National Aeronautics and Space Administration

The Earth Observer. July - August 2013. Volume 25, Issue 4.

the earth observer

Editor's Corner

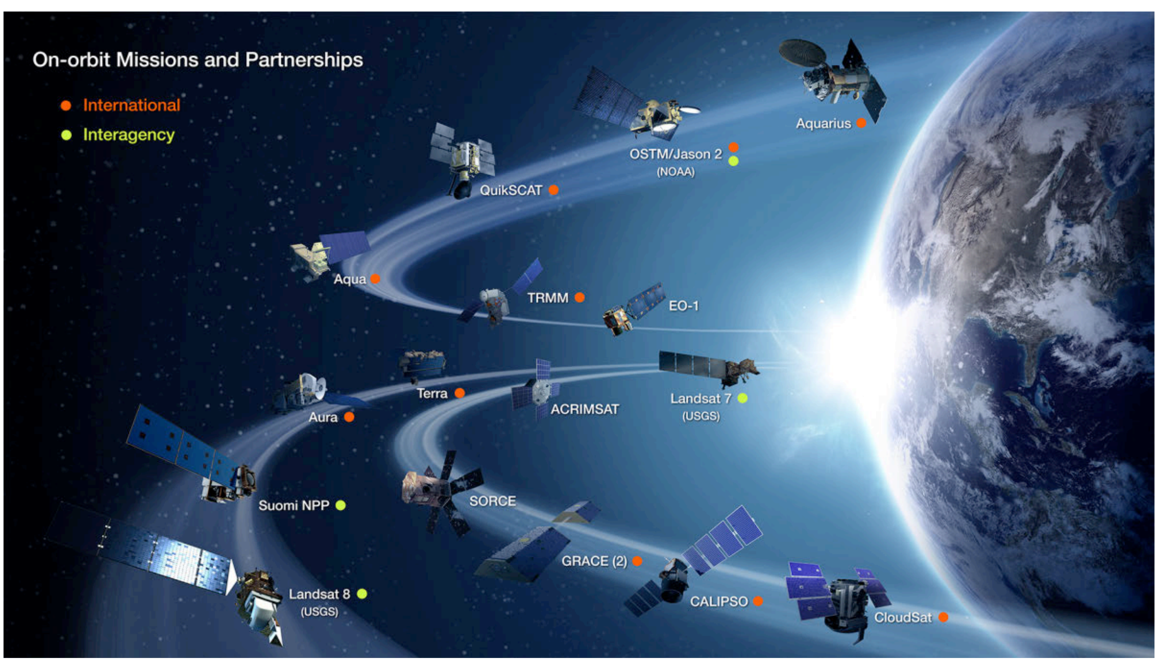
Steve Platnick
EOS Senior Project Scientist

International and interagency collaborations are key to many of NASA's successes. In Earth science, long-lasting partnerships continue to advance our understanding of the Earth and have led to climate data records that extend back several decades.

For the past 11.5 years, Jason-1 has been a shining example of a successful international and interagency partnership. The joint NASA/Centre National d'Études Spatiales (CNES) ocean altimetry satellite mission built upon the time series of ocean surface topography measurements that originated in 1992 with the launch of the NASA/CNES TOPEX/Poseidon spacecraft. The result is a comprehensive multi-decade record of global ocean surface topography that has provided new insights into ocean circulation, tracked rising seas, and enabled more-accurate weather, ocean, and climate forecasts.

Jason-1, which was launched in December 2001, precisely mapped sea level, wind speed, and wave height for more than 95% of Earth's ice-free ocean, every 10 days. Unfortunately, Jason-1 had to be decommissioned on July 1, 2013, after its last remaining transmitter failed. The good news is that the Ocean Surface Topography Mission/Jason-2 spacecraft—a joint NASA/CNES/NOAA/EUMETSAT partnership, launched on June 20, 2008—is still in orbit and continues the ocean surface topography time series.

continued on page 2



Currently NASA operates 16 Earth-observing satellite missions, many of them international and/or interagency partnerships. **Image credit: Jenny Mottar** [NASA Headquarters] eos.nasa.gov

In This Issue

Editor's Corner Front Cover

Feature Articles

An Overview of Europe's Expanding Earth-Observation Capabilities 4
NASA Celebrates Earth Day and More 16
NASA's Venture Continues: An Update on the EVS-1 Investigations 19

Blog Log 33

Meeting/Workshop Summaries

The NASA LCLUC Spring 2013 Science Team Meeting 35
GOFC–GOLD Fire Implementation Team Meeting (2013) 41
2013 CLARREO Science Definition Team Meeting Summary 47
CERES Science Team Meeting 50
First Meetings of the 2012-2017 Landsat Science Team 54

In The News

Warm Ocean Causing Most Antarctic Ice Shelf Mass Loss 60
Climate Conditions Determine Amazon Fire Risk 62

Regular Features

NASA Earth Science in the News 64
NASA Science Mission Directorate – Science Education and Public Outreach Update 66
Science Calendars 67

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

Looking toward the future, the Jason-3 mission is scheduled to launch in 2015, and will continue the international cooperation, with NOAA and EUMETSAT leading the efforts, along with partners NASA and CNES. Beyond that there are plans to launch at least two Jason Continuity of Service (CS) missions (the first planned by the end of 2017) to ensure adequate overlap with Jason-3 until the Surface Water Ocean Topography Mission (SWOT) Decadal Survey mission launches (planned for 2020). While exact responsibilities for Jason-CS are still being defined, the successful model for U.S.–European collaboration will continue into the future.

In keeping with our international theme, on page 4 of this issue we provide an overview of the European Space Agency's (ESA) Earth observing program. The article includes discussion of several ongoing collaborative efforts between NASA and ESA. These activities include validating data from ESA's CryoSat and NASA's ICESat missions with data from ESA's CryoSat Validation Experiment (Cryovex) and NASA's Operation IceBridge field campaigns; data homogeneity efforts to improve the long-term ozone record collected by both NASA/NOAA and ESA/EUMETSAT instruments; and planning activities over Antarctic calibration sites to ensure accuracy of long-term datasets from the ESA Earth Explorer missions and NASA's upcoming Soil Moisture Active Passive (SMAP) mission.

NASA also recognizes the importance of maintaining a steady stream of opportunities for the Earth science community to participate in innovative mission development and implementation. To this end, NASA established the Earth Venture (EV) line of missions, which has been described previously in *The Earth Observer*[1]. In our last two issues, we reported on the EV Instrument (EVI-1) and EV Mission (EVM-1) selections—TEMPO and CYGNSS respectively[2]. In this issue, we provide updates on the five suborbital investigations funded through the first EV Suborbital opportunity (EVS-1), selected in May 2010—all of which are now well underway. These suborbital investigations and their science complement satellite observations and support NASA's broader range of Earth system science research. To learn more, turn to page 19 of this issue.

[1] "A New Venture for NASA Earth Science," appeared in the September-October 2010 issue and described the three types of Venture missions [**Volume 22, Issue 5,** pp. 13-18].
[2] For details on TEMPO, see the March–April 2013 issue [**Volume 25**, **Issue 2**, pp. 10-15] and for information on CYGNSS, see the May–June 2013 issue [**Volume 25**, **Issue 3**, pp. 12-20].

New EV opportunities are on the horizon. On June 25, NASA posted the final text of the EVS-2 solicitation. These new investigations will be competitively selected by mid-2014. Meanwhile, the draft text for EVI-2 was released on June 4. More information on the EVS-2 solicitation can be found on page 32 of this issue.

Many of the EVS-1 missions have been flown in collaboration with other field campaigns and missions. This summer a new NASA field campaign—Studies of Emissions, Atmospheric Composition, Clouds and Climate Coupling by Regional Surveys (SEAC4RS)—will kick off in early August and continue through September. The NASA DC-8 and ER-2 science aircraft will each carry a suite of instruments to investigate how air pollution and natural emissions affect atmospheric composition and climate. The flights will be based out of Houston, TX to allow coincident measurements with the EVS-1 DISCOVER-AQ mission.

In another ongoing interagency success story, the Landsat Data Continuity Mission (LDCM)—a joint NASA/U.S. Geological Survey (USGS) mission—was renamed Landsat-8 on May 30 when operations were turned over to USGS. A few minor issues notwithstanding, the in-orbit checkout for LDCM has gone very well. The satellite has collected more than 400 scenes per day since April 12. The article on page 56 describes a cooperative effort between the USGS, NASA, and ESA to combine ground cross-calibration of the Landsat-8 and Sentinel-2 instruments to generate consistent radiometric data—allowing comparison of data between the two missions.

On May 15, 2013, members of the AErosol RObotic NETwork (AERONET[3]) program celebrated 20 years of success. Through collaboration with colleagues, universities, and agencies across the globe, AERONET has greatly expanded and now supports over 500 instruments and approximately 400 sites in more than 80 countries and territories. AERONET data will be used to complement measurements from the upcoming DISCOVER-AQ and SEAC4RS missions. Congratulations to the AERONET team on reaching this milestone, and in particular, to Principal Investigator, **Brent Holben** [NASA's Goddard Space Flight Center] for two decades of outstanding leadership.

As all these investigations and the collaborations that support them surely provide more than enough opportunity to stay busy, we sincerely hope you can find time to enjoy the remainder of your summer! ■

[3] AERONET is a federation of ground-based remote sensing aerosol networks established by NASA and the PHOTONS network (*loaphotons.univ-lille1.fr/photons*) that provides a long-term, continuous, and readily accessible public domain database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergy with other databases.

The three NASA-built instruments and associated ground support equipment for the U.S./European Jason-3 ocean altimetry satellite are removed from a Cargo Lux *Boeing 747-800* transport plane in Luxembourg on May 21, 2013, following a transatlantic flight. The instruments left the NASA/Jet Propulsion Laboratory (JPL) on May 19 and arrived at the Thales Alenia Space Integration Center in Cannes, France on May 22. There they will be integrated with the Jason-3 spacecraft and tested in preparation for a March 2015 launch from Vandenberg Air Force Base in California. **Image credit:** NASA/JPL-Caltech

An Overview of Europe's Expanding Earth-Observation Capabilities

Simonetta Cheli, European Space Agency, ESRIN, simonetta.cheli@esa.int
Claus Zehner, European Space Agency, ESRIN, claus.zehner@esa.int
Ernest Hilsenrath, NASA/Retired, University of Maryland Baltimore County/Joint Center for Earth Systems Technology Fellow, hilsenrath@umbc.edu

Established in the mid-1990s, ESA's Living Planet Programme heralded a new approach to satellite observations for Earth science, with focused missions defined, developed, and operated in close cooperation with the scientific community, worldwide.

Introduction

The European Space Agency (ESA) has been managing an Earth Observation Programme since the launch of its first Meteosat meteorological satellite in 1977. Following the success of this first mission, a subsequent series of Meteosat satellites, two Earth Remote Sensing satellites (ERS-1, ERS-2), and the Envisat mission provided a wealth of valuable data about Earth, its climate, and its changing environment. For the last 30 years special emphasis has been given to calibrating instruments, validating data products, developing improved algorithms, and documenting these processes. This has been a joint effort of specialized laboratories, partner space agencies, and user communities to ensure that the missions are an innovative asset for research and public services. As a result, ESA has become a major provider of Earth-observation data to the Earth-science community.

Established in the mid-1990s, *ESA's Living Planet Programme* heralded a new approach to satellite observations for Earth science, with focused missions defined, developed, and operated in close cooperation with the scientific community, worldwide. Over time, three categories of Earth-observing missions have emerged: Earth Explorer (research), Earth Watch (meteorological), and Global Monitoring for Environment and Security (GMES[1]) Sentinel missions; these are described in more detail, below. **Figure 1** shows ESA's past, present, and planned Earth-observing satellites missions divided roughly into the three current mission categories.

[1] For more information on GMES, visit: *www.esa.int/Our_Activities/Observing_the_Earth/GMES/Overview3.*

Breakdown of ESA's Living Planet Programme

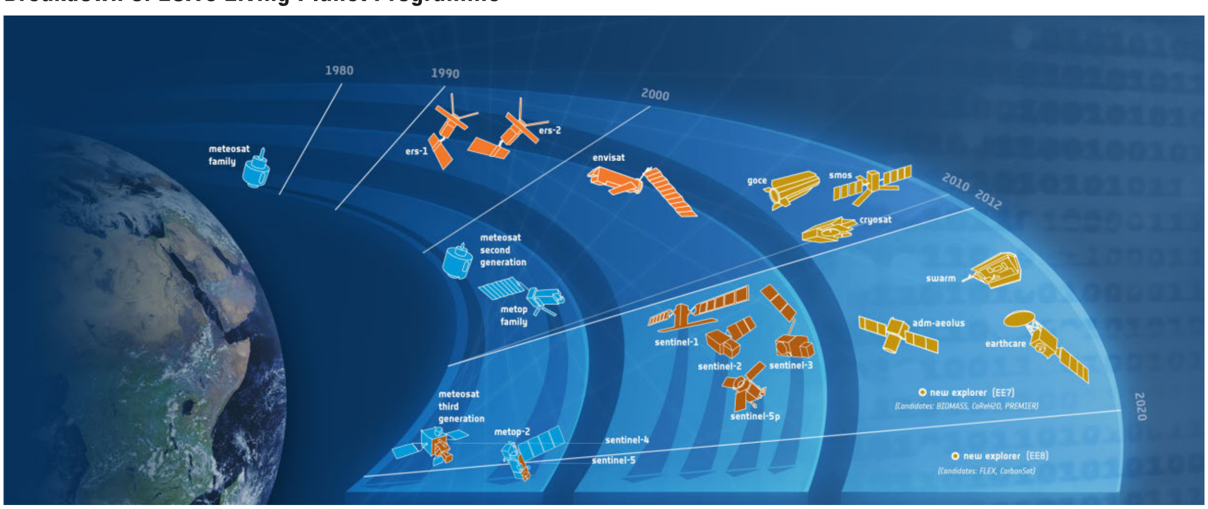


Figure 1. Since 1977, ESA has launched a series of satellites to explore the Earth's environment. *Earth Watch* (meteorological) missions are driven by weather forecasting and climate monitoring needs. *GMES Sentinel* missions are driven by users' needs to contribute to the GMES. *Earth Explorer* (research) missions are driven by scientific needs to advance our understanding of how the ocean, atmosphere, hydrosphere, cryosphere, and Earth's interior operate and interact as part of an interconnected planetary system. **Image credit**: ESA

ERS and Envisat—Europe's Earth Observing Research Pioneers

ERS and Envisat predate the formal establishment of the Earth Explorer and Sentinel missions described below. Hence, these missions straddle the space between the Sentinel and Earth Explorer streams in Figure 1. Both missions successfully demonstrated remote-sensing technology that provides new information on Earth science and applications that are being applied to future research missions and by operational service agencies.

European Remote Sensing Satellites

The first ERS satellite (ERS-1), launched in 1991, was ESA's first Sun-synchronous, polar-orbiting, remote-sensing mission. ERS-1 carried a comprehensive payload including an imaging Synthetic Aperture Radar (SAR), radar altimeter, and other instruments to measure ocean surface temperature and winds. In March 2000 a computer and gyroscope control failure led to the end of ERS-1 operations after it had far exceeded its planned lifetime. ERS-2, which overlapped with ERS-1, was launched in 1995 and, in addition to a duplicate of the ERS-1 payload, carried an additional sensor—the Global Ozone Monitoring Experiment (GOME). Both satellites collected a wealth of valuable data on Earth's land surfaces, oceans, and polar regions—data used to monitor natural disasters such as severe flooding and earthquakes in remote areas of the world. Shortly after the launch of ERS-2, ESA linked the two satellites in the first *tandem mission*[2], which lasted for nine months. During this time the increased frequency and level of data available to scientists offered a unique opportunity to observe changes over a very short time—as both satellites orbited Earth only 24 hours apart. GOME data were used for atmospheric ozone research and included in a European satellite-ozone dataset that complemented the established NASA/National Oceanic and Atmospheric Administration (NOAA) satellite-ozone dataset. In July 2011 ERS-2 was retired and the process of de-orbiting the satellite began.

The user demand for Envisat data remains very high: about 600 new user proposals were registered at ESA during 2012, requesting Envisat data. So far, there are about 4500 Envisat-user projects.

Envisat

The Environmental Satellite (Envisat[3]), the largest civilian Earth-observing satellite ever built by any space agency, was launched in 2002. It was an advanced polar-orbiting satellite that provided measurements of the atmosphere, oceans, land, and ice for over 10 years—twice as long as its planned lifetime. Envisat built on the successful ERS legacy; carried an ambitious and innovative payload that enabled acquisition of advanced Earth-observation science data and also ensured the continuity of data measurements from the two ERS satellites, described earlier.

Envisat data collectively provided a wealth of information to allow studies of atmospheric chemistry, ozone depletion, biological oceanography, ocean temperature and colour, wind-generated ocean waves, hydrology (i.e., humidity and floods), agriculture and arboriculture, natural hazards, digital elevation modelling (using interferometry), maritime traffic monitoring, atmospheric dispersion (i.e., pollution) modelling, cartography, snow, and ice. The archive of data received from the satellite supports long-term monitoring of environmental and climatic changes.

In April 2012 contact with Envisat was suddenly lost and the mission came to an abrupt end. However, 10 years of Envisat's archived data continue to be analyzed and applied to studies of our planet. The user demand for Envisat data remains very high: about 600 new user proposals were registered at ESA during 2012, requesting Envisat

[2] *Tandem mission* means that ERS-1 and ERS-2, carrying nearly an identical instrument manifest, flew in close orbital proximity for a time to intercompare their respective instruments and to calibrate the new ones on ERS-2.

[3] For more information about Envisat and its instruments, visit: *earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments*.

data. So far, there are about 4500 Envisat-user projects. **Figure 2** illustrates the growing number of Earth science projects for science and applications stemming from Envisat data.

Earth Explorer Missions – In Orbit and Upcoming Launches

The *Earth Explorers* are research missions designed to address key scientific challenges identified by the science community, while demonstrating breakthrough technologies in observing techniques. These missions involve the science community in defining new missions from the outset, through a peer-reviewed selection process that ensures efficient mission development and provides end-user-requested data. This approach provides Europe with an excellent opportunity for international cooperation, involves the global scientific community, and also aids in the technological development of new missions. Described below are three current Earth Explorer missions in orbit, three planned missions, and a recently selected mission.

The Earth Explorers are research missions designed to address key scientific challenges identified by the science community, while demonstrating breakthrough technologies in observing techniques.

GOCE: Gravity Mission

Launched on March 17, 2009, the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission was the first Earth Explorer. GOCE was designed to provide information for understanding critical Earth system variables driven by the Earth's gravitational field. The gravitational gradients are measured by a set of six, three-axis accelerometers. GOCE has provided data used to accurately develop global and regional models of Earth's gravity field and geoid, advance research in areas of ocean circulation and ocean dynamics, address the physics of Earth's interior, characterize geodesy and surveying, and monitor sea-level change. While the mission is ongoing, all mission requirements were fully met by the end of 2012. GOCE also mapped gravity signals significantly beyond the original goal of *spherical harmonic degree* 200 [equal to 100 km (~62 miles)]. Using data from GOCE,

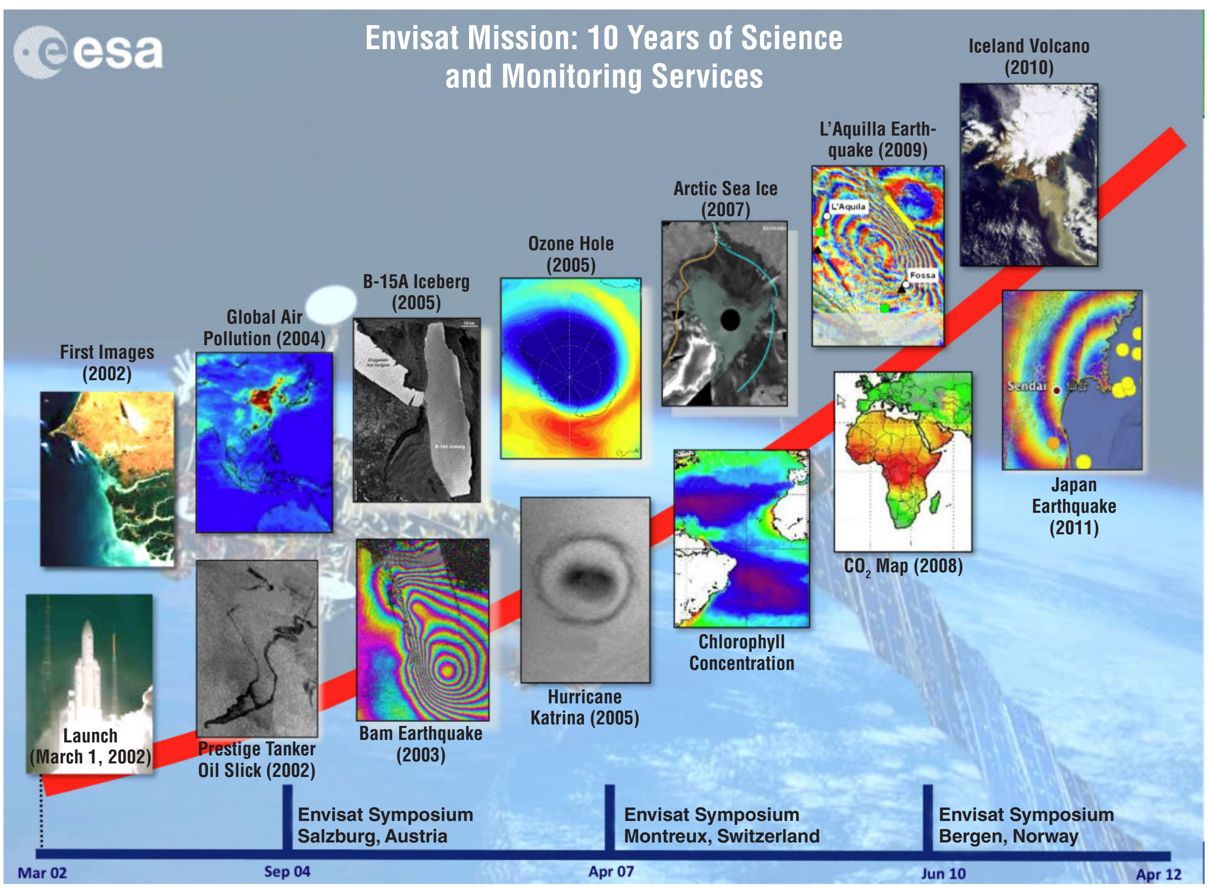


Figure 2. During its lifetime Envisat beamed back over 100 TBytes of data. To date, these data have been used in more than 4000 scientific projects and in numerous near real-time applications. A few of the mission's more noteworthy achievements are pictured above. **Image credit**: ESA

global ocean currents can be extracted directly from satellite altimetry data. The GOCE orbit was lowered to 235 km (~146 mi) at the end of January 2012, thereby increasing the accuracy and resolution of the measurements from 100 to 80 km (~62 to 50 mi)], and improving GOCE's view of smaller ocean dynamics. The satellite was further lowered to 225 km (~140 mi) at the end of May 2013. **Figure 3** illustrates GOCE's ability to derive ocean-current velocities.

SMOS: Water Mission

Launched on November 2, 2009, the Soil Moisture and Ocean Salinity (SMOS) mission collects global observations of soil moisture and ocean salinity using its unique L-Band Radiometer Microwave Imaging Radiometer with Aperture Synthesis (MIRAS). Soil moisture data are required for hydrological studies; ocean salinity data are vital to improve our understanding of ocean circulation patterns. SMOS completed its nominal three-year mission lifetime in November 2012, but continues to provide valuable results beyond its initial mission objectives, measuring ice thickness and wind speed. **Figure 4** illustrates the sea surface salinity (SSS) gradient off the northeast coast of the U.S. as measured by MIRAS.

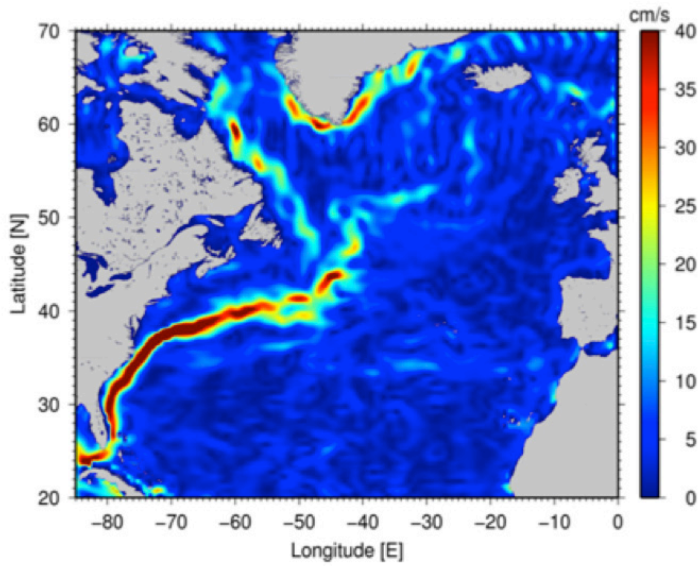


Figure 3. Geostrophic surface velocities for the North Atlantic as derived from GOCE and satellite altimetry. Velocities range from 0-50 cm/sec (red to blue). **Image credit:** ESA

CryoSat: Ice Mission

Launched on April 8, 2010, the CryoSat-2 is Europe's first ice mission[4]. Its principal instrument is the Synthetic Aperture Radar/Interferometric Radar Altimeter, which is designed to measure centimeter-scale changes in the thickness of floating ice in oceans and the ice sheets that blanket Greenland and Antarctica. These CryoSat-based measurements provide accurate, synoptic, Arctic measurements of ice thickness and volume in unprecedented detail and, when combined with other satellite data, show how the volume of Earth's ice is changing. This information gives researchers a better understanding of the relationship between ice and the Earth's climate system. **Figure 5** illustrates CyroSat-2's ability to track seasonal changes in sea-ice thickness.

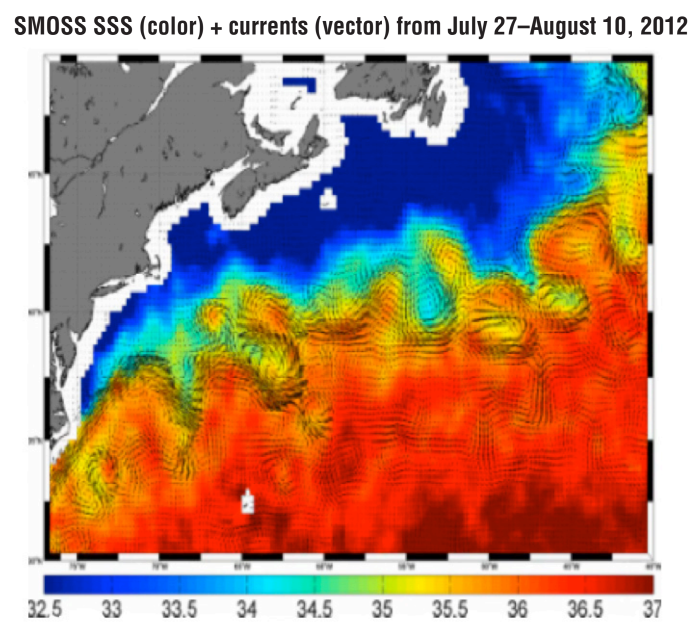


Figure 4. This figure illustrates the ocean circulation features off the U.S. northeast coastline. A SMOS 10-day-average sea surface salinity map is shown in the background with vectors representing surface currents derived from altimeter and surface wind products. Red shades represent the warm and salty central Atlantic waters, while blue shades indicate fresh and cold slope and shelf waters. **Image credit**: French Research Institute for Exploitation of the Sea

Swarm: Magnetic Field Mission

With a target launch date set for the end of 2013, Swarm is a constellation of three satellites that will provide high-precision and high-resolution measurements of the strength and direction of Earth's magnetic field using an advanced magnetometer, accelerometer, and electric field instruments. The geomagnetic field models resulting from the Swarm mission are expected to provide new insights into the Earth's interior, further our understanding

[4] CryoSat-2 replaces CryoSat, which was lost in October 2005 due to a launch failure.

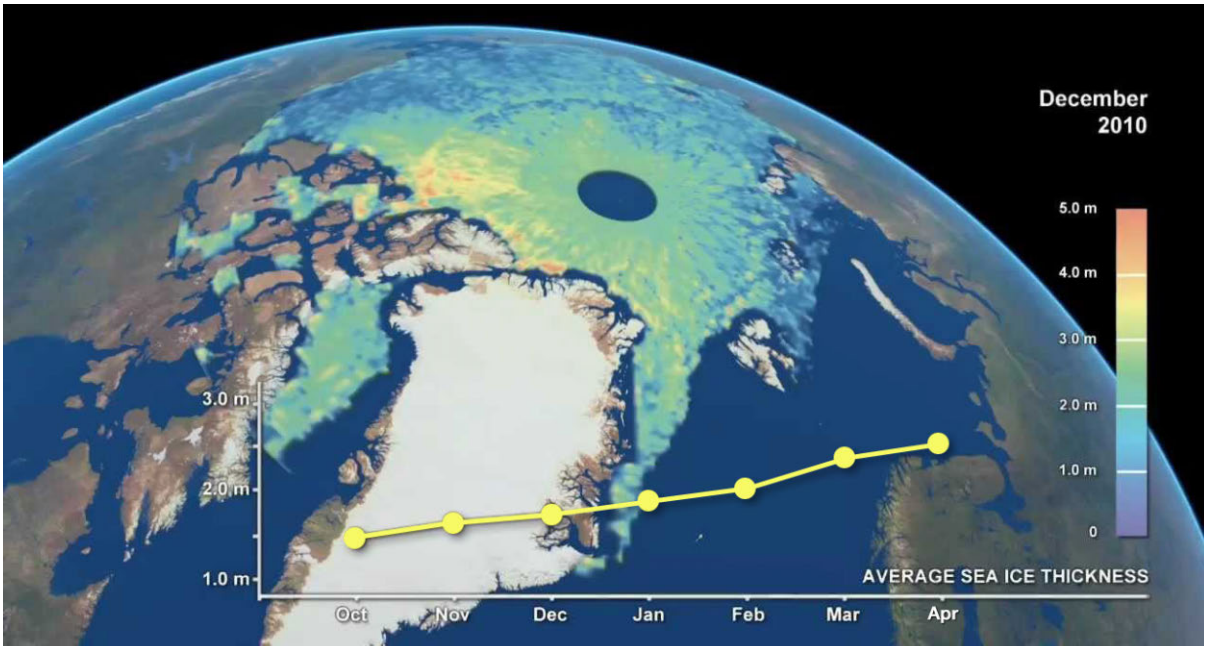


Figure 5. Arctic sea-ice thickness measured by CryoSat-2 from October 2010 to March 2011. **Image credit**: ESA-University College London-Planetary Vision 2012

of atmospheric processes related to climate and weather, and have practical applications in many different areas such as space weather and radiation hazards.

