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Editor's Corner

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It has been a remarkable year for NASA's Earth Science Division, with the successful launch of three satellite missions (GPM, OCO-2, SMAP) and two instruments deployed on the International Space Station (ISS-RapidScat, CATS)—a tremendous achievement. Congratulations to the members of each team for the hard work it takes to achieve such success.

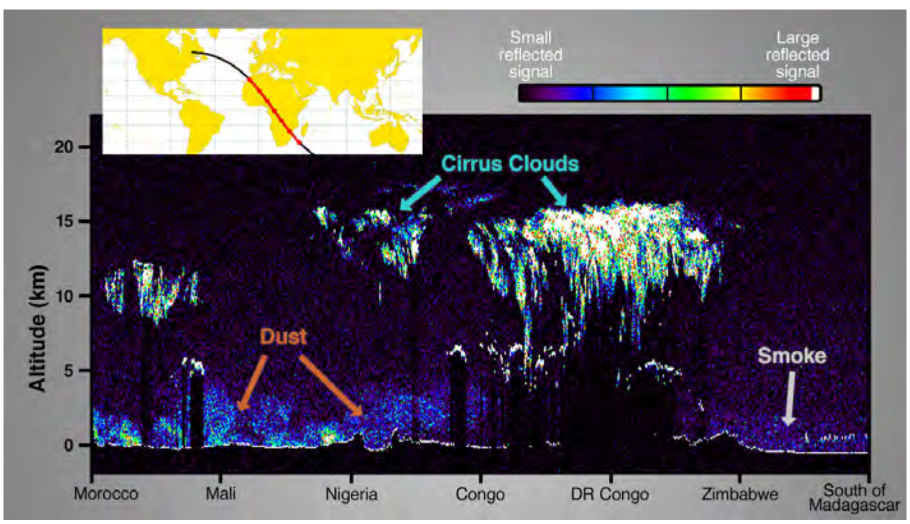
The GPM Core Observatory celebrated the first anniversary of its launch on February 27. To mark the occasion, NASA released the agency's most comprehensive global rain and snowfall product to date from the GPM mission. The Integrated Multi-satellite Retrievals for GPM (IMERG), uses data from the GPM satellite constellation—a network of 12 international satellites and the GPM Core, which itself acts as a calibration standard for all of the constellation's satellites. The first global visualization of initial IMERG data can be downloaded from NASA's Scientific Visualization Studio at *svs.gsfc.nasa.gov/goto?11784*.

Related to GPM, this issue includes an article describing the October 2013 to October 2014 Integrated Precipitation and Hydrology Experiment (IPHEx) field campaign—with an intensive observation period conducted from May through July 2014. IPHEx was designed to support the continued development, evaluation, and improvement of GPM's precipitation algorithms across the missions' constellation of satellites. Algorithms and data product validation used ground-based and airborne activities to take appropriate measurements of precipitation patterns and the effects of mountainous terrain on such phenomena. The campaign involved over 100 government and university investigators, and approximately 40 undergraduate and graduate students in science, technology, engineering, and mathematics (STEM) disciplines with direct or indirect efforts. Please turn to page 4 to learn more about the IPHEx campaign—including some intriguing preliminary results.

As reported in our last issue[1], after launch on January 10, CATS was successfully deployed on the International Space Station's Japanese Experiment Module—Exposed Facility (JEM–EF) and is the first NASA-developed payload ever to fly on JEM–EF. On February 26 CATS released its first data image (shown on this issue's front

[1] See the Editorial of the January–February 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 1**, pp. 1-3].

continued on page 2



On February 26, the Cloud-Aerosol Transport System (CATS) instrument onboard the International Space Station released its first data image. It is a cross-section of the atmosphere obtained as the space station passed over northern Africa on February 11, revealing clouds, dust, and smoke from fires, as well as variations in topography. To learn more visit *www.nasa.gov/content/goddard/africa-from-a-cats-point-of-view/#.VRG-trrQnKA*. **Image credit:** NASA

the earth observer

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

cover) revealing a "slice" of the atmosphere over Africa on February 11. Cirrus clouds, dust particles, and smoke from biomass burning are visible in the cross section. Clouds and aerosols remain two of the biggest questions in terms of impact on future potential climate change.

