHG missions are being proposed—but were only briefly mentioned at the workshop. The first is the follow-on OCO-3, which would fly on the International Space Station (ISS) and have a notional launch in 2019. The ISS orbit will afford OCO-3 the ability to collect diurnal changes of GHG, up to about 52° latitude. The second is the Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS), which will employ a multifrequency laser, and identified as another *Tier 2* priority mission by the 2007 Decadal Survey. Its earliest possible launch is 2022.

[12] *Fugitive* emissions result from CH_4 (dominate component of natural gas) leakage from extracting oil and gas from shale deposits far beneath the surface. This process is known as fracking.

[13] MicroCarb is being developed in collaboration with the Laboratoire des Sciences du Climat et de l'Environnement (LSCE).

The discussion on a prospective GHG Constellation concluded with a presentation describing the WMO's Integrated Global Greenhouse Gas Information System (IG3IS) program. IG3IS is envisioned as an independent, observationally based information system for determining trends and distributions of GHGs in the atmosphere. IG3IS is expected to provide information for policy managers while ensuring the data are consistent with the WMO's coordinated global network of high-quality observations and models.

Ozone Measurement Coordination and Intercomparison

Global ozone amounts, both columns and profiles, have been available from U.S. satellites since the 1970s using both ultraviolet (UV) and IR techniques. European missions have also been observing ozone since 1995. As a project of the ACC, several agencies and institutions embarked on an extensive effort to intercompare the various ozone datasets. The major source of ozone data records for this project comes from the missions conducted by NASA and the U.S. National Oceanic and Atmospheric Administration (NOAA), and the ESA Climate Change Initiative.

NASA reported on their efforts to produce long-term total ozone datasets at 5° x 5° latitude/longitude grids from the series of backscatter UV spectrometers that have flown on U.S. satellites[14]. Attendees from NASA's Goddard Space Flight Center (GSFC) explained how measurements and data assimilation together could create a precise gridded total ozone dataset that has pole-to-pole coverage from 1979 to the present. Biases would be removed by normalizing the various instruments to the Goddard Merged Ozone Dataset (MOD).

On the European side, investigators (including participants from DLR, KNMI[15], and BIRA-IASD[16]) employed datasets from GOME, SCIAMACHY, OMI, and instruments on board MetOp, using various retrieval techniques. These techniques employed look-up tables, on-line radiative transfer calculations, differential optical absorption spectroscopy, and other direct fitting techniques. One study employed chemical data assimilation to smooth and fill in gaps in the grid.

The satellite ozone datasets were compared to the ground-based network data as a baseline; agreement was of the order of 0 to 2%. In one study, all the satellite data were corrected to ground-based data. An examination of all datasets show they were free of solar zenith angle and latitude dependence nearly to the poles. Comparisons among the satellite datasets showed similar agreement—see **Figure 3** for an example. Agreement is within ±2%, with little indication of time-dependent differences (e.g., <0.5%/decade). Further analyses were presented on how data could be combined to improve accuracy and how data gaps could be filled, particularly for nighttime using multiple instruments. Also discussed was how

[14] This includes data from the Solar Backscatter Ultraviolet (SBUV) instrument onboard Nimbus-7; the series of Total Ozone Monitoring Spectrometers (TOMS) onboard Nimbus-7, Japanese ADEOS, Russian Meteor-3 and NASA Earth Probe; and the series of SBUV/2 instruments on NOAA's Polar Orbiting Environmental Satellites (POES).

[15] KNMI is the Royal Netherlands Meteorological Institute [Koninklijk Nederlands Meteorologisch Instituut].
[16] BIRA-ISAD is the Belgian Insitute for Space Aeronomy; the acronym combines the Dutch and French names. [*Dutch*: Belgisch Instituut voor Ruimte-Aëronomie; *French*: Institut d'Aéronomie Spatiale de Belgique (IASB)].

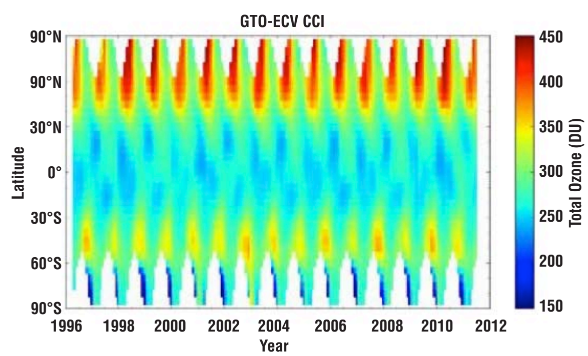
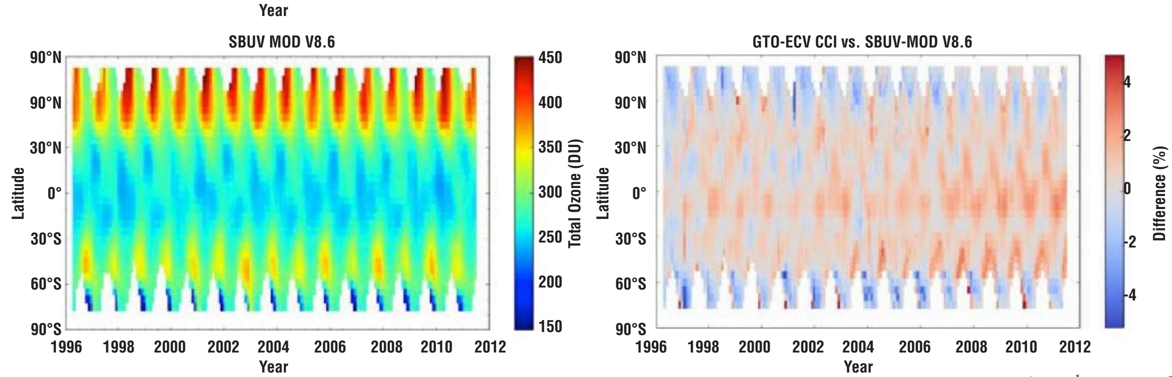


Figure 3. Shown here are *zonal averages* (average data around a latitude band) as a function of time from two merged satellite datasets from 1996 to 2011. The GOME Type Ozone (GTO), which are compiled using data from GOME, SCIAMACHY, and GOME-2, are shown in the top left; zonal averages from the SBUV Merged Ozone Data (MOD), which consist of data from a series of SBUV/2 instruments flying onboard the NOAA Polar Operational Environmental Satellites (POES) are shown in the lower left; and the difference between the two is shown on the right. The differences range from ±2%, with only a small latitudinal dependence. **Image credit**: Diego Loyola [DLR]



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AIRS Science Team Meeting Summary

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Introduction

The NASA Atmospheric Infrared Sounder (AIRS) Spring 2015 Science Team Meeting (STM) was held April 21-23, 2015, at the California Institute of Technology in Pasadena, CA. The AIRS Project at NASA/Jet Propulsion Laboratory (JPL) hosted the meeting; this report highlights some of the key results that were presented. The complete list of presentations can be viewed on the agenda posted at *airs.jpl.nasa.gov/events/34*. Presentation contents are posted at *airs.jpl.nasa.gov/events/34?s=true.*

Meeting Overview

The Spring AIRS STM alternates with the NASA Sounder STM held in the Washington, DC area during the fall[1]. While the Spring AIRS STMs focus specifically on the combined AIRS/Advanced Microwave Sounder Unit (AMSU) instruments on NASA's Aqua spacecraft, presentation topics include synergy between AIRS and other sounding systems, including other hyperspectral infrared sounders. The meeting being reported on here began with an opening plenary session, followed by a series of technical sessions across the three days that addressed:

- Project Status;
- Atmospheric Composition;
- Carbon Dioxide;
- Weather and Climate;
- Cloud Products and Science;
- Retrievals and Products;
- Applications;
- Instrument Calibration and Status; and
- Product Validation.

Highlights from the Technical Sessions

Meiyun Lin [Princeton University/National Oceanic and Atmospheric Administration (NOAA)'s Geophysical Fluids Dynamics Laboratory] described efforts to quantify lower tropospheric ozone using a combination of satellite observations and model simulations. Lower tropospheric ozone can be carried downward from the stratosphere by tropopause folds, or transported across the ocean from pollution sources over other continents. Lin showed that up to 20% of local ozone in the western U.S. may be transported from distant sources—notably from East Asia. Lin also discussed a third source: ozone produced by local pollution. Tropospheric ozone is a major pollutant, and these efforts have direct bearing on air quality regulations because most such regulations are intended to control only the local and regional pollution sources.

Xun Jiang [University of Houston] described comparisons of AIRS carbon dioxide retrievals with retrievals from the Tropospheric Emission Spectrometer (TES) onboard NASA's Aura platform and from the Japanese Greenhouse gases Observing SATellite (GOSAT), with observations obtained by *in situ* instruments, and with simulations generated by chemistry transport models. Jiang explained how she calculated the zonal means of the individual data sources and generated their annual and semiannual cycle components. She found that total carbon dioxide (CO_2) amounts (from GOSAT) and surface amounts (from *in situ* instruments) are more variable than mid-tropospheric amounts (from AIRS and TES). This is apparent in a decrease in cycle amplitudes with altitude. The models generally agree with the mid-troposphere satellite observations.

Yi-Hui Wang [JPL] used AIRS observations to show that large-scale ocean surface temperature features associated with semipermanent meanders in the Kuroshio Current in the western Pacific Ocean affect the overlying troposphere. She isolated the oceanic signal by regressing sea surface temperature observations onto a Kuroshio index varying at annual and longer time scales. A similar regression onto AIRS Level-3 atmospheric temperature data revealed overlying vertical and horizontal structure. The regressed signal from the European Centre for Medium-range Weather Forecasts (ECMWF) reanalysis had significantly smaller amplitudes than AIRS. Wang attributed the atmospheric differences to incomplete physical representations of small-to-medium scale interactions between ocean and atmosphere in the forecast model.

Brian Kahn [JPL] showed comparisons of ice cloud properties retrieved by AIRS and by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua platform. Because of its high spectral resolution, AIRS is more sensitive to small ice cloud particles in thin clouds than MODIS; on the other hand, AIRS lacks the very fine spatial resolution of MODIS. Kahn showed results that indicate that the best agreement is found over the tropics, where cirrus ice clouds are often thick and continuous. He also showed that disagreement is most often seen in retrievals of spatially heterogeneous, mixed-phase clouds.

[1] For the latest Sounder STM summary, see the January-February 2015 issue of *The Earth Observer* [**Volume 27, Issue 1**, pp. 39-40].

Alireza Farahmand [University of California, Irvine] showed that AIRS near-surface relative humidity retrievals could *hindcast* drought as well or better than standard indicators based on rainfall and soil moisture. He showed that known drought regions were apparent in global maps of AIRS-based drought indicators. Looking regionally at historic droughts, a time series of AIRS indices over North America and Russia showed large and significant indications of impending drought conditions. Farahmand argued that indices incorporating sounder retrievals provide drought forecast information to supplement more traditional information. He discussed plans for including the AIRS drought indicators in operational drought forecasting systems.