ADM-Aeolus: Wind Mission

With a 2015 target launch date, the Atmospheric Dynamics Mission *(*ADM)-Aeolus mission will advance global wind profile observations and provide much-needed information to improve weather forecasting. ADA-Aeolus will orbit in a Sun-synchronous, dusk/dawn orbit at 408 km (~253 mi) and employ a highly sophisticated Doppler wind lidar with a large telescope that collects light backscattered from gas, dust, and droplets of water in the atmosphere. Data from ADA-Aeolus are expected to pave the way for future operational meteorological satellites dedicated to measuring Earth's wind fields.

EarthCARE: Cloud and Aerosol Mission

With a target launch date in 2016, the Earth Clouds Aerosols and Radiation Explorer (EarthCARE[5]) mission is being implemented in cooperation with the Japan Aerospace Exploration Agency (JAXA) to improve the representation and understanding of Earth's radiative balance in climate and numerical weather forecast models. This will be achieved by global measurements of the vertical structure and horizontal distribution of cloud and aerosol fields together with outgoing radiation. The payload comprises two active instruments—a high-resolution atmospheric lidar and radar—and two passive instruments—a multispectral imager and a broadband radiometer. EarthCARE will orbit in an early-afternoon, Sun-synchronous orbit at 393 km (~244 mi).

Biomass

At ESA's User Consultation Meeting in March 2013 the scientific community made a recommendation to select the Biomass mission as the Earth Explorer 7; ESA member states subsequently approved that decision in May 2013. Biomass will employ a novel P-band synthetic aperture polarimetric radar operating at 435 MHz with a 6-MHz bandwidth; the satellite will fly at 637-666 km (~395-414 mi) in a near-polar, Sun-synchronous orbit. Data from Biomass will address one of the most fundamental questions necessary to our understanding of the land component in the Earth system—namely, the status and dynamics of forests—as represented by the distribution of

[5] To learn more about EarthCARE, see the March–April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, p. 45].

biomass and how it changes over time. Gaining accurate and frequent information about forest properties at observable scales will equip the scientific community with the information needed to address a range of critical issues with far-reaching benefits for science and society. Moreover, Biomass will greatly improve our knowledge of the size and distribution of the terrestrial carbon pool, and provide much-improved estimates of terrestrial carbon fluxes. In addition, the mission responds to the pressing need for biomass observations in support of global treaties such as the United Nations Framework Convention on Climate Change initiative for the Reduction of Emissions due to Deforestation and Forest Degradation.

Selecting the Next Earth Explorer

More Earth Explorer missions are planned for the future. As a result of the call for proposals for Earth Explorer 8, two missions were approved to move forward to Phase A/B1 as of November 2010. This phase includes a feasibility study and consolidation of the various components that make up a satellite mission. The two missions are:

- **Fluorescence Explorer (FLEX)**— a proposed three-year mission that would enable global monitoring of the steady-state chlorophyll fluorescence in terrestrial vegetation; and
- **CarbonSat**—a proposed three-to-five year mission that would measure global atmospheric amounts of carbon dioxide (CO_2) and methane (CH_4) with high spatial resolution and coverage, which can be used for inverse modelling. The CarbonSat instrument would take advantage of the technology and experience derived from the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) onboard EnviSat.

Earth Watch Missions

The *Earth Watch* missions are designed to provide Earth observation data for operational services, including the operational meteorological missions of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT[6]). EUMETSAT's main purpose is to deliver operational weather- and climate-related satellite data, images, and products to the European National Meteorological Services, as well as to other users, worldwide.

The ESA–EUMETSAT partnership was established in 1986 and implemented with a series of operational geostationary (Meteosat) and polar-orbiting (Metop) satellites; ESA builds the satellites that are then operated by EUMETSAT[7]. This program represents a new flagship model for cooperation between ESA and EUMETSAT, providing enhanced capabilities for weather and climate science as well as economic and societal benefits. EUMETSAT benefits extensively from ESA developments in satellite and instrument technology, algorithm development, launch operations, data processing, and calibration and validation experience.

The ESA–EUMETSAT partnership was established in 1986 and implemented with a series of operational geostationary (Meteosat) and polar-orbiting (Metop) satellites; ESA builds the satellites that are then operated by EUMETSAT. This program represents a new flagship model for cooperation between ESA and EUMETSAT, providing enhanced capabilities for weather and climate science as well as economic and societal benefits.

Geostationary Satellites

The Meteosat First Generation (MFG) series was a series of seven satellites—beginning with the first ESA launch in 1977—that provided Earth imagery and enabled continuous tracking of global weather patterns. Meteosat data formed the basis for weather forecasts in Europe for over two decades. The final launch took place in 1997.

[6] For more information about EUMETSAT, visit: *www.eumetsat.int*. This is also a good source for information on the MFG, MSG, and MTG series.
[7] This is similar to the arrangement that NASA and NOAA has had for the Geostationary Operational Environmental Satellite (GOES) System.

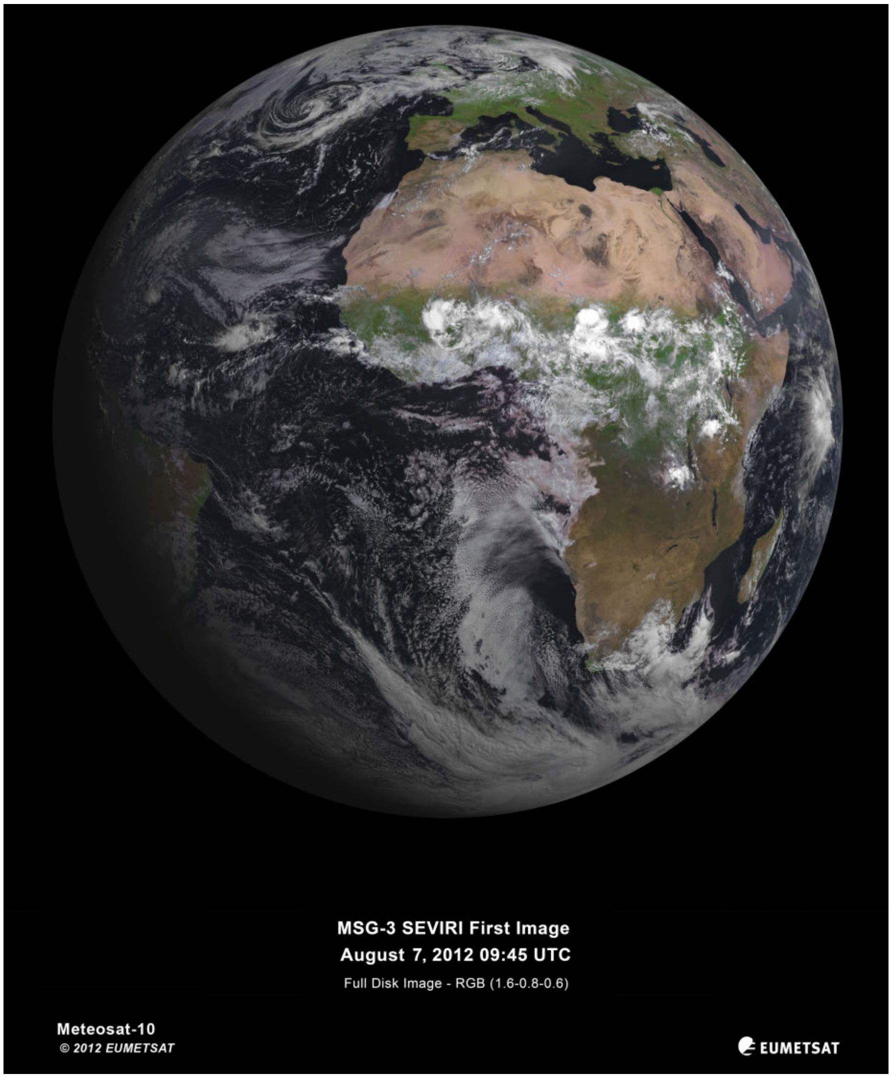


Figure 6. This image was taken from the Meteosat Second Generation-3 satellite (or Meteosat 10) that launched on May 7, 2012. The satellite is in a geostationary orbit located at 0° longitude. The image was generated by the SEVERI instrument using the red-green-blue channels and has a spatial resolution of 1 km (0.62 miles) at the satellite nadir. **Image credit:** EUMETSAT

Meteosat Second Generation (MSG) is a series of four launches, which began with Meteosat-8 (or MSG-1) in 2002. It is a significantly enhanced follow-on system to MFG, with a ground-based infrastructure, that will operate consecutively until 2020. The MSG satellites carry two instruments: the Spinning Enhanced Visible and InfraRed Imager (SEVIRI), which has the capacity to observe the Earth in 12 spectral channels and provide image data that are core to operational forecasting needs; and the Geostationary Earth Radiation Budget (GERB) instrument that supports climate studies by measuring the balance between the incoming radiation from the Sun and the outgoing reflected and scattered solar radiation plus the thermal infrared emission to space.

The Meteosat Third Generation (MTG) satellite program is envisioned as a series of six launches—beginning no earlier than 2020. Each MTG mission will consist of two parallel-positioned satellites: an imager platform (MTG-I) and a sounder platform (MTG-S). MTG-I will have the Flexible Combined Imager (FCI) and Lightning Imager (LI); MTG-S will have the Infrared Sounder (IRS), a hyperspectral thermal imager, and the InfraRed Sounder (IRS), an interferometer. In addition, MTG-I will also host the GMES/Sentinel-4 air quality observatory described below. These new observational capabilities should truly enable a "step change" in operational meteorology capabilities. The program should guarantee access to geostationary orbit meteorological data until at least the late 2030s. MTG will continue visible and infrared (IR) imagery and IR and ultraviolet (UV)/near-IR sounding observations from geostationary orbit, the data from which will result in three-dimensional information on humidity, temperature, and wind to support *nowcasting*—weather forecasting with a six-hour horizon.

Polar-orbiting Satellites

The EUMETSAT Polar System (EPS) is Europe's first polar-orbiting operational meteorological satellite system; it is the European contribution to the Initial Joint Polar-orbiting Operational Satellite System (IJPS)—a joint effort between EUMETSAT and NOAA. EUMETSAT polar-orbiting satellites (i.e., MetOp satellites) carry a suite of state-of-the-art sounding and imaging instruments that offer improved atmospheric sounding capabilities to both meteorologists and climatologists.

The EPS Space Segment includes three successive Metop satellites and is being developed and procured in a cooperative agreement between ESA and EUMETSAT. Metop-A was launched in October 2006, and Metop-B in September 2012. In April 2013, following the end of its commissioning period, Metop-B replaced Metop-A as EUMETSAT's prime operational polar-orbiting satellite, Metop satellites fly in a polar, low-Earth orbit corresponding to local "morning" while the U.S. and other partners are responsible for "afternoon" coverage[8, 9]. The series will provide data for both operational (meteorology) and research (climate) studies. The combined instruments on the Metop satellites have remote sensing capabilities to observe the Earth both day and night, as well as under cloudy conditions.

Each Metop satellite has a nominal lifetime in orbit of five years with a six-month overlap between consecutive satellites, thus providing more than 14 years of service. The European and U.S. meteorological satellites carry similar instruments for operational weather forecasting, however some instruments such as the AVHRR, provided by NASA and NOAA are identical on both NOAA and Metop satellites. In addition, the Metop satellites carry a set of European sensors aimed at improving atmospheric soundings, as well as measuring atmospheric ozone and near-surface wind vectors over the ocean. With this arrangement, NOAA and EUMETSAT satellites are highly complementary, providing the meteorological community with powerful tools with which to forecast weather.

The European and U.S. meteorological satellites carry a suite of identical sensors, for which NOAA provides most of the joint instruments on the satellites. In addition, the Metop satellites carry a set of European sensors aimed at improving atmospheric soundings, as well as measuring atmospheric ozone and near-surface wind vectors over the ocean. With this arrangement, NOAA and EUMETSAT satellites are highly complementary, providing the meteorological community with powerful tools with which to forecast weather.

Definition of the follow-on EUMETSAT Polar System is now under way, to replace the current satellite system in the 2020 timeframe and to contribute to the IJPS. Mission requirements have been defined to support operational meteorology and climate change research. Satellite platforms, instruments, and ground-support infrastructures are under study in coordination with NOAA, ESA, and other European space agencies. Similar to Metop, the satellites will fly in a Sun-synchronous, low-Earth orbit, with a descending node at 9:30 AM local time, providing global observations with revisit times of 12 to 24 hours, depending on the instrument. This program began in 2005 under the name of Post-EPS; when the design and development phase began in 2012, it was under a new program called EPS Second Generation (EPS-SG).

Sentinel Missions

Sentinel is part of the GMES/Copernicus Space Component, which will collect robust, long-term, climate-relevant datasets. Together with other satellites, their combined data archives will be used to produce Global Climate Observing System (GCOS[10]) Essential Climate Variables (ECV[11]) for climate monitoring, modeling, and prediction. The five Sentinel missions are based on a constellation of two satellites each to fulfill revisit and coverage requirements, providing robust datasets for operational services. The Sentinel missions will launch beginning in 2013; they are briefly summarized hereafter. For additional information on the Sentinel missions, visit: *www.esa.int/Our_Activities/Observing_the_Earth/GMES/Overview4*.

- **Sentinel-1:** Scheduled to launch anywhere from late 2013 to early 2014, this polar-orbiting, all-weather, day-and-night mission will enable a SAR in C-band that will support GMES/Copernicus operational services for land, marine, and risk-assessment applications. It builds on ESA's and Canada's heritage SAR systems on ERS-1, ERS-2, Envisat, and Radarsat.

---

[8] NASA and its international partners operate several Earth-observing satellites that closely follow one after another. This coordinated group of satellites (called the Afternoon Constellation, or the A-Train, for short) are in a polar orbit and cross the Equator at about 1:30 PM local time.
[9] The "morning" and "afternoon" orbits result in four overpasses per day rather than two for one satellite, and result in improved numerical weather predictions.
[10] GCOS is intended to be a long-term, user-driven operational system capable of providing comprehensive observations. For more information, visit: *www.wmo.int/pages/prog/gcos/index.php?name=AboutGCOS*.
[11] To view the chart of 50 ECVs defined by GCOS, visit: *www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables*.

- **Sentinel-2:** Planned for launch in 2014, this is a polar-orbiting, multispectral, high-resolution imaging mission for GMES land monitoring to provide imagery of vegetation, soil and water cover, inland waterways, and coastal areas. Sentinel-2 will also provide information for emergency services. It is a follow-on enhancement of the French Système Pour l'Observation de la Terre (SPOT).

- **Sentinel-3:** Planned for launch in 2014, this mission is composed of two operational satellites with a one-day (over land) and two-day (over ocean) revisit time. Each satellite will carry an Ocean and Land Colour Instrument (OLCI), Sea and Land Surface Temperature Radiometer (SLSTR), and a microwave payload that includes a SAR Radar Altimeter (SRAL), and a two-frequency Microwave Radiometer (MWR). This mission will address surface topography, sea and land surface temperature, ocean carbon, and land color.

- **Sentinel-4:** Planned for launch in 2019, this geostationary-orbit mission is devoted to atmospheric monitoring (see previous section on MTG). UV and NIR spectrometers will be used to continuously monitor air pollution and its precursors—from North Africa to Northern Europe—at 6 x 6-km^2 (~2.3 x 2.3-mi^2) spatial and one-hour temporal resolutions.

- **Sentinel-5 Precursor:** This mission is a polar-orbiting, Sun-synchronous mission scheduled to launch in 2015. It is designed to reduce data gaps between Envisat and Sentinel-5 for global atmospheric composition measurements including ozone, aerosols, and atmospheric pollution precursors. The instrument will be a follow-on to the Ozone Monitoring Instrument (OMI) flying on NASA's Aura satellite, with additional channels in the NIR.

- **Sentinel-5:** This mission will monitor the atmosphere from polar orbit aboard an EPS-SG satellite projected for launch in 2020. It will continue the atmospheric composition data collected from Envisat and employ UV and IR spectrometers that will measure profiles and column amounts of trace gases and aerosols important for atmospheric chemistry and climate studies.

Figure 7. This figure is an artist's rendition of the Sentinel-3 satellite. The SRAL antenna is the larger circular structure on the bottom of the spacecraft. Sentinel-3A will be launched into a Sun-synchronous orbit at 10:00 Local Sidereal Time. **Image credit:** ESA

European Space Data Policy and Distribution

ESA has leveraged the continuous technological progress made possible by the computer and Internet revolution, and implemented a free and open data policy that has enabled maximum exploitation of ESA data.

ESA also distributes satellite data from international partner agencies—called Third Party Missions (TPM). The data from these missions are distributed under specific agreements with the owners or operators of those missions, which can be either public or private entities outside or within Europe*.

ESA has defined a new Earth Observation Data Policy (EODP) that applies to all missions including those mentioned in this article. The revised ESA EO data policy defines two groups of datasets: *free* and *restrained*. Data from both types of datasets are provided free of charge; however, user registration is needed to access the data. Online Earth science datasets can be accessed through an easily navigated registration interface. To access, visit: *earth.esa.int/web/guest/home* and click *Register* at the top-right corner of the page.

For more information on the EODP, visit: *earth.esa.int/web/g]t/missions/content?p_r_p_564233524_assetIdentifier=revised-esa-earth-observation-data-policy-7098*.

* Detailed information about ESA Earth-observation missions, data access, user tools, events, proceedings, and highlights can be found at *earth.esa.int/web/guest/home*.

ESA–NASA Earth-observation Collaborations

Collaboration with worldwide research and operational space agencies and international environmental organizations is a high priority for ESA. The Agency has conducted joint field campaigns for data validation with mission partners and has worked closely with international science teams for algorithm development and data homogeneity and accessibility.

Collaboration with worldwide research and operational space agencies and international environmental organizations is a high priority for ESA. The Agency has conducted joint field campaigns for data validation with mission partners and has worked closely with international science teams for algorithm development and data homogeneity and accessibility.

ESA and NASA have the largest Earth-observing programs in the world and have developed strong collaboration for postlaunch activities over the last several years. These activities include algorithm refinements, calibration/validation, data homogenization, and data distribution. Collaborations are established as either bilateral agreements or facilitated through international organizations such as the GCOS, World Meteorological Organization (WMO), and Committee for Earth Observing Satellites (CEOS). CEOS is an assembly of all the world's space agencies, the existence of which allows even further international collaborations[12].

Bilateral scientific meetings are held by ESA and NASA at least once per year, backed by regular, top-level management meetings. Three ESA–NASA working groups were set up in 2010 to prepare for and organize cooperation in the field of missions and technology, calibration/validation activities and field campaigns, ground segments and data homogenization, and distribution policies. Subsequent working groups were organized to include further broadening of calibration/validation activities to advance science goals, generate agreement on free and open data distribution policies, and develop programmatic guidelines for further potential coordination, as discussed below. The material that follows gives a few examples of ongoing and planned collaborative activities for ESA and NASA. Beyond these, additional collaborative opportunities have been identified for calibration/validation and data sharing from the SMOS and Aquarius, Soil Moisture Active Passive (SMAP), ADM-Aeolus, and Biomass missions.

[12] For more information about CEOS, visit: *www.ceos.org*.

Greenland and Antarctic Ice Sheet Mass Loss

Excellent collaboration has been achieved with ESA's CryoSat Validation Experiment (CryoVEx) and NASA's Operation IceBridge field campaigns to validate data from ESA's CryoSat and NASA's ICESat[13] missions. The recently performed Ice-sheet Mass Balance Intercomparison Exercise (IMBIE) was a combined ESA–NASA effort to perform experiments to better understand discrepant results concerning the mass balance of ice sheets over Greenland and Antarctica. The different techniques were intercompared among different groups using the same satellite-derived data. The IMBIE 2012 reported that by combining datasets for a 19-year time series starting in 1992, Greenland and Antarctica lost ice-sheet mass equivalent to a global sea-level rise of 11.1 ± 3.8 mm (~0.44 ± 0.15 in). This collaboration involved approximately fifty institutions and was given great visibility in both the scientific and international media.

Excellent collaboration has been achieved with ESA's CryoSat Validation Experiment (CryoVEx) and NASA's Operation IceBridge field campaigns to validate data from ESA's CryoSat and NASA's ICESat missions.

Upwelling Signals in the Gulf of Panama

ESA and NASA are using data from SMOS and Aquarius to identify upwelling, which usually signals nutrient-rich waters from the ocean depths rising to the warmer, sunlit zone at the surface. A test area recently has been identified in the Gulf of Panama, where low spatial coverage is available with *in situ* measurements, but where strong seasonal signals exist. Consistency in measurement error has been demonstrated between SMOS and Aquarius instruments. More meetings are planned in 2013 to further develop synergy between these two missions in the areas of soil moisture, ocean surface salinity, and cryospheric applications.

Essential Climate Variables

The collaboration between both parties extends also to the GCOS ECV. Cross-calibration activities are planned over Antarctic calibration sites to ensure accuracy of long-term datasets, and to characterize climate-change issues using relevant data from missions such as ESA's Earth Explorers and NASA's upcoming SMAP mission.

Long-term Ozone Records

Under the auspices of CEOS and its Constellation projects, a joint effort has been undertaken to further improve the long-term ozone record collected by both NASA/NOAA and ESA/EUMETSAT instruments: There are over 30 years of ozone data from NASA, and about 20 years from ESA. Homogenizing or reconciling differences in these datasets is crucial to understanding anthropogenic ozone depletion and the impact of climate on ozone recovery. Ongoing collaborative studies include compiling spectroscopic databases, refining algorithms, and continuing calibration/validation activities; an active international chemical climate-modelling program supports this activity. Through ESA's TPM program Canada is also participating, with their Atmospheric Chemistry Experiment (ACE) and Optical Spectrograph and InfraRed Imaging System (OSIRIS) satellites. The result of this collaboration will impact how future ozone data will be collected, processed, and archived for the upcoming NASA/NOAA Joint Polar Satellite System (JPSS) and ESA GMES/Sentinel missions. Ozone data are also a GCOS ECV and therefore a high priority among the three agencies. ESA–NASA collaboration through CEOS also continues with the working groups and Constellation efforts such as the Atmospheric Composition Constellation (ACC) that is formulating an air-quality satellite constellation of three geostationary missions to be launched by Europe, the U.S., and Korea[14].

---

[13] ICESat stands for Ice, Clouds, and Land Elevation Satellite. Operation IceBridge is a series of field experiments "bridging" the data-gap between ICESat (which ended in 2009) and ICESat-2 (with launch planned for 2016).

[14] To learn more about this combined effort, read "NASA Ups the TEMPO in Air Pollution" [**Volume 25, Issue 2**, pp. 10-15].

Landsat 8 and Sentinel-2

Recently, a cooperative effort between the U.S. Geological Survey, NASA, and ESA under the GMES/Copernicus Programme was established that will employ the U.S. Landsat 8 and Sentinel-2 land-imaging missions. The objective of the effort is the interoperability of data products from the Landsat 8 satellite and the two identical Sentinel-2 satellites—i.e., Sentinel-2A and -2B. The collaborative approach initially foresees ground crosscalibration of the instruments to generate consistent calibration data from the three satellite-based instruments. The goal is to guarantee space-based data from multiple instruments, with comparable radiometric performance over similar ground scenes, thus enabling synergistic use of data for end users.

Hosting Instruments

Although there are precedents for hosting each other's instruments for flight missions in the ESA and NASA planetary and astronomy programs, no such exchange has occurred for Earth science. However, there are examples of international exchanges, such as the Dutch OMI being flown on NASA's Aura spacecraft, Japan's Advanced Microwaving Scanning Radiometer–EOS (AMSR-E) on Aqua, and NOAA sounders on EUMETSAT satellites. Recent discussions between ESA and NASA's Earth-science programs have begun, including discussion about gravity measurements for NASA's Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) and GOCE missions. The science teams have already shown synergy between GOCE and GRACE in developing static global gravity field models, which are applicable to several Earth-science disciplines. Follow-on studies are assessing the possibility of having GRACE and GOCE fly as a constellation, as well as the feasibility of flying a new U.S. instrument on an ESA Earth Explorer mission.

NASA and ESA represent the two largest space agencies in the world and both have extensive Earth science missions that have provided vast amounts of Earth observation data for Earth science and for various services that benefit society.

Summary

NASA and ESA represent the two largest space agencies in the world and both have extensive Earth science missions that have provided vast amounts of Earth observation data for Earth science and for various services that benefit society. The ESA missions have resulted in high-quality and freely available datasets, which are being exploited by the worldwide science and applications communities. ESA will continue to launch research missions to explore Earth system science using advanced technologies. They will continue to provide to EUMETSAT space hardware and algorithms needed for the European meteorological services. ESA is also providing the space component for the European Global Monitoring for Environmental Security initiative. As NASA begins to deploy the Decadal Survey and smaller, focused missions, many collaborative opportunities with ESA are arising in all aspects of mission development and implementation. Synergy resulting from such collaboration will result in better use of Earth observations and likely afford opportunities for financial efficiency. ■

NASA Celebrates Earth Day and More

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

Events took place on Saturday, April 6, and Monday, April 22 (Earth Day 2013), at Union Station in Washington, DC. Over one hundred middle- and high-school students and hundreds of outside visitors enjoyed the various presentations, activities, and demonstrations that NASA had to offer.

During the month of April NASA teamed with Earth Day Network[1] to commemorate *Earth Month*—a month-long initiative to raise awareness about our home planet and to celebrate the forty-third Earth Day. Events took place on Saturday, April 6, and Monday, April 22 (Earth Day 2013), at Union Station in Washington, DC. Over one hundred middle- and high-school students and hundreds of outside visitors enjoyed the various presentations, activities, and demonstrations that NASA had to offer. To view photos from both events, visit: *www.flickr.com/photos/eospso/sets*.

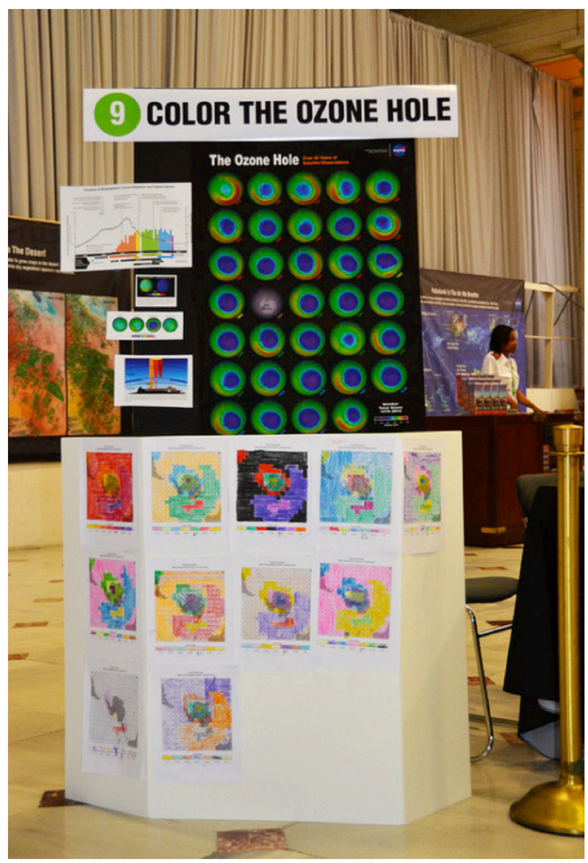
STEM Science Fair—April 6

On April 6 Earth Day Network supported the Science, Technology, Engineering, and Math (STEM) Science Fair event, open to all Washington, DC students in grades 6-12. Judges from NASA, Grant Thornton[2], Union Station, and Earth Day Network evaluated more than 30 student projects and gave 12 awards for excellent and exciting work.

For the duration of the event NASA offered a variety of hands-on, interactive activities and demonstrations that highlighted particular themes in Earth science, and additional topics to include planetary science, heliophysics, and astrophysics. Activities included

[1] Earth Day Network (EDN) works with over 22,000 partners in 192 countries to broaden, diversify, and mobilize the environmental movement. For more information, visit: *earthdaynetwork.org*.
[2] Grant Thornton is a global audit, tax, and advisory organization.

STEM science fair participants, parents, teachers, and the general public were invited to participate in a variety of NASA activities and demonstrations. **Image credit:** NASA



Ginger Butcher [NASA's Goddard Space Flight Center (GSFC)/Sigma Space Corporation—*Aura Education/Public Outreach Lead*] showed how scientists use colored maps to observe ozone concentrations over Antarctica [*top poster*] while helping participants design their own colored maps of ozone concentrations [*bottom trifold display board*]. **Image credit:** NASA

Participants pieced together puzzles of Earth and learned about satellite remote sensing. **Image credit:** NASA

Earth Day participants created a cloud in a bottle and explored the relationship between temperature and pressure. **Image credit:** NASA

The *Carbon Footprint Estimator* activity allowed participants to calculate their carbon footprint to discover where they rate on the Green-o-Rometer. **Image credit:** NASA

an ultraviolet (UV) detection demonstration, a satellite-image comparison game, carbon-footprint-estimator activity, a chance to assemble rain gauges, a digital photo booth, a mystery image challenge, a cloud-in-a-bottle demonstration, satellite-image puzzles, and an ozone-hole-coloring activity. Several of the activities mentioned are shown in the photos above.

The *NASA Science Gallery* was also on display and featured twelve large image "curtains" to help tell fascinating stories about our changing planet. The gallery and accompanying story-telling brochure can be found at *eospso.gsfc.nasa.gov/sites/default/files/publications/NASA%20Science%20Gallery%20Brochure.pdf*.

The 2013 NASA Earth Day exhibit featured a 30-ft (~9-m) Earth tent located inside the East Hall of Union Station. **Image credit:** NASA

Ralph Kahn [GSFC—*Senior Research Scientist*] stands in front of one of the *NASA Science Gallery* images that describes how annual Arctic minimum sea ice extent has been on the decline in recent decades. **Image credit:** NASA

Edward Celarier [GSFC/Universities Space Research Association—*Associate Research Scientist*] at the hyperwall comparing the Earth at night image [shown here] to global nitrogen dioxide (NO_2) measurements to illustrate the relationship between urbanization (i.e., as indicated by the presence of city lights) and pollution (i.e., as indicated by NO_2 emissions). **Image credit:** NASA

Steven Platnick [GSFC—*Senior Project Scientist*] discussed the importance of NASA's Earth-observing satellite fleet during a hyperwall presentation. **Image credit:** NASA

Official Earth Day—April 22

On April 22 NASA representatives engaged and interacted with hundreds of people from around the world who passed through Union Station on Earth Day. To open the event **Jack Kaye** [NASA Headquarters—*Associate Director of Research for the Earth Science Division*] provided remarks from the Earth Day Network stage and emphasized that every day is Earth Day at NASA.