The most recent Earth Science launch was SMAP, launched on January 31. On February 25, SMAP's unique 6-m (20-ft) mesh reflector antenna was unfurled. An onboard pyro opened restraints on the furled antenna, which then sprang partially open; a motor then pulled the reflector fully open to its full circular configuration. The total procedure took over approximately 33 minutes. This was a major milestone on the path to the three-year science mission to map global soil moisture.

On February 27 and 28, SMAP successfully completed the initial test of its science instruments and revealed its first soil moisture image. Since the antenna was not yet spinning when these images were obtained, the swath widths are only 40 km (25 mi). Visit *www.nasa.gov/jpl/smap/nasas-soil-moisture-mapper-takes-first-smapshots/#.VQLle1qSXKA* to view the image.

After some additional tests and final orbital maneuvers on March 19, the spin mechanism was released, allowing the antenna to "spin up" to nearly 15 revolutions per minute (rpm) in a two-stage process. The spinning initially went to 5 rpm on March 23 for a few days of testing before gradually stepping up to the nominal 14.6 rpm on March 26. Now that the antenna is spinning, SMAP will be able to measure a 1000-km (620-mi) swath of Earth below, allowing it to map the globe every two to three days.

To learn more about the achievement of NASA's five newest Earth Science missions see the News Story on page 50 of this issue.

The last issue also reported on the imminent launch of DSCOVR, which took place on February 11 at 6:03 PM EST from Cape Canaveral Air Force Station in Florida onboard a SpaceX Falcon 9 rocket. Just 12 days after launch, the mission was already halfway through its 1.5-million-km (930,000-mi) journey toward the first Sun–Earth LaGrange point (L1). As the spacecraft moves further away from Earth, however, the influence of the Sun's gravity results in a curved trajectory (versus a "straight-line" approach), not unlike what happens to a ball when it is thrown as it reaches the top of its arc. The journey to L1 will take another 100 days, reaching the Lissajous Orbit Insertion (LOI) point on or about June 7. Scientists are excited to have DSCOVR reach its destination and have its two Earth Science instruments—the Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology Advanced Radiometer (NISTAR)—begin taking the first observations of our home planet from the L1-point.

Meanwhile, NASA continues to plan for future missions. The Pre-Aerosol, Clouds, and ocean Ecosystems (PACE[2]) mission was recently approved to proceed and directed to GSFC. PACE will make advanced global ocean color measurements to provide unprecedented data records on ocean ecology and global biogeochemistry, and aerosol and cloud properties. In addition to flying an ocean color imager, the PACE project is exploring acquisition options for a polarimeter that will improve the mission's science capabilities.

Jeremy Werdell [GSFC] has been appointed to be the PACE Project Scientist. Werdell was a member of the PACE Science Definition Team and has been part of GSFC's Ocean Ecology Laboratory's Ocean Biology Processing Group since 1999. He currently leads the SeaWiFS Bio-optical Archive and Storage System (SeaBASS), NASA bio-Optical Marine Algorithm Data set (NOMAD), and in-water bio-optical algorithm development. His research interests extend to on-orbit calibration of ocean color satellite instruments, validation of remotely-sensed data products, collection and analysis of *in situ* biogeochemical oceanographic measurements, and data assimilation to study how the global ocean and various regional ecosystems are changing with time.

Antonio Mannino [GSFC] has been chosen PACE Deputy Project Scientist for Oceans. Mannino has been part of GSFC's Ocean Ecology Laboratory since 2002, and has served as lead/colead for the GEO-CAPE mission preformulation ocean science working group, a MODIS ocean science team member, PI for the Ocean Biology and Biogeochemistry field support group, contributor to the ACE ocean science working group, chief scientist on field campaigns, and liaison for NASA in collaborating on ocean color with the Korean Ocean Satellite Center. His research interests include developing and applying satellite products, biogeochemical models, and field measurements to study coastal and global ocean biogeochemical cycles.