Larrabee Strow [University of Maryland, Baltimore County] shared research on creating Level-1C products from AIRS and the hyperspectral Cross-track Infrared Sounder (CrIS) onboard the Suomi National Polar-orbiting Partnership satellite. Derived from calibrated Level-1B radiances, Level-1C products have occasional problematic channels removed, and their observations are translated onto a common frequency set. The advantages of Level-1C include higher quality and the support of common analysis methods. Strow showed results that indicate excellent agreement between AIRS and CrIS Level-1C at locations where the instruments observe simultaneously. He argued that the AIRS and CrIS instruments are stable enough to detect climate signals on the order of 0.1 K/decade.

Closing Discussion and Summary

Participants at the Spring 2015 AIRS STM showed results based on nearly 12 years of observations. In addition to AIRS, three high-resolution infrared sounders and several microwave sounders are now in orbit. Reconciling and understanding the rich information in these large and detailed datasets are major scientific challenges, and will remain so for years. Further results on this effort will be presented at the Fall 2015 NASA Sounder STM, which will be held in October 2015, in Greenbelt, MD. ■

Geostationary Orbit as a New Venue for Earth Science Collaboration: Eleventh CEOS Atmospheric Composition Constellation Workshop

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combined UV and IR measurements could improve ozone retrievals in the lower troposphere.

As the ozone total column amounts project was moving along fairly satisfactorily, it was decided at the previous ACC Workshop, held in June 2014, to conduct a similar study for ozone profiles measured from the same nadir-looking instruments. Initial results using Solar Backscatter Ultraviolet Radiometer-2 (SBUV-2) and GOME-2 were presented. GSFC representatives showed how SBUV-2 profiles suffered from poor vertical resolution and how errors increased at high solar zenith angles. Representatives from the U.K.'s Rutherford Appleton Laboratory indicated that, using data from both UV and IR instruments on MetOp satellites, their algorithm could detect tropospheric ozone in the boundary layer. They further claimed that surface ozone could be retrieved if channels in the visible (i.e., the Chappius Bands) were included. The investigator from the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) illustrated tropospheric ozone features from IASI data. Since the IASI instrument is the operational sounder on MetOp, the data source will be available as long as MetOp satellites are in orbit.

Validating and reconciling these datasets is essential to make the data worthwhile for the users, both for research and policy makers—e.g., assessing the effectiveness of the Montreal Protocol. To meet strict requirements for accuracy and stability, a validation protocol is being established to intercompare the various datasets. Examples of protocol elements include horizontal and vertical resolution, spatial sampling, revisit time, and colocation.

Summary

Over the course of the three-day meeting, much was accomplished on behalf of the CEOS. With commitments from three space agencies, a constellation of five missions (three satellites in geostationary and two in low-Earth orbit) will measure air quality, with launch dates between 2016 and 2022. Efforts are underway to fine-tune instrument specifications, develop algorithms, plan calibration and validation activities, and harmonize the data flowing from all of the members of the ACC. ACC is also providing a forum for developing a GHG Constellation as six missions are planned, with possibly two more that are under consideration. The early stages of a constellation are already in place with NASA's OCO-2 and JAXA's GOSAT satellites already in orbit. The ACC also provides a forum for international collaboration to establish an ozone dataset suitable for climate research and for testing the effectiveness of the Montreal Protocol. ■

CERES Science Team Meeting Summary

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Overview

The spring 2015 Clouds and the Earth's Radiant Energy System (CERES) Science Team meeting was held May 5-7, 2015, at NASA's Langley Research Center (LaRC) in Hampton, VA. **Norman Loeb** [LaRC—*CERES Principal Investigator*] hosted and conducted the meeting. The major objectives of the meeting were to review the status of CERES instruments and data products, and to highlight the creation and improvement of key ancillary datasets used to generate CERES Earth radiation budget climate data records (CDRs).

Meeting presentations can be downloaded from the CERES website by clicking the "CERES Meetings" button on the left navigation bar at *ceres.larc.nasa.gov*.

Programmatic and Technical Presentations

The agenda for the first day of the meeting consisted of a series of programmatic and technical presentations.

Norman Loeb gave the opening "State of CERES" address. He covered a number of different topics and discussed the consolidation of the budget for the CERES measurement science team. He reported that the number of published journal articles and citations using CERES data products increased significantly during the past two years. Loeb summarized the status of major software deliveries for Terra and Aqua *Edition 4* and Suomi National Polar-orbiting Partnership (NPP) *Edition 1*, and provided the schedule of when data products will be publically available. Loeb also presented the CERES flight schedules, showing Flight Model 6 (FM6[1]) launching on the first Joint Polar Satellite System (JPSS-1) mission no earlier than late 2016 and the Radiation Budget Instrument (RBI) launching on JPSS-2 in 2021.

Kory Priestley [LaRC] then gave an update on CERES FM6 and the RBI. He presented an overview of the JPSS-1 satellite integration and testing activities. FM6 integration with the satellite is to be completed in May 2016 and then the satellite will be shipped to the launch site, Vandenberg Air Force Base, in September 2016. Priestley also presented an overview of the RBI instrument, showing drawings of the instrument modules and how it meets the CERES project requirements. The schedule timelines made it clear that RBI delivery is tied to JPSS-2 mission milestones.

[1] CERES has had seven Flight Models (FM) built. The Pre-FM flew onboard the Tropical Rainfall Measuring Mission (TRMM); FM-1 and -2 fly onboard Terra; FM-3 and -4 fly onboard Aqua; FM-5 flies onboard Suomi NPP; and FM-6 will fly onboard JPSS-1.

Susan Thomas [Science Systems and Applications, Inc. (SSAI)] provided information on the status of the CERES FM1 through FM5 instruments. She reported that the instrument gain and spectral response functions for FM1 through FM4, for both *Edition 3* and *Edition 4*, have been delivered through December 2014 for production processing. Thomas also presented validation results showing the major instrument calibration improvements in Edition 4, and presented CERES FM5 instrument performance and calibration results, which are well within the expected ranges.

Patrick Minnis [LaRC] summarized the recent activity of the *Clouds Working Group*, and also reported on Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) radiance comparisons between *Collection 5* and *Collection 6*. He also reported on validation efforts to compare single-layer cloud phase determination from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) with those from MODIS onboard Aqua using the CERES cloud algorithm. Minnis also provided analysis of the INSAT-3D[2] geostationary satellite images, with plans to include the data in the clouds-processing software.

Wenying Su [LaRC] reported on the validation of the CERES *Edition 4* Angular Distribution Models (ADMs). She presented the shortwave (SW) and longwave (LW) flux uncertainties found in instantaneous measurements and at global scales. Su also outlined the differences in footprint size for Suomi NPP and Aqua, based on Visible Infrared Imaging Radiometer Suite (VIIRS) and MODIS cloud property retrievals, respectively, and how these affect the Suomi NPP fluxes inverted using Aqua ADMs. She also discussed the use of rotating azimuth plane scans for building a set of ADMs for RBI, should they be needed.

David Kratz [LaRC] reported on the status of the SW surface-only flux algorithms, which focused on a preliminary analysis of the LW and SW surface-only flux algorithm results using the Edition 4 inputs that indicated improved accuracies for most locations. Validation study results were also presented, demonstrating that revisions to both the LW and SW algorithms appear to be working well, though further revisions to the cloud transmission method and/or overcast albedo method are needed for SW Model B.

[2] INSAT-3D launched in July 2013 and is one in a series of meteorological, data relay, and satellite aided search and rescue satellites developed by the Indian Space Research Organisation (ISRO).

Seiji Kato [LaRC] presented an update on the activities of the *Surface and Atmospheric Radiation Budget Working Group*. He reported that the *Edition 4* Synoptic Radiative Fluxes and Clouds (SYN) production code had processed four validation months with no major issues. He also described Modern Era Retrospective Analysis for Research and Applications 2 (MERRA2) evaluation and surface flux differences—with and without data from the Atmospheric Infrared Sounder (AIRS) onboard Aqua. Kato also presented comparisons of Edition 4 emissivity values.

Dave Doelling [LaRC] reported on the activities of the *Time Interpolation and Space Averaging (TISA) Working Group*. He summarized the TISA team's approaches for an automated method to detect spurious data in geostationary (GEO) satellite imagery, which included a comparison between the human vs. automated mask detection rates. Doelling also reviewed efforts for producing Edition 4 monthly, one-hourly cloud properties using one-hourly, five-channel GEO cloud retrievals. The TISA Edition 4 processing codes for the one-degree-resolution Single Scanner Footprint (SSF1deg) and Synoptic Radiative Fluxes and clouds (SYN1deg) products were delivered and contained approximately twice the number of parameters as the previous Edition 3.

Paul Stackhouse [LaRC] presented an update on the CERES Fast Longwave and Shortwave Radiative Fluxes (FLASHFlux) product. He reported on his experiences and provided two examples of using the Renewable Energy Project Analysis Software (RETSCreen) Performance Plus, which the Canadian government developed to help it make clean-energy decisions and is now used in a number of countries around the world, including Brazil, South Korea, and the U.S. Stackhouse also presented images of daily averages in support of the Arctic Radiation IceBridge Sea and Ice Experiment (ARISE) field campaign.

Norman Loeb discussed upcoming improvements to the Energy Balance and Filled (EBAF) *Edition 4.0* product. This version will be based upon the latest algorithm improvements used in CERES processing and an updated methodology for determining clear-sky top-of-atmosphere (TOA) radiative fluxes in partly cloudy conditions. The new algorithm will use more MODIS channels in the narrowband-to-broadband regressions and will be extended to conditions in which the underlying surface is heterogeneous (i.e., a mix of ice and ocean, snow and land). This change will have the greatest impact on SW TOA fluxes at high latitudes. At the surface, bias corrections will be adjusted to account for improvements in algorithms and input data. The uncertainty estimate used in the Lagrange multiplier algorithm will also be revised. The current plan is to release five years of EBAF Edition 4.0 data from 2005 through 2010 in early 2016.

Jonathan Gleason [LaRC] described the activities of the CERES Data Management Team (DMT). He announced that a second release of the CERES AuTomAted job Loading sYSTem (CATALYST) contained a significant number of enhancements while the initial version has processed more than 380 thousand jobs thus far. Gleason also announced the second release of the Production Request (PR) Tool and its enhancements to include search function improvements. He reported that the DMT has made 22 software and data deliveries since October 2014.

John Kusterer [LaRC] gave an update on the activities of the Atmospheric Sciences Data Center (ASDC), during which he showed user and processing metrics for each CERES product. He reported that ASDC is participating in a Private Cloud Pilot[3] and will be identifying potential processing candidates to run on the Private Cloud in the coming months. Kusterer also presented Big Earth Data Initiatives to include tasks working on current versions of CERES data using Open-source Project for a Network Data Access Protocol (OPeNDAP), Global Change Master Directory (GCMD) and Earth Observing System (EOS) Clearing HOuse (ECHO) Reconciliation, Global Imagery Browse Service (GIBS), and Digital Object Identifier (DOI).