The NASA exhibit featured an Earth tent with over a dozen hands-on activities and demonstrations, the Science Gallery, and the *hyperwall*—a nine-screen, high-definition video wall. In addition to the hands-on activities and demonstrations offered on April 6, a lunar-exploration activity, an aeronautics activity, and a demonstration of Newton's Three Laws of Motion, which allowed participants to assemble and test film-canister rockets, were also offered. Scientists gave 15-minute presentations in front of the hyperwall, covering a variety of topics that included an overview of NASA's Earth-science missions, the possibility of finding another Earth-like planet, exploring Mars, studying chemistry from space, measuring the retreat and thinning of Antarctic glaciers and sea ice, and describing new Earth observing missions.

The NASA participants thank all those who helped celebrate Earth Day at Union Station this year, and hope that if you were unable to attend you celebrated in your own special way. ■

NASA's Venture Continues: An Update on the EVS-1 Investigations[1]

Alan Ward, NASA's Goddard Space Flight Center/Global Science and Technology, alan.b.ward@nasa.gov
Kimberly Land, NASA's Langley Research Center/ManTech International Corporation, kimberly.w.land@nasa.gov
Karen Yuen, NASA/Jet Propulsion Laboratory, karen.yuen@jpl.nasa.gov

Introduction

The National Research Council's (NRC) 2007 Decadal Assessment for Earth Science (known familiarly as the *Decadal Survey*[2]) called for the establishment of a new category of missions that would be "…stand-alone using simple, small instruments/spacecraft/launch vehicles." The Survey further stated that maintaining a steady stream of opportunities for the Earth science community to participate in innovative mission development and implementation is key to the success of the program.

Pursuant to that goal, NASA established the Earth Venture (EV) line of missions and placed them under the auspices of its Earth System Science Pathfinder (ESSP) Program *(science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder*). These missions are broken into three categories—Sub-Orbital (EVS), Full Orbital (EVM), and Instrument (EVI)—the details of which have been described previously in *The Earth Observer*[3]. To date, there have been three Earth Venture (EV) Announcements of Opportunity (AO)—EVS-1 (EV-1[4]), EVM-1 (EV-2), and EVI-1[5]. The EVS-2 AO has just been released—see Announcement on page 32.

This article provides an update on the five suborbital investigations funded through the EVS-1 (EV-1) AO, which were selected in May 2010 and are now all well underway. They are relatively small as compared to satellite missions—with budgets of up to $30M spread over no more than five years, and meant to provide focused science investigations amenable to extended airborne campaigns. These investigations are stand-alone—i.e., their science is not meant to replace satellite missions, but rather to complement them. Indeed, EVS-1 science supports NASA's broader range of Earth system science research. All data, once calibrated and validated, are open and available to all researchers.

The Earth Observer solicited short summaries from each of the EVS-1 principal investigators of their investigations to date. The investigations cover a variety of research, ranging from the tropics to the arctic, from the top of the atmosphere to near the surface.

Five High-flying Expeditions to Study Earth Science—EVS-1 Updates

The Earth Observer solicited short summaries from each of the EVS-1 principal investigators of their investigations to date. The investigations cover a variety of research, ranging from the tropics to the arctic, from the top of the atmosphere to near the surface. The five investigations are self-contained and operate independently of each other—the only common element is that they happen to have been funded through EVS-1. Together they give an idea of the diversity of investigations taking place in NASA's Earth Science division. This article is comprised of these summaries.

---

[1] Primary authors are listed below the title; other contributors are listed throughout.
[2] NRC, 2007: *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, The National Academies Press.
[3] See "A New Venture for NASA Earth Science" in the September–October 2010 issue of *The Earth Observer* [**Volume 22**, **Issue 5**, pp. 13-18].
[4] *A note on nomenclature:* EVS-1 was formerly classified as EV-1; EVM was formerly classified as EV-2. The earlier classifications are still sometimes used.
[5] To learn more about the EVM-1 (EV-2) selection read "NASA Intensifies Hurricane Investigations with CYGNSS" in *The Earth Observer*'s May–June issue [**Volume 25**, **Issue 2**, pp. 12-21]; to learn more about the EVI-1 selection, read "NASA Ups the TEMPO on Air Pollution" in the March–April issue [**Volume 25**, **Issue 3**, pp. 10-15].

feature articles

AirMOSS

Principal Investigator: Mahta Moghaddam, University of Southern California, *mahta@usc.edu*

Project Manager: Yunling Lou, NASA/Jet Propulsion Laboratory, *yunling.lou@jpl.nasa.gov*

URL: *airmoss.jpl.nasa.gov*

While carbon dioxide (CO_2) and methane (CH_4) are probably the best-known climate-change-related carbon compounds, they are also part of a larger picture. Much like water and energy, carbon in various forms circulates through Earth's atmosphere as part of the *carbon cycle.* Improving our knowledge of the climate impact of these two greenhouse gases thus requires improving our overall ability to know where all of the carbon in the Earth system is located at any given time.

The Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) mission is seeking to reduce the uncertainty in the estimate of the Net Ecosystem Carbon Exchange (NEE) and is focusing its efforts on RZSM over North America—since the continent's vast and highly varied vegetated surfaces are a critical component of the global carbon cycle.

Changes in soil moisture impact carbon uptake (e.g., photosynthesis) and carbon release (e.g., respiration). Such local phenomena are multiplied to the grand scale when addressed globally, as Earth's vegetated surfaces exchange large amounts of CO_2 and other gases with the atmosphere. On this scale, scientists want to quantify the difference between the rate of carbon uptake and rate of carbon release, generally. This *net ecosystem carbon exchange* (NEE) is a key parameter for understanding Earth's carbon cycle.

NEE quantifies these so-called *carbon fluxes*, but current continental-scale estimates contain high levels of uncertainty. One of the biggest sources of uncertainty is how much moisture lies beneath the surface in the region where the roots intersect with the soil; this is called *root zone soil moisture* (RZSM). RZSM is defined here as the volumetric moisture (m^3/m^3 in %) in the soil column from the surface to the rooting depth of plants. RZSM impacts carbon *uptake* because water availability to plant roots is a prerequisite for activating photosynthesis: Plants without sufficient water available at their roots could not become photosynthetically active. Conversely, RZSM impacts carbon *release* through respiration processes, where vegetation and organisms in soil consume available organic matter and release CO_2 to the atmosphere[6].

RZSM varies considerably over short distances and is believed to account for 60–80% of the variability in NEE carbon flux components. Therefore, to improve estimates of NEE it is crucial to gather more observations of RZSM. And yet to date—except at a few specific *point* locations—it has remained an unobserved quantity.

The Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) mission is seeking to reduce the uncertainty in the estimate of the NEE and is focusing its efforts on RZSM over North America—since the continent's vast and highly varied vegetated surfaces are a critical component of the global carbon cycle.

AirMOSS will reach its goals by:

- providing high-resolution regional observations of RZSM over the major North American biomes;
- quantifying the impact of RZSM on estimates of regional carbon fluxes contributing to NEE; and

[6] Under normal conditions, respiration is impacted by soil moisture but also strongly by soil temperature. Recent studies have found that drier conditions cause respiration to be dominated by soil water content in the root zone through a strong and usually nonlinear process. For other ecosystems under dry conditions, a sharp decline in respiration has been reported.

- upscaling the reduced-uncertainty regional estimates of carbon fluxes to the North American continental scale.

The benchmark AirMOSS dataset represents a major breakthrough over current point-scale RZSM measurements and will provide a missing critical piece of information for carbon-flux models. The team will input the RZSM data into different models[7], to calculate NEE. Without the AirMOSS measurement and modeling framework, large uncertainties in NEE estimation will remain.

Measurement/Sampling Strategy

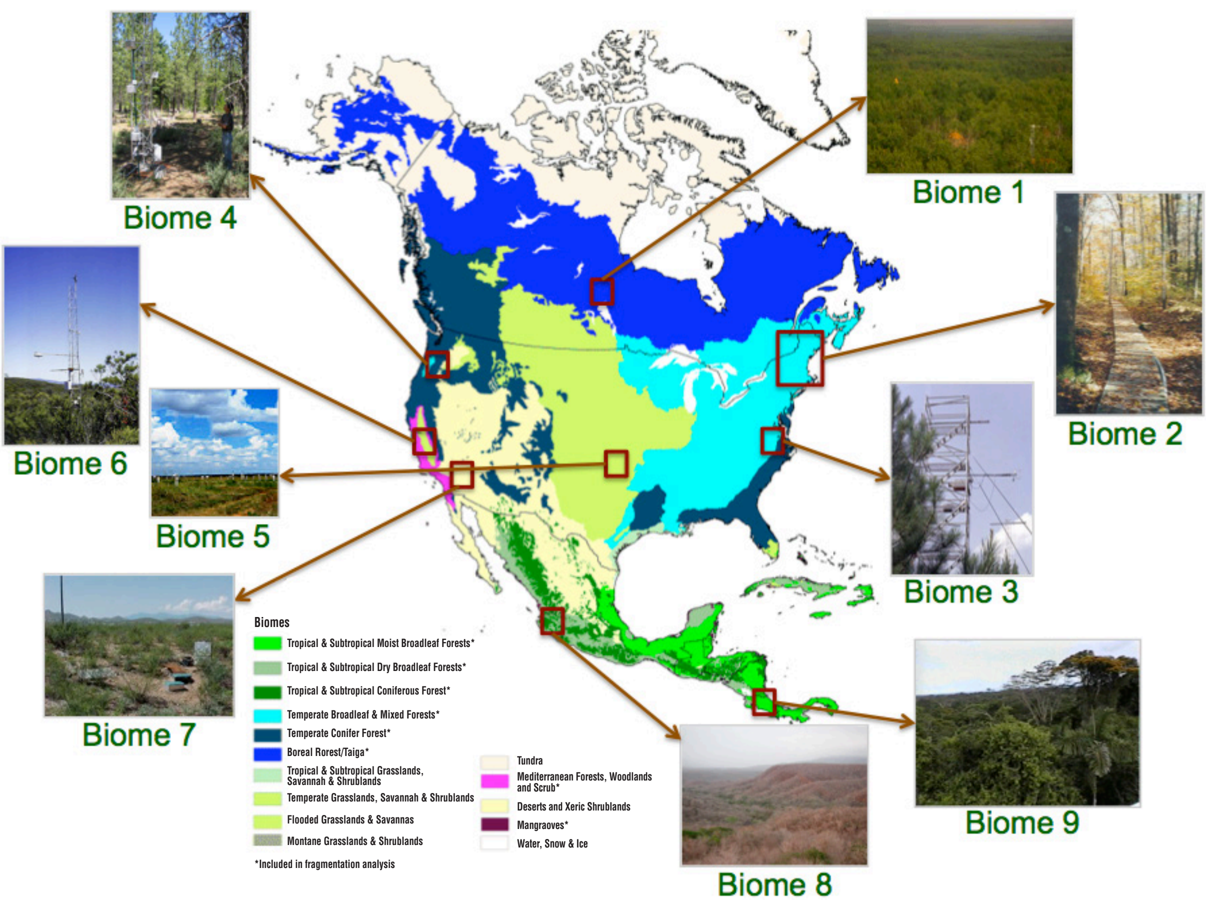
To measure RZSM, AirMOSS uses an airborne P-band synthetic aperture radar (SAR) with a 70-cm wavelength that has the capability to penetrate substantial vegetation canopies and soil to depths greater than 1 m (~3.3 ft). The AirMOSS instrument, built at the NASA/Jet Propulsion Laboratory (JPL) is flown on a Gulfstream-III (G-III) aircraft, operated by NASA's Johnson Space Center (JSC). Extensive ground, tower, and aircraft *in situ* measurements are used to validate RZSM and carbon-flux model estimates.

AirMOSS is planning campaigns for three years, during which the airborne P-band SAR will fly over nine major North American biomes—see **Figure 1**. These biomes reach as far north as the boreal forests of Canada, and as far south as the tropical forests of Costa Rica. AirMOSS will fly between three and nine times over each of these regions to sufficiently sample their interseasonal variations. Having three campaign years allows the AirMOSS mission to also sample interannual variations. The first campaign year started in September 2012 and will conclude in August 2013. So far,

AirMOSS will fly between three and nine times over each of these regions to sufficiently sample their interseasonal variations. Having three campaign years allows the AirMOSS mission to also sample interannual variations. The first campaign year started in September 2012 and will conclude in August 2013.

[7] Specifically hydrologic data assimilation and ecosystem demography models.

Figure 1. The map gives an idea of the nine biomes that will be surveyed during AirMOSS, covering the width and breadth of North America, and ranging from the Arctic to the tropics.



AirMOSS has completed over 60 science flights and several engineering and calibration flights, for a total of 100 flights.

Data Products

The AirMOSS radar imagery is produced at JPL and archived at the Alaska Satellite Facility (ASF). RZSM maps are produced at the University of Southern California—the home institution of the AirMOSS principal investigator; some of the RZSM products are also generated at JPL. These "snapshot" maps of soil moisture at the root zone are being assimilated into hourly RZSM estimates by other members of the AirMOSS science team at the U.S. Department of Agriculture (USDA) and NASA's Goddard Space Flight Center (GSFC). These, in turn, are used by science team members at Harvard University to produce estimates of NEE—first over areas covered by the AirMOSS flights, and then scaled up to cover the entire North American domain. The RZSM maps retrieved from the radar, the hourly estimates of RZSM, and NEE estimates are archived at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Data Center. The final product of AirMOSS will be a new estimate of NEE for North America with a quantified assessment of uncertainty, which is expected at the end of the mission in 2015. In the meantime, the science team is delivering intermediate products.

*Over the past two years, NASA's Airborne Tropical TRopopause EXperiment (ATTREX)—managed by NASA's Ames Research Center—has been helping scientists fill the gaps in their understanding of the Tropical Tropopause Layer (TTL) environment, using the long-range, high-altitude Global Hawk **unmanned aircraft system** (UAS).*

ATTREX

Principal Investigator: Eric Jensen, NASA's Ames Research Center (ARC), *eric.j.jensen@nasa.gov*

Project Manager: Dave Jordan, NASA's Ames Research Center, *dave.e.jordan@nasa.gov*

URL: *espo.nasa.gov/missions/attrex*

While current models do a reasonable job representing *tropospheric* water vapor, the same cannot be said of that in the *stratosphere*. Specifically, there are still significant gaps in our understanding of the physical processes at work in the *tropical tropopause layer* (TTL)—the layer of atmosphere below the stratosphere over the topics at an altitude of approximately 13 to 18 km (8 to 11 miles)—which controls much of the composition of the stratosphere, globally.

The impacts of water vapor on Earth's climate and energy balance loom large and are most pronounced in the stratosphere, where even slight changes in humidity can have climate impacts that are comparable to the impact that decades of changes in greenhouse gas concentrations have had. Future climate assessments are therefore critically dependent on accurate measurements of stratospheric humidity.

Likewise, the chemical processes at work in the TTL regulate the amount of ozone (O_3) entering the stratosphere and are not well represented in current climate models. Stratospheric O_3 concentration has a significant impact on Earth's climate. In simple terms, this is "good ozone" that protects Earth's biosystems from the harmful effects of ultraviolet radiation. The thinning of the ozone layer in the stratosphere over polar regions results in the annual Antarctic *ozone hole*—an areal diminution of O_3 in spring.

Over the past two years, NASA's Airborne Tropical TRopopause EXperiment (ATTREX)—managed by NASA's Ames Research Center—has been helping scientists fill the gaps in their understanding of the TTL environment, using the long-range, high-altitude Global Hawk *unmanned aircraft system* (UAS). To learn more about this UAS, see ***NASA's Global Hawk at a Glance*** on page 24.

Current computer models are using assumptions about how much moisture is being pulled out of the atmosphere (*dehydration*) during the formation of cirrus clouds. Those assumptions, if inaccurate, can lead to significant errors. Therefore, data, such as those being collected during ATTREX flights, will be used to study the size, shape, and distribution of ice crystals in the cirrus clouds as well as understand the dehydration caused by their formation in order to make the models more accurate.

Current computer models are using assumptions about how much moisture is being pulled out of the atmosphere (dehydration) during the formation of cirrus clouds. Those assumptions, if inaccurate, can lead to significant errors.

Round One

The first ATTREX Global Hawk flights from NASA's Dryden Flight Research Center (DFRC) occurred during October and November 2011. Three long flights into the tropics, with durations ranging from 15 to 24 hours, were conducted. The flights targeted cold tropical tropopause regions where *in situ* cirrus form, downstream of areas of deep convection and spread out (or *detrain)* in the TTL, and where rapidly changing concentrations of tracer chemical species are likely. Each of the flights included multiple vertical profiles over the tropics, which typically extended from cruise altitudes of 54,000 to 60,000 ft (~16.4 to 18.2 km) down to 45,000 ft (~13.7 km). Real-time measurements of temperature and cloud structures below the aircraft provided unique opportunities for *in situ* observations of the chemical and physical properties of ice clouds in the TTL and were used to decide when and where to execute the vertical profiles.

Round-Two

From February to early March 2013, six more ATTREX flights were conducted from DFRC into the deep tropics—see **Figure 2**. Again, the flights targeted cold tropopause regions where TTL cirrus and convective transport into the upper TTL are likely. Flights well across the Equator into the Southern Hemisphere provided surveys of changes in TTL composition as a function of latitude. This second round of flights placed an even greater emphasis on vertical profiling through the TTL than the round-one flights. The number of TTL profiles per flight ranged from 16 to 24. Several more flights took place in January 2013, when the tropical tropopause was unusually cold and dry.

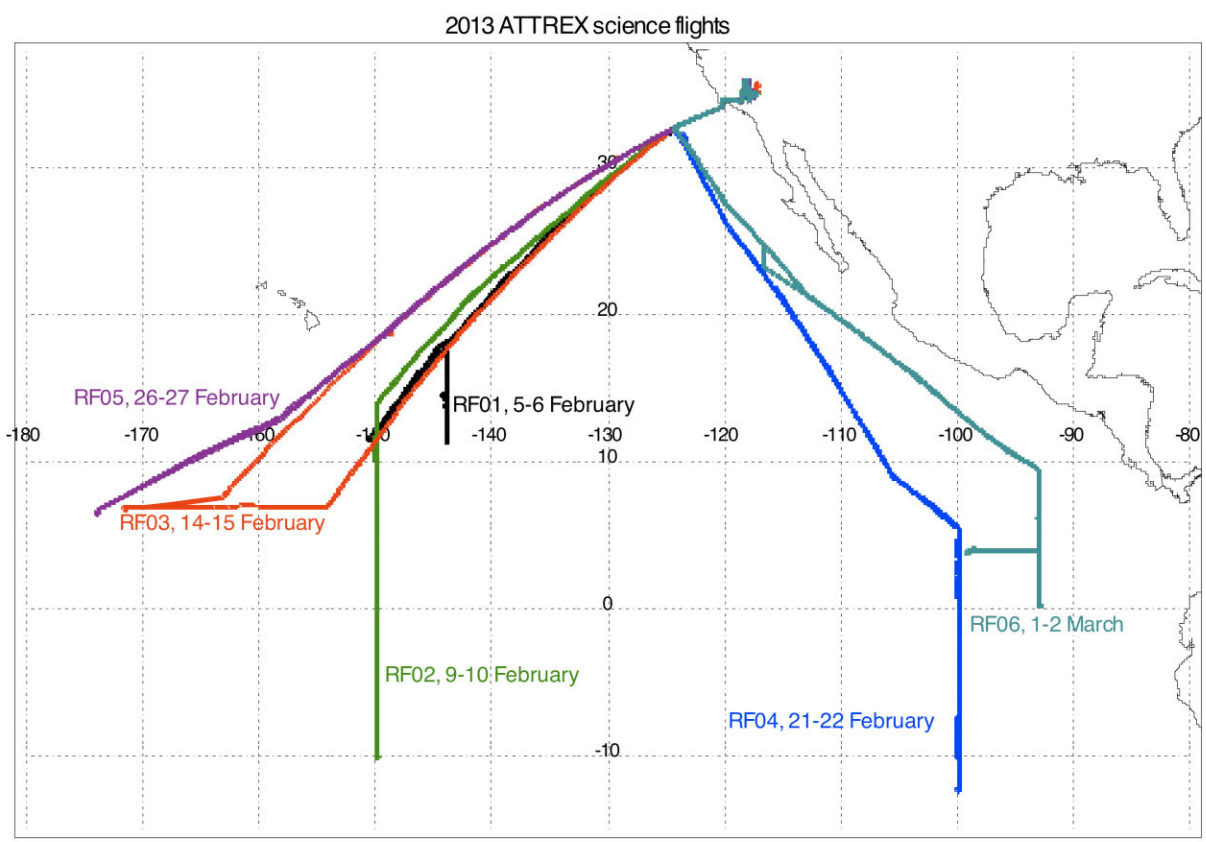


Figure 2. Flight paths for some of the second-round ATTREX Global Hawk flights conducted during February-March 2013.

As intended from the outset when the ATTREX mission was awarded in 2010, having Global Hawk flights from Guam in 2014 has permitted the inception, planning, and approval of two additional aircraft campaigns to be coordinated with ATTREX.

Round-Three

A third round of ATTREX flights will be based out of Guam, with flights planned in January-February 2014 to collect winter-season data. Additional flights are planned for early summer (May-June 2014). Deployment from Guam will allow direct access to the Western Pacific—in contrast to the flights based out of DFRC that required a six-to-eight-hour transit to reach the tropics. The *Western Pacific tropopause cold pool*—a sampling region critical to understanding TTL processes—is essentially directly overhead at Guam. The lowest TTL temperatures occur in these areas, and this region is where models predict that parcels of air frequently experience their final dehydration before entering the stratosphere. Therefore, being able to spend a full 24-hour Global Hawk flight sampling the region of interest should allow for more in-depth analysis than was possible in previous flights.

Joint Observations with Other Field Campaigns

As intended from the outset when the ATTREX mission was awarded in 2010, having Global Hawk flights from Guam in 2014 has permitted the inception, planning, and approval of two additional aircraft campaigns to be coordinated with ATTREX. The U.K.'s Coordinated Airborne Studies of the Tropics (CAST) program will bring the Facility for Airborne Atmospheric Measurement's (FAAM) British Aerospace (BAe)-*146* aircraft to Guam, with a payload focused on measurements of atmospheric tracers and halocarbons. The BAe-146 flights will be used primarily to survey the chemical composition of the planetary boundary layer and the lower free troposphere south of Guam, down to the Intertropical Convergence Zone. Meanwhile, the National Science Foundation (NSF) Convective Transport of Active Species in the Tropics (CONTRAST) program will bring the NSF/National Center for Atmospheric

NASA's Global Hawk at a Glance

Wingspan: 116.2 ft (~35.4 m)

Length: 44.4 ft (~13.5 m)

Height: 14.6 ft (~4.2 m)

Gross take-off weight: 26,700 lbs (~12,111 kg)

Internal payload capacity: 1500 lbs (~680 kg)

Pod payload capacity: 700 lbs per side (~318 kg)

Ferry range: 11,000 nautical mi (~20,300 km)

Maximum altitude: < 65,000 ft (~20km)

Loiter velocity: 343 knots true air speed (TAS)

Maximum endurance: 31 hrs

When NASA needed a vehicle to support high-altitude, long-duration science investigations it turned to a vehicle originally designed for the military. In 2008 DFRC and Northrop Grumman (NG) reached a five-year, no-cost agreement to use the Global Hawk UAS. The two preproduction Global Hawks used for NASA's flight studies are ideally suited for science research and, as illustrated by their use in two of the EVS-1 investigations, can be custom-fit to support a variety of scientific research. NASA and NG have just recently agreed to extend their agreement until 2018.

To learn more about the Global Hawk please see "Flying High: NASA's Global Hawk and GloPac Mission" in the September–October 2010 issue of *The Earth Observer* [**Volume 22**, **Issue 5,** pp. 4-9].

Research (NCAR) Gulfstream V (GV) aircraft to Guam. The GV payload includes instruments that will measure a number of the same tracers measured by CAST and ATTREX instruments. The GV sampling will focus on characterizing the chemical composition and O_3 photochemical budget in the primary deep convection detrainment altitude range [from (~6.2 mi (~10 km) up to the GV's ceiling of about ~9.3 mi (~15 km)]. Stacked flights with the three aircraft will provide measurements from the surface to the lower stratosphere.

CARVE

Principal Investigator: Charles Miller, NASA/Jet Propulsion Laboratory, *charles.e.miller@jpl.nasa.gov*

Project Manager: Steve Dinardo, NASA/Jet Propulsion Laboratory, *steven.dinardo@jpl.nasa.gov*

URL: *ilma.jpl.nasa.gov/portal*

Recent observations have revealed that CO_2 concentrations in our atmosphere have grown to 400 parts per million (ppm). This rate of growth, which has increased since the onset of the industrial revolution in the mid-1850s, is unsettling and has been linked to human activity. Quantifying and predicting the precise impacts these increased levels of CO_2 (and other greenhouse gases such as CH_4) will have on global climate, however, remains elusive.

The Arctic—specifically its vast stretches of permanently frozen tundra, or *permafrost*—represents a major land-based sink for carbon—particularly as CO_2 and CH_4. No other area on Earth is warming more rapidly than the Arctic, nor is any other ecosystem more vulnerable to change. Scientists fear that melting permafrost could release large amounts of carbon, with unknown climate consequences. Unfortunately, there is still a great deal of uncertainty surrounding the carbon balance of the Arctic ecosystems—such as those in Alaska. Fundamental parts of the Arctic's complex biological-climatologic-hydrologic systems are not well studied. To date, there has been no space-based or suborbital system that provides *simultaneous* measurements of the surface controls and atmospheric concentrations required to quantify, and therefore better understand, these processes.

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is a five-year mission that will collect detailed measurements of important greenhouse gases on local-to-regional scales in the Alaskan Arctic and demonstrate new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle-climate processes.

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is a five-year mission that will collect detailed measurements of important greenhouse gases on local-to-regional scales in the Alaskan Arctic, and demonstrate new remote sensing and improved modeling capabilities to quantify Arctic carbon fluxes and carbon cycle–climate processes. Through intensive seasonal aircraft campaigns, ground-based observations, analysis, and modeling, CARVE scientists will study the relationships between atmospheric and surface state variables for Alaskan terrestrial ecosystems. The data will be used in a multidisciplinary investigation to determine spatiotemporal patterns, sensitivity to change, and potential responses of Arctic carbon budgets to observed and projected climate change. CARVE measurements and integrated science data will provide unprecedented experimental insights into Arctic carbon cycling and its response to climate change.

CARVE's science objectives are to fill these critical gaps in climate-change science knowledge by:

- directly testing hypotheses attributing the mobilization of vulnerable Arctic carbon reservoirs to climate warming;

- delivering the first direct measurements and detailed maps of CO_2 and CH_4 sources on regional scales in the critical Arctic ecozone; and
- demonstrating new remote sensing and modeling capabilities to quantify feedbacks between carbon fluxes and carbon cycle/climate processes in the Arctic region.

Measurement

CARVE employs a robust and flexible strategy to reconcile Arctic carbon fluxes estimated from atmospheric concentrations of CO_2 and CH_4, as measured with an absorption spectrometer and *in situ* techniques (a top-down approach), with carbon fluxes estimated from coincident measurements of surface-state controls using a microwave instrument (a bottom-up approach). The carve measurement strategy is shown schematically in **Figure 3**.

Unlike many field campaigns that rely on "workhorse" aircraft like the NASA ER-2 or DC-8, CARVE is deploying the Short C-23 *Sherpa*—a highly-reliable, Arctic-proven aircraft. This aircraft has the mass, volume, and power capacities to accommodate the payload (described below) with robust margins, and the flight performance required to meet the CARVE science objectives. Since it is piloted, the Sherpa can fly in both uncontrolled and controlled airspace. In addition to being well suited for the CARVE mission, this aircraft has the added benefit of being able to avoid scheduling conflicts and related risks; it can also minimize cost and technical risk.

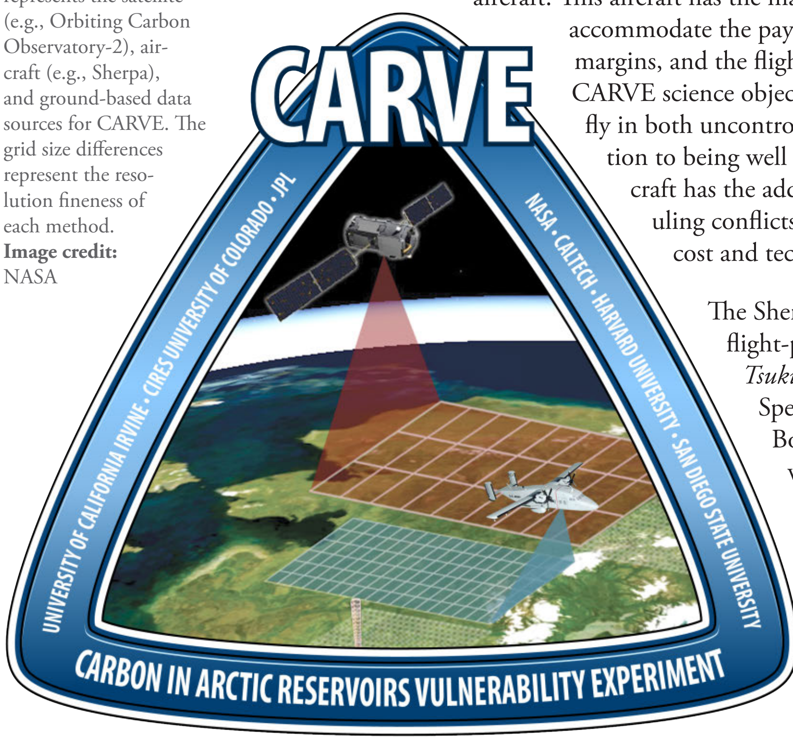


Figure 3. This graphic represents the satellite (e.g., Orbiting Carbon Observatory-2), aircraft (e.g., Sherpa), and ground-based data sources for CARVE. The grid size differences represent the resolution fineness of each method. **Image credit:** NASA

The Sherpa is outfitted with a suite of three flight-proven instruments: a copy of the *Tsukuba* airborne Fourier Transform Spectrometer (FTS) (procured from ABB Bomem under a fixed-price contract), with optical filters optimized to meet CARVE science requirements; an In Situ Gas Analyzer (ISGA), comprised of commercial-off-the-shelf hardware including a Picarro continuous gas analyzer, calibration standards, and whole-air sample flasks; and an infrared camera.