Brian Cairns [GISS] has been chosen as PACE Deputy Project Scientist for Atmospheres. Cairns has worked extensively on the use of polarimetric remote sensing of Earth to determine aerosol and cloud properties using ground-based and airborne observations. He was one of the developers of the airborne Research Scanning Polarimeter (RSP) instrument, completed in 1999, integrated on five different platforms, and used in seventeen different field deployments from Mexico to the Canadian Arctic. Cairns was also instrument scientist for the Aerosol Polarimetry Sensor, which was on NASA's ill-fated Glory mission in 2011. He has also been a member of science-working groups appointed by NASA HQ to define both ACE and PACE missions.

This issue also includes an article that describes NASA's Fire Information for Research Management System (FIRMS), which delivers global fire locations in easy-to-use formats using data from MODIS onboard NASA's Aqua and Terra Earth-observing satellites. MODIS allows scientists to identify wildfires or significant heat sources, called *hotspots*. Knowing the location of hotspots gives fire crews and wildland managers a "leg up" in locating a potential fire. Turn to page 14 to learn more about FIRMS.

There is also a special article on page 18 to commemorate the fiftieth anniversary of the first launch in the Nimbus Program, on August 28, 2014.. Nimbus-1 was the first of seven Earth-observing satellites in a series that spanned 30 years. The last, Nimbus-7, ceased operations in 1995, but its Program's legacy lives on, as it was one of the forerunners of Earth System Science as it exists today. Many historical and current instruments on NASA, NOAA, USGS, and other Earth-observing satellites can trace their origins one or more Nimbus missions.

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Acronyms used in the Editorial and Article Titles

CATS	Cloud–Aerosol Transport System
DSCOVR	Deep Space Climate Observatory
EST	Eastern Standard Time
GISS	NASA's Goddard Institute for Space Studies
GPM	Global Precipitation Measurement
GSFC	NASA's Goddard Space Flight Center
ISS–RapidScat	International Space Station–Rapid Scatterometer
JPSS	Joint Polar Satellite System
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
OCO-2	Orbiting Carbon Observatory-2
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SMAP	Soil Moisture Active Passive
USGS	U.S. Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite

[2] The 2007 Earth Science Decadal Survey, Earth *Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, identified the Aerosol–Ecosystems–Climate (ACE) mission as a *Tier-2* mission.

How's the Weather up There? The IPHEx GPM Ground Validation Campaign

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As with all satellite-based remote-sensing activities, data gleaned from instruments on orbital platforms must be validated by comparison with in situ data—that is, data retrieved directly in and around the area of interest.

There's a very old social gambit, usually spoken to a very tall person by one much shorter: "How's the weather up there?"—the inference being that there is a difference between what is being experienced by the individuals of disparate heights.

That inference is being put to the test in the real world—as regards precipitation, anyway—with the Integrated Precipitation and Hydrology Experiment (IPHEx) field campaign, held between October 2013 and October 2014 to validate data from the Global Precipitation Measurement (GPM[1]) mission. The GPM mission is an international network of satellites that together provide next-generation global observations of precipitation from space led by NASA and the Japan Aerospace Exploration Agency (JAXA). GPM builds upon and significantly extends the Tropical Rainfall Measuring Mission (TRMM). In addition to NASA and JAXA, who partnered in TRMM, participants in GPM include the French Centre National d'Études Spatiales (CNES), the Indian Space Research Organization (ISRO), the U.S. National Oceanic and Atmospheric Administration (NOAA), and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

Rationale for IPHEx

As with all satellite-based remote-sensing activities, data gleaned from instruments on orbital platforms must be validated by comparison with *in situ* data—that is, data retrieved directly in and around the area of interest. The satellite-based aspects of the GPM mission began with the launch of the GPM Core Observatory[2] in February 2014; ground validation activities were taking place even before the satellite reached orbit. One such prelaunch field campaign was *IFloodS,* or the Iowa Flood Studies, which took place in northeast Iowa from May 1 to June 15, 2013[3]. The campaign was designed to explore the hydrologic and weather conditions that could lead to flooding—studies that provided both applications support for agriculture in the area and a means to assess algorithms and future GPM product application for the then-planned GPM mission.