Sarah Crecelius [SSAI] provided the "CERES Education and Outreach Overview," noting that since January 2010 the *My NASA Data* website (*mynasadata.larc.nasa.gov*) has attracted over 717,000 users. She also reported on the projects and companies that the Students' Cloud Observations On-line (S'COOL) project has supported, including Pubic Broadcast Service (PBS) SciGirls, Earth Day, and #SkyScience.

Invited Science Presentations

A special session took place Wednesday afternoon to discuss improvements to key ancillary datasets used in CERES processing—see **Table 1**.

[3] Private Cloud Pilot is a reuse of computer hardware to demonstrate the capability of an on-demand processing within the LaRC Science Directorate, similar to the Amazon Cloud.

Table 1: CERES contributed science presentations from day two (Wednesday, May 6).

Speaker	Institution	Topic
Seung-Hee Ham	Oak Ridge Associated Universities ORAU	Correction of directional effects of incident radiation on ocean surface emissivity for CERES LW irradiance computations
Xianglei Huang	University of Michigan	A global database of spectral surface emissivity for the entire LW spectrum: Development, validation, and application

Table 1 (cont.): CERES contributed science presentations from day two (Wednesday, May 6)

Speaker	Institution	Topic
Jae Lee	University of Maryland	Diurnal differences in OLR climatologies and anomaly time series
Rhys Parfitt	Imperial College, U.K.	A study of GERB shortwave calibration evolution: A cross-comparison study with CERES
Takmeng Wong	LaRC	ERBS tilted nonscanner update
Robert Levy	GSFC	Creating a consistent aerosol optical depth (AOD) record from MODIS and VIIRS
Michael Bosilovich	GSFC	Status of GMAO reanalysis and future plans
Jae Lee	University of Maryland	Day-night differences in AIRS Version-6 water vapor
Seiji Kato Fred Rose	LaRC SSAI	MERRA-2/AIRS/MODIS temperature/humidity comparisons
Andrew Dessler	Texas A&M University	Using CERES data to constrain climate sensitivity
Noel Baker	ORAU	Constraining climate model ensemble projections using radiation process-oriented performance metrics
Hailan Wang	SSAI	The role of DYNAMO observations in improving GMAO reanalysis and CERES-like surface atmosphere radiation estimation
Laura Hinkelman	University of Washington	Evaluation of MERRA using CERES EBAF
David Fillmore	Tech-X Corporation	SARB aerosol datasets-assimilation of Terra MODIS, Aqua MODIS, and Suomi NPP VIIRS MODIS-like AOD
Hai-Tien Lee	University of Maryland	Global warming, tropical expansion, and ENSO in OLR (a QC benchmark exercise)
Kyle Itterly	SSAI	On the sensitivity of the diurnal cycle in the Amazon to convective intensity

Robert Levy [NASA's Goddard Space Flight Center (GSFC)] opened the session by discussing how to adapt the MODIS aerosol dark model to use VIIRS radiance, beginning with how the algorithm works and continuing through improvements between *Collection 5* and *Collection 6*. Part of the change is due to improved calibration techniques—especially on Terra MODIS. The VIIRS aerosol product produced at Interactive Data Processing Segment (IDPS) for Suomi NPP uses different land and ocean algorithms. The ocean algorithm has a MODIS heritage *circa* 1997. When the current MODIS dark target aerosol algorithm is used to process VIIRS data, a 15% high bias is seen over oceans and a 5% low bias is found over land. The VIIRS bias seems to be related to calibration and is consistent with reported MODIS-VIIRS calibration differences. The routine NASA-VIIRS aerosol product will be processed at University of Wisconsin.

Michael Bosilovich [GSFC] provided information on improvements in MERRA2 analysis, which is updated to the Goddard Earth Observing System (GEOS) 5 model with a goal of incorporating modern satellite observations while reducing spurious trends in the data. MERRA-2 will include satellite-derived aerosol optical depth. The earlier reported imbalance between precipitation and evaporation caused by analysis adjustments and sensitivity to observing system changes has been corrected. The precipitation is improved over ocean, but excess precipitation occurs in the tropics associated with high terrain. The model shows an increase in upper tropospheric water vapor as compared to MERRA, due to improved model parameterizations, especially in the tropics. TOA cloud forcing is very consistent with CERES EBAF, except for excess Western-Pacific convection. Release of MERRA-2 data is expected in July 2015.

Jae Lee [University of Maryland] presented results on the latest AIRS water vapor dataset—*Version 6.19*. To correct for a bias in total precipitable water retrievals that results in lower daytime vs. nighttime measurements, the algorithm has removed SW channels and added LW channels near weak water vapor lines, and removed peaks in the strongest water vapor lines. A second-pass water-vapor-retrieval step was also added. The updated version corrected the total precipitable water problem and removed stratospheric values that exceeded physical limits.

Fred Rose [SSAI] presented a comparison of the current GEOS 5.4.1, MERRA, MERRA-2, and European Centre for Medium-Range Weather Forecasts (ECMWF) ReAnalysis [ERA] to AIRS and EBAF data. The GEOS 5.4.1 and MERRA-2 are 50% and 100% moister, respectively, as compared to AIRS. MERRA-2 had a lower skin temperature and larger air temperature

Table 2: CERES contributed science presentations from day three (Thursday, May 7).

Speaker	Institution	Topic
Ping Yang	Texas A&M University	A new parameterization of ice cloud radiative properties
Bill Smith, Jr.	LaRC	New global estimates of cloud ice and liquid water path from MODIS using a profiling method
S. Sun-Mack	SSAI	Build 3D cloud properties with A-Train CALIPSO, CloudSat, CERES, and MODIS (C3M) data
Tyler Thorsen	University of Washington	The capabilities of lidar datasets for radiative heating rate and flux calculations
Kris Bedka	LaRC	A CERES-consistent cloud property climate data record using AVHRR data: Version 1 delivery results
Xiquan Dong	University of North Dakota	A radiation closure study of Arctic cloud properties
Patrick Taylor	LaRC	The influence of sea ice on Arctic low cloud properties and radiative effects
Robyn Boeke	SSAI	Evaluation of the Arctic radiation budget in Coupled Model Intercomparison Project Phase 5 CMIP5 models

diurnal variation than AIRS. The global mean clear-sky outgoing LW radiance (OLR) would be reduced by 1 W/m^2 between GEOS 5.4.1 and MERRA-2. There was little difference between the MERRA2 runs with and without AIRS data.

David Fillmore [Tech-X Corporation] presented results of assimilating MODIS Collection 6 and VIIRS aerosol data into the Model for Atmospheric Transport and Chemistry (MATCH). The model provides estimates of aerosol properties when instantaneous values are not available in higher level CERES products. Fillmore also noted that the MODIS Collection 6 aerosol levels are smaller over ocean and larger over land when compared to those from VIIRS. The MATCH assimilation process reduces bias and increased correlation between VIIRS and MODIS aerosol optical depth.

Contributed Science Presentations

A variety of topics were covered during the contributed science presentations (see **Tables 1** and **2**), which took place on the second and third days of the meeting. These included climate model assessments, validation efforts, and discussions about algorithm improvements.

Two presentations focused on surface emissivity. **Seung-Hee Ham** [SSAI] introduced a correction for the spherical albedo and emissivity assumption used in the Fu-Liou radiation model[4] for ocean surfaces. Using this model, along with meteorological, cloud and aerosol profiles, Ham could calculate broadband fluxes throughout the atmosphere and surface, and provide a consistency check between inputs and observations for CERES products. This method creates a negative bias of between 1 and 2 W/m^2 in surface irradiance as compared to a directional model. The bias increases with surface temperature and decreases with humidity. Using the anisotropic factor, Q, a polynomial was generated to correct the spherical albedo. **Xianglei Huang** [University of Michigan] investigated the impact of improved emissivity models for various surface types, especially in the far infrared. In this work, a gridded database of Cooperative Institute for Meterological Satellite Studies (CIMSS) MODIS emissivity retrievals at 6 infrared wavelengths was matched to 11 surface types. These emissivities are validated against results from the Infrared Atmospheric Sounding Interferometer (IASI)[5], which have a systematic bias in the emissivity of 0.01.

Several scientists reported on how CERES compares to other instruments. **Jae Lee** showed a comparison of AIRS OLR diurnal climatology to CERES OLR from the EBAF product for a 12-year coincident period. The global AIRS all-sky and clear-sky OLR is 7 and 7.5 W/m^2 higher during the day (measured at 1:30 PM local Equatorial crossing time) than at night (1:30 AM), respectively. The global CERES all-sky OLR mean is close to the AIRS night value. The CERES global and AIRS day-night average clear-sky OLR are closely matched despite using very different methods in determining clear-sky OLR. These differences may be a result of sampling. **Rhys Parfitt** [Imperial College, U.K.] described how the Geostationary Earth Radiation Budget (GERB) SW channel can be compared with CERES FM2 by using the ratio of radiances when they had similar viewing geometry. The

[4] The Fu-Liou radiative transfer model is used for radiative transfer calculations.

[5] IASI is on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) MeTOp polar-orbiting platform.

unfiltering factor is used to account for wavelength variations in sensor filters and used to convert filtered radiance into unfiltered radiances; it turns out to be the better variable than radiance or *scene type*—which includes information about the underlying surface (e.g., ocean, land, snow) and cloud cover—when attempting to understand instrument spectral response. **Takmeng Wong** [LaRC] presented results from a new correction to the Earth Radiation Budget Experiment (ERBE) SW Nonscanner instrument measurements that accounts for the tilt in the Nonscanner instrument, which affects the last six years of the dataset—coincident with CERES observations. The tilt resulted in a 16-W/m^2 reduction in SW flux. Once instrument calibration was confirmed (with a pitch maneuver), the tilt angle was calculated to be 16.2°. After incorporating the correction into the ERBE flux inversion algorithm, the revised TOA fluxes were consistent with CERES to within 0.2 W/m^2—see **Figure**.

The use of CERES and model data has been applied to understanding climatic change. **Hai-Tien Lee** [University of Maryland] used the High-resolution Infrared Radiation Sounder (HIRS)-derived OLR peaks, as a proxy for the subtropical subsidence zone, to define the tropics. The research shows that the width of the tropics has been increasing by 0.34° in latitude per decade. The reanalysis shows a good correlation, but larger increase in the width (between 0.36° and 0.46° per decade). A comparison with the Multivariate El Niño and Southern Oscillation (ENSO) Index [MEI] shows good correlation with the tropics contracting during El Niño and expanding during La Niña events. **Kyle Itterly** [SSAI] created statistics for five bins based on the amount of convection in the Amazon River Valley. The OLR peaks three hours earlier on convective days then stable ones. He also related stability indices to onset, intensity, and duration.

Andrew Dessler [Texas A&M University] discussed Equilibrium Climate Sensitivity (ECS) using a simple parameterization model. The climate sensitivity is evaluated from deviation to the normal using observations and Representative Concentration Pathway 8.5 (RCP8.5) climate models. The various models agree on sensitivity from temperature, lapse rate, relative humidity, and albedo deviations when compared with MERRA observations. The control run agrees with the sensitivity due to change in clouds, giving a feedback of approximately 0.7 W/m^2 K. CERES TOA and model data supports an ECS of 3.0 ± 1.4 °C.