The L-band radiometer/radar and a nadir-viewing spectrometer provide the first simultaneous measurements of surface parameters that control gas emissions (i.e., soil moisture, freeze/thaw state, surface temperature) and total atmospheric columns of CO_2, CH_4, and carbon monoxide (CO). The gas analyzer links greenhouse gas measurements directly to World Meteorological Organization standards.

Investigations

The CARVE science investigation entails intensive seasonal deployments in Alaska during the spring, summer, and fall of each year from 2012 to 2015. Deployments will occur when Arctic carbon fluxes are large and rapid. Further, at these times, the sensitivities of ecosystems to external forces such as fire and anomalous variability of temperature and precipitation are maximized. Continuous ground-based measurements will be taken to provide temporal and regional context as well as calibration for CARVE airborne measurements.

CARVE flight plans sample multiple permafrost domains and ecosystems, and deliver detailed measurements over ground-based measurement sites, fires, and burn-recovery chronosequences. The deployment plans are robust and resilient, providing large schedule margins against poor weather and the flexibility to exploit unusual findings or geophysical conditions. There are no required time-critical events.

CARVE has flown some campaigns and begun analysis of the gathered measurements. At the time writing this article, however, the principal investigators had not published their results.

DISCOVER-AQ

Principal Investigator: James Crawford, NASA's Langley Research Center, *james.h.crawford@nasa.gov*

Project Manager: Mary Kleb, NASA's Langley Research Center, *mary.m.kleb@nasa.gov*

Project Scientist: Ken Pickering, NASA's Goddard Space Flight Center, *kenneth.e.pickering@nasa.gov*

URL: *discover-aq.larc.nasa.gov*

Satellites used to observe atmospheric pollutants generally provide *column measurements* that accurately reflect the total abundance of a constituent from the surface to the top of the atmosphere. Unfortunately, these measurements do not meet the needs of environmental regulators who are most interested in tracking pollutants in the lowest layer of atmosphere, where poor air quality—resulting from unhealthy levels of O_3 and particulate matter (PM)—can adversely affect human populations and ecosystems. To address this disconnect, NASA researchers and their partners are providing an unprecedented view of air pollution with a project called Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ). With two NASA aircraft and an extensive ground network, the investigation seeks to improve our understanding of the factors that control air quality and influence our ability to monitor pollution events from space.

DISCOVER-AQ provides multiple perspectives on the factors that control air quality and that influence our ability to monitor pollution events from space. Working with state and local agencies responsible for monitoring air quality, DISCOVER-AQ implements a complex observing system that complements existing ground-based monitoring sites.

Measurement Strategy

DISCOVER-AQ provides multiple perspectives on the factors that control air quality and that influence our ability to monitor pollution events from space. Working with state and local agencies responsible for monitoring air quality, DISCOVER-AQ implements a complex observing system that complements existing ground-based monitoring sites. On-the-ground augmentation of these sites includes remote sensors (AERONET[8] sunphotometers and Pandora[9] spectrometers) to provide continuous monitoring of particulate and gaseous pollution in the atmospheric column above each site. Some sites are further augmented with lidars, balloon-based monitors, and research-grade instruments to be operated alongside monitors used by state and local regulatory agencies.

NASA's King Air aircraft provides a regional picture by flying over the monitoring sites at 27,000 ft (~8.2 km), observing the distribution of particulate pollution (with the High Spectral Resolution Lidar) and columns of gaseous pollution (with the Airborne Compact Atmospheric Mapper). NASA's P-3B aircraft completes the picture

[8] AERONET stands for Aerosol Robotic Network—a global network of sunphotometers. To learn more, visit: *aeronet.gsfc.nasa.gov*.

[9] Pandora is a miniature spectrometer with a Sun-tracking head sensor that measures Sun and sky radiance from 270 to 530 nm in 0.5-nm increments with 1.6° field-of-view. The measurements can be used to derive the concentrations of a variety of atmospheric constituents—e.g., O_3 and nitrogen dioxide (NO_2).

by repeatedly profiling the lower atmosphere over ground sites, providing details on how the vertical distribution of pollution changes throughout the day.

Overview of Flights

DISCOVER-AQ collected observations over the Baltimore, MD–Washington, DC area in July 2011 and more recently over the southern San Joaquin Valley in California, January-February 2013. The Baltimore–Washington flights have been described previously[10]. As analysis for the first two deployments continues, flights over Houston, TX are planned for September 2013 and a final deployment is scheduled for summer 2014, with a likely destination of Denver, CO. The focus of the remainder of this summary will be on the San Joaquin Valley flights.

Results from the San Joaquin Valley Investigations

The most recent flights examined air quality during winter over California's Central Valley, where cold, stagnant conditions allow the concentrations of fine particles to reach unhealthy levels, exceeding national air-quality guidelines. Sampling was conducted on a total of 10 days between January 16 and February 6, 2013. During the first week of the deployment, the team was able to use five flights to document an extended period of pollution build-up as particulate levels in the southern end of the valley tripled. **Figure 4** shows the time series of surface $PM_{2.5}$ at Bakersfield[11] along with the concurrent time series of *aerosol optical depth* (AOD) from the AERONET sunphotometer. The similarity in the respective trends of the two measurements is

[10] For more background on DISCOVER-AQ and the Baltimore–Washington flights refer to "Paving the Way for Space-Based Air Pollution Sensors" in *The Earth Observer's* July–August 2011 issue [**Volume 23**, **Issue 4**, pp. 9-12].

[11] $PM_{2.5}$ stands for particulate matter with diameters less than 2.5 µm. This term is used to describe a complex mixture of fine particles and liquid droplets composed acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. $PM_{2.5}$ is one of the criteria pollutants tracked by the U.S. Environmental Protection Agency.

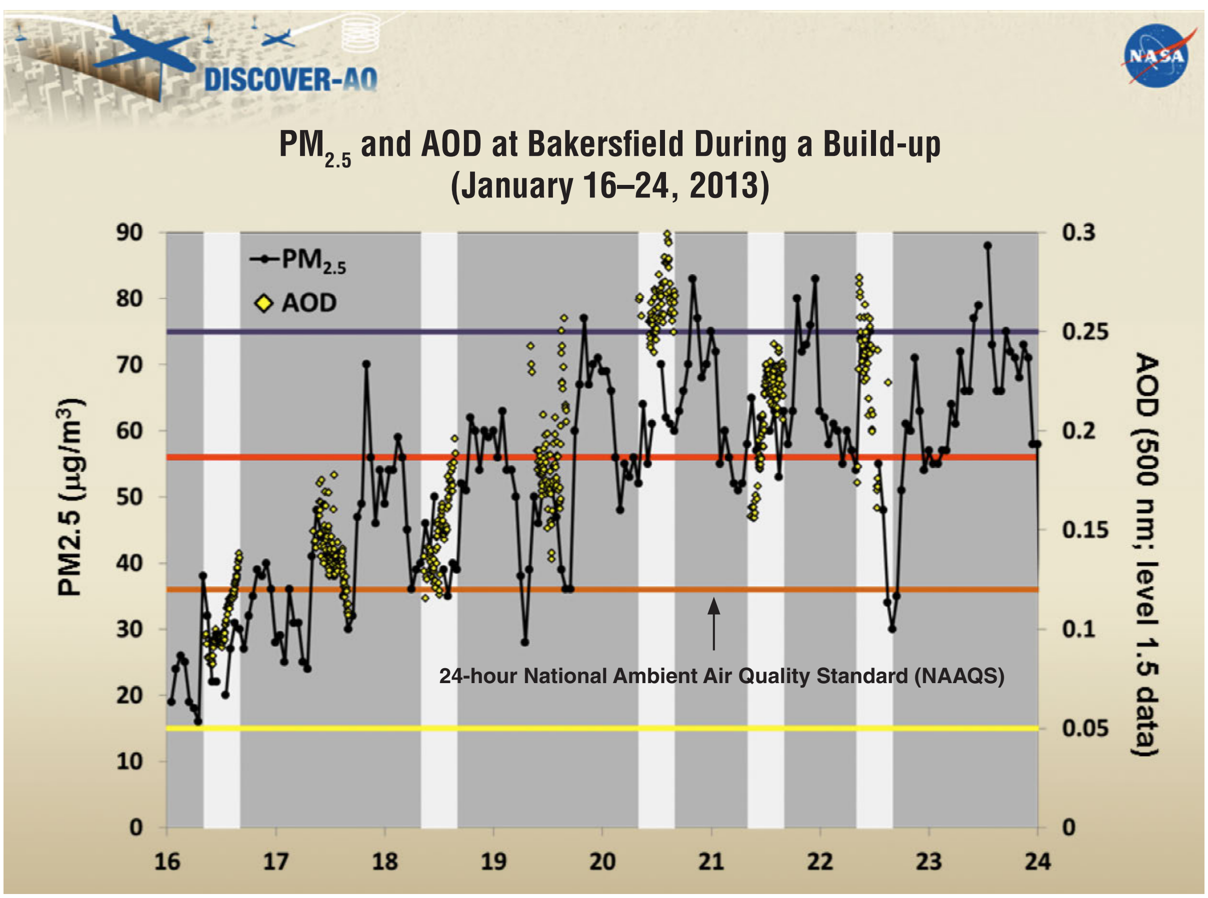


Figure 4. Time series of surface $PM_{2.5}$ and AERONET Aerosol Optical Depth (AOD) at Bakersfield, CA, January 16–24, 2013. Horizontal lines indicate the various pollution threat levels. Vertical strips represent flight periods.

encouraging for applying observations of AOD from satellites for surface air quality. However, higher AOD values are often observed in areas that are not experiencing high loading of fine particles; this emphasizes the importance of information on other factors such as humidity and how particles are distributed in the atmospheric column.

An important factor in these intense pollution episodes of low AOD was the shallowness of the polluted layer, which was almost always limited to the lowest 2000 ft (~0.6 km) above the surface. This created a challenge for the P-3B aircraft, which is normally restricted from flying below 1000 ft (~0.3 km) over populated areas. The problem was mitigated by performing missed approaches down to 100 ft (~30.5 m) over six different airfields across the valley and in close proximity to ground monitors.

Statistical analyses of the data from the California campaign will examine the linkage between surface and column observations. Such analyses from the Baltimore-Washington campaign have already shown that surface O_3 is more highly correlated with tropospheric column amounts (as observed by the P-3B and the Pandora spectrometers) than is surface NO_2—a pollutant critical to the formation of O_3. This is due to the much greater spatial variability for NO_2 than for O_3. However, the correlation of surface O_3 with tropospheric columns from the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite was not as robust. This is attributed to the decreasing detection efficiency of OMI's ultraviolet spectrometer in the lower troposphere.

The value of DISCOVER-AQ is heightened by the recent selection of the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument as NASA's first Earth Venture-Instrument. TEMPO will provide the first geostationary observations of air quality, monitoring major air pollutants across the North American continent hourly during daytime.

DISCOVER-AQ data are contributing to a better understanding of the interplay between emissions, meteorology, and chemistry controlling the distribution and evolution of pollutants defining air quality. Observations are contributing to the development of improved satellite retrievals, assessment of air quality models, and optimization of future air quality monitoring strategies. The value of DISCOVER-AQ is heightened by the recent selection of the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument as NASA's first Earth Venture-Instrument. TEMPO will provide the first geostationary observations of air quality, monitoring major air pollutants across the North American continent hourly during daytime. The instrument, to be completed in 2017, will be launched on a commercial satellite into geostationary orbit in the 2019 timeframe.

HS3

Principal Investigator: Scott Braun, NASA's Goddard Space Flight Center, *scott.a.braun@nasa.gov*

Project Manager: Marilyn Vasques, NASA's Ames Research Center, *marilyn.vasques@nasa.gov*

URL: *espo.nasa.gov/missions/hs3*

Nearly 100 million Americans live within 50 miles of a coastline—exposing them to the potential destruction caused by land-falling hurricanes, as was so amply demonstrated in the fall of 2012, when Hurricane Sandy struck the U.S. East Coast. While hurricane *track prediction* has greatly improved in the last 30 years, improvements in hurricane *intensity forecasts* have lagged, primarily because of our poor understanding of the processes involved in intensity change. The Hurricane and Severe Storm

HS3 involves three deployments of NASA's Global Hawk UAS from NASA's Wallops Flight Facility (WFF) on the coastline of Virginia during the 2012, 2013, and 2014 hurricane seasons, with distinct payloads onboard to address these science questions. WFF provides easy access to storms over the Atlantic Ocean, Gulf of Mexico, and Caribbean.

Sentinel (HS3) Mission is designed to investigate some basic questions to further address this issue:

- What impact does the large-scale environment, particularly the Saharan Air Layer (SAL), have on hurricane intensity change?
- What is the role of storm internal processes, such as deep convective towers?
- To what extent are these intensification processes predictable?

HS3 involves three deployments of NASA's Global Hawk UAS from NASA's Wallops Flight Facility (WFF) on the coastline of Virginia during the 2012, 2013, and 2014 hurricane seasons, with distinct payloads onboard to address these science questions. WFF provides easy access to storms over the Atlantic Ocean, Gulf of Mexico, and Caribbean. The Air Vehicle-1 (AV-1) Global Hawk carries an *over-storm* payload; AV-6 carries an *environmental* payload. Details of these payloads are provided in the following two sections.

First Flights

HS3's first deployment in September 2012 involved only AV-6, which carried three instruments to examine the environment and outflow layer of storms. The scanning High-resolution Interferometer Sounder (S-HIS), Advanced Vertical Atmospheric Profiling System [(AVAPS) also known as a *dropsonde*], and Cloud Physics Lidar (CPL) collectively provided measurements of the vertical structure of temperature, relative humidity, winds, Saharan dust, and clouds.

The first flight was the "ferry" from DFRC to the WFF on September 6-7, during which time the Global Hawk flew along the *outflow region* of Hurricane Leslie, obtaining unprecedented information on the cloud, thermodynamic, and wind characteristics of this difficult-to-observe feature of hurricanes—see **Figure 5** for the flight path. This was the first time that the Global Hawk took off from DFRC and landed at a remote deployment site—in this case, WFF.

The next five flights sampled long-lived Hurricane Nadine, the only storm to occur during the major portion of the deployment—but one that persisted for virtually the entire period of observations. On September 11-12, AV-6 overflew Nadine as it first became a tropical depression and then a tropical storm, sampling the environment

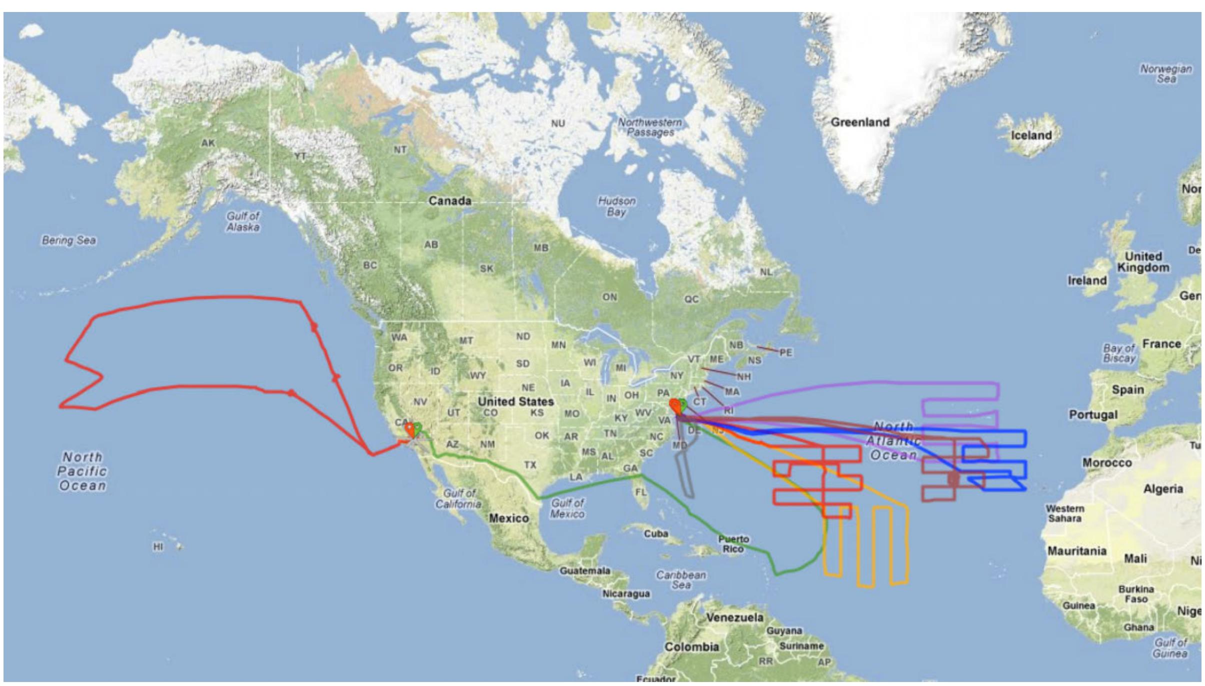


Figure 5. This map shows the Global Hawk AV-6 flight tracks during HS3. In the Atlantic, tracks indicates flight patterns for AV-6 during the Leslie (green line) and Nadine (all others) flights. The red track in the Pacific is for the AV-1 science flight that took place in November 2012.

around the developing storm, including the well-defined SAL on the storm's northern and eastern sides. A second flight through Nadine took place on September 14–15, as the tropical storm was moving northward in the central Atlantic under the influence of strong vertical wind shear. While dry air was observed to be impinging on the western side of the storm at upper levels, at lower levels there was evidence for a limited intrusion of Saharan air into the northern side of the eyewall. The vertical wind shear produced a major burst of convection near the center, allowing Nadine to strengthen into a hurricane. A third flight occurred on September 19-20, once Nadine had weakened to a tropical storm over cooler waters near the Azores. HS3 observations showed that Nadine was still a vigorous tropical storm with a well-defined warm core through most of the troposphere. The National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center (NHC) used data from HS3 to help inform its decision to maintain Nadine as a tropical storm—instead of downgrading the storm to post-tropical status. The last two flights, also in the Azores region (September 22-23 and 26-27), investigated Nadine's interaction with an extratropical trough and recovery as wind shear decreased before the storm slowly reintensified. Nadine continued to drift in the Eastern Atlantic nearly three weeks after its initial formation, making it the fourth longest-lived Atlantic hurricane on record.

Second Flights

Both Global Hawks will fly from WFF in August–September 2013. The AV-1 has not previously been used for hurricane science observations, so numerous hardware additions have been made to prepare it for relevant science flights. HS3 conducted one test flight and a successful science flight into a strong Pacific mid-latitude weather system from DFRC between November 5-6, 2012.

Onboard AV-1's first flight into hurricanes, the High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP) conically-scanning Doppler radar will provide three-dimensional wind and precipitation fields, the Hurricane Imaging Radiometer (HIRAD) will measure surface wind speeds and rainfall, and the High-Altitude Monolithic Microwave Integrated Circuit Sounding Radiometer (HAMSR) will provide measurements of temperature, water vapor, and liquid water profiles; total precipitable water; sea-surface temperature; rain rates; and vertical precipitation profiles. Most of these instruments represent NASA-developed advanced technologies, and in some cases are precursors to future satellite sensors.

The deployment will occur between August 20 and September 23 during what is, according to estimates from NOAA, expected to be another busy hurricane season. Observations from the dropsonde system were routinely shared with the NHC and U.S. and international modeling centers in 2012 and will be this year, as well. In addition, data from the over-storm Global Hawk (AV-1) will also be shared with the NHC to provide more-frequent updates on storm position and precipitation structure.

Venture Class missions, such as the five described in this article, represent a significant portion of NASA's future science missions. Each of these small, targeted, principal-investigator-led science investigations easily complement NASA's larger research missions. Many of the EVS-1 missions are addressing "gaps" in our current scientific understandings and the data being returning helps to improve our overall knowledge of Earth system science.

Conclusion

Venture Class missions, such as the five described in this article, represent a significant portion of NASA's future science missions. Each of these small, targeted, principal-investigator-led science investigations easily complement NASA's larger research missions. Many of the EVS-1 missions are addressing "gaps" in our current scientific understanding and the data being returned help to improve our overall knowledge of Earth system science. As is evident from these pages, each EVS-1 investigation has made significant progress toward fulfilling their objectives in a short time.

More Venture Class solicitations are planned for the future, with awards at regular intervals for investigations using cutting-edge instrumentation carried on airborne platforms (EVS)—see Announcement: *The EVS-2 Announcement is Posted to ROSES* on page 32—on small space-based missions (EVM), or as secondary instruments or hosted payloads (EVI) on larger platforms. Managed and funded by NASA's Earth

System Science Pathfinder (ESSP) Program at NASA's Langley Research Center, these missions provide innovative approaches to address Earth science research with periodic windows of opportunity to accommodate new scientific priorities. In addition to Venture, ESSP manages *legacy ESSP missions* that were selected under prior AOs that are currently in operation, as well as noncompetitive, directed projects—those designed to meet unique needs, such as the replacement of a mission that did not fulfill its intended mission requirements[12]. ■

[12] Other than Venture Class missions, ESSP manages the Gravity Recovery and Climate Experiment (GRACE), CloudSat, Cloud–Aerosol Lidar Infrared Pathfinder Satellite Observation (CALIPSO), and Aquarius missions, as well as the future second Orbiting Carbon Observatory (OCO-2) and OCO-3 instrument.

announcement

The EVS-2 Announcement is Posted to ROSES

On June 25, 2013, NASA posted the final text of the EVS-2 solicitation at:

nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7B8501AD49-0806-82C9-7F91-CF74AD5C66DA%7D&path=open

This Amendment to the Research Opportunities in Space and Earth Sciences (ROSES) 2013 (Appendix *A.30*) solicits proposals for complete suborbital, principal investigator-led investigations to conduct innovative, integrated, hypothesis, or scientific question driven approaches to pressing Earth system science issues. These new investigations will be competitively selected by mid-2014 to provide additional opportunity for investment in innovative Earth system science activities to enhance our capability to better understand the current state of the Earth and to predict future change. Notices of Intent to propose are requested by **November 8, 2013**. The due date for full 35-page proposals is **January 10, 2014**.

Blog Log

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

This periodic installment features new blogs about NASA's Earth-science research and fieldwork, and provides links to where you can access the full blog and view color photographs online. In this issue, we highlight three recent *Notes from the Field* blogs and invite you to check out the *Climate 365* Tumblr page. If you know of any blogs that should be shared in the *Blog Log*—perhaps one of your own—please email Heather Hanson at *heather.h.hanson@nasa.gov*.

[Blog introductions are modified text from featured blogs; images are also from featured blogs.]

Iowa Flood Studies

The Global Precipitation Measurement (GPM) mission consists of an international network of nine satellites that will provide next-generation global observations of precipitation from space. Among the applications of GPM mission data are improvements to our understanding and forecasting of tropical cyclones, extreme weather, and floods.

On April 8, 2013, NASA and Iowa Flood Center staff set up about 20 disdrometers throughout the field area. **Image credit: Aneta Goska** [Iowa Flood Center]

From May 1 to June 15, 2013, **Walt Peterson** [NASA's Wallops Flight Facility] led the Iowa Flood Studies (IFloodS) campaign in eastern Iowa to evaluate how well GPM mission satellite rainfall data can be used for flood forecasting. He manages all of GPM's *ground validation* operations—i.e., the field campaigns that ensure that satellite measurements from space of rainfall and precipitation are accurate. Peterson and his team, as well as their partners at the Iowa Flood Center at the University of Iowa, measured rainfall with ground instruments, ground radar, and satellites, and then evaluated flood-forecasting models. Considering the historic drought in Iowa last spring, the team was more than pleased with the very wet turn out this year. To learn about their experiences and what they might mean for future flood forecasts, visit: *earthobservatory.nasa.gov/blogs/fromthefield/category/iowa-flood-studies/page/3*.

Greenland Aquifer Expedition

Lora Koenig [NASA's Goddard Space Flight Center] would like to welcome you back[1] to yet another exciting and *chilling* blog—the *Greenland Aquifer Expedition*. This time, Koenig and her team set out for southeast Greenland to investigate not ice, but water that they believe is trapped within the ice. To give you a bit of background, during the Arctic Circle Traverse (ACT), two of the team's members were involved with a drilling project to investigate how much snow falls in southeast Greenland. When they pulled up the drill after drilling the last ice core, they found water dripping out the end of the core barrel—which was quite a shock!

Clément Miège [University of Utah] collects some of the water dripping from the drill during the Greenland Aquifer Expedition. **Image credit:** NASA

[1] Lora Koenig last shared her experiences from West Antarctica in the January-February 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 1**, p. 20].

This spring, Koening and her teammates went back to Greenland to find out more about the captive water—which they termed a *perennial firn aquifer*. During the expedition they camped on the ice for a little over a week, gathering information about the water's basic properties and which tools worked best to explore it. To read what it's like to take part in exploratory field research, visit: *earthobservatory.nasa.gov/blogs/fromthefield/category/greenland-aquifer-expedition/page/3.*

Landsat 8 Launch

On February 11, 2013 at 1:02 PM Eastern Standard Time (10:02 AM PST), an Atlas V rocket successfully carried the Landsat Data Continuity Mission (LDCM) spacecraft into orbit from Vandenberg Air Force Base (VAFB) in California[2]. LDCM has since been renamed Landsat 8 and continues to function nominally.

But before Landsat 8 began providing the U.S. Geological Survey with hundreds of land scenes per day, a series of interesting events had to unfold just right. To learn about these events and relive the countdown, we encourage you to check out the *Landsat 8 Launch* blog at *earthobservatory.nasa.gov/blogs/fromthefield/category/landsat-8-launch/page/2*.

The payload fairing, with LDCM inside, gets hoisted in preparation for stowing atop an Atlas V rocket. **Image credit:** NASA/Vandenberg Air Force Base

Climate 365

Did you know that nine of the ten warmest years since 1880 have been in the last decade? NASA's study of Earth's climate and atmosphere has long been a central focus of its science mission. This year, individuals from NASA's Earth Science News Team, communications teams at NASA's Goddard Space Flight Center and the NASA/Jet Propulsion Laboratory, and the NASA websites *Earth Observatory* (*earthobservatory.nasa.gov*) and *Global Climate Change* (*climate.nasa.gov*) are participating in a yearlong effort to highlight NASA's ongoing monitoring of Earth's climate—called *Climate 365*. If you haven't started following them on Tumblr, we invite you to do so at *climate365.tumblr.com*. ■

This pair of images shows Muir Glacier's continued retreat and thinning in the second half of the twentieth century. From 1941 to 2004 the front of the glacier moved back about 7 mi (~11.3 km) while its thickness decreased by more than 2625 ft (~800 m)—according to the National Snow and Ice Data Center. **Image credit:** NASA

[2] See the March–April 2013 issue of *The Earth Observer* to learn more about Landsat 8's (previously LDCM's) capabilities [**Volume 25**, **Issue 2**, pp. 4-9].

The NASA LCLUC Spring 2013 Science Team Meeting

Catherine Nakalembe, University of Maryland, College Park, cnakalem@umd.edu
Chris Justice, University of Maryland, College Park, justice@hermes.geog.umd.edu
Garik Gutman, NASA Headquarters, ggutman@nasa.gov

Introduction

The NASA Land-Cover/Land-Use Change (LCLUC) program held its annual spring Science Team meeting April 2-4, 2013, in Rockville, MD. The LCLUC program has become a truly interdisciplinary and international collaborative endeavor. Science Team meetings provide ideal venues for developing and implementing such collaboration and provide opportunities for NASA-funded scientists and program alumni to share findings and establish and further develop working relationships. Despite recent travel constraints, there were a record 150 participants—including scientists and graduate students from across the U.S. and several international participants—indicative of continued growth in interest about the science program.

This report presents a summary of the two-day meeting; full presentations and posters are provided at *lcluc.hq.nasa.gov/meetings.php?mid=45*.

DAY ONE

Opening Presentations

After a welcome message, **Garik Gutman** [NASA Headquarters—*LCLUC Program Manager*] presented a brief review of the program, highlighting internal linkages to other NASA programs within the Carbon Cycle and Ecosystems Focus Research Area, including the Terrestrial Ecosystems Program, the Biodiversity Program, and the Applied Sciences Program. He stressed the importance of LCLUC's links to other national programs, primarily that with the U.S. Global Climate Research Program (USGCRP).

Gutman then recognized the leadership that **Dan Brown** [University of Michigan—*LCLUC Scientist*]] provided for a National Research Council (NRC) committee that conducted an assessment of land-change modeling[1]. The special team was asked to assess the analytical capabilities and science and/or policy applications of existing modeling approaches, and to describe the theoretical and empirical basis and the major technical, research, and data-development challenges associated with each approach. The team also described opportunities to better integrate land-observation strategies (including ground-based surveys as well as satellite and remote sensing data) with land-change modeling to better fulfil scientific and decision-making requirements.

[1] This study was convened in 2011–2012 and was co-sponsored by NASA LCLUC and U.S. Geological Survey (USGS) through the USGCRP LULCC Interagency Working Group.

Gutman's opening remarks set the stage for the session on *LCLUC in Wetlands*. He emphasized that the wetlands component is rooted in the goals of the 1971 International Ramsar Convention on Wetlands, which sought to enable targeted assessment and collection of monitoring information, vital to ensure effective management planning for wetlands[2]. Gutman also stated that satellite-based remote sensing is a critical tool for these assessments, as it provides synoptic information on types of wetland vegetation, water dynamics, and land-management impacts.

Gutman also reviewed the data aspects of the program, which adhere to NASA's policy on free and open sharing of data; these data are available via several NASA, USGS, and National Geospatial-Intelligence Agency (NGA) portals. Gutman went on to summarize the ongoing NASA Research Opportunities in Space and Earth Sciences (ROSES[3]) 2012 LCLUC solicitation round and solicitations from the Carbon Cycle Science and Interdisciplinary Science Programs. He noted that Support for Early Career Scientists (ECS) will continue, and that training will still be an integral part of each

[2] For more information, visit: *www.ramsar.org*.
[3] For more information about ROSES, visit: *nspires.nasaprs.com/external/solicitations*.

LCLUC Science Team meeting participants. **Image credit: Lydia Prentis**

Table 1. Summary of presentations given during the *LCLUC in Wetlands* session.