Collectively, the IPHEx field campaign involved well over 100 government and university investigators, and included approximately 40 undergraduate and graduate students in science, technology, engineering, and mathematics (STEM) disciplines who participated either directly or indirectly in the IPHEx field effort. Aside from NASA and NOAA scientists, IPHEx investigators included representatives from local and national universities, and faculty and staff from Duke University, the University of North Carolina (UNC)-Asheville, the University of North Carolina, North Carolina Central University, North Carolina State University, Georgia Institute

[1] To learn more about GPM, please refer to "GPM Core Observatory: Advancing Precipitation Measurements and Expanding Coverage" in the November–December 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 6**, pp. 4-11] or visit pmm.nasa.gov. *pmm.nasa.gov.*

[2] The GPM mission centers on the deployment of the GPM Core Observatory and consists of a network, or *constellation*, of additional satellites that together will provide next-generation global observations of precipitation from space.

[3] For more information on IFloodS, see "A Flood—of Information—Is Needed" in the January–February 2014 issue of *The Earth Observer* [**Volume 26, Issue 1,** pp. 12-18].

of Technology, the University of Connecticut, the University of Utah, Colorado State University, the University of Georgia, and Smith College, among others. Key observing sites were developed in cooperation with the U.S. National Park Service, the U.S. Geological Survey, and local colleges and universities, including Western Carolina University, Asheville-Buncombe Technical Community College, Wilson College, Haywood Community College, the Pisgah Astronomical Research Institute, and the Maggie Valley Sanitary District.

Ground validation activities continue now that the GPM Core Observatory is in orbit. IPHEx was a postlaunch field campaign, designed to support the continued development, evaluation, and improvement of GPM's precipitation algorithms across the missions' constellation of satellites. Ground-based and airborne activities all combined to take appropriate measurements of precipitation patterns and the effects of mountainous terrain on such phenomena, in an effort to validate GPM's relevant algorithms and data products.

IPHEx was a post-launch field campaign, designed to support the continued development, evaluation, and improvement of GPM's precipitation algorithms across the missions' constellation of satellites.

IPHEx Location

As shown in **Figure 1**, the IPHEx campaign took place in the Southern Appalachian Mountains, specifically western North Carolina and the adjacent Coastal Plain along the Atlantic Ocean and the Piedmont Region, which comprises the central portion of NC between the Coastal Plain and the Mountain regions to the west. Several precipitating cloud systems were also sampled over the Atlantic Ocean off the coast of NC.

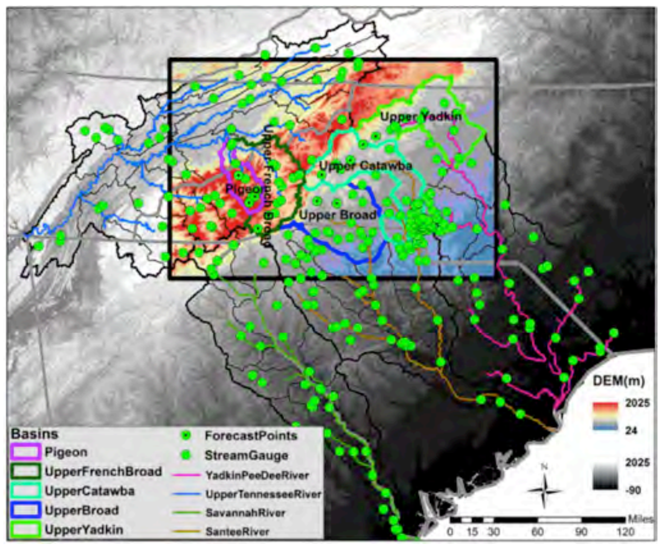

Figure 1. *Southern Appalachian Mountain location for IPHEx activities.* The study region during the 2013-2014 field campaign is outlined. Several of the rivers and river basins named here are discussed in the text. **Image credit:** Ana Barros

This region provided the science team with mountainous terrain during warm seasons that they could use to examine the nature and distribution of precipitation over complex terrain that varies over a relatively small area and over many different elevations. The region was chosen to allow IPHEx's teams to see how mountain precipitation affects and is affected by relevant processes at lower elevations. It was, if you will, the perfect place to study, "How's the weather *up there*… and *down here*."

The irregular and complex terrain provided locations for the ground-based-instrumentation (see *IPHEx Instrumentation* on page 6) that allowed IPHEx scientists and staff to collect data on mesoscale convective systems and fronts (usually driven by westerly winds), convective systems and tropical storms (usually driven by southeasterly and southerly winds), and phenomena that cause convection to begin and subsequently to be suppressed. In addition, observing interactions between fog and several layers of clouds in the inner-mountain region allowed the science team to examine the effects of mountains and mountain ranges on the microphysical properties of precipitation—information needed to validate GPM-based measurements of such properties from low-Earth orbit.