Noel Baker [Oak Ridge Associated Universities] presented *intelligent ensembles,* an approach to weight model runs based on their accuracy in parameters that are important to the user. The global radiation parameters of the RCP 8.5 model runs for the time period before the present are compared to observations to determine the weights. Using this method, the global surface temperature, precipitation, and surface radiation is between 10-and-20% higher than the multimean ensemble results. However, this is not consistent across regions due to different physical processes being dominate in any given region. Additional studies are planned to understand the causes of these differences.

Hailian Wang [SSAI] examined the impact of including higher-density surface observations obtained during the Dynamics of Madden-Julian Oscillation (DYNAMO) field campaign, which took place in the Indian Ocean from October 2011 to March 2012, in the Global Modeling and Assimilation Office (GMAO)

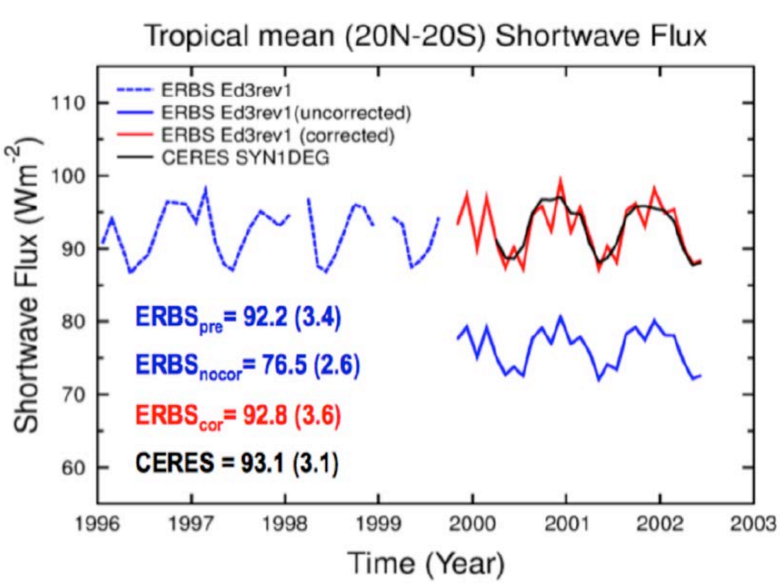

Figure. Tropical mean reflected shortwave flux at the top-of-atmosphere from a reprocessed version of data from the Earth Radiation Budget Experiment (ERBE) nonscanner instrument onboard the Earth Radiation Budget Satellite (ERBS) for January 1996 through June 2002, and from CERES for March 2000 through June 2002. The ERBE/ERBS nonscanner operated nominally from November 1984 to September 1999, but suffered an anomaly during a routine calibration operation on October 5, 1999, that caused the instrument to be stuck in an off-nadir position with the sensor field-of-view partially blocked by the instrument housing. Takmeng Wong and colleagues developed a revised algorithm to remove the effect of the instrument tilt anomaly, enabling six more years (October 1999 through August 2005) of data to be recovered. This figure shows the ERBS record prior to the anomaly (blue dashed line), the uncorrected (solid blue line), and corrected (red line) ERBS record after the anomaly, and the CERES record from the Synoptic Radiative Fluxes and clouds (SYN1deg) product (black line). **Image credit:** Takmeng Wong, NASA's Langley Research Center

MERRA2 assimilation cycle. The resulting meteorological fields were used in the Fu-Liou model to calculate CERES-like fluxes. The surface downward longwave increased by 5 W/m^2 regionally. During dry periods, the OLR increased between 2 and 3 W/m^2.

Laura Hinkelman [University of Washington] compared the MERRA2 radiative fluxes with CERES EBAF observations. The difference in TOA fluxes is attributed to MERRA2 data having too much high cloud cover in the tropics and not enough low clouds in stratus regions and mid-latitude continents. Another explanation may be low aerosol values. The SW flux time-series correlation is poor, but overall the energy budgets matched closely.

The morning session on the last day addressed how CERES-produced cloud properties can be improved. **Ping Yang** [Texas A&M University] has defined a two-habit model (THM), for use in retrieving ice microphysical properties. (This is an alternative ice crystal model to the single hexagon column model that is often used.) The THM showed much better agreement with field-measurements and consistency between visible- and infrared-derived optical depth. The THM was implemented in the Fu-Liou radiation model. The resulting fluxes under clouds composed of ice crystals showed good agreement with CERES TOA observation. The LW Cloud Radiative Forcing (CRF) shows good agreement, but SW CRF still has some problems. **Bill Smith, Jr.** [LaRC] described an empirical method to describe cloud ice and water content profile distributions based on Visible Infrared Solar-Infrared Split Window Technique (VISST)-retrieved properties. The climatological profiles were created using Atmospheric Radiation Measurement (ARM) MICROBASE and CloudSat data and model outputs. The single-layer assumption is the biggest source of error. **Sunny Sun-Mack** [SSAI] determined the best four MODIS imager channels as a function of snow/ice cover and day/night for finding analog pixels to match CALIPSO and CloudSat off-track profiles. The analog MODIS properties showed good global agreement when compared with the original properties (i.e., optical thickness, cloud mask, height, particle size) and skill similar to CALIPSO comparisons. The correlation as a function of distance showed good agreement out to 30 km (~19 mi).

Tyler Thorsen [University of Washington] discussed the strengths and weaknesses of ground- and space-based lidars in accurately representing the cloud and aerosol vertical profiles. CALIPSO does not detect some of the surface aerosol levels, but supports better radiative heating profiles than ground-based measurements.

The CERES cloud properties were compared against other data products. **Kris Bedka** [LaRC] presented results of a cloud property CDR obtained by processing Advanced Very High Resolution Radiometer (AVHRR) data using the CERES clouds algorithm. The CDR contains cloud mask, phase, optical depth, effective radius, effective pressure, effective temperature, and effective height. It also contains top and base information, overshooting top detection, clear-sky skin temperature, and CERES-derived SW broadband albedo and LW broadband flux. An updated AVHRR calibration was applied before processing. The cloud fraction was slightly less when MODIS data were used for the same months. **Xiquan Dong** [University of North Dakota] compared the Edition 2 and Edition 4 CERES cloud properties to the ARM Northern Slope of Alaska measurements. The Edition 4 optical depth and Liquid Water Path (LWP) agreed well with single layer water clouds over snow-free surfaces from the ARM measurements. The CERES particle radii are 2 μm larger than surface observations. Under snow surfaces, the CERES optical depths are slightly lower, LWPs are slightly higher, and radii are 4 μm larger than ARM measurements.

The meeting ended with several talks on the impact of Artic sea ice on the climate. **Patrick Taylor** [LaRC] explored relationships between Arctic cloud properties and sea ice concentration as a function of boundary-layer stability and season using CERES, CALIPSO, CloudSat, and MODIS (C3M) data. He found that cloud fraction decreases with increased sea ice concentration. Artic sea ice changes produce a negative feedback in the summer, dominated by a SW Cloud Radiative Effect (CRE) and a positive feedback in fall and winter, dominated by LW CRE. **Robyn Boeke** [SSAI] used the Coupled Model Intercomparison Project 5 (CMIP5) dataset to investigate how the sensitivity in cloud amount (LW CRE) is related to surface temperature change. The models differ on whether surface albedo or a cloud greenhouse effect would be the significant factor.

Summary

The meeting was very productive with validation of the Edition 4 algorithms entering production and observation and model comparisons using the CERES data. An energetic exchange took place that addressed the best path forward to acquire and produce key ancillary datasets needed in the future as new satellites are flown with CERES and the future RBI.

The next CERES Science Team meeting will be held September 1-3, 2015, at the University of Washington, Seattle, WA. ■

Early Adopters Prepare the Way to Use ICESat-2 Data

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Introduction

NASA's Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) mission is currently on schedule for an October 2017 launch from Vandenberg Air Force Base in California. ICESat-2 uses a new measurement concept that is expected to provide added value to the user community through its highly dense and fine precision observations, improved measurements over sloped areas, and huge degree of freedom in how the data can be analyzed[1].

Under the rubric of new ways of "doing business," the ICESat-2 Mission Applications Team has organized the *ICESat-2 Early Adopter Program*. This program allows those groups and individuals who have a direct or clearly defined need for a particular mission's data products, have an existing application or decision-making activity, and who are planning to apply their own resources (i.e., funding, personnel, facilities, etc.) to demonstrate the utility of that mission's data for their particular application. *Application* is defined in this usage as an innovative use of a mission's data products in decision-making activities for societal benefit.

The Early Adopter Program has a goal to accelerate the use of mission data products after launch of the satellite by providing specific support to those Early Adopters (EAs) who volunteer and commit to engage

Artist's rendering of ICESat-2. **Image credit:** NASA

in prelaunch research. It is expected that this prelaunch research will result in a fundamental understanding of how these data products can be scaled and integrated into organizations' policy, business, and management activities to improve decision-making efforts—see **Figure 1**. The EAs may either be organizations who will use the data in decision making (*end-users*) or scientists or technical people in a science-based organization who will conduct the prelaunch research for an end-user, and then work with the decision-making organization to ensure routine use of the new product.

To date, only two missions have established an Early Adopter Program: NASA's Soil Moisture Active-Passive (SMAP) mission[2], hosting a total of 54 EAs, and ICESat-2, currently with 16 EAs and more on the way. The Early Adopter Program is a structured format for mission applications that is quickly catching on and revolutionizing the way NASA approaches application of mission data products.

To demonstrate the role of EAs in mission activities, this article will address ICESat-2 mission specifics to provide a context for explaining how an ICESat-2 Applications

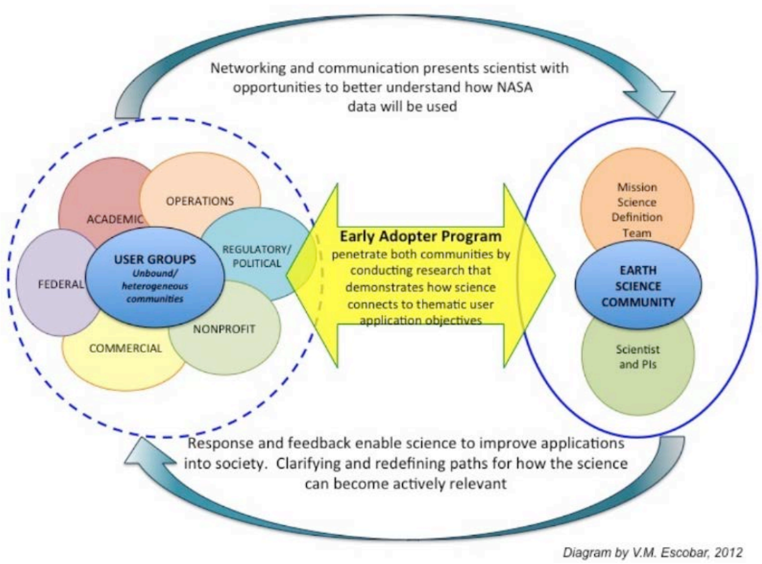

Figure 1. This diagram illustrates the communication feedback loop between the Early Adopter User Groups [*left*] and Earth Science Community [*right*]. **Image credit:** Vanessa Escobar

[1] To learn more, see "Improving Operational Awareness Through ICESat-2 Applications Workshops: Cross-mission Development" in the May–June 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 3**, pp. 15-20].