Speaker	Institution	Presentation Title
Laura Hess	University of California, Santa Barbara	Land and resource use on the Amazon floodplain under evolving management systems and environmental change: fish, forests, cattle, and settlements
Marc Simard	NASA/Jet Propulsion Laboratory (JPL)	Vulnerability assessment of mangrove forests in the Americas
Kyle McDonald	City College of New York	Global-scale assessment of threatened river delta systems: Evaluation of connections between the continental land mass and ocean through integrated remote sensing and process modeling
In-Young Yeo	University of Maryland, College Park (UMCP)	Mapping and monitoring of wetland dynamics for improved resilience and delivery of ecosystem services in the Mid-Atlantic region
Mei Yu*	University of Puerto Rico	Vulnerability and adaptive management of tropical coastal wetlands in the context of land use and climate changes
Prasad S. Thenkabail	U.S. Geological Survey's Western Geographic Science Center	Remote sensing of inland valley wetlands of Africa and their pivotal role in Africa's green and blue revolution (Invited Presentation)

* See **Figure** on page 40.

international LCLUC Science Team meeting enhanced with the new Trans-Atlantic Training (TAT) Initiative[4].

Chris Justice [University of Maryland, College Park (UMCP)—*LCLUC Program Scientist*] emphasized the importance of the LCLUC Science Team for research and communication and the impact of developing a strong U.S. *community of practice* for LCLUC scientists. He noted that community building is particularly important for ECS and students involved in the LCLUC research program. Justice then outlined the meeting objectives and session organization. He encouraged LCLUC scientists to look for opportunities and to apply to non-LCLUC NASA programs that include LCLUC impacts on climate, atmospheric composition, hydrology, and the carbon cycle. He posited that there is a broad shift in climate science to include adaptation, and stressed that land use is a key component in adaptation science.

Session Overviews

The remainder of the meeting was organized into technical sessions that included: LCLUC in Wetlands; Programmatic Perspectives and Initiatives; Synthesis of LCLUC in Northern Eurasia and Next Steps; Final Results on Agricultural Land Use; Monsoon Asia Regional Focus Projects; and two Rapid Discussion sessions, featuring five-minute poster presentations from ECS and IDS investigators, respectively. Each of these will be summarized, below.

[4] TAT is a planned international activity to develop stronger awareness of new NASA and ESA products and to promote capacity building among recent university graduates and post-graduates in Earth-observation research areas.

LCLUC in Wetlands

Few areas are more vulnerable to anthropogenic change than wetlands. Estimates are that nearly half the world's wetlands have been altered by the activities of humans. The impact of LCLUC is thus an active area of research. **Table 1** summarizes the presentations included in this session, all of which are available at the URL provided earlier.

Programmatic Perspectives and Initiatives on LCLUC

A series of presentations followed that addressed cross-cutting, programmatic foci.

- **Dan Brown** gave a report on the previously mentioned NRC review of land-use models—see Garik Gutman's opening remarks.
- **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Landsat Data Continuity Mission*[5] *(LDCM) Project Scientist*] reviewed the status of the LDCM. On March 29, 2013, the USGS posted a sample Level 1T product that showed a region of the Rocky Mountains on March 18.
- **Jeff Masek** [GSFC—*Landsat Project Scientist*] reported on Landsat 8, including a proposed collaboration with the European Space Agency's (ESA) Sentinel-2 program. If the efforts are successful they may expand to include other missions (e.g., the Indian Space Research Organisation's (ISRO) ResourceSat-2 spacecraft).

[5] As of May 30, NASA handed control of the mission over to USGS, and it became known as Landsat 8.

- **Chris Justice** reviewed the use of high-resolution data for LCLUC studies, highlighting the need to streamline access to such data by LCLUC principal investigators, and establishing standard data-processing tools to reduce the processing burden on LCLUC users.

Rapid Presentations—Early Career Scientists

ECSs provided a series of five-minute presentations as an opportunity to provide a brief overview of their research and draw attention to their posters. **Table 2** summarizes the presentations that took place.

DAY TWO

The second day's activities began with an overview by **Jack Kaye** [NASA Headquarters—*Associate Director for Research of NASA's Earth Science Program*], including recent and planned satellite missions. He described challenges currently facing the agency under sequestra-

Table 2. Summary of research presented during the Early Career Scientists' Rapid Presentations.

Speaker	Institution	Research Focus
Inbal Becker-Reshef	University of Maryland, College Park	Developing an interdisciplinary remote-sensing-based method to forecast wheat production in the dominant export countries, and provide insight on the potential societal benefit of such information in terms of global wheat markets and civil unrest.
Gillian Galford	University of Vermont	Linking LCLUC to subsidized inputs, environmental controls, or socioeconomic factors, and examining how socioeconomic and environmental factors interact with subsidized inputs to change poverty status in Malawi.
Kathryn Grace	University of Utah	Examining the links between agriculture and human health in the context of climate change in three West African countries to determine if variation in food availability/stability corresponds to variations in fertility and maternal/child health outcomes.
Jason Julian	University of Oklahoma	Studying land-management impacts on water quality in New Zealand across political boundaries, with an initial task of detecting date, location, and extent of forest harvests and grazing events, and connecting this information with weather, water quality, and socioeconomic data.
Stephen Leisz	Colorado State University	Studying the impacts of the East-West Economic Corridor from Da Nang, Vietnam, to Khon Kaen, Thailand, on the changing landscape of central Vietnam, southern Laos, and eastern Thailand, and its influence on the region's LCLUCs and urbanization processes.
Jessica McCarty	Michigan Tech Research Institute	Examining the role of environmental, socioeconomic, institutional, and LCLUC factors to explain the patterns and drivers of anthropogenic fires in post-Soviet Eastern Europe—specifically, a case study comparison of Belarus, European Russia, and Lithuania.
Kelly Wendland	University of Idaho	Evaluating the impact of conservation strategies on LCLUC at a transboundary site between Guatemala, Honduras, and El Salvador.
Tatiana Loboda and Julie Silva	University of Maryland, College Park	Mapping, quantifying, and attributing LCLUC in the Mozambican portion of the Tri-National Park to socioeconomic causes.
Yuyu Zhou	Joint Global Change Research Institute	Understanding and simulating spatially explicit global urban expansion in the context of climate change.
Kelly Cobourn	Boise State University	Understanding how water-rights institutions influence agricultural decision–making in the face of climate–driven changes in water availability.

Table 3. Summary of presentations given during the *Synthesis of LCLUC in Northern Eurasia* session.

Speaker	Institution	Presentation Content
Pasha Groisman	National Oceanic and Atmospheric Administration/ University Corporation for Atmospheric Research	Status update on the recent activities and near-term plans for the Northern Eurasian Earth Science Partnership Initiative (NEESPI[†]).
Volker Radeloff	University of Wisconsin	Synthesis of studies on institutional change and LCLUC effects on carbon, biodiversity, and agriculture after the collapse of the Soviet Union—seeking to understand the impact of socioeconomic shock on LCLUC.
Kathleen Bergen	University of Michigan	LCLUC Synthesis: Forested land-cover and land-use change in the Far East of Northern Eurasia under the combined drivers of climate and socioeconomic transformation.
Hank Shugart	University of Virginia	Synthesis of forest growth, response to wildfires, and carbon storage for Russian forests using a distributed, individual-based forest model.

[†]Throughout its history, NEESPI has served as an umbrella program for 156 individual research projects. Over 750 scientists from more than 200 institutions and 30 countries have participated in NEESPI.

Table 4. Summary of presentations given during the *Final Results on Agricultural Land Use* session.

Speaker	Institution	Presentation Title
Dan Slayback	NASA's Goddard Space Flight Center	Assessing the impact of disappearing tropical Andean glaciers on pastoral agriculture
Michael Coe	Woods Hole Research Center	Linking historical and future land-use change to the economic drivers and biophysical limitations of agricultural expansion in the Brazilian Cerrado
Jack Mustard	Brown University	Rates and drivers of land-use/land-cover change in the agricultural frontier of Mato Grosso, Brazil
David Roy	South Dakota State University	Changing field sizes of the conterminous United States, a decennial Landsat assessment
Lahouari Bounoua	NASA's Goddard Space Flight Center	Satellite-supported inverse biophysical modeling approach for the detection of irrigated agricultural land and the determination of the amount of irrigation in arid and semi-arid regions

tion requirements and answered questions on the future of the program. Of particular note, Kaye recognized the unique role of LCLUC in the program since it includes social science.

Synthesis of LCLUC in Northern Eurasia

By way of background for these discussions, it must be noted that while climate change is a global concern, it is particularly acute in Earth's polar regions. For example, change is happening in Northern Eurasia at a rate faster than that found in many other locations. This session was organized to highlight the research investigating links between LCLUC and the changing climate of this environmentally sensitive region. **Table 3** summarizes the presentations that took place.

Final Results on Agricultural Land Use

Agriculture and LCLUC are inexorably intertwined, as humans make space for agricultural fields by altering the land surface. Those alterations in turn impact the local—and even regional and global—climate, causing changes in precipitation patterns that may impact crop production. This session highlighted some of the ongoing research to better quantify the links between agriculture and LCLUC. **Table 4** summarizes the presentations that took place.

Rapid Presentations—Interdisciplinary Science (IDS) Program

After these discussions came a series of five-minute presentations that gave IDS program participants an

Table 5. Summary of research presented during the Interdisciplinary Science Program *Rapid Presentations*.

Speaker	Institution	Presentation Title
Son Nghiem	NASA/Jet Propulsion Laboratory	Mega urban changes and impacts in the decade of the 2000s
Soe Myint	Arizona State University	Understanding impacts of desert urbanization on climate and surrounding environments to foster sustainable cities using remote sensing and numerical modeling
Douglas Stow	San Diego State University	Urban transition in Ghana and its relation to LCLUC through analysis of multiscale and multitemporal satellite image data
Geoffrey Henebry	South Dakota State University	Storms, forms, and complexity of the urban canopy: How land use, settlement patterns, and the shapes of cities influence severe
Mark Friedl	Boston University	Four-dimensional modeling of the regional carbon cycle in and around urban environments: An interdisciplinary study to advance observational and modeling foundations
Lahouari Bounoua	NASA's Goddard Space Flight Center	Combining satellite data and models to assess the impacts of urbanization on the continental United States surface climate

Table 6. Summary of research presented during the *Monsoon Asia Regional LCLUC* session.

Speaker	Institution	Presentation Title
Ruth DeFries	Columbia University	Multi-sensor fusion to determine climate sensitivity of agricultural intensification in South Asia
Xiangming Xiao	University of Oklahoma	Quantifying changes in agricultural intensification and expansion in monsoon Asia during 2000-2010

opportunity to report on their research. **Table 5** summarizes the presentations that took place.

Monsoon Asia Regional LCLUC

Human activity has significantly altered the landscape in Asia from its native state. These changes in LCLUC have been shown to have significant impacts on the Asian monsoon, with subsequent societal impacts. **Table 6** summarizes the presentations.

International Activities

Tackling LCLUC-related complex issues of and determining their links to climate change requires developing effective means to foster global collaboration. This session highlighted activities toward this end.

- **Krishna Vadrevu** [UMCP] summarized the LCLUC Regional Workshop held in Southern India earlier this year.
- **Rama Nemani** [NASA's Ames Research Center] discussed the newly proposed South Asia Regional-science Initiative (SARI).
- **Giovana Espindola** [National Institute for Space Research (INPE), Brazil—*Global Land Project (GLP) Executive Officer*], representing the international GLP, gave an update on the GLP Second Open Science Meeting, to be held March 19–21, 2014, in Berlin, Germany, and an upcoming special issue of *Current Opinion in Environmental Sustainability on Land Transformation: Between Global Challenges and Local Realities*, scheduled for November 2013.
- **Premysl Stych** [Charles University, Prague, Czech Republic] reported on the GOFC–GOLD[6] South/Central European Regional Information Network (SCERIN) and the TAT initiative. Stych introduced the GeoNetWork for Capacity Building (GeoNetCaB) intended to create conditions to improve and increase GEO/GEOSS capacity building activities and framework, with special emphasis on developing countries.

[6] GOFC–GOLD stands for Global Observation of Forest Cover and Land Cover Dynamics, and falls under the auspices of the Global Terrestrial Observing System (GTOS)—*www.fao.org/gtos/index.html.*

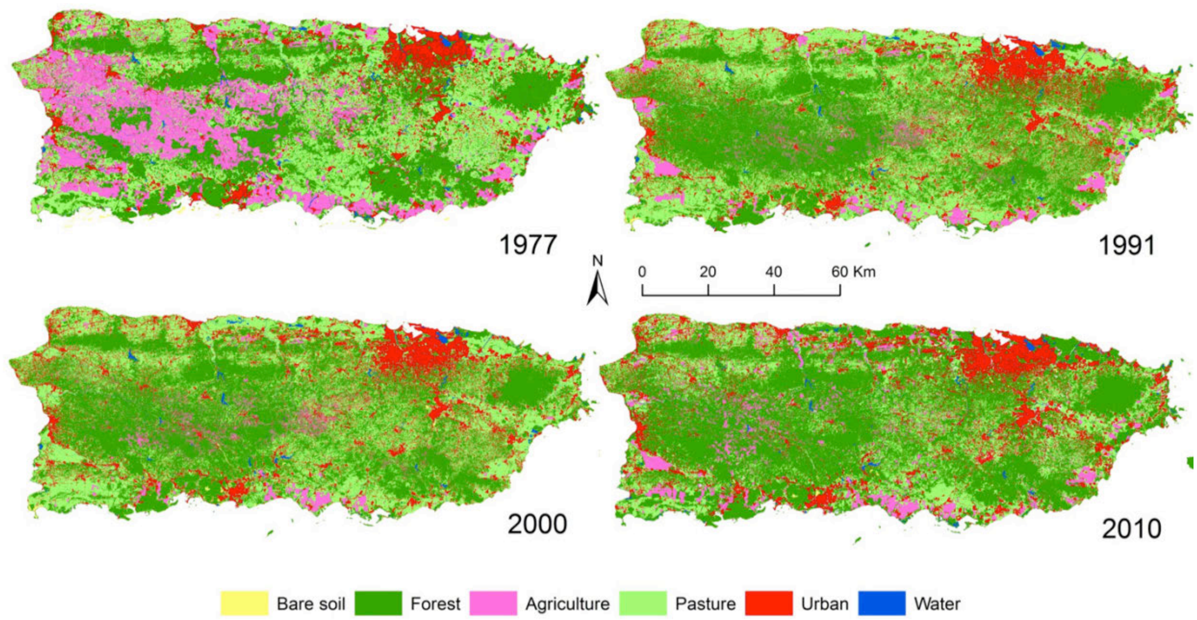


Figure. These maps summarize annual land-cover changes in Puerto Rico for 1977, 1991, 2000, and 2010. The study shows extensive urbanization in the San Juan area between 1977 and 1991 but no major changes between 1991 and 2000, and between 2000 and 2010. Agricultural land greatly reduced between 1977 and 1990. While some agricultural land was reclaimed by the forest during that time, there has been no significant change since 1991. Total areas of both forest and vegetated wetlands have increased with reduced fragmentation in vegetated wetlands. **Image credit: Mei Yu** [University of Puerto Rico]

Concluding Discussion

Chris Justice led a final discussion on the future of LCLUC and how synthesis is an important part of the research program. **Garik Gutman** closed the meeting, stating that LCLUC will continue international efforts facilitating continued collaborations with ESA, INPE, ISRO, and GLP. He pointed to the current priorities of the program, emphasizing that social science remains an integral part of LCLUC studies and that the program will continue to balance activities thematically and geographically; foster generation of global land-use products for models; promote LCLUC products internally and externally through the program's web site, the Facebook page, and LCLUC brochures; keep LCLUC proposal calls on a regular annual basis; and continue the twice-a-year Science Team meeting structure. Gutman concluded by encouraging the LCLUC community to use the aforementioned avenues to foster collaborations and strengthen the community. ■

Anne Douglass Wins William Nordberg Memorial Award

Anne Douglass from the Atmospheric Chemistry and Dynamics Laboratory at NASA's Goddard Space Flight Center (GSFC) was selected as the 2013 recipient of the *William Nordberg Memorial Award*, which is GSFC's highest award in the area of Earth science. Douglass, was honored for her many years of satellite mission leadership, studying atmospheric composition, and her pioneering work in using measurements to test models.

Specifically, Douglass was recognized for her discoveries using data from the Upper Atmosphere Research Satellite (UARS) and from instruments on NASA's Aura satellite, and emphasizing their impact on providing a physical basis for models to represent observed atmospheric processes.

The staff of *The Earth Observer* wishes to congratulate Douglass on this achievement.

GOFC–GOLD 2013 Fire Implementation Team Meeting

Krishna Prasad Vadrevu, University of Maryland, College Park, krisvkp@umd.edu
David Roy, South Dakota State University, David.Roy@sdstate.edu
Louis Giglio, University of Maryland, College Park, lgiglio@umd.edu
Luigi Boschetti, University of Idaho, luigi@uidaho.edu
Ivan Csiszar, NOAA/NESDIS Center for Satellite Applications Research, ivan.csiszar@noaa.gov
Chris Justice, University of Maryland, College Park, cjustice@umd.edu

Introduction

The Global Observation of Forest and Land Cover Dynamics (GOFC–GOLD) Fire-Implementation Team (IT) meeting was held April 15-16, 2013, at Wageningen University in the Netherlands. The meeting was sponsored by the GOFC–GOLD program; Global Change System for Analysis, Research, and Training (START); NASA; European Space Agency, and Wageningen University.

The Fire-IT meeting was organized as a part of the GOFC–GOLD Symposium that included other meetings that focused on land cover, biomass, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD), and the GOFC–GOLD regional networks. Participants in the Fire-IT meeting reviewed current progress, recent developments, and future prospects for Earth observations for fire science and applications. **Chris Justice** [University of Maryland, College Park (UMCP)] and **Johann Goldammer** [Global Fire Monitoring Center (GFMC), Germany] co-chaired the meeting, the highlights of which are summarized in this article; presentations can be accessed at *gofc-fire.umd.edu/meeting/static/Netherlands_2013/index.php.*

Current status of GOFC–GOLD Fire-IT and areas of progress in satellite fire research

Chris Justice provided an overview of GOFC–GOLD Fire-IT goals, securing fire observation continuity and operationalization, advocating for free and open sharing of data products (including user-oriented data-delivery systems), and enhancing data use. He noted that the GOFC–GOLD Fire-IT requires a decadal process of setting requirements, defining best practices, promoting operational research and development, and engaging users. The GOFC–GOLD Fire-IT is currently pursuing the following strategic tasks:

- implementing an operational global fire early-warning system;
- developing meteorological agency support to establish a global geostationary fire network;
- ensuring operational fire-monitoring capabilities from the Visible Infrared Imaging Radiometer Suite (VIIRS[1]) on the Suomi National Polar-orbiting Partnership (NPP) satellite and instruments on the European Space Agency's (ESA) Sentinel-3[2] mission;
- increasing access to near-real-time and direct-readout data;
- advocating international space agency coordination of global "Landsat-class"-resolution data processing and availability (e.g., Sentinel-2 and -3);
- supporting the GOFC–GOLD regional fire networks and developing capacity-building programs that use satellite fire data;

[1] To learn more about VIIRS, please see section on *Fire observations from new instruments* on page 42.
[2] The European Space Agency's Earth observing missions are discussed at length in the article on page 4 of this issue.

GOFC-GOLD Fire-IT meeting participants. **Image credit:** Wageningen University technical staff

- providing a coordination mechanism for defining requirements and implementing fire observations in support of the international conventions;
- providing *Essential Climate Variables* (ECVs) related to fire to the United Nations Framework Convention on Climate Change (UNFCCC), Committee on Earth Observation Satellites (CEOS); and
- defining the role of fire in United Nations REDD—for example, via the GOFC-GOLD REDD Sourcebook.

Justice then provided an overview of the status of fire observation capabilities and research, and summarized the "next generation" of operational polar orbiters (i.e., those either recently launched or planned for launch in the next few years, as discussed in the next section of this article), which all include sensors with specifications applicable to fire monitoring. He also described how multi-source fire information is being integrated into fire early-warning systems (e.g., the regional Advanced Fire Information System) and how long-term fire-data records from the Advanced Very High Resolution Radiometer (AVHRR) series are being processed. He explained that the CEOS Land Product Validation (LPV) protocol has established a clear pathway for regional/global burned-area product validation, and said that both near-real-time and retrospective fire-emission datasets are being updated continuously. Near- real-time global daily active fire monitoring is implemented through NASA's Land Atmosphere Near real-time Capability for the The Land, Atmosphere Near-Real-Time Capability For the Earth Observing System (EOS) [LANCE] system and the web-based Fire Information for Resource Management System (FIRMS). Justice also described recent progress in other areas, including increased coordination between direct-readout stations and through the GeoNetcast global-distribution capability. He reported that GOFC–GOLD and Fire-IT members have participated in a number of capacity-building activities in developing countries and also have engaged in regional fire networks through scientific workshops.

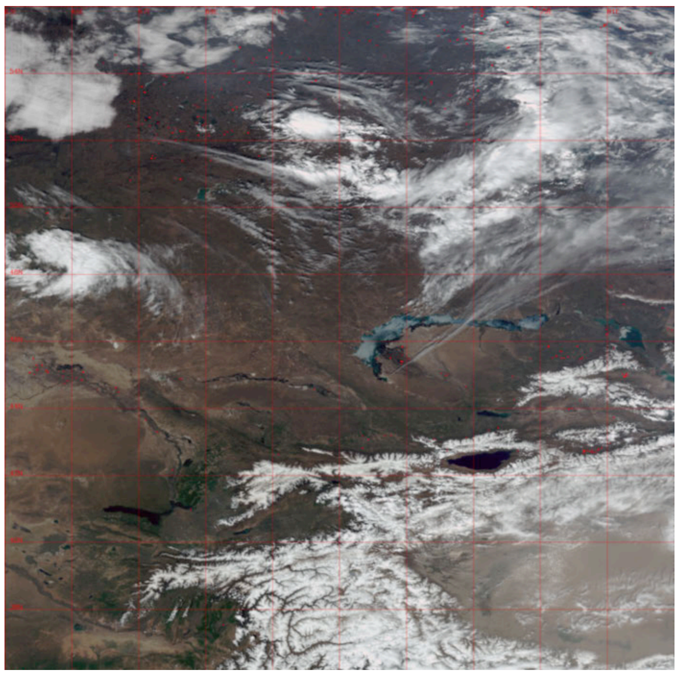


Figure 1. Individual fires (red dots) detected by VIIRS on Suomi NPP have been overlain on a VIIRS-band M5-M4-M3 red-green-blue composite image to show fires in Central Asia on April 13, 2012 at 7:53 UTC. **Image credit:** Ivan Csiszar [NOAA] and the NOAA/University of Maryland VIIRS Active Fire Team

Fire observations from new instruments

First in this theme, **Louis Giglio** [UMCP] presented an updated report on international fire observations from new instruments, and **Ivan Csiszar** [National Oceanic and Atmospheric Administration (NOAA)] presented *via* Skype the status of the VIIRS fire products. This material is summarized below.

The Suomi NPP spacecraft was launched in 2011 and is a precursor for the upcoming series of Joint Polar Satellite System (JPSS) series of missions, with JPSS-1 scheduled for launch in 2017 and JPSS-2 in 2021. VIIRS instrument is (will) be on each of these missions. VIIRS on Suomi NPP will continue the fire record that began with the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra and Aqua satellites—see **Figure 1**. The most useful VIIRS bands for fire monitoring are M13 (a dual-gain band with high saturation) and M15 (providing background thermal conditions), augmented with a spatial aggregation scheme. The early assessment of VIIRS fire capability is encouraging—with a relatively higher number of fires captured by VIIRS at nadir as compared to MODIS. The VIIRS spatial resolution is higher than that of MODIS, so VIIRS is expected to detect smaller fires at nadir. The MODIS *Collection 6* algorithm that includes Fire Radiative Power (FRP) is currently being tested on VIIRS and evaluated against the current VIIRS active-fire detection algorithm (MODIS *Collection 4*). Validation of VIIRS fire data using airborne datasets from the U.S. Forest Service (USFS) is underway. The VIIRS active-fire products website (*viirsfire.geog.umd.edu*) provides the latest information on fire detections using a web-GIS interface for data download. Fire data from VIIRS can also be obtained from the NOAA Comprehensive Large Array-data Stewardship System

(CLASS) and the NASA Level-1 and Atmospheres Archive and Distribution System (LAADS) websites[3]. The VIIRS fire product latency is currently six hours, but CLASS latency is insufficient for near-real-time applications. The GOFC–GOLD fire community is advocating for a LANCE-like capability for VIIRS.

The German Aerospace Center, the Deutsche Zentrum für Luft- und Raumfahrt's (DLR), launched the Technologieerprobungsträger-1 (TET-1) in July 2012—a small satellite designed to be a "Technology Experiment Carrier" with a designed based on the earlier Bispectral and Infrared Remote Detection (BIRD) satellite.

The joint U.S. Geological Survey/NASA Landsat Data Continuity Mission was launched in February 2013—and subsequently renamed Landsat 8 as of May 30, 2013. It has two sensors useful for fire research: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). OLI has 12-bit radiometric resolution, notable when compared to the 8-bit radiometric resolution of Landsats 5 and 7. TIRS has two thermal bands, with improved saturation as compared to the single thermal band on Landsats 5 and 7. OLI's first false-color image was obtained on March 18, 2013 and showed improved contrast over burned areas near Galena, CO—see **Figure 2**.

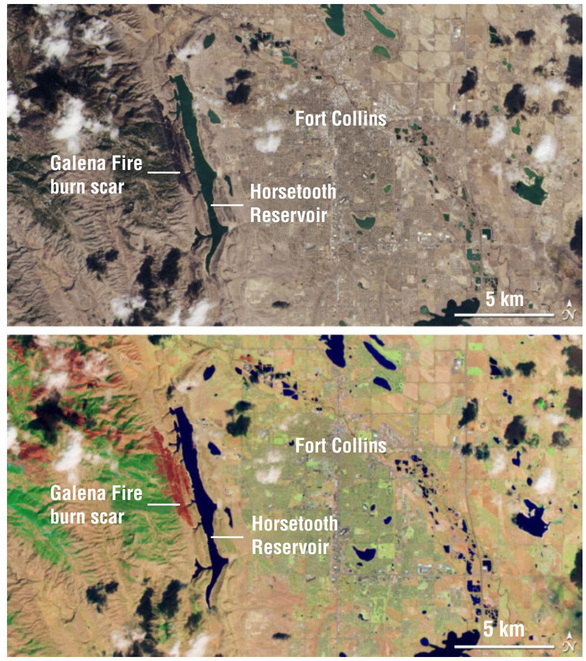


Figure 2. This image pair shows the area surrounding Fort Collins, CO, on March 18, 2013, as observed by Landat-8's OLI [*top image*] and TIRS [*bottom image*] instruments. A burn scar from the Galena Fire, which burned 1348 acres (~5.5 km2), mostly in Lory State Park, is clearly visible in both images. **Image credit:** NASA's Earth Observatory/USGS

ESA's Sentinel-2 and -3 multisatellite missions are expected for launch in 2014. The Sentinel-2 Multi-Spectral Instrument (MSI) is designed for continuity of French Système Pour l'Observation de la Terre (SPOT) moderate-resolution data with visible and short-wave infrared (SWIR) bands and a five-day revisit. Fuel mapping, burned-area mapping, and active-fire detection are possible. Sentinel-3 will carry instruments that include the Sea and Land Surface Temperature Radiometer (SLSTR) based on the Advanced Along Track Scanning Radiometer (AATSR[4]) sensor heritage. It will have nine spectral bands with dual-view scan, swath width of 1420 km (~882 mi) [nadir]/750 km (~460 mi) [backwards] with spatial sampling of 500 m (~1640 ft) for visible and near-infrared and 1-km (~3281-ft) for mid-infrared and thermal infrared. SLSTR will have two fire channels centered on 3.74 µm and 10.85 µm. The products generated from the Sentinels will be offered in near-real time and are proposed to be cost free.

Global geostationary network and fire products

Louis Giglio and **Martin Wooster** [King's College, U.K.] presented an update on the Global Geostationary Network of fire observations and how the network will improve over the next few years. The experimental Wildfire Automated Biomass Burning Algorithm (WFABBA) is currently generating fire data from multiple satellites:

- In NOAA's Geostationary Operational Environmental Satellite (GOES) series, GOES-13/-14 (GOES-East) provides coverage for North and South America, GOES-15 (GOES-W) covers North America, and GOES-12 provides more-frequent South American coverage;
- the Meteosat-9, operated by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), covers Europe and Africa[5]; and
- the Multifunctional Transport Satellites (MTSAT)-1R and -2, operated by the Japan Meteorological Agency (JMA), cover Asia and Australia.

The near-global WFABBA is an operational fire product from the NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) that is available in near-real time. Fire-mask imagery is available online at *wfabba.ssec.wisc.edu*.

There are other capability enhancements, either underway or planned: Geostationary fire monitoring in Southeast Asia has improved by using data from the Korean geostationary Communication, Ocean

[3] To access data from CLASS, visit: *nsof.class.noaa.gov*. To access data from LAADS, visit: *earthdata.nasa.gov/data/data-centers/modaps-laads*.

[4] AATSR is onboard ESA's Environmental Satellite (Envisat), which is still in orbit but has been inoperative since April 2012.

[5] A more-complete summary of Europe's current and planned Earth observing missions appears on page 4 of this issue.

and Meteorological Satellite (COMS) in conjunction with MTSAT-2. An operational Fire Radiative Product (FRP) from the Spinning Enhanced Visible and Infrared Imager (SEVERI) onboard the Meteosat series of satellites is available from the EUMETSAT Land Surface Analysis Satellite Application Facility (LSA SAF) (*landsaf.meteo.pt*); a GOES-based FRP product will be forthcoming. The upcoming European geostationary Meteosat Third Generation imaging and sounding satellites (MTG-I and MTG-S, respectively), planned for launch in the 2017-2018 timeframe will allow for an improved geostationary fire product as it will comprise four imaging and two sounding satellites. In particular, the Flexible Combined Imager (FCI) on MTG will take measurement in 16 channels, of which eight are placed in the solar spectral domain between 0.4-2.1µm, delivering data with a 1-km spatial resolution. The additional eight channels will deliver data in thermal domain between 3.8-13.3 µm with 2-km (~1.2 mi) resolution. With respect to validating the geostationary fire products, Landsat data, and some airborne reference data over selected areas of the world are available. Data from TET-1 may also play an important validation role. In addition, integration of geostationary data with polar orbiter products from MODIS, VIIRS, and Sentinel-3 and -4 should be expanded. A series of GOFC–GOLD geostationary fire workshops is needed to provide the direction and impetus for recent advances, as is a "progress review and next steps workshop" to explore new opportunities.