IPHEx Science Objectives

The science objectives for IPHEx were to:

- Collect datasets appropriate to physical validation of GPM data algorithms for observations over complex terrain;
- provide measurements that improve our understanding of precipitation processes over complex terrain; and
- better understand the impact of GPM products with their uncertainties in hydrologic application.

Science topics were quite comprehensive. Only a few are listed here, to give the flavor of the study's breadth and depth. These topics determined which measurements were to be taken. These included:

- Coupling of precipitation ice processes to dominant rainfall production and the nature of radar and radiometer signatures in these processes;
- characteristic drop size distributions (DSD) and microphysical mechanisms including spatiotemporal variability;
- roles of fog and other mechanisms in the vertical structure of reflectivity profiles;
- effects of landform and land cover on storms; and
- error characteristics of GPM instrumentation and their relationship(s) with local and regional hydrometeorological regimes.

Two suites of activities were planned and implemented during IPHEx. The first was an extended observing period (EOP) from October 2013 through October 2014; the second was an intense observing period (IOP) from May through July 2014, which included aircraft observations.

IPHEx Implementation

Two suites of activities were planned and implemented during IPHEx. The first was an *extended observing period* (EOP) from October 2013 through October 2014; the second was an *intensive observing period* (IOP) from May through July 2014, which included aircraft observations, as discussed later in this article. Each had its own set of requirements and success criteria, as will be discussed later.

In addition to the aircraft measurements, a real-time, hydrologic forecasting testbed became operational during the IOP, which built upon a successful benchmark project that ran from 2007 to 2012. The Integrated Precipitation and Hydrology Experiment - Hydrologic Applications for the Southeast U.S. (IPHEx-H4SE) was designed to compare results between hydrological models for four major river basins in the U.S. Southeast.

Concurrent with—but not formally part of—IPHEx, three additional monitoring activities took place: (1) examination of aerosol-cloud-rainfall interactions; (2) measurements of soil moisture over several land use and land cover types using the airborne the airborne Scanning L-band Active Passive (SLAP) instrument; and (3) performing trace gas analysis of streamflows to assess groundwater transit times.

The GPM-led IPHEx campaign also had important collaborations with partners that included the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Testbed Southeast Pilot Studies (HMT-SEPS) program and the NASA Aerosol Cloud Ecosystem (ACE[4])/Radar Experiment (RADEX) study teams. The HMT-SEPS activity was focused on collecting precipitation and related meteorological measurements to support activities related to improved flood and weather prediction from "summit to sea" in the Southeastern U.S. The NASA ACE/RADEX team collaborated with GPM scientists to collect complementary measurements of clouds and weakly-precipitating cloud systems. The goals of the RADEX Team were to examine the physics of cloud-to-precipitation water-content transitions, determine the characteristics of cloud ice, and assess radar technology needs in relation to potential future aerosol, cloud, and precipitation satellite missions.

IPHEx Instrumentation

A wide variety of instrumentation was used for IPHEx activities. A representative subset of these instruments is summarized in **Table 1**, next page, which gives an overview of their nature and breadth. For full details, visit *gpm.nsstc.nasa.gov/iphex/instruments.html.* Please note that while the requirements for the EOP and IOP differed, EOP instruments were also used during the IOP. Technologies ranged from the relatively simple, such as rain gauges, to the highly sophisticated, such as dual-polarization radar.

[4] The 2007 National Research Council (NRC) Decadal Survey report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond,* identified ACE as a *Tier 2* priority mission; it is now under NASA pre-formulation study.