[2] To learn more about the EA program for SMAP, which was the first mission to employ the concept, see "The SMAP Early Adopters Program and the Impact on Prelaunch Research" in the January-February 2015 issue of *The Earth Observer* [**Volume 27, Issue 1**, pp. 24-28]

Workshop both embodied and represented the goals of the EA Program.

ICESat-2 Mission Characteristics

The Advanced Topographic Laser Altimeter System (ATLAS) instrument onboard ICESat-2 employs a micro-pulse, multibeam, photon-counting approach, which provides more extensive and denser coverage compared to its predecessor, the Geoscience Laser Altimeter onboard ICESat, which used an analog detector system[3]. ATLAS is currently in integration and testing, with delivery and integration into the spacecraft planned for summer 2016.

The ICESat-2 mission has four science objectives related to studies of ice sheets, sea ice, and vegetation, which drive the instrument design. The objectives are to:

- quantify polar ice-sheet contributions to current and recent sea-level changes and their linkages to climate conditions;
- quantify regional signatures of ice-sheets to assess mechanisms driving those changes and improve predictive ice-sheet models;
- estimate sea-ice thickness to examine exchanges of energy, mass, and moisture between ice, the ocean, and the atmosphere; and
- measure vegetation canopy height as a basis for estimating large-scale distribution of biomass and changes in biomass.

The processing of the ICESat-2 data will be done at NASA's Goddard Space Flight Center (GSFC) and data products will be distributed to the public via the National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC). More information on the mission and applications activities can be found via the ICESat-2 website at *icesat.gsfc.nasa.gov/icesat2*.

[3] To learn more about the differences between ATLAS and GLA, please refer to "MABEL and the ICESat-2 Mission: Photon-counting Altimetry from Air and Space" in the September–October 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 5**, pp. 5-6].

ICESat-2 Mission Applications Program

The ICESat-2 Mission Applications Program works in conjunction with the ICESat-2 Project Science Office to provide a framework for building a broad and well-defined user community during the prelaunch phases of the mission to maximize the use of data products after launch. The goals of the program are to provide insight into the range of potential uses of new satellite observations and help communicate the value and impact of mission products. Through a multiscale communications approach, the program explores if and how ICESat-2 measurements can effectively be used by potential end-users given their own measurement requirement needs.

The focus of the ICESat-2 Applications Team—the current membership of which is listed in **Table 1**—is to explore the advantages of the photon-counting approach, by working with the users to identify opportunities for using the new measurements in specific applications. To do this, the Mission and the Applications Team is selecting a group of ICESat-2 EAs who will be provided the opportunity to partner with a Science Definition Team or Project Science Office member that guides them on the use of prelaunch simulated ICESat-2 data and communicates to the Mission the lessons learned and successes of their research efforts. These activities help to ensure that users will begin using ICESat-2 data as soon as they become available after launch, and allow for faster integration of ICESat-2 data into decision-making activities that benefit society. The applications activities facilitate collaboration with broad communities of data users involved in the following areas of interest to the mission: ice sheets, sea ice, vegetation, atmosphere, inland water, and the ocean. These thematic areas are intentionally chosen to correlate with the science objectives of ICESat-2 and are intended to help the people involved in the mission better understand the potential utility of the mission's data and foster innovative use of the measurements to inform actionable decisions that are relevant and of value to society.

Table 1. ICESat-2 Applications Team Members as of June 2015

Role in ICESat-2 Mission	Members	Affiliation
ICESat-2 Deputy Project Administrator (DPA)	Vanessa Escobar	NASA's Goddard Space Flight Center (GSFC)/SSAI
ICESat-2 Applications Coordinator	Sabrina Delgado Arias	GSFC /SSAI
ICESat-2 Program Applications Lead	Molly Brown	University of Maryland
ICESat-2 Science Team Applications Liaison	Mike Jasinski	GSFC

Table 1 (cont.). ICESat-2 Applications Team Members as of June 2015

Role in ICESat-2 Mission	Members	Affiliation
ICESat-2 Deputy Project Scientist	Tom Neumann	GSFC
ICESat-2 Science Team Leader	Lori Magruder	University of Texas
NASA Headquarters Applied Sciences Representative	Woody Turner	NASA Headquarters (HQ)

A key element of the ICESat-2 Applications Program is communication and engagement with interested communities to discover and demonstrate innovative uses and practical benefits of ICESat-2. Various engagement events are held throughout the year to elicit feedback from the mission scientists and end-users regarding product utility, uses, and challenges. These events include:

- **workshops:** meetings that are widely announced and open to the public with the intent that a broad diversity of topics is used to facilitate information to audiences with diverse interests;
- **focus sessions:** small events tailored to specific communities to provide detailed information about a connected group of products or applications; and
- **tutorials:** information transfer events that address potential synergies designed to leverage innovation on how to best combine datasets from other missions (NASA and others) with those of ICESat-2.

As an example, the nature and tone of a specific workshop is discussed in the remainder of this article.

The Second ICESat-2 Applications Workshop

Building on the success of the first workshop[4] (which was held at GSFC on April 12, 2012), the ICESat-2 Applications Team hosted its Second Applications Workshop at the GSFC Visitor Center in Greenbelt, MD, on March 10-11, 2015. The two-day workshop brought together 52 participants (including some who participated remotely) from universities, government agencies, and the commercial/private sector, including four of the mission's EAs. The workshop participants discussed the functionality of the ICESat-2 data products and their potential application to inform activities and decisions that leverage the mission's science objectives. (The full workshop report will be posted to the ICESat-2 Events and Activities page at *icesat.gsfc.nasa.gov/icesat2/apps-events.php*).

The goals for the workshop were to:

- provide an overview of the ICESat-2 Mission and its planned data products;
- define critical needs shared by the different communities present;
- identify potential applications for the planned ICESat-2 data products and potential products of value to the community that are not currently planned by the mission; and
- foster the development of new collaborations.

Early Adopter Presentation Summaries

The ICESat-2 EAs play a vital role in linking science to decision-supported applications. The workshop showcased the prelaunch research of three EAs and had the participation of four EAs in total—see **Table 2**. Those presenting their research were asked to address the following questions for the workshop:

- What decision(s) is your Early Adopter research informing?
- What is the expected impact?
- Why should we, as a society, care?

[4] To read a report about the first workshop, visit *go.nasa.gov/1JxjNj6*.

Table 2. ICESat-2 Early Adopters (Early Adopters can cover multiple applications)

Early Adopter PI(s) and Institution	ICESat-2 Contact	Applied Research Topic
Prediction of Changing Ice Environment		
Pamela G. Posey** [Naval Research Laboratory, NASA's Stennis Space Center]	Sinead L. Farrell [NASA's Goddard Space Flight Center (GSFC)]	Use of ICESat-2 data as a validation source for the U.S. Navy's ice forecasting models

** Angela Ottoson [U.S. National Ice Center] presented on behalf of Pamela G. Posey for the National Research Laboratory.

Table 2 (cont.). ICESat-2 Early Adopters (Early Adopters can cover multiple applications)

Early Adopter PI(s) and Institution	ICESat-2 Contact	Applied Research Topic
Andrew Roberts [Naval Postgraduate School] Alexandra Jahn [University of Colorado at Boulder] Adrian Turner [Los Alamos National Laboratory]	Ron Kwok [NASA/Jet Propulsion Laboratory (JPL)]	An ICESat-2 emulator for the Los Alamos sea ice model to evaluate Department of Energy, Department of Defense, and National Center for Atmospheric Research sea ice predictions for the Arctic
Andy Mahoney [University of Alaska Fairbanks (UAF), Geophysical Institute]	Sinead Farrell and Ron Kwok	Repeat altimetry of coastal sea ice to map landfast sea ice (i.e., fast ice) extent for research and operational sea ice analysis
Stephen Howell [Environment Canada, Climate Research Division]	Ron Kwok	Use of ICESat-2 data for Environment Canada observational applications and prediction systems
Inventorying, Monitoring, and Planning for Land Management		
Nancy F. Glenn [Boise State University, Boise Center Aerospace Laboratory]	Amy Neuenschwander [University of Texas]	Improved terrestrial carbon estimates with semiarid ecosystem structure
Lynn Abbott* and Randy Wynne, [both at Virginia Polytechnic Institute and State University]	Sorin Popescu [Texas A&M University]	Detection of ground and top of canopy using simulated ICESat-2 lidar data
Wenge Ni-Meister* [Hunter College of The City University of New York]	Sorin Popescu	Mapping vegetation with on-demand fusion of remote sensing data for potential use of U.S. forest service inventories and fire fuel estimates
G. Javier Fochesatto, [UAF, Geophysical Institute] Falk Huettmann [UAF, Institute of Arctic Biology]	Lori Magruder [University of Texas]	Using ICESat-2 prelaunch data in high latitude terrestrial ecosystems to allow for continuous monitoring of boreal forests and Arctic tundra
Hazard Monitoring and Forecasting		
Volcanoes – Pyroclastic Flow Hazards		
Greg Babonis [State University of New York at Buffalo]	Alex Gardner	Applications of ICESat-2 in volcanic and geohazards-related research
Wildfires		
Birgit Peterson [U.S. Geological Survey]	Amy Neuenschwander	Evaluation of ICESat-2 ATLAS data for wildland fuels assessments
Floods		
Charon Birkett* [UMD, Earth System Science Interdisciplinary Center (ESSIC)]	Mike Jasinski	The application of altimetry data for the operational water level monitoring of lakes and reservoirs

* Participated in the workshop.

Table 2 (cont.). ICESat-2 Early Adopters (Early Adopters can cover multiple applications)

Early Adopter PI(s) and Institution	ICESat-2 Contact	Applied Research Topic
Guy J-P. Schumann* [University of California, Los Angeles (UCLA), Joint Institute for Regional Earth System Science & Engineering]	Mike Jasinski	Assessing the value of the ATL13 inland water level product for the Global Flood Partnership
Kuo-Hsin Tseng [National Central University, Taiwan, Center for Space and Remote Sensing Research]	Mike Jasinski C.K. Shum [Ohio State University, School of Earth Sciences]	Using ICESat-2 ground and water level elevation data towards establishing a seasonal and flash flood early warning system in the lower Ganges-Brahmaputra-Meghna River Basin
Rodrigo C.D. Paiva [Federal University of Rio Grande do Sul, Brazil, Hydraulic Research Institute]	Mike Jasinski C.K. Shum	Improved river hydrodynamics estimates from ICESat-2 for hydrology predictions
Sea Level Rise and Coastal Hazards		
Sudhagar Nagarajan [Florida Atlantic University]	Bea Csatho [University of Buffalo]	Incorporation of simulated ICESat-2 (MABEL) data to increase the time series and accuracy of Greenland/Antarctica Ice Sheet DDEM (Dynamic DEM) - A feasibility study
Air Quality		
Lucia Mona [Institute of Methodologies for Environmental Analysis of the National Research Council of Italy (CNR-IMAA)]	Steve Palm	Aerosol optical properties in polar regions with ICESat-2 lidar

* Participated in the workshop.