Burnt area products and validation

The session included presentations on burnt area validation using data from MODIS on Terra, Aqua, Landsat, and the Medium Resolution Imaging Radiometer (MERIS) on Envisat respectively—each following CEOS protocols. There was also an overview presentation on CEOS land product validation aspects.

Luigi Boschetti [University of Idaho] presented material on global burned-area product validation. There is a need to validate the spatial location and areal extent of burning and also the date of burning if the product has data information. Temporal validation of the MODIS *MCD45* burned-area product is achieved by comparison with the dates of MODIS-detected active fires. Validation of burned-area spatial extent should be based on the CEOS burned-area validation protocol, i.e., using reference burned-area data extracted at different locations—for example, by using multitemporal Landsat data. Reference data availability is a limitation for validation, although free Landsat 8 and future Sentinel-2 data may fill such a gap.

Itziar Alonso-Canas [University of Alcala, Spain] reported on ESA's fire Climate Change Initiative (CCI), which is developing a global burned-area product based on European sensors and MODIS active-fire detections. At the pixel level, the product will include burnt-area information, the date of detection, and a confidence level. At the grid level, 15-day files at 0.5° x 0.5° resolution will include standard error and burned land-cover information. Validation will be performed following CEOS guidelines and using Landsat data. A preliminary intercomparison of multiple burned areas in Australia suggests that fire-CCI product estimates are closer to MODIS burned areas than outputs from Global Land Products for Carbon Model Assimilation (Globcarbon) and the Global SPOT Vegetation (VGT) burnt area product 2000-2007(L3JRC). **David Roy** [South Dakota State University] led the discussion on the burnt-area validation theme.

Kevin Tansey [University of Leicester, U.K.] reported on the Global Climate Observing System (GCOS[6]) -Terrestrial Observing Panel for Climate (TOPC) fire-ECV, including the CEOS Land Product Validation (LPV) subgroup. TOPC is a panel within the GCOS Secretariat. The LPV publishes protocols to support the validation of land parameters and variables derived from satellite data. It provides advice, feedback, and contributions to GCOS documentation. Through interaction with climate scientists, GOFC–GOLD is involved in discussions with GCOS to ensure that fire disturbance is strongly represented as a part of fire-related ECVs.

Fire Early Warning Systems (EWS)

This session included four presentations three on operational Fire EWS and fourth one on GOFC source book. These are summarized below:

Bill de Groot [Canadian Forest Service] summarized the global fire Early Warning System (EWS), which seeks to develop a globally consistent suite of fire-danger and early-warning products to support international collaboration and to reduce the disastrous effects of wildfires. Fire danger and early-warning information have been developed at a 0.5° x 0.5° resolution and can be accessed from *www.fire.uni-freiburg.de/gwfews*. The system is being refined to include spatial rainfall, biomass as it affects emissions and fire behavior, and fuel consumption as a function of the rate of fire spread.

Tim Brown [Desert Research Institute, Arizona State University] described the seasonal forecast model used for the EWS. The program for Climate, Ecosystem and Fire Applications (CEFA) is a partnership between the Desert Research Institute and federal land management agencies involved in generating operational seasonal

[6] The GCOS is an international institution cosponsored by the World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC) of the United Nation's Educational, Scientific, and Cultural Organization (UNESCO), United Nations Environment Programme (UNEP), and International Council for Science (ICSU).

forecast products for the global fire EWS. CEFA datasets found at *cefa.dri.edu* are being used for fire research in the U.S.

Jesús San-Miguel-Ayanz [Joint Research Center (JRC), Italy] discussed the European Forest Fire Information System (EFFIS). Similar to the global fire EWS, EFFIS has been developed by the JRC; see *effis.jrc.ec.europa.eu*. It provides European Union-level fire assessments during both pre- and post-fire phases to support fire prevention, preparedness, firefighting, and operations. The EFFIS is currently being expanded to other countries outside the European Union and is being refined to include fire behavior and spread, fire smoke dispersion, and influences on human health.

Philip Frost [Council for Scientific and Industrial Research (CSIR), South Africa] reported on the Advanced Fire Information System (AFIS). Led by the Meraka Institute and supported by the South African National Space Agency (SANSA), the CSIR developed the AFIS to provide near-real-time fire information to a variety of operational and science fire-data users, including disaster managers, firefighters, farmers, and forest managers located across Southern and Eastern Africa. The AFIS now provides near-real-time fire information to users in Southern Africa, South America, Eastern Europe, and East Africa, and includes an African fire EWS that uses MODIS and Meteosat Second Generation (MSG) fire-detection products (*afis.co.za*). A new AFIS mobile application for iOS and Android mobile devices and a fire-reporting tool enable both dissemination of and alerts for fire information and user upload of geotagged photographs and on-the-fly creation of fire reports for user-defined areas of interest. **David Roy** remarked that this latter capability was particularly relevant as fire information systems evolve beyond data dissemination systems.

Luigi Boschetti provided details on the role of fire in REDD and outlined the fire component of the GOFC–GOLD REDD Sourcebook[7], which includes methods and procedures for monitoring, measuring, and reporting anthropogenic greenhouse gas emissions and carbon stocks in the forestry sector.

Fires and emissions

In this session, researchers highlighted the use of satellite fire products for emissions estimation.

Martin Wooster provided updates on research into fire radiative energy (FRE), which has been difficult to measure using MODIS, because the sensor provides only a few observations per day. To refine FRE estimates, use of a spatiotemporal sampling design for MODIS data shows promise. To aid in resolving *bow-tie effects*—geometric artifacts arising from the arrangement of the instrument's sensors—recommendations include summing FRP measured within ±40° of nadir in the MODIS *Collection 6* CMG fire product. Geostationary FRP-based estimates underestimate dry matter combustion as compared to data from the Global Fire Emissions Database (GFED). The problem of merging geostationary and MODIS FRPs is yet to be solved. There are discrepancies between FRE-based emissions estimates compared to GFED emissions; merging FRE and burnt areas might help solve the problem. Field-based FRP emission factors for estimating biomass-burning emissions are available in the literature. New FRP products are expected from Suomi NPP VIIRS and Sentinel-3 SLSTR.

Johannes Kaiser [European Centre for Medium-range Weather Forecasts (ECMWF, U.K.] described efforts to assimilate FRP data into emissions models. Real-time emissions from vegetation fires at a global scale are available at 0.1° and 0.5° resolution from Global Fire Assimilation System (GFAS—v1.0) *via* the Monitoring Atmospheric Composition and Climate (MACC) website—*www.gmes-atmosphere.eu/about/project_structure/input_data/d_fire*. The main inputs for GFAS include MODIS-derived Aqua/Terra FRP data. Both the night and day FRP observations are used with ecosystem-specific FRP-GFED conversion factors to convert FRP to dry matter, and then to emissions. Currently, two approaches are used: either using FRP to empirically scale to emissions as observed in plumes, or scaling the FRP to dry matter, as prescribed in GFED. The former approach seems to be geographically dependent, whereas the latter is dependent on the fire type. The MACC GFAS is producing daily biomass burning estimates for forty smoke constituents in real-time and the data are publicly available. The GFAS system is being refined to include a plume-rise model, merging of geostationary FRP observations and improved emission factor formulation. Validation remains a difficult issue.

Guido van der Werf [Vrije Universiteit (VU) University, Netherlands] summarized the GFED, which has data extending back to 1997 and is used primarily by the atmospheric community. The *Version 3* GFED was released in 2010 (0.5°, monthly) and GFED *Version 4* burned-area quantification has been completed covering 1995-2012; the emissions product generation is in progress (0.25°, daily). A particular issue being introduced in the new GFED is the emissions role of "small fires." One recent view is that small fires are those that are insufficiently large or hot to be detected as an active fire by MODIS nor detected by the MODIS burned-area algorithm. However, resolving what constitutes small fires requires additional effort from the remote sensing community. Validations of emissions across large spatial scales need integration of both top-down and bottom-up approaches.

[7] The GOFC–GOLD REDD Sourcebook is a living document and is updated periodically; it is available at *www.gofc-gold.wur.nl/redd*.

Krishna Vadrevu [UMCP] provided an evaluation of tropospheric emission products in relation to fires, suggesting that data products from some instruments [e.g., carbon monoxide (CO) from MOPITT[8]] correlate well as compared to others [e.g., carbon dioxide (CO_2) from GOSAT[9] and nitrogen dioxide (NO_2) from SCIAMACHY[10]]. Further, there are correlation differences when fire counts were used as a dependent variable as compared to FRP in relation to tropospheric gases. With respect to MOPITT CO data over the South and Southeast Asian region, both fire counts and FRP show good correlation of more than 70%. In contrast, correlation of GOSAT CO_2 data with fire counts was less than 40% and with FRP it was much less (<15%). NO_2 data from the Ozone Monitoring Instrument (OMI) onboard NASA's Aura satellite seem to correlate better with fire counts than SCIAMACHY data; the differences were attributed to satellite overpass time. In summary, relating emissions retrieved from tropospheric satellites with fire counts and FRP should be done with caution, and directly relating satellite-retrieved emissions to fires need more research.

Perspective on user needs and fire research

This session included three presentations which are summarized below:

Johann Goldammer provided the perspective of someone who uses fire management data. The regional networks within the U.N. Global Wildland Fire Network (GWFN) provide feedback for researchers on fire management user needs. There is a growing need to strengthen these networks through building *regional fire centers*. The main function of these centers will be to serve as an open repository for fire information, bridging the gap between policy-makers and practitioners involved in fire management. GFMC is involved in strengthening the existing regional centers and building new ones. A recent initiative is being undertaken with the Balkan Environment Center (BEC) and the Balkan Wildland fire observatory group. The center is involved in real-time monitoring of fires and building a decision-support system for early warning and risk assessment. These institutes have a cooperative agreement with GFMC and are looking forward to working with the GOFC-GOLD Fire-IT community.

Ioannis Gitas [Aristotle University, Greece] presented on fire research activities of his group and stressed the need for institutional cooperation at a regional level.

Johannes Kaiser [ECMWF] discussed user needs from an atmospheric science perspective and described the International Biomass Burning Initiative (IBBI), a new international science initiative on quantifying biomass burning emissions. The International Global Atmospheric Chemistry (IGAC), Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), and the World Meteorological Organization (WMO) are joint sponsors. IBBI which follows on from IGAC Biomass Burning Experiemnt (BIBEX), works closely with atmospheric researchers, and is interested in developing a relationship with the GOFC-GOLD Fire-IT.

Everett Hinkley [USFS] spoke from a forest management perspective. The USFS National Remote Sensing Program has been working with the GOFC–GOLD Fire program for several years and has been leading operational programs that have a significant remote sensing component, including fire mapping and monitoring. For example, the Rapid Disturbance Assessment and Services (RDAS) provide tactical and strategic remote sensing support in response to fire disturbances in addition to direct-readout operation services for MODIS and VIIRS data. Additionally, the USFS Active Fire Mapping (AFM) Program provides an information portal for monitoring wildfire activity in the conterminous U.S., Alaska, Hawaii, and Canada, including generation of value-added products. The USFS is also involved in unmanned aircraft systems support to test new and improved sensor technologies on wildfires, data transfer, and visualization. Through involvement with the GOFC–GOLD-Fire community, USFS researchers can strengthen their research both nationally and internationally.

Summary

In summary, discussions among the workshop participants highlighted the need for:

- international space agencies to provide validated fire products of known accuracy;
- strengthening the Global Geostationary Fire Network through operational production of global fire products;
- refining fire-emissions products by validation and by integrating/reconciling top-down and bottom-up emission estimation approaches;
- expanding the fire component of the GOFC–GOLD REDD Sourcebook;

continued on page 53

[8] MOPITT stands for Measurements of Pollution in the Troposphere; the instrument flies onboard NASA's Terra satellite.

[9] GOSAT is the Japan Aerospace Exploration Agency's Global Greenhouse Gas Observing Satellite.

[10] SCIAMACHY stands for Scanning Imaging Absorption Spectrometer for Atmospheric Cartography; it was an instrument on ESA's Envisat.

2013 CLARREO Science Definition Team Meeting Summary

Rosemary Baize, NASA's Langley Research Center, rosemary.r.baize@nasa.gov
Bruce Wielicki, NASA's Langley Research Center, bruce.a.wielicki@nasa.gov
Amber Richards, NASA's Langley Research Center/Science Systems and Applications, Inc., amber.l.richards@nasa.gov

Introduction

The fourth meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at NASA's Langley Research Center (LaRC) in Hampton, VA, April 16-18, 2013. Over 25 investigators participated in the discussion from LaRC, NASA's Goddard Space Flight Center (GSFC), NASA/Jet Propulsion Laboratory (JPL), National Oceanic and Atmospheric Administration (NOAA), National Institute of Standards and Technology (NIST), Los Alamos National Laboratory (LANL), University of Wisconsin (UW), Harvard University, University of Maryland, University of Michigan, and University of California, Berkeley (UCB). Highlights of the meeting are summarized herein.

Advances in CLARREO High-Accuracy Instruments

NASA Earth Science Technology Office (ESTO)-funded efforts have led to the production at UW of a demonstration system for CLARREO's infrared (IR) instrument [which is at Technology Readiness Level (TRL) 6] that achieves CLARREO-accuracy levels. Vacuum tests have shown 24-hr stability of the On-orbit Absolute Radiance Standard (OARS) phase-change cell black body to be 5 mK—see **Figure 1**—which is a key requirement for performing on-orbit radiometric verification. Preliminary results at 800 cm^{-1} and 450 cm^{-1} successfully demonstrated the ability to meet the on-orbit 0.1-K (3-σ) uncertainty requirement.

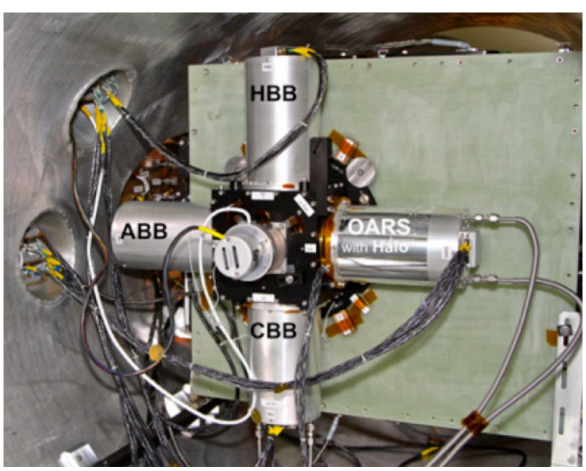


Figure 1: Shown here is the UW Absolute Radiance Interferometer (ARI) prototype with phase-change cell black body OARS in a vacuum chamber. NASA's ESTO made funding available to bring the ARI to TRL 6, by verifying operation and performance in a vacuum environment. **Photo credit:** University of Wisconsin

The CLARREO reflected solar (RS) instrument SOlar, Lunar for Absolute Reflectance Imaging (ARI) Spectroradiometer [SOLARIS] was highlighted as the *Image of the Day* at NASA's Earth Observatory Website on April 16, 2013. SOLARIS was deployed in the field for a once-in-a-lifetime opportunity to make coincident calibration measurements with Landsat 7 and the Landsat Data Continuity Mission (LDCM), renamed to Landsat 8 as of May 2013.

CLARREO Observation System Simulation Experiment—Progress and Prospects for Future Use

Important steps have been taken to address the clear and present need for faster radiative transfer model processing. The development of the Principle Component Radiative Transfer Model (PCRTM) is intended to enable CLARREO Observation System Simulation Experiments (OSSEs) that sample the diversity of climate model physics in the Coupled Model Intercomparison Project—Phase 5 (CMIP5) archive. Work conducted at UCB and LaRC show that PCRTM achieves longwave and shortwave radiative spectra calculations 25-30 times faster than the current MODTRAN[1] model. This foundational work enables a much larger number of OSSEs, permitting more-comprehensive examination of the signatures of climate change and, ultimately, differentiation of climate models using both future CLARREO observations and observations from other sensors calibrated by CLARREO to higher absolute accuracy—see **Figure 2**, for example.

In the coming year UCB plans to continue its work, examining groupings of low-, medium-, and high-sensitivity climate models with varying model structure and physical parameterizations to probe key science questions related to climate change.

The topic generated a lot of discussion on how OSSEs can be used to inform the next decadal survey—for example, by helping to identify the driving science questions and what data are needed.

[1] MODTRAN stands for Moderate Resolution Atmospheric Transmission; it was developed by Spectral Sciences Inc. and the U.S. Air Force to serve as a standard atmospheric band model for the remote sensing community. The most recent release, *Version 5*, has a spectral resolution of 0.2 cm^{-1} using its 0.1-cm^{-1} band model algorithm.

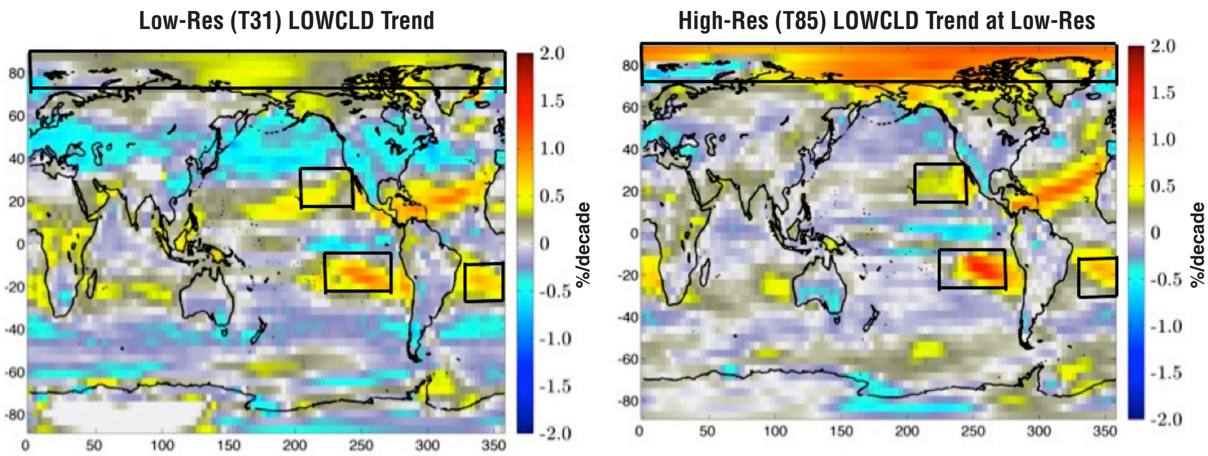


Figure 2: Depicted are results from a regional analysis of the CLARREO OSSE cloud-feedback signals showing the ability to differentiate climate models. The results show that shortwave spectral measurements in visible and near-infrared water-vapor overtone lines are best suited to differentiate model results. Bringing the prototype PCRTM model into the OSSE framework will enable a larger number of simulations to be processed for a wider range of CMIP5 models with varying climate sensitivity. **Image credit:** UC Berkeley

Utilizing Reference Intercalibration to Realize Greater Value from Existing Sensors

A study comparing climate variables derived from data from the Atmospheric Infrared Sounder (AIRS), Infrared Atmospheric Sounding Interferometer (IASI) and Cross-track Infrared Sounder (CrIS) showed deviations in the annual means of the three instruments data processing[2]. While cloud heights were in excellent agreement, differences in cloud optical depth were as large as 2, regional temperatures differed by as much as 3 K, and regional relative humidity differed by as much as 15%. These differences appear to be instrument-related, justifying the need for a common absolute reference on-orbit (e.g., CLARREO).

The CLARREO team has developed a technique that combines hyperspectral IR and Global Positioning System-Radio Occultation (GPS-RO) data to assess (and potentially to confirm) the stratospheric temperature trends observed by radiosondes. Comparison of Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)- and AIRS-retrieved temperature profiles from 2007 to 2011 show excellent agreement at low vertical resolution.

Researchers are now using a new *multi-instrument intercalibration* (MIIC) Framework to support low-Earth-orbit (LEO)–geostationary-Earth-orbit (GEO) and LEO–LEO instrument intercalibration—see **Figure 3**,

[2] These instruments are on Aqua, the Suomi National Polar-orbiting Partnership, and the European Organization for the Exploitation of Meteorological Satellites' (EUMETSAT) Operational Meteorological (MetOp) satellite, respectively.

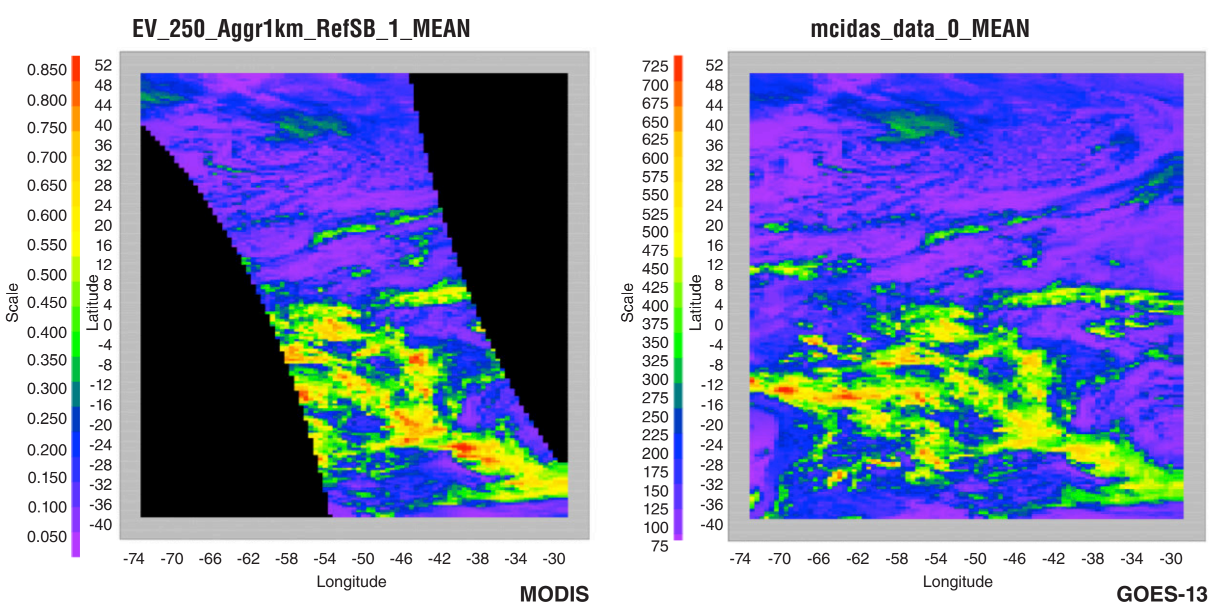


Figure 3: The MIIC Framework event prediction software finds coincident measurements from instruments on separate spacecraft. Reflectance data from Band 1 (wavelengths 620-670 nm) of the Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua [*left*] are matched to Geostationary Operational Environmental Satellite (GOES -13) 650-nm reflectance data [*right*]—at 1645 UT on January 1, 2011. Both data are averaged onto 0.5°-grid cells using server-side functions prior to network transmission. **Image credit:** LaRC

for example. The MIIC Framework leverages the Open-source Project for a Network Data Access Protocol (OPeNDAP) network protocol and server-side functions to efficiently acquire matched event data from within large volumes housed at remote data centers. Efforts are underway to expand services, so that the community can more readily access intercalibration events from the NOAA Comprehensive Large Array-Data Storage System (CLASS) archive.

Economic Arguments for the High Societal Value of the Earth-observing System

Data obtained from CLARREO can be used to accelerate decisions on public policy concerning climate change, and to link to global economic benefits, providing *gross domestic product* (GDP) savings of approximately one-half percent. This topic generated enthusiasm and led to discussion on how this analysis can be applied to the entire Earth-observing system. A paper describing the initial value of information results has been accepted for publication in the *Journal of Environment, Systems, and Decisions.*

The Way Forward

The meeting concluded with a discussion on the next steps that the CLARREO SDT needs to take. These directions are based on several activities, as noted here.

Bruce Wielicki [LaRC] commended the team on the work they have done over the past two years and for the papers that are just beginning to be released. To date there have been 31 journal papers published, from pre-formulation studies (20 during 2012), 9 journal papers submitted/in review, and 24 more in preparation. Therefore, ***the SDT should continue to advance the science of high-accuracy, hyperspectral measurements and share the results with the broader community.***

Efforts have converged around an International Space Station mission implementation that meets approximately 70% of the baseline science mission value at some 40% of the cost. The International Letter of Agreement with the National Centre for Earth Observation in the U.K., set to expire this fall, is going to be extended. Therefore, ***the SDT should continue to explore lower-cost mission implementation options (including partnership options).***

As RS and IR Calibration Demonstration Breadboards (developed at LaRC and GSFC, respectively) have successfully demonstrated the measurement concepts (thereby retiring the top risks), and NASA ESTO-funded efforts at LASP and UW have shown the ability to achieve CLARREO-level accuracies, ***the SDT should incorporate results from recent tests of the Calibration Demonstration Systems into the science analysis, and should collaborate with NIST to review performance and to initiate comparisons.***

The next CLARREO SDT meeting is scheduled to take place in Washington, DC in October 2013. ■

announcement

Landsat Tree Cover Data Release

The Global Land Cover Facility (GLCF), based at the University of Maryland, College Park, is pleased to announce the release of the *Landsat Tree Cover Continuous Fields dataset*. The GLCF is funded by NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program.

The dataset's tree-cover layers contain estimates of the percentage of horizontal ground in each 30-m (~98-ft) pixel covered by woody vegetation greater than 5 m (~16 ft) in height. The data represent two nominal epochs, 2000 and 2005, compiled from the NASA/U.S. Geological Survey (USGS), Global Land Survey (GLS) collection of Landsat data. The product is derived from all seven bands of Landsat-5 Thematic Mapper (TM) and/or Landsat-7 Enhanced Thematic Mapper Plus (ETM+), depending on the GLS image selection.

The continuous classification scheme of the data product enables better depiction of land-cover gradients than traditional discrete classification schemes. Importantly for detection and monitoring of forest changes (e.g., deforestation and degradation), tree cover provides a measurable attribute with which to define forest cover and its changes. Changes in tree cover over time can be used to monitor and retrieve site-specific histories of forest change.

Please note that this dataset is *version 0*—i.e., a *beta release*. We are requesting feedback for any issues that you might come across. To report issues send an email to the GLCF team at *glcf@umd.edu*.

For more information and to download the dataset, visit: *landcover.org/data/landsatTreecover*.

CERES Science Team Meeting

Edward A. Kizer, NASA's Langley Research Center/Science Systems and Applications, Inc., edward.a.kizer@nasa.gov

Overview

The Spring 2013 Clouds and the Earth's Radiant Energy System (CERES) Science Team meeting was held May 7-9, 2013, at NASA's Langley Research Center (LaRC) in Hampton, VA. **Norman Loeb** [LaRC—*CERES Principal Investigator*] conducted the meeting.

The major objectives of the meeting included providing review and status of CERES instruments and data products. These included a(n):

- status report on the CERES Project;
- update on the status of shortwave (SW), longwave (LW), and total channels on existing CERES instruments—i.e., Terra (2), Aqua (2), and Suomi National Polar-orbiting Partnership (NPP);
- update on CERES Flight Model 6 (FM6) and beyond;
- update on calibration of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer Suite (VIIRS);
- status report on Terra and Aqua *Edition-4* cloud algorithm validation;
- status report on the CERES Suomi NPP single scanner footprint (SSF) *Edition-1* cloud algorithm;
- status report on CERES Edition-4 *angular directional model* (ADM) development;
- reports from the Surface-Only Flux Algorithms (SOFA), Surface and Atmospheric Radiation Budget (SARB), and Time-Space Averaging (TISA) Working Groups;
- status report on Energy Balance And Filled (EBAF) *top of atmosphere* (TOA) and surface products;
- update from the Data Management Team (including Terra/Aqua/Suomi NPP);
- update from the LaRC's Atmospheric Sciences Data Center (ASDC); and
- CERES education and public outreach efforts.

These discussions are summarized here. A full copy of each presentation can be downloaded from the CERES website at *ceres.larc.nasa.gov* (click the *CERES Meetings* button on the left navigation bar).

Tuesday, May 7

The first day of the meeting consisted of a series of programmattic and technical presentations—see **Table 1**.

David Considine [NASA HQ—*Modeling, Analysis and Predictability Program Officer*] presented the *NASA Headquarters Perspective* and initiated the meeting with discussions about the language within and impacts of the Fiscal Year 14 (FY14) Presidential Budget. Considine stated that the National Oceanic and Atmospheric Administration (NOAA) will focus on weather and not on climate. The FY14 budget

Table 1: CERES Programmatic and Technical Sessions, Tuesday, May 7, 2012.

Speaker	Institution	Topic†
David Considine	LaRC	NASA Headquarters Perspective
Norman Loeb	LaRC	State of CERES
Kory Priestley	LaRC	CERES FM1-FM6 instrument update (Part 1)
Susan Thomas	SSAI	CERES FM1-FM6 instrument update (Part 2)
Jack Xiong	GSFC	Status of VIIRS On-orbit Calibration
Patrick Minnis	LaRC	CERES Clouds Working Group Report
Wenying Su	LaRC	Updates on the Edition-4 ADM
David Kratz	LaRC	Status of the Edition-4 SOFA Algorithms
Seiji Kato	LaRC	SARB Working Group Update
Dave Doelling	LaRC	TISA Working Group Report
Norman Loeb	LaRC	EBAF TOA Update
Fred Rose	SSAI	EBAF Surface Update
Jonathan Gleason	LaRC	CERES Data Management Team Status

†All acronyms used in Table in this article are defined in text and/or listed at *ceres.larc.nasa.gov/acronyms_main.php*.

Table 2: CERES Contributed Science Presentations from Wednesday, May 8.

Speaker	Institution	Topic[†]
Bing Lin	LaRC	Surface Energy Budget Estimations Based on Satellite Radiation, Turbulence, and Precipitation Measurements
Takmeng Wong	LaRC	Comparisons of Surface Radiative Fluxes between CERES EBAF and Reanalysis Data
Laura Hinkelman	UW	Improving Performance of Snowmelt Models through use of CERES Radiation Data
Roger Davies	UA	Multi-angle Imaging SpectroRadiometer (MISR) Albedo and Cloud Height Changes
Xianglei Huang	UM	Thoughts on Constraining the Ice Cloud Feedback over the Tropical Pacific in Future Climate Change

[†]All acronyms used in Table in this article are defined in text and/or listed at *ceres.larc.nasa.gov/acronyms_main.php*.

removed NOAA's responsibility for climate sensors and gave the responsibility to NASA. The Radiation Budget Insrument[1] has the status of a Decadal Survey Mission and is still expected to fly on the second Joint Polar Satellite System (JPSS-2) mission, as it is the most cost-effective option.