Table 1. Sample of primary IPHEx ground-based instrumentation characteristics

Campaign Phase	Instrument (Type)	Number Implemented	Measurement
EOP	Rain gauge	60	Precipitation amount
	Disdrometer	20	Precipitation amount, type, fall speeds, and drop size distribution (DSD)
	Micro Rain Radar (MRR)*	1	Rain rates, DSD, radar reflectivity, fall speeds
	Rawindsonde	1	Profiles of pressure, temperature, humidity, and wind collected for targeted tropical cyclones and large storm events
IOP	NASA's S-band Dual Polarimetric Radar (NPOL)*	1	Spatial structure of precipitation, hydrometeor classification, DSD, and rain mapping
	Dual-Frequency, Dual-Polarized, Doppler Radar (D3R)*	1	Same as NPOL but at higher frequencies and expansion to light rain mapping.
	MRR*	4	Same as during the EOP but increased number of units
	NOAA X-band Dual Polarimetric Radar (NOXP)**	1	Same as NPOL but with intra-mountain coverage
	Rawinsonde	1 site	IOP sounding profiles of pressure, temperature, humidity and wind collected at 3-hour intervals during intensive operations
	Aerosol-Cloud-Humidity Interactions, Exploring and Validating Enterprise (ACHIEVE) Facility***	1	Cloud radar reflectivity, water vapor profiling, and aerosol contents
	Wind Profiler**	4	Vertical profiles of precipitation rate, DSD, and wind

* Some instrumentation details: MRR is a 24-GHz, vertically pointing Doppler radar; NPOL is an S-band (10-cm) scanning dual-polarization radar; and D3R, also a dual-polarization radar, operates at nominal frequencies of 13.91 GHz and 35.56 GHz (K_a and K_u bands, respectively, similar to the GPM Core satellite's Dual-frequency Precipitation Radar (DPR).
** NOXP is a scanning X-band (3-cm) dual-polarimetric mobile radar provided by NOAA.
*** Deployed by NASA's ACE/RADEX Team

In addition to ground-based instrumentation, NASA's ER-2—a high altitude aircraft typically operating at 60,000 ft (18 km) or higher—provided much of the airborne satellite-simulator remote sensing capability. The high-altitude vantage point acted as a proxy for the GPM Core satellite's own observations. Of note is that the IPHEx field campaign is the first time four different radar frequencies made simultaneous measurements from a single NASA aircraft. Some of the ER-2 airborne instrumentation is presented in **Table 2.**

...the IPHEx field campaign is the first time four different radar frequencies made simultaneous measurements from a single NASA aircraft.

Table 2. ER-2 instrumentation and measurements for IPHEx

Instrument	Measurement
Advanced Microwave Precipitation Radiometer (AMPR)	Multi-frequency (10-85 GHz) dual-polarized measurements of precipitation-sized ice, liquid water, and water vapor
Conical Scanning Millimeter Imaging Radiometer (CoSMIR)	Multi-frequency (50-183 GHz) dual-polarized measurements of precipitation rates, water vapor, and temperature profiles
Cloud Radar System (CRS)	94-GHz (W-band) measurements of reflectivity and Doppler velocity in clouds
ER-2 X-band Radar (EXRAD)	Radar measurements at 9.6 GHz of cloud, wind, and precipitation structure

Table 2. ER-2 instrumentation and measurements for IPHEx (continued)

Instrument	Measurement
High-altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)	K_a/K_u-band, dual-beam Doppler radar system for cloud and precipitation observation

A second aircraft, the Cessna *Citation* based at the University of North Dakota (UND), provided *in situ* measurements within clouds. The Citation carried cloud physics probes to sample cloud and precipitation particles and water contents for hydrometeor diameters ranging from approximately 1 µm to 2 cm (see **Table 3**). The cloud physics measurements made from the Citation were collected at the same time as the ER-2 measurements by flying below the ER-2. The coordinated Cessna flights serve to bridge satellite observations of precipitation-making cloud processes with measurements of the precipitation falling from the clouds to the ground—as observed by ground-based radars and supporting gauge networks.