Summaries of the three formal EA presentations follow.

Angela Ottoson [U.S. National Ice Center (NIC)] presented on behalf of **Pamela Posey** [U.S. Naval Research Laboratory (NRL)]. She described Posey's EA work with the NRL and the end-user perspective on behalf of the NIC. Specifically, Ottoson described NRL's efforts to test the prelaunch data (i.e., from Operation IceBridge and from the MABEL[5] ICESat-2 airborne simulator) to evaluate the use of ICESat-2 data for use within the Arctic Cap Nowcast/Forecast System (ACNFS[6])—one of two U.S. Navy's operational ice forecasting systems. The ACNFS produces a number of products (e.g., ice thickness, ice concentration) that are pushed daily to the NIC and that enable them to produce daily and weekly charts, as well as special support information on ice conditions. The NIC expects that improving the quality of data assimilated by ACNFS will enhance the system's prediction capabilities, and will thereby, improve the quality of NIC's ice analyses and tactical sea ice forecast products. Furthermore, NIC expects that this could also result in an increase in the public's understanding of recent changing conditions in the Arctic and Antarctic regions.

Guy Schumann [University of California, Los Angeles, Joint Institute for Regional Earth System Science and Engineering] talked about the potential to integrate the ICESat-2 Inland Water Elevation data product (*ATL13*[7]) into the Global Flood Partnership (GFP) for large-scale hydrodynamic modeling and flood event monitoring activities. GFP's Global Flood Service and Toolbox (GFSP), one of three pillars of the GFP, hosts data outputs and tools from many flood models. The *ATL13* could help with model calibration and validation studies at regional to global scales and has the potential to be assimilated into the GFP operational platform where it may help improve flood mapping and forecasts used to inform decisions made by international aid and development organizations (e.g., decisions made

[5] MABEL stands for Multiple Altimeter Beam Experimental Lidar.

[6] ACNFS will be replaced by the Ocean Forecast System (GOFS 3.1) once it becomes operational. According to NRL, GOFS 3.1 will have the added capability of forecasting ice conditions in the Southern Hemisphere.

[7] For a complete list of ICESat-2 data products please see "Improving Operational Awareness Through ICESat-2 Applications Workshops: Cross-Mission Development" in the May–June 2014 issue of *The Earth Observer* [**Volume 26, Issue 3**, pp. 18-19].

continued on page 39

Satellites Enable Coral Reef Science Leap from Darwin to Online

Audrey Haar, NASA's Goddard Space Flight Center, audrey.j.haar@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.

With Earth-observing satellite data, scientists can now monitor the health of coral reefs, even in the most remote regions scattered around the globe where it is otherwise difficult to see changes.

Satellites fill a void by providing a more complete view of remote reefs. The information is monitored globally through *Coral Reef Watch*, an online tool operated by the National Oceanic and Atmospheric Administration (NOAA) that provides near real-time and long-term monitoring, forecasting, and reporting of tropical coral reef conditions.

This information is being used to monitor the quality and temperature of the waters around reefs worldwide. Water temperatures that exceed certain thresholds for a period of time can lead to a loss of corals. Satellite data processed through Coral Reef Watch provide early warning signs of natural and human-caused pressures that result in reef decline and loss.

Until recently, global maps of coral reefs had not changed significantly from the maps produced by Charles Darwin in 1842—see **Figure 1**. Darwin based his historic maps on observations from his expeditions around the world. Later, French scientist Louis Joubin updated those maps in 1912 using information he received through letters from people living near coral reefs around the world.

It wasn't until about 15 years ago that coral reef mapping leapfrogged to modern times. A new global map of coral reefs was created with over a thousand Landsat 7 satellite images collected between 2000 and 2003.

"Until we made the map of coral reefs with Landsat 7, global maps of reefs had not improved a lot since the amazing maps that Darwin drafted," said **Frank Muller-Karger** [University of South Florida—*Professor of Oceanography*]. Previous Landsat missions were designed to look at land and were typically "turned off" over the ocean to conserve power.

The Enhanced Thematic Mapper Plus sensor, the main instrument onboard Landsat 7, led to the development of the Millennium Global Coral Reef Map (*imars.marine.usf.edu/MC*), which is distributed openly and is used by researchers and coral reef managers around the world.

The Landsat 8 satellite with the Operational Land Imager (OLI) sensor offers significantly improved capabilities over its predecessor—see **Figure 2**. "The Landsat 8 OLI is allowing us to outline the reefs around the world and measure area and estimate depth in ways never possible before," said Muller-Karger.

Muller-Karger teamed with the NOAA Coral Reef Watch program under a 2013 NASA Applied Sciences grant to develop new products using U.S. and international satellites for a coral reef ecosystem stress alert program.

Coral is a living organism that makes rocklike deposits of their skeletons. These marine animals leave these deposits to accumulate to form reefs over hundreds to thousands of years. These reefs provide a habitat for more than 1 million species of plants and animals while also protecting coastlines from storm damage and erosion and providing a tourism destination. Factors influencing the

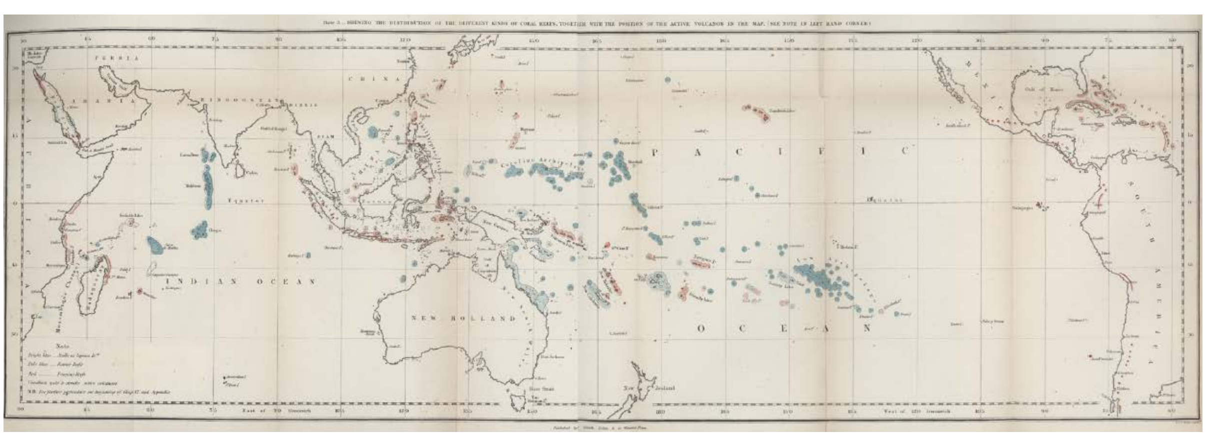

Figure 1. The structure and distribution of coral reefs by Charles Darwin was developed during his voyage of the Beagle from 1832 to 1836. When Darwin returned, his theory of the origin of coral reefs, communicated to the Geological Society of London on May 31, 1837, made his scientific reputation. This map was first published in "The Structure and Distribution of Coral Reefs" (London, 1842). **Image credit:** The Earth Sciences Library, University of Cambridge

Figure 2. The extensive coral reefs on the northern shore of Vanua Levu, Fiji's second largest island, can be seen in this natural color Landsat 8 image acquired on May 10, 2015. The Operational Land Imager (OLI) onboard Landsat 8 was designed to have higher sensitivity than the Enhanced Thematic Mapper Plus (ETM+) onboard Landsat 7. This higher sensor sensitivity has had a positive impact on coral reef delineations, area measurements, and depth estimations. **Image credit:** NASA/Landsat

health of coral reefs include rising sea levels, powerful storms, pollution, coastal development, mining pressures for cement, overfishing, and other human activities such as the construction of artificial islands and ports.

A condition known as *coral bleaching* occurs when extremely warm waters force temperature-sensitive corals to evict the tiny algae that live inside the coral animal in symbiosis and help them thrive. These algae give the coral animals their color. Without these algae, the corals turn white and eventually die if the condition persists.

In addition to Landsat, several other temperature-sensing satellites provide data to measure the cumulative heat buildup around coral reefs of the world. If the heat builds up over several weeks, coral reef health is affected and bleaching or death occurs. Stress also occurs if corals experience extreme winter cold temperatures. Among these satellite sensors are the Moderate-resolution Imaging Spectroradiometer (MODIS) instruments onboard Terra and Aqua. Similar readings are being collected by NASA/NOAA's Visible Infrared Imaging Radiometer Suite (VIIRS) instrument onboard the Suomi National Polar-orbiting Partnership satellite, as well as from the Advanced Very High Resolution Radiometer (AVHRR) instruments onboard NOAA's Geostationary Operational Environmental Satellite series, and some other satellites operated by international partners. These instruments provide current information on sea surface temperatures, to identify areas vulnerable to bleaching.

As scientists look to the future, they seek even more advanced solutions to the problem of measuring biodiversity over large areas and how this is changing. Hyperspectral satellite information promises to identify the types of habitats within the reef. These new satellite instruments could see variations of coral reef color and improve the understanding of at least some aspects of habitat and biological diversity from space. It may even be able to see when corals bleach.

"You need Earth-observing cameras with small pixel sizes that allow a closer look at the corals. The scale needed is much less than 100 m (328 ft). With VIIRS and MODIS, for example, the best achievable spatial resolution is between 250 and 500 m (820 and 1640 ft). We need instruments capable of resolving reefs at scales ranging from 1 to 40 m (3 to 131 ft)," said **Nima Pahlevan** [NASA's Goddard Space Flight Center—*Chief Research Scientist at the Terrestrial Information System Laboratory*].

Towards that end of obtaining better quality images, NASA's Hyperion onboard the proof-of-concept Earth-Observing-1 (EO-1) mission offers 30-m (98-ft) spatial resolution as a test of an orbital space-borne hyperspectral camera sensing Earth's surface.

Another experimental instrument was the Hyperspectral Imager for the Coastal Ocean (HICO), which flew on the International Space Station. HICO offered 90-m (295-ft) spatial resolution, providing detailed images of coral reef regions. Hyperion and HICO are both experimental instruments, requiring images to be scheduled or offering the ability to capture only a few images per orbit. That is why scientists desire a hyperspectral instrument on a satellite to capture a regular stream of images, providing insight on changes to coral reefs.

There are also other hyperspectral instruments in the pipeline. NASA is considering when to fly the Hyperspectral Infrared Imager (HyspIRI). NASA already flies several hyperspectral sensors on aircraft, such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) instruments and the Portable Remote Imaging Spectrometer (PRISM) instrument.