Norman Loeb [LaRC] presented the *State of CERES* and discussed CERES themes that were included in the proposal for the Senior Review Report[2] submitted in March 2013. He showed a graph of the number of journal publications and citations attributable to CERES that indicated a continual increase in both, with a grand total of 709 peer-reviewed journal articles and 19,951 citations. Loeb also showed a schedule with key milestones needed to process and produce CERES Edition-4 products with software deliveries. Loeb discussed the future of CERES pertaining to FM6 and the recently named CERES-C, RBI.

Kory Priestley [LaRC] presented the *CERES FM1-FM6 Instrument Status Report* and described issues uncovered during FM6 ground calibration. Priestley discussed the CERES Instrument Working Group's efforts to resolve nonuniform scatter in the Solar Diffuser Mirror Attenuator Mosaic (MAM); lamp brightening of the Internal Calibration Module (ICM); and decreased response of the ICM reference detector photodiode.

Susan Thomas [Science Systems and Applications, Inc. (SSAI)] discussed the Suomi NPP/CERES FM5 instrument's data validation status, concluding that the instrument's characteristics are within the expected range after completing the first year of on-orbit measurements. Thomas also reported that the CERES FM5 SW measurements are higher than corresponding FM3 and FM1 measurements. She stated that for the CERES FM1-FM4 instrument intercomparison there is an ongoing investigation to correct Edition-3 daytime LW trends between Terra and Aqua measurements.

Wednesday, May 8

The second day of the meeting featured a series of presentations from invited guests, followed by several contributed science presentations from team members—see **Table 2** above.

Invited Science Presentations

This session featured five, 45-minute presentations from special invited guests, each of whom described aspects of their research relating to CERES.

Seiji Kato [LaRC] presented *Surface Radiation Budget from CERES and the A-Train*[3]. He presented comparisons of CERES-calculated surface irradiances with observed irradiances. Land surface albedo, surface emissivity, and aerosol radiative effect uncertainties were also addressed. Kato concluded that net atmospheric irradiance estimated by CERES is 109 ± 10 W/m^2, while sensible heat plus latent heat flux is approximately 94 W/m^2. Kato also expressed a need to investigate the difference between Northern and Southern Hemisphere midlatitude clouds over the oceans and the difference in cloud properties over land and oceans.

Carol Clayson [Woods Hole Oceanographic Institution (WHOI)] presented an overview of the *Surface Turbulent Heat Fluxes*. She expressed concern over the lack of *in situ*

[1] RBI is a planned follow-on instrument to CERES; JPSS is a joint effort between NASA and NOAA.

[2] NASA's Science Mission Directorate periodically conducts comparative reviews of missions and data analysis to maximize the scientific return for the cost of the science programs. The most recent "Senior Review" for Earth Science missions took place in March 2013.

[3] NASA and its international partners operate several Earth-observing satellites that closely follow one after another along the same orbital track—called the Afternoon Constellation (or A-Train), for short.

measurements of turbulent fluxes over both land and oceans. Clayson pointed out the known difficulties of capturing *in situ* measurement of turbulent fluxes, showing a movie of an instrument mounted on a ship's bow. Strategies for improving ocean and land turbulent-flux measurements were also presented.

Robert Adler [University of Maryland, College Park (UMCP)] presented *Mean Global Precipitation and Error Estimates: Global Precipitation Climate Project (GPCP), Tropical Rainfall Measurement Mission (TRMM), and CloudSat*. He provided results from a GPCP global precipitation analysis based on several satellite datasets and a gauge dataset. Adler also compared the GPCP data to a Tropical Rainfall Measuring Mission TRMM Composite Climatology (TCC) to verify surface rainfall rates. Comparisons between TCC and CloudSat were addressed to determine if there is significant "missed rain" in the tropics. Adler also suggested that careful analysis and improved retrievals are required to understand the global water and energy budget.

Wesley Berg [Colorado State University (CSU)] presented *Observational Challenges and Uncertainties in Estimating Global Precipitation from Satellites*. He showed evidence that large-scale changes in cloud properties assumed to be constant can have significant impacts on climate variability. Berg also presented several plots of TRMM rainfall measurements and contributions of light rain as well as measurements from the TRMM Microwave Imager and Precipitation Radar.

Tristan L'Ecuyer [University of Wisconsin-Madison (UW-Madison)] presented *Objective Closure of the Surface Energy Fluxes*, focusing on precipitation data from TRMM and CloudSat He discussed differences between his calculated energy budget with sensible heating, latent heating, and downwelling longwave radiation values versus those published by Trenberth[4] and Stephens[5]. L'Ecuyer also presented plots related to sensitivity studies. He concluded that the energy and water cycles can be objectively balanced at annual and continental scales within realistic error estimates.

Contributed Science Presentations

During this session, the team heard from two CERES co-investigators from LaRC as well as several university researchers. Table 2 summarizes these presentations with details available at the URL above.

Thursday, May 9

The final day of the meeting featured more contributed science presentations from university researchers as well as CERES co-investigators, addressing updates on new data products and science results. Two of these presentations are summarized herein; all are listed in **Table 3**.

Jason Cole [Canadian Centre for Climate Modeling and Analysis (CCCMA)] presented *One-dimensional (1D) and Three-dimensional (3D) Forward Radiative Transfer*

[4] Trenberth, Kevin E., John T. Fasullo, Jeffrey Kiehl, 2009: Earth's Global Energy Budget. *Bull. Amer. Meteor. Soc.*, **90**, 311–323—doi: http://dx.doi.org/10.1175/2008BAMS2634.1.

[5] Stephens, Graeme L., Juilin Li, Martin Wild, et al., 2012: An update on Earth's energy balance in light of the latest global observations. *Nature Geoscience* **5**, 691–696—doi:10.1038/ngeo1580.

Table 3: CERES Contributed Science Presentations from Thursday, May 9.

Speaker	Institution	Topic
S.-H. Ham	Oak Ridge Associated Universities	Examining Cloud 3D Effects on Shortwave Radiance and Irradiance Using A-Train Measurements
Jason Cole	CCCMA	1D and 3D Forward Radiative Transfer Models for the EarthCARE Mission
Joseph Corbett	SSAI	Improvements to the CERES Sea Ice ADMs
Weijie Wang	University of Virginia/SSAI	Hadley Circulation Variability Inferred from Longwave Cloud Radiative Effect
Gerald "Jerry" Potter	GSFC	Distributing Observations and Reanalysis Along with the CMIP5 Model Output: An Update on obs4MIPs and ana4MIPs
Paul Stackhouse	LaRC	FLASHFlux Update
David Doelling	LaRC	Development of the MTSAT-1R Visible Footprint Point Spread Function
Moguo Sun	SSAI	Validation of the TISA Edition-4 LW Narrowband to Broadband, ADM, and Regional Normalization Algorithm

Table 3: CERES Contributed Science Presentations from Thursday, May 9 (continued).

Speaker	Institution	Topic
Patrick Taylor	LaRC	Variability of Monthly Diurnal Cycle Composites of TOA Radiative Fluxes in the Tropics
Xiquan Dong	University of North Dakota	Validation of CERES Edition-4 MBL Cloud Properties over AZORES and DCS Clouds over SGP
Fu-Lung Chang	SSAI	Overlapping Cloud Retrieval Using VIIRS
Kris Bedka	SSAI	Extending the CERES Cloud Climate Record Using MODIS and AVHRR Data
Alok Shrestha	SSAI	Applying CERES Aqua ADMs to NOAA-9 Scanner Observations
Olivier Chomette	Laboratoire de Météorologie Dynamique	Unfiltered Radiances Comparisons Between CERES and ScaRaB
Hai-Tien Lee	UMCP	Assessment of HIRS OLR Intersatellite Calibration Error
John Kusterer	LaRC	ASDC Update
Norman Loeb	LaRC	Interannual Variations in Atmospheric Energy and Moisture Budgets

Models for the EarthCARE Mission, and explained EarthCARE. He also discussed the 1D and 3D radiative transfer models that will be implemented into the scene-construction algorithms—where 3D is important—and that the models should be tested with A-Train data.

Jerry Potter [NASA's Goddard Space Flight Center (GSFC)] presented *Providing Observations and Analysis for the Earth System Grid Federation: Update and Plans,* and examined how to bring as much observational scrutiny as possible to the Intergovernmental Panel on Climate Change process and how best to tap the wealth of Earth observations. Potter presented the Ultra-scale Visualization Climate Data Analysis Tool (UV-CDAT), which is customized to work with data from the Earth Science Grid Federation (ESGF). Potter presented a live demonstration of the tool, during which he compared EBAF Outgoing Longwave Radiation outputs with those from Modern-Era Retrospective Analysis for Research and Applications (MERRA) and Climate Systems Forecast Reanalysis (CSFR).

The next CERES Science Team meeting will be held October 29-31, 2013, at the Scripps Institution of Oceanography at the University of California, San Diego, CA. ■

GOFC–GOLD 2013 Fire Implementation Team Meeting

continued from page 46

- providing space agencies with requirements for and technical input on new fire-related missions; and
- funding for strengthening regional fire network activities, including organizing training programs, developing regional data validation activities, improving satellite data access, and establishing and developing cooperation with other regional networks.

The meeting was considered successful in bringing experts together to discuss the latest topics in satellite fire research. ■

First Meetings of the 2012-2017 Landsat Science Team

Thomas R. Loveland, U.S. Geological Survey, Earth Resources Observation and Science Center, loveland@usgs.gov
James R. Irons, NASA's Goddard Space Flight Center, james.r.irons@nasa.gov
Michael A. Wulder, Canadian Forest Service Pacific Forestry Centre, Natural Resources Canada, mwulder@nrcan.gc.ca

Introduction

In late 2012 the U.S. Geological Survey (USGS), in partnership with NASA, announced the membership of the Landsat Science Team (LST)—cochaired by **Tom Loveland** [USGS Earth Resources Observation Systems (EROS) Data Center] and **James "Jim" Irons** [NASA's Goddard Space Flight Center (GSFC)]. The team of scientists and engineers was selected through a competitive process to serve five-year terms—from 2012-2017—and to provide technical and scientific input to the USGS and NASA on issues critical to the success of the Landsat program. As recognized national and international leaders in land remote sensing, LST members will contribute to USGS and NASA scientific and technical strategies affecting Landsat users. Team members will play a key role in ensuring that the Landsat Data Continuity Mission (LDCM) is successfully integrated with past, present, and future remotely sensed missions for the purpose of observing national and global environmental systems. (The new LST is shown in the photo above.)

Landsat Science Team. **Image credit: Dave Hair** (USGS)

The team has met twice since their late-2012 selection[1]. The first meeting was held December 12-13, 2012, in Washington, DC, at the Stewart Udall Department of the Interior Building. The second meeting was held February 10-14, 2013, in Buellton, CA, in conjunction with the LDCM launch. This summary provides a brief overview of the key elements of the two meetings.

All presentation materials used during the December meeting are available at *landsat.usgs.gov/science_LST_December_12_13_2012.php*; those used during the February meeting can be viewed at *landsat.usgs.gov/science_LST_February_10_14_2013.php.*

[1] **Editor's Note**: Since the December meeting and part of the February meeting took place prior to LDCM's launch on February 11, the descriptions are written with future tense—i.e., anticipating the launch. However, all of the milestones mentioned were met on schedule and the mission became operational on May 30, 2013. It is now under USGS control and renamed Landsat 8.

December 12-13, 2013

The initial LST meeting focused on introducing the science and engineering expertise of each of the new LST members and shaping a team agenda for implementation over the next five years that contribute to LDCM utlization and to long-term Landsat mission objectives. Loveland and Irons, along with **Matt Larson** and **Sarah Ryker** [both from USGS[2]] outlined USGS and NASA priorities for the team; these included:

- quickly determining whether advances in LDCM technology and specification improve Landsat science and applications;
- developing Landsat-based geospatial environmental information products that represent land condition and change; and
- understanding the requirements of the diverse Landsat user community.

The team received technical updates on the status of all Landsat missions. **Kristi Kline** [EROS—*Landsat Project Manager*] reported that Landsat 5 had recently

[2] Larson and Ryker are respectively Associate Director and Deputy Associate Director for the USGS' Climate and Land Use Change Mission Area.

experienced a gyroscope failure and has no redundant stability. Because of the gyroscope issue, along with the November 2011 traveling-wave-tube-amplifier failure that forced the end of Thematic Mapper acquisitions, the USGS initiated the decommissioning process. Kline reported that Landsat 7 is collecting approximately 350 images per day. Finally, she summarized progress in repatriating historical international coverage scenes to the EROS Landsat archive. The Landsat global archive consolidation is underway and over 400,000 new scenes were added to the archive during 2012, further contributing to the now nearly four-million images available for download.

John Dwyer [EROS—*LDCM Ground System Scientist*] summarized plans to improve Landsat products, including enhancing the geometric qualities of Landsat archive products through use of LDCM Operational Land Imager (OLI) geometry and an improved digital elevation model. He also discussed plans for consistent Landsat archive and LDCM product specifications, which will be done by providing information to convert all Landsat data to top-of-atmosphere or radiance measurements.

Del Jenstrom [GSFC—*LDCM Deputy Project Manager*] and **Jim Irons** gave a detailed briefing on the status of LDCM development. They reported that the observatory—with its tests nearly complete—would soon be shipped from the Orbital Science Corporation facility in Gilbert, AZ, to Vandenberg Air Force Base, in Lompoc, CA. Jenstrom concluded by stating that everything was on-track for a successful February 2013 launch.

Garik Gutman [NASA Headquarters (HQ)—*Land-Cover and Land-Use Change Program Manager*] and **Jeff Masek** [GSFC—*Landsat Project Scientist*] briefly discussed the status of NASA activities related to Landsat and land-change science. **Gutman** provided a review of his program's research activities[3] and **Masek** focused on strengthening the relationship among NASA, the USGS, and European Space Agency (ESA) for collaboration between Landsat and Sentinel-2 missions, which would lead to improved temporal frequency of moderate-resolution imagery. To facilitate the technical aspects of the Sentinel-2 collaboration, NASA and ESA have initiated a sensor-intercomparison study.

The majority of the remainder of the December meeting involved presentations by each of the new members, in which they outlined their respective Landsat research plan. **Table 1** summarizes the researchers, their affiliations, and research foci.

[3] A full report on the most recent LCLUC Science Team Meeting appears on page 35 of this issue.

Table 1. Summary of LST members' research foci.

Researcher(s)	Affiliation(s)	Research Area
Richard Allen **Ayse Kilic** **Justin Huntington**	University of Idaho University of Nebraska Desert Research Institute	Developing and enhancing Landsat derived evapotranspiration and surface energy balance products
Martha Anderson **Feng Gao**	U.S. Department of Agriculture's (USDA's) Agricultural Research Service	Mapping vegetation phenology, water use, and drought at high-spatiotemporal resolution fusing multiband and multi-platform satellite imagery
Alan Belward	European Commission Joint Research Centre	Understanding the global land-use marketplace
Warren Cohen	USDA's Forest Service	Ecological applications of Landsat data in the context of U.S. Forest Service science and operational needs
Dennis Helder	South Dakota State University	Landsat data continuity: Advanced radiometric characterization and product development
Jim Hipple	USDA's Risk Management Agency	Integrating field-level biophysical metrics derived from Landsat science products into a National Agricultural Data Warehouse
Patrick Hostert	Humboldt University of Berlin	Synergies between future Landsat and European satellite missions for better understanding coupled human-environment systems

Table 1. Summary of LST members' research foci (continued).

Researcher(s)	Affiliation(s)	Research Area
David Johnson	USDA's National Agricultural Statistical Service	Operational monitoring of U.S. croplands with Landsat 8
Robert Kennedy	Boston University	Using time-series approaches to improve Landsat's characterization of land-surface dynamics
Leo Lymburner	Geoscience Australia	Multitemporal analysis of biophysical parameters derived from the Landsat series of satellites
Joel McCorkel	GSFC	Absolute radiometric and climate variable intercalibration of Earth-observing sensors
David Roy	South Dakota State University	Continuity of the Web Enabled Landsat Data (WELD) product record in the LDCM era
Crystal Schaaf	University of Massachusetts, Boston	North American land surface albedo and nearshore shallow bottom properties from Landsat and MODIS/VIIRS†
Ted Scambos	University of Colorado	Cryospheric applications of Landsat 8
John Schott	Rochester Institute of Technology	The use of LDCM for monitoring fresh and coastal water
Yongwei Sheng	University of California, Los Angeles	Developing decadal high-resolution global water products from LDCM and Landsat data
Eric Vermote **Chris Justice**	GSFC University of Maryland, College Park	Development of Landsat surface reflectance Climate Data Records
Jim Vogelmann	EROS	Ecological disturbance monitoring using Landsat time-series data
Curtis Woodcock	Boston University	Better use of the Landsat temporal domain: Monitoring land-cover type, condition, and change
Mike Wulder	Canadian Forest Service	Integrating the past, present, and future of Landsat
Randolph Wynne	Virginia Tech	Making multitemporal Landsat work

† MODIS stands for Moderate Resolution Imaging Spectroradiometer; VIIRS stands for Visible Infrared Imaging Radiometer Suite.

The last order of business was to select LST leaders and to identify priorities. **Curtis Woodcock** and **David Roy** were elected to serve as team coleaders. They will represent the ideas and consensus of the team and will work with the USGS (Loveland) and NASA (Irons) cochairs in organizing team activities. The team concluded the December meeting by identifying four priorities:

- evaluating new LDCM capabilities and identifying new science and applications opportunities;
- defining science and applications requirements for future Landsat satellites and working toward long-term observation continuity;
- identifying international land-imaging constellation opportunities; and
- establishing strategies and technical elements for Landsat land-condition and -change science products.

February 10-14, 2013: LDCM Launch

The LST convened in Buellton, CA, to promote Landsat science, participate in the LDCM launch events, finalize postlaunch data evaluation plans, and review and discuss current Landsat mission activities. Prior to the formal LST meeting, **Mike Wulder**, **Kass Green**, **Jim Irons**, and **Tom Loveland** participated in a prelaunch media

[*Left to right.*] **Jim Irons** [GSFC], **Tom Loveland** [USGS], **Kass Green** [Kass Green & Associates], and **Mike Wudder** [Canadian Forest Service] participate in a media briefing just prior to the launch of LDCM. **Image credit: Dave Hair** (USGS)

briefing (see photograph above); **Tony Morse**, **Rick Allen**, **Jim Vogelmann**, **Robert Kennedy**, **Yongwei Sheng**, and **Alan Belward** gave Landsat science presentations to guests attending launch.

The LST meeting began on February 10, 2013, with a high-level discussion about the upcoming launch and the scientific and societal importance of Landsat. **Anne Castle** [U.S. Department of the Interior (DOI)—*Assistant Secretary for Water and Science*] and **Lori Caramanian** [DOI—*Deputy Assistant Secretary for Water and Science*] emphasized the importance of Landsat in managing DOI lands and the need for communication between the LST and the DOI-sponsored Landsat Advisory Group.

Michael Freilich [NASA HQ—*Earth Science Division Director*] and **David Jarrett** [NASA HQ—*Landsat Program Executive*] emphasized Landsat's role in Earth-science research. They emphasized that launch day should be a celebration of the work of the many dedicated engineers; after launch, it is time for the scientists to get more involved. **Matt Larsen** and **Sarah Ryker** expressed optimism about the future of Landsat, the strength of the NASA-USGS Landsat partnership, and need to continue expanding Landsat science and applications.

Barbara Ryan [Intergovernmental Group on Earth Observations—*Secretariat Director*] discussed the impacts that the free data policy has had on improving Landsat's societal benefits. She received a warm welcome from the team and accolades for her leadership within USGS that led to the establishment of the Landsat free-data policy. Ryan encouraged the team to communicate the advances in terrestrial monitoring that have resulted from free Landsat data.

Jim Irons wrapped up the prelaunch session with his reflections on the nearly 14-year effort to develop and launch the next Landsat. Landsat 7 was launched in April 1999 and planning for LDCM started soon after that. However, a series of course changes extended the time between launches. Fortunately, due to the unprecedented durability of both Landsat 5 and 7, data continuity was not compromised. Irons concluded that everything was nominal for launch; the LST gave him a spontaneous standing ovation—in recognition of his tireless leadership and long-standing commitment to Landsat.

The team gathered early on February 11 at the launch viewing area in Lompoc, CA, to witness the flawless and successful LDCM launch. Afterward, team members met with launch guests and media representatives to discuss the importance of the Landsat mission.

A significant amount of what remained of the meeting was devoted to an in-depth review of LDCM capabilities and plans. **Del Jenstrom** provided positive updates on the status of LDCM. **Jim Irons** and **John Dwyer** laid out the postlaunch commissioning schedule that included the acquisition of the first Earth images in mid-March, an underflight with Landsat 7 in late March, ascent to the World Reference System-2 final orbit in early April, and imaging for checkout and calibration through mid-May. Operational status and transfer of ownership from the USGS to NASA is planned for late-May. Once LDCM is transferred to the USGS, the mission will be renamed Landsat 8.

In a joint technical session with the Landsat Calibration Validation Team, the LST members were given detailed technical reports on LDCM data quality and availability plans. **Gene Fosnight** [EROS—*Landsat Data*

Acquisition Manager] summarized plans for using the Long Term Acquisition Plan (LTAP) to ensure the collection of seasonal coverage over Earth's landmass. The LDCM LTAP uses vegetation phenology, cloud-avoidance predictions, and cloud climatology, along with focused collections for missed imaging opportunities and thematic campaigns (e.g., agriculture, coral reefs, volcanoes, glaciers) to determine the daily imaging plans. Fosnight acknowledged that the free-data policy has changed user requirements and that there is now greater demand for images for cloudy regions (e.g., high latitudes, tropics). With LDCM's greater daily acquisition capacity (at least 400 scenes per day, compared to Landsat 7's design requirement of 250 scenes per day) the ability to meet science needs will be much improved. Fosnight concluded by asking for suggestions for ways to increase the science relevance of LDCM acquisition plans.

Phil Dabney [GSFC—*LDCM Instrument Scientist*], **Brian Markham** [GSFC—*LDCM Calibration Scientist*], **Jim Storey** [USGS/Stinger Ghaffarian Technologies, Inc.—*LDCM Geospatial Imaging Scientist*], and others provided in-depth reviews of LDCM measurement radiometry and geometry. Dabney laid out the OLI[4] requirements and discussed the generational change in Landsat imaging technology.

Specifically, OLI is a pushbroom sensor with an unobscured telescope, and has 12-bit radiometric resolution across the visible/short-wave infrared (VIS/SWIR) spectrum. OLI was designed to:

- collect 400 scenes per day;
- collect images coincident with the Thermal Infrared Sensor (TIRS);
- cover a 185-km (115-mi)-wide swath with resolution of 30 m (98 ft) (VIS/SWIR) and 15 m (49 ft) (panchromatic); and
- collect data for nine VIS/SWIR spectral bands, with seven bands that provide continuity with the Enhanced Thematic Mapper plus (ETM+) and two additional bands (the ultrablue *coastal* band covering 0.43–0.45 µm, and the *cirrus* band, covering 1.360–1.390 µm.

OLI has robust calibration capabilities that include internal calibration lamps, shutter collections, lunar views, and validation using vicarious field campaigns.

TIRS is a two-channel thermal imager providing data continuity for the Landsat thermal band. The pushbroom imager developed by GSFC operates in concert with, but independently of, OLI, and is based on quantum well infrared photodetector technology. TIRS collects data for two long-wave spectral bands (between 10.30 and 11.30, and 11.50 and 12.50 µm, respectively) that span the spectral range previously serviced by a single TM/ETM+ thermal band, images at 100 m (~328 ft) spatial resolution, and includes calibration-data collection. **Dennis Reuter** [GSFC—*TIRS Instrument Scientist*] reported that based on prelaunch testing, TIRS performance remained constant through environmental testing. Further, most performance parameters meet or exceed requirements[5].

Brian Markham gave a detailed review of LDCM-versus-Landsat 7 spectral-band performance. The pushbroom instrument design and OLI's onboard calibration capabilities result in OLI and TIRS data improvements over Landsat 7 ETM+ results. Radiometric precision is improved due to reductions in analog system noise, 12-bit data quantization, and reduced radiance saturation. For example, the OLI signal-to-noise ratios are between 8 and 10 times better than ETM+ performance. Overall improvement in radiometric consistency is expected due to extensive onboard calibration based on shutter design, solar diffusers, and stimulation lamps.

Jim Storey gave an overview of LDCM geometry and emphasized the role that changes in imaging technology have had on image geometry. He expects improved geometric stability due to lack of a moving scan mirror and associated jitter, as well as better geolocation accuracy because of the spacecraft's use of Global Positioning System (GPS) navigation and modern star trackers. However, Storey pointed out that there are LDCM image geometry challenges resulting from the pushbroom design. Storey concluded that since OLI/TIRS Level-1T products use Global Land Survey control, users should not experience significant differences when comparing LDCM with Landsat archive products.

Brian Markham wrapped up the session on LDCM data characteristics with a summary of LDCM calibration/validation team plans to evaluate actual OLI and TIRS science data once imaging commences in mid-March. The team will address detector-to-detector relative calibration, absolute calibration, and response nonlinearity, as well as a range of issues having to do with instrument operability, noise, and uniformity.

Kristi Kline gave a short Landsat update. The number of daily Landsat 7 acquisitions has been increased, with more than 370 images per day now being collected (a notable improvement over the Landsat 7 design requirement of 250 scenes per day). She also reported that more than 1.5 million international images, across all Landsat missions, have now been transferred to EROS because of the Landsat Global Archive Consolidation

[4] OLI was built by Ball Aerospace and Technology Corporation

[5] For more details on Landsat 8 and its instruments see *LDCM: Continuing the Landsat Legacy* in the March-April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 4-9].

initiative. Looking ahead, Kline said the USGS Landsat project would continue to add international images to the archive. She also noted that changes to the current suite of Landsat products are anticipated to ensure consistency with LDCM data, including activities related to improvement of geometric and radiometric accuracy, addition of a data quality band, and testing of new cloud assessment approaches.

Steve Covington [Aerospace Corporation—*Landsat Flight Systems Manager*] reported on the decommissioning status and process for Landsat 5. The process has begun to lower Landsat 5 from its 705-km (438-mi) orbit and begin the passivation of spacecraft systems. Once the Landsat 5 fuel supply is exhausted, chemical, electrical, and kinetic systems will be disabled and the decommissioning of the Landsat 5 mission operations center will take place (estimated to occur in summer 2013). A final Landsat 5 footnote: During the meeting, NASA and USGS were informed by Guinness World Records that Landsat 5 set the record for "longest operating Earth-observation satellite."

Bianca Hoersch [ESA—*Sentinel-2 Mission Manager*] discussed the status of the ESA Sentinel-2 mission. Sentinel-2 is a Landsat-class multispectral imaging mission with 13 spectral bands at 10-, 20-, and 60-m (~33-, 66-, and 197-ft) resolution. Two identical Sentinel-2 missions are planned; the first is scheduled for launch in mid-2014. When both Sentinel-2 spacecraft are in orbit, the revisit rate will be five days at the Equator. Hoersch discussed areas of collaboration between Sentinel-2 and LDCM, which include joint calibration and validation activities (common test sites and field campaigns), cross-mission image top-of-atmosphere radiance comparisons, workshops comparing science results, and using common elevation and ground control points for image registration.

Kass Green [Kass Green & Associates—*President*] is the liaison between the LST and the DOI-sponsored National Geospatial Advisory Committee's (NGAC) Landsat Advisory Group (LAG); she gave a report on LAG activities. The LAG is a subcommittee of the NGAC, and provides advice on requirements, objectives, and actions of the Landsat Program of relevance to continued delivery of societal benefits for the nation and the global Earth-observation community. Green described two LAG reports, the first of which addressed the impacts of charging for Landsat data. It concluded that a return to the data charging policy would severely restrict data use, stifle innovation, inhibit scientific analysis, and negatively impact international relations and U.S. space leadership[6]. The second report evaluated the annual savings associated with the use of Landsat for ten operational Federal applications; it concluded that at least $183 million per year is saved through Landsat use[7].

Holli Riebeck [GSFC—*Education and Outreach Specialist*] and her team reviewed their Landsat outreach activities, including efforts to improve Landsat and LDCM visibility, and a new *Adopt a Pixel* activity. The new project involves *citizen scientists* who adopt a place on the map and, every week or two go to that location and take georeferenced pictures in each cardinal direction, as well as up and down. The photos are uploaded (*www.flickr.com/groups/landsat-adopt-a-pixel/*) to a website and Landsat analysts can use the photos for their studies. At the end of the presentation, the members of the LST congratulated the NASA Education and Public Outreach Team for their outstanding efforts during LDCM launch events.

Finally, LST members gave short research summaries, emphasizing how they plan to use LDCM imagery. As part of the status summaries, each principal investigator also identified synergies with other team members. The team also had an in-depth discussion on how to approach individual and shared priority topics. Most of the discussion addressed LST input to Landsat 9 planning. The team concluded that requirements definition was crucial and an activity where LST experience could help clarify future Landsat capabilities. Next steps for the team include analysis of capabilities needed for key land remote sensing applications, assessment of the science supported by Landsat, and evaluation of Landsat roles in national and international commitments and treaties. The LST is especially focused on stressing the importance of Landsat continuity. While the discussed needs for continuity were diverse, the key elements were the critical science considerations related to continuation of long-term global land change investigations and ensuring the forward-going confidence of commercial and government users in the availability of Landsat for value-added applications, monitoring, and reporting needs.

The next LST meeting will be held October 29-31, 2013, tentatively in Sioux Falls, SD, at EROS. ■

[6] To view the report, visit: *www.fgdc.gov/ngac/meetings/september-2012/ngac-landsat-cost-recovery-paper-FINAL.pdf.*

[7] To view the report , visit: *www.fgdc.gov/ngac/meetings/september-2012/ngac-landsat-economic-value-paper-FINAL.pdf.*

Warm Ocean Causing Most Antarctic Ice Shelf Mass Loss

Whitney Clavin, NASA/Jet Propulsion Laboratory, whitney.clavin@jpl.nasa.gov
J.D. Harrington, NASA Headquarters, j.d.harrington@nasa.gov
Maria-José Viñas Garcia, NASA's Goddard Space Flight Center, maria-jose.vinasgarcia@nasa.gov

EDITORS 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.

Ocean waters melting the undersides of Antarctic ice shelves are responsible for most of the continent's ice-shelf mass loss, a new study by NASA and university researchers has found. Scientists have studied the rates of *basal melt*, or the melting of the ice shelves from underneath, of individual *ice shelves*—the floating extensions of glaciers that empty into the sea—but this is the first comprehensive survey of all Antarctic ice shelves. The study found basal melt accounted for 55% of all Antarctic ice-shelf mass loss from 2003 to 2008, an amount much higher than previously thought.