Table 3. Cessna *Citation*-based instrumentation and measurements

Instrument	Measurement
King Liquid Water Probe	Cloud liquid water content (LWC)
2D-C (Cloud) and 2D-S (Stereo) probes	Cloud and precipitation particle spectra
High-volume Precipitation Spectrometer (HVPS)-3	Precipitation particle-size spectra (50 µm-1.92 cm)
Cloud Particle Imager (CPI)	High-resolution ice crystal and cloud-droplet imaging
Cloud Spectrometer and Impacter (CSI)	Total condensed atmospheric water content measurement and droplet size spectrum (2-50 µm)
Cloud Droplet Probe (CDP)	Droplets in the range of 2-50 µm, in concentrations as high as 2000 cm^{-3}
Nevzorov Airborne Hot-Wire Probe	LWC and total water content (TWC)
Rosemount Icing Detector	Rate of ice formation via supercooled water for LWC measurements
Condensation Nuclei (CN) counter	Aerosols [e.g., condensation nuclei, cloud condensation nuclei (CCN)]

IPHEx was the first GPM ground validation field campaign conducted after the Core Observatory's launch in February 2014. Accordingly, at least two primary GPM overpass events were collected with coordinated multi-aircraft and ground-based instrumentation. Additional supporting data were also provided in coordination with other orbiting satellites, including the Tropical Rainfall Measuring Mission (TRMM); A-Train satellites[5], including CloudSat, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and Aqua; and Geostationary Operational Environmental Satellites (GOES).

IPHEx was the first GPM ground validation field campaign conducted after the Core Observatory's launch in February 2014. Accordingly, at least two primary GPM overpass events were collected with coordinated multi-aircraft and ground-based instrumentation.

IPHEx Logistics and Operations

IPHEx Operations during the IOP were coordinated from a central location at the Asheville, NC, airport. Each day began with a weather forecast to support coordinated ER-2 and UND Citation flights and ground operations planning. The IPHEx team members that were in Ashville coordinated operations with GPM overpasses when

[5] For a description of the A-Train please read "Taking the A-Train to New Orleans" in the January-February 2011 issue *of The Earth Observer* [**Volume 23, Issue 1**, pp. 12-23].

possible. They also managed the ground instruments and received instrument status updates, conducted daily status briefings for scientists, and wrote daily mission summaries for archiving with the collected datasets.

The NASA Global Hydrology Resource Center Distributed Active Archive Center provided an operations web portal for logging daily mission, program, and instrument science status reports; weather briefing materials; and to monitor real-time weather information relevant to operations. The IPHEx portal also served as a means to archive both real-time, quick-look products and raw data products from the instruments deployed in the field. The NASA Airborne Science Mission Tools Suite served as the primary platform for conducting aircraft operations and guidance during the IPHEx campaign, which included communications between aircraft scientists and the ground, and mission scientists and remote ground instrument locations (e.g., NPOL, D3R, and NOXP radars) via chat-based services.

Unlike previous GPM ground validation field campaigns, the IPHEx campaign emphasized orographic modification—i.e., how mountainous terrain impacts precipitation. In addition, this was the first ground validation campaign to "follow" water once it was on the ground.

IPHEx Early Findings

With the last of the field campaign activities having finished just a few months ago as of this writing, results are only beginning to become available. A few examples of already noteworthy findings are presented here that clearly show the utility of the combined, integrated, synergistic approach built into the IPHEx structure. More will follow as time goes on.

Rainfall Variability as a Function of Locale

Figure 2 illustrates the unique microphysical processes governing the spatial and temporal variability of rainfall in the inner region of the Southern Appalachians. Unlike previous GPM ground validation field campaigns, the IPHEx campaign emphasized *orographic modification*—i.e., how mountainous terrain impacts precipitation. In addition, this was the first ground validation campaign to "follow" water once it was on the ground. To accomplish this, the researchers relied upon *Quantitative Precipitation Estimates* (QPE), which estimate the amount of precipitation that has fallen across a given region, and *Quantitative Precipitation Forecasts* (QPF), which output the expected amount of melted precipitation accumulated over a specified time period over a specified area, to help them track the water once it reached the ground. They used this information for a number of hydrological applications, including operational streamflow forecasting—as will be described later.

One important result that IPHEx observations have confirmed is that the contrasting amount of rainfall that occurs on ridges as opposed to valleys can be traced directly to how drop size distributions (DSD[6]) of precipitation vary over an area of land through the course of a day-night cycle. These observations are statistically significant and have a robust physical basis, which means they can be used to guide precipitation retrievals in complex terrain—as long as the algorithm takes the terrain into account.