Future hyperspectral data from space will allow high-quality observations that could be used to map the diversity of changing global coastal zones. This will allow scientists to better quantify how organisms change, and ultimately how humans can better use nature to sustain a healthy society. ■

Beijing Quadrupled in Size in a Decade, NASA Finds

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

A new study by scientists using data from NASA's Quick Scatterometer (QuikScat) satellite has demonstrated a novel technique to quantify urban growth based on observed changes in physical infrastructure. The researchers used the technique to study the rapid urban growth in Beijing, China, finding that its physical area quadrupled between 2000 and 2009—see **Figure**.

A team led by **Mark Jacobson** [Stanford University] and **Son Nghiem** [NASA/Jet Propulsion Laboratory] used data from QuikScat to measure the extent of infrastructure changes (e.g., new buildings and roads) in China's capital. They then quantified how urban growth has changed Beijing's wind patterns and pollution, using a computer model of climate and air quality developed by Jacobson.

New infrastructure alone—i.e., the buildings and roads themselves, not including additional pollution created by the new city dwellers and their vehicles—created a ring of impacts around the older parts of Beijing. The impacts included increasing winter temperatures by about 5 to 7 °F (3 to 4 °C) and reducing wind speed by about 2 to 7 mph (1 to 3 m/s), making the city air more stagnant.

"Buildings slow down winds just by blocking the air, and also by creating friction," Jacobson explained. "You have higher temperatures because covering the soil reduces evaporation, which is a cooling process." Roads and roofs heat up more during the day than soil or vegetation would because they are drier. The heat and more stagnant air create a cascade of consequences, such as increased ground-level ozone pollution.

Beijing's official city limits enclose an area larger than the state of Connecticut, but much of that real estate is undeveloped and likely to remain so—e.g., nature preserves and rugged mountains. The Chinese capital is far from the only world city whose official area differs from its actual footprint.

"There are so many definitions of urban extent, both legislative and administrative," Nghiem pointed out. "To learn how physical change affects the environment, you cannot use an arbitrary political definition. The reality is what's happening on the ground." The new method allows researchers to pinpoint just that.

Other satellites such as the Landsat series, operating since 1972, and the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument onboard the Suomi National Polar-orbiting Partnership (NPP) satellite also track urbanization in various parts of the world. These mostly use visible evidence, such as changes in the extent of city lights or clearing of vegetation, as stand-ins for growth. These measures have recognized limitations, however. For example, city neighborhoods without streetlights may be indistinguishable from the countryside at night. Nghiem's technique can enhance and complement existing measurements.

Nghiem used advanced data-processing techniques on measurements from NASA's QuikScat scatterometer, a

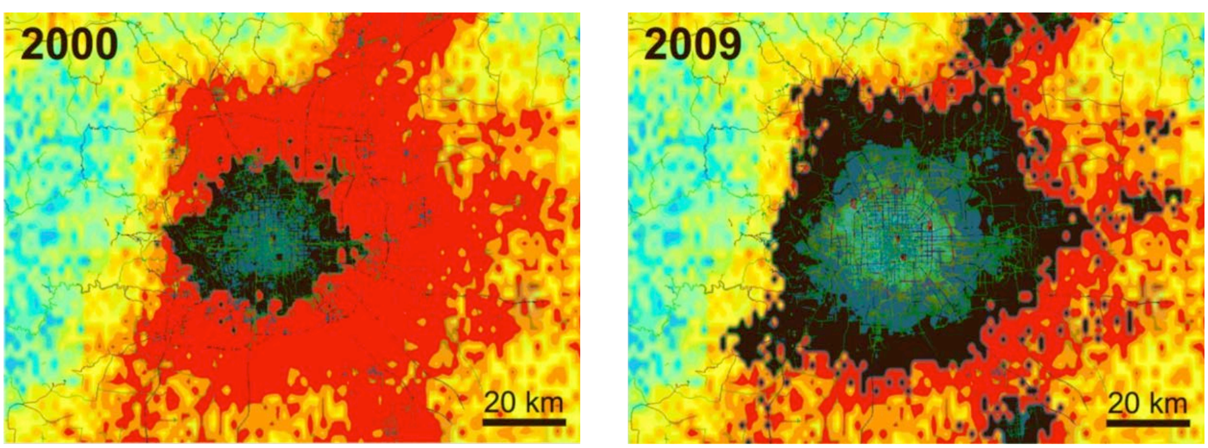

Figure. This image pair shows data from NASA's QuikScat satellite that has been used to show the changing extent of Beijing between 2000 [*left*] and 2009 [*right*] through changes to its infrastructure. The black and blue-gray rings in the center of the image indicate buildings, with the tallest and largest buildings in the city's commercial core appearing lighter gray. Other colors show changes in areas not yet urbanized (e.g., clearing land or cutting down trees), with the rate of change indicated by color. Blue-green indicates the least change, yellow-orange more change, and red the greatest change. **Image credit:** NASA/JPL satellite radar managed by JPL that operated from 1999 to 2009. Like all radars, QuikScat sent pulses of microwaves toward Earth and recorded the waves that bounced back, called backscatter. Nghiem's technique takes advantage of the fact that human-built structures produce stronger backscatter than soil or vegetation. The larger or taller the buildings are, the stronger the backscatter. His data-processing method improves the "focus" of the QuikScat image from a pixel size of about 15 mi (25 km) per side to 0.6 mi (1 km) per side, allowing the researchers to capture detail at the scale of a few city blocks.

Nghiem emphasized that the study set only the lower bounds for the impacts of urbanization on local weather and pollution. "If you were to develop a city that didn't allow any pollution sources, not even a single gas-powered car, you would still have these bad effects."

The complete study is online at *onlinelibrary.wiley.com/doi/10.1002/2014JD023008/full*. ■

Early Adopters Prepare the Way for Using ICESat-2 Data

continued from page 35

by United Nations rescue missions after flood events). Two case studies conducted as part of the EA prelaunch research—a large-scale Niger Inland Delta study and a small-scale study over an existing or potential MABEL target area—will help assess the value of ICESat-2 water level data product for GFP. Schumann also mentioned that the ATLAS Atmosphere Cloud Layer Characteristics (*ATL09*) atmosphere product represents another opportunity to refine forecasts through improved rainfall estimates in GFP models; this could lead to a possible collaboration with the U.S. National Oceanic and Atmospheric Administration (NOAA).

Charon Birkett [University of Maryland, Earth System Science Interdisciplinary Center (ESSIC)] discussed ESSIC's EA proposal to incorporate ATLAS data into the radar-altimetry-driven Global Reservoir and Lake Monitor (G-REALM) program. G-REALM's primary stakeholder is the U.S. Department of Agriculture's Foreign Agriculture Service (USDA FAS). Through G-REALM, ESSIC provides the USDA FAS with archival and operational information on global lake level variation (proxy for volume of stored water) to inform irrigation potential considerations via its *Crop Explorer*[8] operational system. The archive measurements help the USDA assess the hydrological drought for a particular lake basin, while the weekly operational information helps the USDA assess the agricultural drought situation within a lake basin. ICESat-2 is expected to enhance the lake level variation product by both improving the height measurements during winter (when lakes are covered with snow and ice) and by providing a global picture. The utility of ICESat-2 data products within G-REALM for USDA FAS, however, will depend on ICESat-2's temporal resolution and delay time. A low (seasonal) temporal resolution compared to the monthly resolution required, means that ICESat-2 can only be used as an archival validation source. Charon is currently seeking new G-REALM stakeholders that have requirements for very high-latitude lakes and reservoirs to extend the ICESat-2 EA research to other end users.

Summary and Looking Ahead

The workshop's feedback to the mission, the relationship fostered between the user community and the ICESat-2 mission, and the efforts of the EAs, combine to provide the ICESat-2 mission with a better understanding of how their data products may be used and also highlight challenges and current knowledge data gaps across various disciplines early in mission development.

The Project Office emphasized during the workshop that it is not exhaustive in its knowledge and appreciates input from the user community. The mission science team asked the community to communicate knowledge of any long-term monitoring sites (i.e., large targets, not single gauges) for ICESat-2's validation program, which includes not only monitoring, but also identifying very specific experimental sites. Efforts in these directions as well as those discussed earlier in this article are ongoing, and will likely guide the structure of future workshops and other EA communications activities.

The workshops and EA activities generally bring unique value to ICESat-2, and also bring value to NASA as a whole. The feedback mechanisms from the EA program and the applications engagement provide tangible and societally relevant outcomes that connect NASA mission science to society in a fashion that is virtually invisible but nonetheless important to people's everyday lives and our understanding and management of ecosystems, generally. ■

[8] For more information about Crop Explorer, visit *www.pecad.fas.usda.gov/cropexplorer/global_reservoir*.

NASA Earth Science in the News

Maria-Jose Vinas Garcia, NASA's Earth Science News Team, maria-jose.vinasgarcia@nasa.gov

New NASA Data Show How the World is Running Out of Fresh Water, June 16; *The Washington Post*. According to new research that used data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites, the world's largest underground aquifers—sources of fresh water for hundreds of millions of people—are being depleted at alarming rates — see **Figure** below. The study provides the first detailed assessment that demonstrates that water levels in major aquifers are not keeping pace with demands from agriculture, growing populations, and industries such as mining. Twenty-one of the world's 37 largest aquifers have passed their sustainability tipping points, meaning more water was removed than replaced during the decade-long study period. Thirteen aquifers declined at rates that put them into the most troubled category. The aquifers under the most stress are in poor, densely populated regions, such as northwest India, Pakistan, and North Africa, where alternatives are limited and water shortages could quickly lead to political and economic instability. The researchers, led by **Jay Famiglietti** [NASA/Jet Propulsion Laboratory (JPL)—*Senior Water Scientist*] said these findings indicate a long-term problem that's likely to worsen as reliance on aquifers grows.

NASA High-Resolution Global Maps Predict Future Weather Across World Cities, June 15; *International Business Times*. NASA scientists have simulated the global climate to project future temperatures and rainfall around the world in high-resolution maps that allow regional predictions. The future-hotspot maps provide daily high and low temperatures and project rainfall across the world for any day between 2050 and 2100. The maps have been created by the NASA Earth Exchange (NEX), a big-data research platform within the Advanced Supercomputing Division at NASA's Ames Research Center. Developed using 21 climate models and terabytes of satellite data, the data give policymakers an idea of how any city fares with regard to drought, floods, heat waves, and other extreme weather events.