Antarctica holds about 60% of the planet's fresh water locked into its massive ice sheet. Ice shelves buttress the glaciers behind them, modulating the speed at which these rivers of ice flow into the ocean. Determining how ice shelves melt will help scientists improve projections of how the Antarctic ice sheet will respond to a warming ocean and contribute to sea-level rise. It also will improve global models of ocean circulation by providing a better estimate of the amount of fresh water ice-shelf melting adds to Antarctic coastal waters.

The study uses reconstructions of ice accumulation, satellite and aircraft readings of ice thickness, and changes in elevation and ice velocity to determine how fast ice shelves melt and compare the mass loss with the amount released by the *calving*, or splitting, of icebergs. "The traditional view on Antarctic mass loss is that it is almost entirely controlled by iceberg calving," said **Eric Rignot** [UC, Irvine/NASA/Jet Propulsion Laboratory (JPL)]. Rignot is lead author of the study published in the June 14, 2013 issue of the journal *Science*. "Our study shows melting from below by the ocean waters is larger, and this should change our perspective on the evolution of the ice sheet in a warming climate."

Ice shelves grow through a combination of land ice flowing to the sea and snow accumulating on their surface. To determine how much ice and snowfall enters a specific ice shelf and how much makes it to an iceberg, where it may split off, the research team used a regional climate model for snow accumulation and combined the results with ice velocity data from satellites, ice shelf thickness measurements from NASA's Operation IceBridge—a continuing aerial survey of Earth's poles—and a new map of Antarctica's bedrock. Using this information, Rignot and colleagues were able to deduce whether the ice shelf was losing mass through basal melting or gaining it through the basal freezing of seawater.

In some places, basal melt exceeds iceberg calving. In other places, the opposite is true. But in total, Antarctic ice shelves lost 2,921 trillion pounds (1,325 trillion kilograms) of ice per year from 2003 to 2008 through basal melt, while iceberg formation accounted for 2,400 trillion lbs (1,089 trillion kg) of mass loss each year.

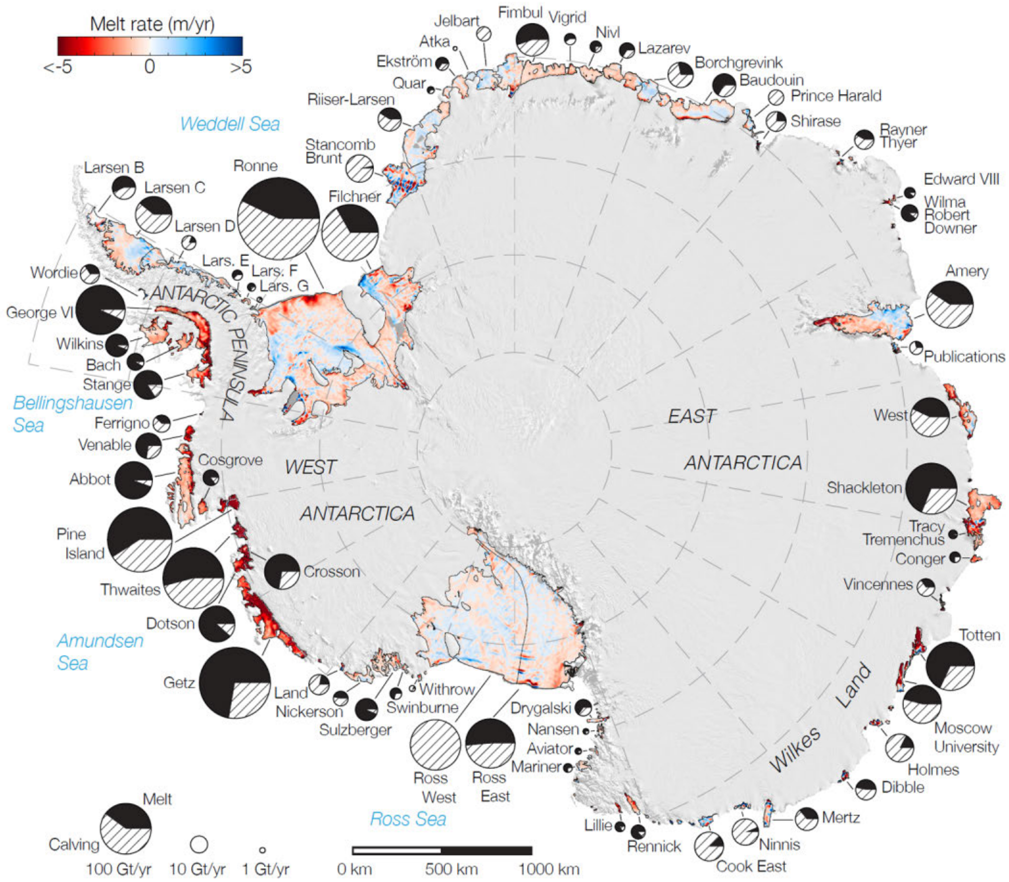
Basal melt can have a greater impact on ocean circulation than glacier calving. Icebergs slowly release melt water as they drift away from the continent. But strong melting near deep grounding lines, where glaciers lose their grip on the seafloor and start floating as ice shelves, discharges large quantities of fresher, lighter water near the Antarctic coastline. This lower-density water does not mix and sink as readily as colder, saltier water, and may be changing the rate of bottom water renewal.

"Changes in basal melting are helping to change the properties of Antarctic bottom water, which is one component of the ocean's overturning circulation," said author and oceanographer **Stan Jacobs** [Columbia University, Lamont-Doherty Earth Observatory]. "In some areas it also impacts ecosystems by driving coastal upwelling, which brings up micronutrients like iron that fuel persistent plankton blooms in the summer."

The study found basal melting is distributed unevenly around the continent. The three giant ice shelves of Ross, Filchner, and Ronne, which make up two-thirds of the total Antarctic ice-shelf area, accounted for only 15% of basal melting. Meanwhile, fewer than a dozen small ice shelves floating on "warm" waters (seawater only a few degrees above the freezing point) produced half of the total melt water during the same period. The scientists detected a similar high rate of basal melting under six small ice shelves along East Antarctica, a region not as well known because of a scarcity of measurements.

The researchers also compared the rates at which the ice shelves are shedding ice to the speed at which the continent itself is losing mass and found that, on average, ice shelves lost mass twice as fast as the Antarctic ice sheet did during the study period.

"Ice shelf melt doesn't necessarily mean an ice shelf is decaying; it can be compensated by the ice flow from the continent," Rignot said. "But in a number of places around Antarctica, ice shelves are melting too fast, and a consequence of that is glaciers and the entire continent are changing as well."



This image shows rates of basal melt of Antarctic ice shelves overlaid on a 2009 mosaic of Antarctica created with data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard NASA's Terra and Aqua spacecraft. Red shades denote melt rates of less than 5 m (~16.4 ft) per year (freezing conditions), while blue shades represent melt rates of greater than 5 m (~16.4 ft) per year (melting conditions). Thin black lines show the perimeters of the ice shelves in 2007-2008, excluding ice rises and ice islands. Each circular graph is proportional in area to the total ice mass loss measured from each ice shelf, in Gt /year, with the proportion of ice lost due to the calving of icebergs denoted by hatched lines and the proportion due to basal melting denoted in black. **Image credit:** NASA/JPL/UC, Irvine/Columbia University

Climate Conditions Determine Amazon Fire Risk

Kathryn Hansen, NASA's Earth Science News Team, kathryn.h.hansen@nasa.gov

EDITORS 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.

Using an innovative satellite technique, NASA scientists have determined that a previously unmapped type of wildfire in the Amazon rainforest is responsible for destroying several times more forest than has been lost through deforestation in recent years.

In the southern Amazon rainforest, fires below the forest treetops, or *understory fires*, have been hidden from view from NASA satellites that detect actively burning fires. The new method has now led to the first regional estimate of understory fire damages across the southern Amazon. "Amazon forests are quite vulnerable to fire, given the frequency of ignitions for deforestation and land management at the forest frontier, but we've never known the regional extent or frequency of these understory fires," said the study's lead author **Doug Morton** [NASA's Goddard Space Flight Center (GSFC)]. The study was published April 22, 2013, in *Philosophical Transactions of the Royal Society B*.

In years with the highest understory fire activity, such as 2005, 2007, and 2010, the area of forest affected by understory fires was several times greater than the area of deforestation for expansion of agriculture, according to Morton. The study goes further and fingers climate conditions—not deforestation—as the most important factor in determining fire risk in the Amazon at a regional scale.

Uncovering the Story Behind Understory Fires

Fires in the Amazon's savanna areas can burn quickly, spreading up to 330 ft (100 m) per minute. Grasses and shrubs in these ecosystems typically survive low-intensity surface fires. In contrast, understory fires at the frontier and beyond appear "unremarkable when you see them burning," Morton said. Flames reach on average only a few feet high, visible from the air as ribbons of smoke that escape through the canopy. They may burn for weeks at a time, spreading only a few feet (~0.5 m) per minute.

Understory fires, however, can damage large areas because Amazon trees are not adapted to fire. The long, slow burn gives way to a creeping death that claims anywhere from 10 to 50% of the burn area's trees. Recovery is also a long and slow, but observable, process.

To identify understory fires, Morton and colleagues used observations from early in the dry season, from June to August, collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra satellite. They tracked the timing of fire damage and recovery, which varies depending on the type of forest disturbance. Areas of deforestation, for example, show up in satellite imagery as land that continues to lack signs of recovery for at least two consecutive years. Conversely, signs of forest degradation from understory fires, visible in the year after the burn, dissipate quickly as the forest regrows. This pattern of damage and recovery over multiple years provides a unique fingerprint of understory fire damages in Amazon forests.

The study shows that between 1999 and 2010, understory forest fires burned more than 33,000 mi^3 (85,500 km^3), or 2.8% of the study area in the southern Amazon forest. Results also show no correlation between understory fires and deforestation. As the pressure for clearing led to the highest deforestation rates ever seen from 2003 to 2004, adjacent forests had some of the lowest rates of fires. "You would think that deforestation activity would significantly increase the risk of fires in the adjacent forested area because deforestation fires are massive, towering infernos," Morton said. "You make a bonfire that is a square kilometer (~0.4 mi^2) in size, throwing ash and live cinders and preheating the adjacent forest. Why didn't we have more understory fires in 2003 and 2004, when deforestation rates were so high?"

The researchers point to climate as the reason that fire-driven deforestation didn't burn more surrounding forests in these years. Frequent understory fire activity coincides with low nighttime humidity, as measured by the Atmospheric Infrared Sounder (AIRS) onboard NASA's Aqua satellite. Scientists say the connection points to a strong climate control on Amazon fires. "You can look within an indigenous reserve where there is no deforestation and see enormous understory fires," Morton said. "The human presence at the deforestation frontier leads to a risk of forest fires when climate conditions are suitable for burning, with or without deforestation activity." Ignition could come from cooking, camping, cigarettes, cars, agricultural waste burning, or any number of human sources.

The new knowledge about the scope of understory fires could have implications for estimates of carbon emissions from disturbed forests. How experts account for those emissions depends on the fate of the forest—e.g., how it is disturbed and how it recovers. "We don't yet have a robust estimate of what the net carbon emissions are from understory fires, but widespread damages suggest that they are important source of emissions that we need to consider," Morton said. For now, scientists are looking into the climate mechanisms that, given an ignition source from humans, predispose the southern Amazon to burn.

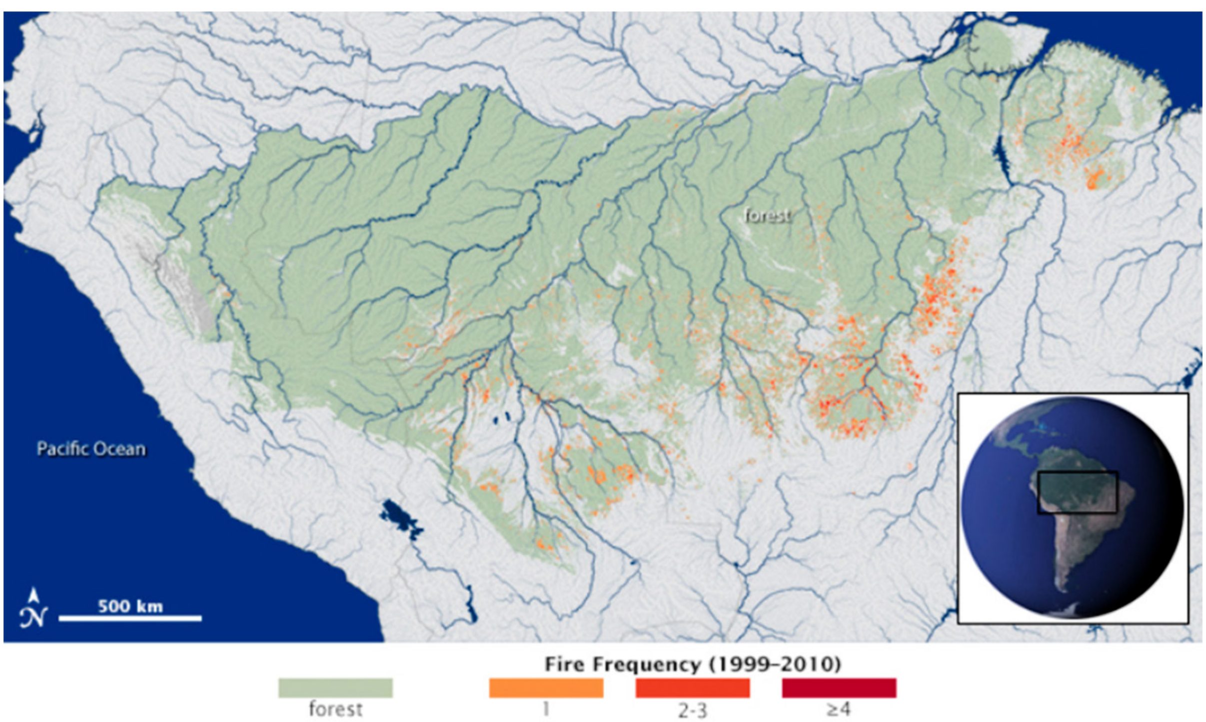
Soil Moisture as a Fire Indicator

Already, scientists at the University of California (UC), Irvine, have delved deeper into the climate–fire connection. New research shows that satellite-based measurements of the region's soil moisture could supplement and sharpen fire season forecasts across the southern Amazon. The first forecast in 2012 and new forecast for 2013, led by **Jim Randerson** [UC, Irvine], are based on a model that primarily considers historical fire data from MODIS instruments along with sea surface temperature data from the National Oceanic and Atmospheric Administration. Previous research has shown sea surface temperature to be a good indicator of the pending Amazon fire season severity.

Now, scientists are interested in fine-tuning the model across smaller geographic regions and finer timescales. Toward that goal, **Yang Chen** [UC, Irvine] and colleagues show that water storage estimates from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites allow monitoring of the evolution of dry conditions during the fire season. Transpiration and evaporation are two ways that water is transported from the ground to the atmosphere. Low water storage in the soil leads to a drier near-ground atmosphere. The result is drier, more flammable vegetation alongside increases in plant litter and fuel availability. Chen's research was published online, April 11, 2013, in *Biogeosciences*. "A severe fire season in the Amazon is often preceded by low water storage in the soil, and this water deficit in the soil can be detected by the satellites several months before the fire season," Chen said.

Soil water storage in the southern Amazon in June is a key indicator of fire season severity. "The GRACE measurements provide unique and precise information about land water storage that changes completely the way we can look at fire prediction," said **Isabella Velicogna** [UC, Irvine/NASA/Jet Propulsion Laboratory], who led the GRACE analysis.

While the water storage estimates are not yet officially part of Randerson and colleagues' forecasts, the study "charts the course forward to leverage GRACE data for operational purposes," Morton said. "The ability to integrate observations from many different NASA instruments is really a hallmark of Earth-system science. In this case, the science also has important, practical applications to mitigating the impacts of fires on the Amazon region and global climate." ■



For the first time, researchers have mapped the extent and frequency of understory fires across a study area (green) spanning 1,200,000 million mi^3 (3,000,000 million km^3) in the southern Amazon forest. Fires were widespread across the forest frontier during the study period from 1999 to 2010. Recurrent fires, however, are concentrated in areas favored by the confluence of climate conditions suitable for burning and ignition sources from humans. **Image credit:** NASA's Earth Observatory

NASA Earth Science in the News

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

Airborne laboratory being used to measure California's snowpack, May 2; *Los Angeles Times*. Starting in early April, researchers began weekly flights over the upper Tuolumne River basin in California, taking sophisticated instrument readings of snow depth and reflected sunlight. This information, coupled with data from ground measurements, promises to paint the most comprehensive snowpack picture that water managers have ever had. "This is the first time that we've actually known how much water there is," said **Tom Painter** [NASA/Jet Propulsion Laboratory (JPL)], a scientist in La Cañada Flintridge, CA, who is overseeing the aerial project with the California Department of Water Resources. The snowpack from West Mountain forms a crucial natural reservoir, melting into runoff that rules dam operations and water allocations from California to the Rocky Mountains.

Rain will get more extreme, thanks to global warming, says NASA study, May 4; *theverge.com*. The forecast for the future of rainfall on Earth is in: *Over the next hundred years, areas that receive lots of precipitation right now are only going to get wetter, and dry areas will go for longer periods without seeing a drop*—according to a new NASA-led study on global warming. "We looked at rainfall of different types," said **William Lau** [NASA's Goddard Space Flight Center (GSFC)], the lead author of the study, in a phone interview with *The Verge*. "The extreme heavy rain and the prolonged drought both increase drastically and are also connected physically." The NASA rainfall study, which is due to be published in an upcoming edition of the *Geophysical Research Letters* journal, examined data from 14 different leading global climate models. Although each one previously predicted rainfall increases in rain-prone areas such as the tropics, and droughts in drier regions, including the American Southwest, the study by Lau and his colleagues is said to be the first to look at rainfall from a global perspective, including over unpopulated areas like the middle of the oceans. "The new part is looking at the entire global rainfall system from a basic science perspective, and what we're finding is amazing," Lau said.

Landsat satellite images of climate change, via *Google Earth Engine*, May 9; *time.com*. For decades the Landsat Program—a partnership between NASA and the U.S. Geological Survey—has collected millions of images of Earth's surface that have been riffled through and stitched together to create a high-definition slide show of our rapidly changing Earth. TIME is proud to host the public unveiling of these images from orbit, which date back to 1984. To view the time-lapse video, visit: *world.time.com/timelapse*.

GROVER the NASA rover takes on Greenland ice sheet, May 14; *newscientist.com*. Like its cousin *Curiosity* currently busy exploring Mars, this rover is exploring a cold and inhospitable land. The Goddard Remotely Operated Vehicle for Exploration and Research (GROVER) is trundling across Greenland to measure changes in the ice sheet with ground-penetrating radar. This should help researchers to better understand the effects of climate change. GROVER is a much cheaper data-gathering option than aircraft or satellite monitoring. Also, as it is fully solar-powered, its impact on the polar environment is minimal. High, V-shaped solar panels let the rover harvest energy both directly from the Sun and also from sunlight bounced off the ice. The idea was developed at student-engineering boot camps, led by Mike Comberiate [GSFC, retired], at GSFC in 2010 and 2011 and further developed with science adviser **Lora Koenig** [GSFC] and students and professors at Boise State University, in Idaho.

Melting glaciers cause one-third of sea-level rise, May 16; *Discovery News*. New research has revealed that the world's glaciers lost 260 gigatons of water each year between 2003 and 2009, making these rivers of ice responsible for almost a third of sea-level rise during that period. The study, published in the journal *Science,* used data from the Gravity Recovery and Climate Experiment (GRACE) and Ice, Cloud, and land Elevation Satellite (ICESat) in addition to ground measurements to pin down estimates of how much ice is lost from glaciers. The results suggest that on-the-ground measurements yield estimates that are too extreme, but some satellite methods do not go far enough. "There was a large amount of uncertainty in how much these glaciers were contributing to sea-level rise prior to this study," lead researcher **Alex Gardner** [Clark University—*geography professor*], told LiveScience. "What our study provides is a really strong estimate for what the glacial contribution was over this time."

Is more global warming hiding in the oceans?, May 31; *livescience.com.* According to a new study, U.S. and Australian researchers including **Josh Willis** [JPL] have combined the historical results from the HMS *Challenger* with modern-era climate-science models—and have generated some surprising results. The study found that we may be significantly underestimating global warming's impact and heat content in the oceans; and that sea-level rise from global warming seems to be split 40/60—i.e., 40% comes from expansion of sea water caused by warming, and the remaining 60% comes from melting ice sheets and glaciers.

Antarctic's mountains revealed by sharpest map yet, June 5; *nationalgeographic.com*. Buried under miles of ice, Antarctica's mysterious mountain ranges are coming into sharper focus thanks to a new map. Created by the British Antarctic Survey, Bedmap2 drew upon millions of new measurements of the frozen continent's surface elevation, ice thickness, and bedrock topography using data from a wide variety of sources collected over several decades. According to **Charles Webb** [NASA Headquarters—*Deputy Program Scientist for Cryospheric Sciences*] new technological advances allow Bedmap2 to be higher in resolution, more precise, and cover more of the continent than the original Bedmap—produced more than ten years ago. For example, Webb noted that the original Bedmap relied mostly on ground-based measurements, which limited the scientists in terms of how much land they could cover. But a NASA program called Operation IceBridge sends out airplanes that fly over the entire continent. The airplanes are equipped with lasers that measure the surface mountains' heights and other features, as well as ice-penetrating radar that maps subglacial bedrock—"…giving [scientists] a more three-dimensional picture of the ice sheet itself," Webb said.

Severe risk of fire in Amazon forests forecast for summer, fall, June 7; *upi.com*. Researchers using a combination of satellite data and ocean-temperature measurements are predicting a severe 2013 fire season for many Amazon forests. Led by **Jim Randerson** [University of California, Irvine], the research team has analyzed historical fire data from NASA's Terra satellite along with sea-surface temperature data from the National Oceanographic and Atmospheric Administration (NOAA) to forecast the pending Amazon fire season severity three-to-six months prior to the onset of the dry season. According to the researchers, as of March surface waters of the tropical North Atlantic Ocean remained warmer than average, while Pacific Ocean temperatures declined from a peak in late fall. These conditions are consistent with increased fire risk across the southern portion of the Amazon later this summer and into early fall. The Brazilian states of Mato Grosso, Para, Rondonia, and Acre, and the Bolivian departments of Santa Cruz and Pando are projected to have average or above-average fire activity in 2013. "The confluence of climate change and people in these areas increases the risk of widespread fire activity when the fire season severity is elevated," research team member **Doug Morton** [GSFC] said. "With this forecasting system we're hoping to build some advanced warning about whether the Amazon region is facing a fire year or a flood year," Morton said. "This year, plan for fires."

NASA checks tundra for greenhouse gases, June 11; *livescience.com*. Tons of carbon and methane lie under the Arctic tundra, trapped in ice. The frozen ground, called *permafrost*, covers nearly a quarter of the Northern Hemisphere. Global warming is thawing patches of permafrost, releasing carbon dioxide and methane—both greenhouse gases—into the atmosphere. An airborne NASA mission called the Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE*) is tracking the gas emissions to better estimate their impact on climate change. "Permafrost soils are warming even faster than Arctic air temperatures, as much as 2.7 to 4.5° F [1.5 to 2.5° C] in just the past 30 years," said research scientist **Charles Miller** [JPL—*CARVE Principal Investigator*]. "As heat from Earth's surface penetrates into permafrost, it threatens to mobilize these organic carbon reservoirs and release them into the atmosphere as carbon dioxide and methane, upsetting the Arctic's carbon balance and greatly exacerbating global warming," said Miller.

****Study upends theory of how Arctic ice shelves lose mass,** June 14; *cbsnews.com*. Warm ocean water is causing the Antarctic ice shelves to melt from the bottom up, a new study says—contradicting the previously accepted notion that the shelves lose the most mass due to iceberg break-off. In the study from University of California, Irvine (UCI), in conjunction with NASA, researchers said that this bottom-up melting accounted for 55% of all Antarctic ice-shelf mass loss from 2003 to 2008, which is a much higher amount than previously predicted. This type of melting is called *basal melt*. Previously, scientists had looked at basal melting from each individual ice shelf, but in this study researchers looked at the melting caused by warm ocean water as a comprehensive survey of all Antarctic ice shelves. "The traditional view on Antarctic mass loss is [that] it is almost entirely controlled by iceberg calving," **Eric Rignot** [JPL/UCI] said in a statement. "Our study shows melting from below by the ocean waters is larger, and this should change our perspective on the evolution of the ice sheet in a warming climate."

* CARVE is discussed in more detail in the feature article on page 19 of this issue.

** See news story in this issue.

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

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

New Featured Resource Collections on NASA Wavelength

NASA Wavelength's new, featured resource collections are all about summer fun! Stop by *nasawavelength.org* and check out the new collections that feature graphic novels, planetarium shows, games, and visualizations. All resources are peer-reviewed by a team of educators and scientists, and filled with information on NASA science activities.

And, remember to keep in touch with the latest teacher activities, professional development opportunities, and fresh, new, educational products by following NASA Wavelength on Twitter *@NASAWavelength* and on Facebook at *www.facebook.com/NASAWavelength*.

FameLab: Exploring Earth and Beyond—Online Competition

Exploring Earth and Beyond is a science communications competition that allows early-career scientists from various disciplines the opportunity to show off their skills. Each contestant has three minutes to convey their research activities without the aid of slides and charts, although hand-held props are acceptable. A panel of experts in both science and science communication will do the judging. Participants are now welcome to submit a video of their presentation online via *YouTube*. Winners will face off at *National Geographic* headquarters in Washington, DC, in April 2014 for a chance to win the grand prize and the opportunity to compete at the FameLab International Finale in the United Kingdom, June 2014. For more information, a complete list of rules and eligibility requirements, and to register, visit: *1.usa.gov/T5Z3oc*.

2014 GLOBE Calendar Art Competition

Entry Deadline: September 30

The GLOBE Program is sponsoring an international art competition to encourage students to highlight and document GLOBE communities around the world. Through a variety of media, GLOBE students will show how their local environment is unique, and how participating in GLOBE has helped them appreciate their surroundings. Winning entries will be featured in the 2014 GLOBE calendar. For more information, visit: *1.usa.gov/14xmpFG*.

Carbon Connections: Online High School Curriculum on Carbon Cycle and Climate

Carbon Connections is a three-unit online curriculum for grades 9-12, designed to improve students' understanding of the carbon cycle and the science of Earth's climate. Each of the three units includes five lessons, which include focus questions, hands-on activities, virtual field trips, videos, and interactive models. The concepts span many science disciplines, and follow carbon in past, present, and future contexts. A dedicated teacher page that hosts a rich array of downloadable resources can be found at *bit.ly/rNDglQ*.

Here, There, and Everywhere Exhibition

Through August 2015; multiple locations.

Here, There, and Everywhere (HTE) is a NASA-funded program that consists of a series of exhibitions, posters, and supporting hands-on activities that use analogies in teaching science, technology, engineering, and mathematics (STEM) to provide multigenerational and family-friendly content in English and Spanish for community centers, libraries, schools, and under-resourced or small science centers. The purpose of the program is to connect crosscutting content in Earth, planetary sciences, and astrophysics with everyday phenomena. These connections will show that what happens in our daily lives also happens on a larger scale across the Universe. The HTE program utilizes multimodal content delivery (e.g., physical exhibits, handouts, interpretive stations, facilitated activities for educators, and online materials), hosted by participating locations for informal science learning. For more information, and to see if HTE is coming to a location near you, visit: *bit.ly/YThbPX*.

EOS Science Calendar

October 7, 2013
Ocean Surface Topography Science Team (OSTST) Meeting and 7th Coastal Altimetry Workshop (CAW-7), Boulder, CO. *www.joss.ucar.edu/meetings/ostst-caw-oct13*

October 15–17, 2013
HyspIRI Science and Applications Workshop, Pasadena, CA. *hyspiri.jpl.nasa.gov/events/2013-hyspiri-science-and-application-workshop*

October 15–18, 2013
NASA Sounder Science Team Meeting, Greenbelt, MD. *airs.jpl.nasa.gov/meetings/science-team-greenbelt*

October 23–25, 2013
GRACE Science Team Meeting, Austin, TX.
www.csr.utexas.edu/grace/GSTM

October 29–31, 2013
CERES Science Team Meeting, San Diego, CA.
ceres.larc.nasa.gov/ceres_meetings.php

October 29–31, 2013
Landsat Science Team Meeting, Sioux Falls, SD.
landsat.usgs.gov

November 5–7, 2013
SMAP Cal/Val Workshop, Oxnard, CA.
smap.jpl.nasa.gov/science/workshops

January 28–31, 2014
SORCE Science Team Meeting, Cocoa Beach, FL
lasp.colorado.edu/home/sorce/news-events/meetings/2014-sorce-science-meeting

February 2–6, 2014
American Meteorological Society Meeting, Atlanta, GA
annual.ametsoc.org/2014

Global Change Calendar

September 9–13, 2013
ESA Living Planet Symposium, Edinburgh, Scotland
www.livingplanet2013.org/index.asp

October 27–30, 2013
Geological Society of America, Denver, CO. *community.geosociety.org/2013AnnualMeeting/Home*

November 11–22, 2013
Conference of Parties (COP)-19, Warsaw, Poland.
www.cop19.org

December 9–13, 2013
American Geophysical Union, San Francisco, CA.
fallmeeting.agu.org/2013

Code 610
National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

PRSRT STD
Postage and Fees Paid
National Aeronautics and Space Administration
Permit 396

(affix mailing label here)

eos.nasa.gov

The Earth Observer

The Earth Observer is published by the EOS Project Science Office, Code 610, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, telephone (301) 614-5561, FAX (301) 614-6530, and is available in color at *eospso.nasa.gov/earth-observer-archive*. Black and white hard copies can be obtained by writing to the above address.

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.

To subscribe to *The Earth Observer*, or to change your mailing address, please call Cindy Trapp at (301) 614-5559, or send a message to *Cynthia.trapp-1@nasa.gov*, or write to the address above. If you would like to stop receiving a hard copy and be notified via email when future issues of *The Earth Observer* are available for download as a PDF, please send an email with the subject **"Go Green"** to *Cynthia.trapp-1@nasa.gov*. Your name and email address will then be added to an electronic distribution list and you will receive a bi-monthly email indicating that the next issue is available for download. If you change your mind, the email notification will provide an option for returning to the printed version.

The Earth Observer Staff

Printed on Recycled Paper

NP-2013-2-007-GSFC