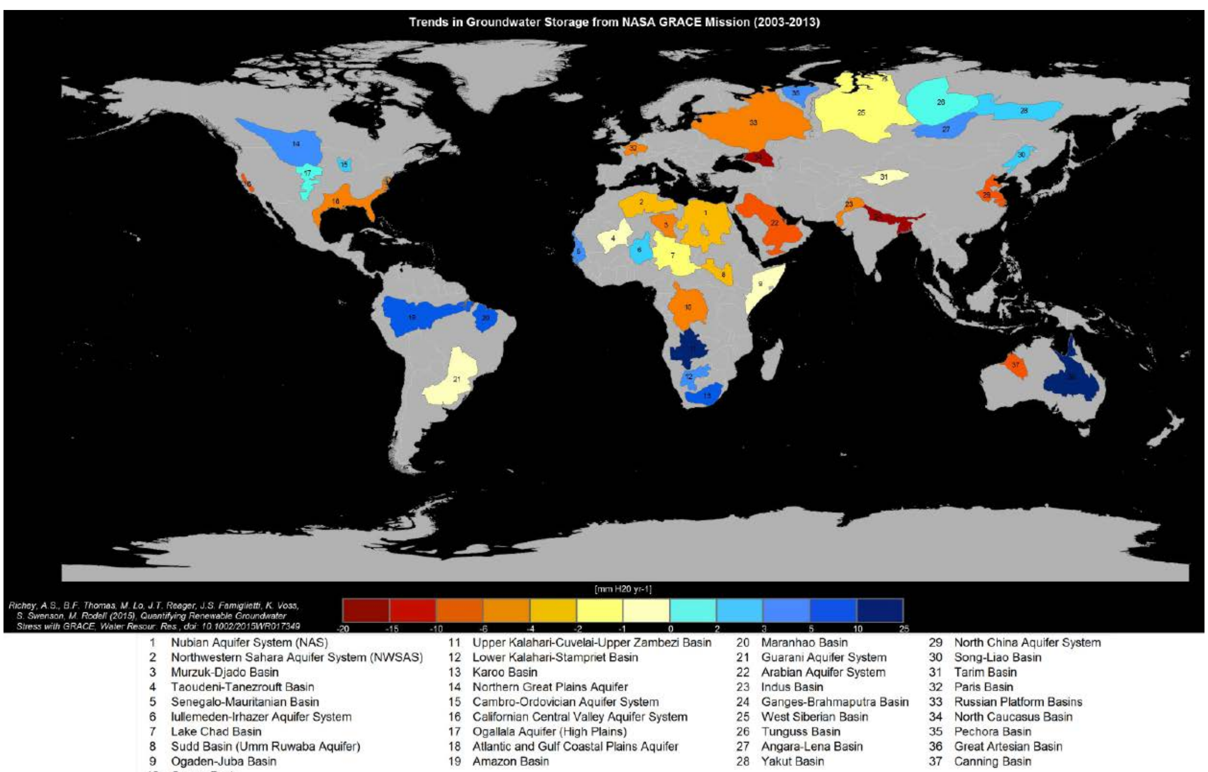

Figure. Groundwater storage trends for Earth's 37 largest aquifers from UCI-led study using NASA GRACE data (2003 - 2013). Of these, 21 have exceeded sustainability tipping points and are being depleted, with 13 considered significantly distressed, threatening regional water security and resilience. **Image credit:** UC Irvine/NASA/JPL-Caltech

NASA: 10,000-Year-Old Antarctic Ice Shelf will Disappear by 2020, May 17; *CNN*. According to a new NASA study, one of the last remaining sections of Antarctica's Larsen B Ice Shelf is dramatically weakening. The research predicts that what remains of the once-prominent ice shelf—which has existed for at least 10,000 years—most likely will disintegrate completely before the end of this decade. Larsen B suffered two major disintegrations in 2002. A team led by **Ala Khazendar** [JPL] found evidence that the remainder of the ice shelf is flowing faster than ever before, which creates large cracks and makes the ice shelf become more fragmented. Once the ice shelf is gone, the ice from the glaciers it buttresses will flow faster into the ocean and contribute to sea level rise. **Eric Rignot** [JPL—*Senior Research Scientist*], who co-authored the paper, said the research gives insight into how ice shelves closer to the South Pole will react with the warming climate. The scientists partly based the research on data collected by Operation IceBridge.

***Beijing Quadrupled in Size in a Decade**, June 26; *phys.org*. A new study by scientists using data from the SeaWinds instrument onboard NASA's Quick Scatterometer (QuikScat) satellite has demonstrated a novel technique to quantify urban growth based on observed changes in physical infrastructure. The researchers used the technique to study the rapid urban growth in Beijing, China, finding that its physical area quadrupled between 2000 and 2009. A team led by **Mark Jacobson** [Stanford University] and **Son Nghiem** [JPL] used data from SeaWinds to measure the extent of infrastructure changes, such as new buildings and roads, in China's capital. They then quantified how urban growth has changed Beijing's wind patterns and pollution, using a computer model of climate and air quality developed by Jacobson.

NASA Joins North Sea Oil Cleanup Training Exercise, June 19; *The Statesman*. NASA, for the first time, participated in Norway's annual oil spill cleanup exercise in the North Sea from June 8-11, 2015. Scientists flew a specialized NASA airborne instrument called the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) on NASA's C-20A piloted research aircraft to monitor a controlled release of oil into the sea, testing the radar's ability to distinguish between more and less damaging types of oil slicks. Norway's Oil on Water exercise has been held annually since the 1980s; in these drills, oil is released onto the ocean and then recovered, giving responders experience with existing cleanup techniques and equipment and a chance to test new technologies. "This year was special, because we had our own dedicated science experiment in the middle of the training exercise," said **Camilla Brekke** [University of Tromso, Norway—*Associate Professor in the Department of Physics and Technology*]. Brekke invited scientists **Cathleen Jones** and **Ben Holt** [both from JPL] to participate in the experiment. The Norwegian exercise released emulsions of differing thicknesses so that the scientists could have a range of conditions to calibrate the UAVSAR data. The experiment also tested the instrument's ability to distinguish between petroleum and plant-based oil, found in algal blooms. Norway is one of a few nations worldwide that allow oil to be discharged at sea to test new cleanup technologies and procedures.

*See news story in this issue.

Interested in getting your research out to the general public, educators, and the scientific community? Please contact ***Maria-Jose Vinas Garcia*** *on NASA's Earth Science News Team at* ***maria-jose.vinasgarcia@nasa.gov*** *and let her 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

Theresa Schwerin, Institute for Global Environmental Strategies, theresa_schwerin@strategies.org
Morgan Woroner, Institute for Global Environmental Strategies, morgan_woroner@strategies.org

Register for Earth to Sky Climate Change Science and Communication Course

Course Date: October 14-16, 2015

Application Deadline: August 15, 2015

Point of Contact: **Anita Davis**, NASA's Goddard Space Flight Center, *anita.l.davis@nasa.gov*.

Join us this Fall for a new *Earth to Sky* regional course, focused on climate science and how best to communicate related information to nonspecialist groups, particularly as applied to Alaska! The heart of the course is comprised of three days of face-to-face sessions held at the Bureau of Land Management's Campbell Creek Science Center in Anchorage, AK, Wednesday through Friday, October 14-16, 2015. We will feature one evening session and a field trip to a local site as a case study for climate change effects and informal education and communication practices as they relate to the topic. The course includes 3.5 hours of preparatory assignments and a one-hour follow-up class webinar session. There is no tuition, and limited funds are available to help defray travel costs.

Target audience: Representatives from federal, state, and municipal agencies, and private organization science communicators, interpreters, environmental educators, and education specialists, including those from not-for-profit groups. Participants should have some experience with communicating with the public and nonspecialist groups. We'll teach you the science basics, so in-depth knowledge of climate science is not required. Partners and collaborators are especially encouraged.

To read more about the course, visit *earthtosky.org/related-news/268-new-ets-regional-course-in-alaska-fall-2015.html.*

NASA Wavelength Blog Post: Summer Reading

We've all experienced it as students and teachers: that loss of contact during the summer months, and the cobwebs that need to be shaken loose at the beginning of a new school year. Summer reading programs are a great way to prevent that loss as they provide effective—and fun—ways to encourage continued learning in an informal setting. (Numerous studies have shown how effective summer reading programs are for building lifelong learners.) With that in mind, *NASA Wavelength* has compiled summer reading lists highlighting some valuable resources you can use to establish summer reading programs with your students, no matter what their age. From graphic novels to textbook chapters, there's a broad range to choose from on Wavelength. See the lists at *nasawavelength.org/blog/summer-reading*.

New on the SciJinks Website:

Wild Weather Jobs

Imagine controlling a satellite orbiting Earth. Much like a remote-controlled airplane, you send messages and tell it what to do. That's what weather satellite controller **Tom Boyd** [National Oceanic and Atmospheric Administration] gets to do every day. Find out how Boyd keeps an eye on weather satellites and monitors their health and safety by visiting *scijinks.gov/satellite-controller*.

Lightning-Snap!

We usually only see lightning when it travels from a cloud to the ground, but before that happens, there might be lots of in-cloud and cloud-to-cloud lightning. What are these? How can we monitor this activity and learn more about violent storms? Find out in a new SciJinks Snap Video at *scijinks.gov/lightning-snap*.

New on the Climate Kids Website:

Careers in Satellite Missions

There are lots of green careers. You can help others make good choices that don't hurt the environment by building things like satellites, used to learn more about the environment. **Sarah Sherman** [NASA/ Jet Propulsion Laboratory] is a systems engineer for NASA's Soil Moisture Active Passive (SMAP) mission. She helped develop and launch a spacecraft that orbits Earth and looks at how much water is in the soil. To learn more about her career, visit *climatekids.nasa.gov/career-satellites*.

What Do All These Graphs Mean?

When we talk about climate change, we need to consider lots of data, often including graphs. But not everyone knows what to look for in a graph. New on Climate Kids, students can learn how to interpret graphs. Visit *climatekids.nasa.gov/graphs*. ■

EOS Science Calendar

September 1–3, 2015
CERES Science Team Meeting, Seattle, WA.
ceres.larc.nasa.gov/science-team-meetings2.php

September 16–17, 2015
AMSR Science Team Meeting, Huntsville, AL.

September 21–23, 2015
GRACE Science Team Meeting, Austin, TX.
www.csr.utexas.edu/grace/GSTM

October 13, 2015
Sounder Science Team Meeting, Greenbelt, MD.
airs.jpl.nasa.gov/events/35

October 19–23, 2015
Ocean Surface Topography Science Team Meeting, Washington, DC.

November 10–13, 2015
SORCE Sun-Climate Symposium, Savannah, GA.
go.nasa.gov/1zRx2Hj

Global Change Calendar

August 2–7, 2015
12th Annual Asia Oceania Geosciences Society Meeting, Singapore.
www.asiaoceania.org/aogs2015

August 16–20, 2015
250th American Chemical Society National Meeting, Boston, MA.
www.acs.org/content/acs/en/meetings

November 9–13, 2015
GEO-XII Plenary and Ministerial Summit, Mexico City, Mexico.
earthobservations.org/index.php

November 30–December 11, 2015
COP-21, Paris, France.
www.cop21paris.org

December 14–18, 2015
American Geophysical Union Fall Meeting, San Francisco, CA.
fallmeeting.agu.org/2015

January 10-14, 2016
American Meteorological Society Annual Meeting, New Orleans, LA.
annual.ametsoc.org/2016

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

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