During the IPHEX IOP, streamflow forecasts were generated daily for 12 headwater catchments (or basins), initialized by NASA-Unified Weather Research and Forecasting (NU-WRF)

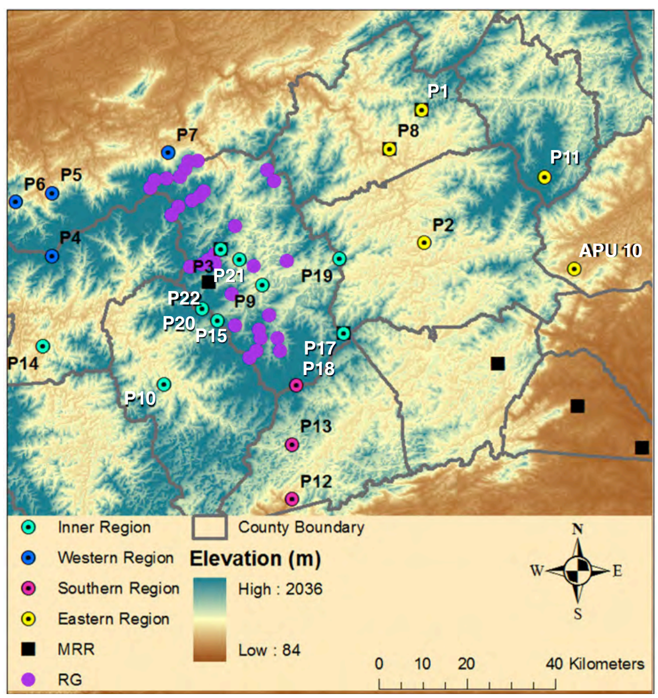

Figure 2. This map indicates the unique microphysical processes governing the spatial and temporal variability of rainfall in the inner region of the Southern Appalachians. In particular, note the range of elevations. The nocturnal rainfall peak was to the west of a line from just east of Parsivel 7 (P7) to just north of P18; the daytime rainfall peak was east of that line. MRR stands for Micro Rain Radar; RG stands for rain gauge; and APU stands for Autonomous Parsivel Unit. **Image credit:** Anna Wilson [Duke University]

[6] A *drop size distribution* is a statistical method to "count raindrops;" they are placed into "bins" based upon their size.

Figure 3 shows precipitation and streamflow observations and predictions for two of the 12 basins for an event that took place on May 15, 2014. This is an excellent example of the kind of event and subsequent analysis that IPHEx was organized to explore.

forecasts as well as forecasts and *hindcasts*[7], using one of two different NOAA QPE products that blend rain gauge and ground-based radar observations, which are abbreviated SW and MW in Figure 3[8].

Figure 3 shows precipitation and streamflow observations and predictions for two of the 12 basins for an event that took place on May 15, 2014. This is an excellent example of the kind of event and subsequent analysis that IPHEx was organized to explore. The left panel of Figure 3 shows results obtained for the Yadkin River, located in the Upper Yadkin River, in the Yadkin/PeeDee basin, which is situated in the inner region of the Southern Appalachians (see Figure 1). The results show that the forecast for the May 15 event using NU-WRF rainfall is more accurate than the forecast using the same model forced by either of the two observational products (i.e., SW and MW). Note the difference in the timing, and especially the intensity of rainfall between the NU-WRF forecasts, Stage IV and MRMS averaged over the basin. As is the case for most small-to-medium size [400 mi^2 (1036 km^2)] basins in complex terrain across the continental U.S., there are no ground observations of rainfall in the Upper Yadkin, and consequently radar estimates alone are inadequate.

The right panel of Figure 3 shows results obtained for the West Fork of the Pigeon River in the upper Tennessee River, located in the Upper Tennessee basin on the eastern slopes of the Southern Appalachians—at a higher elevation than the Upper Yadkin River (see Figure 1 for comparison). In this case, the streamflow forecast is

[7] In a *hindcast,* observed data from a previous time period are used as input to see how accurately the model produces the conditions that were actually observed. In this particular case, data from the previous 24 hours were used as initial conditions for the model.

[8] SW stands for the National Centers for Environmental Prediction (NCEP) "Stage IV" analysis; MW stands for multiradar/multisensor (MRMS) system, an operational precipitation product system intended to enhance decision making and improve forecasts. The distinction is that SW involves a human in the quality control and merger process, while MW is produced as a merged product in a completely automated fashion.

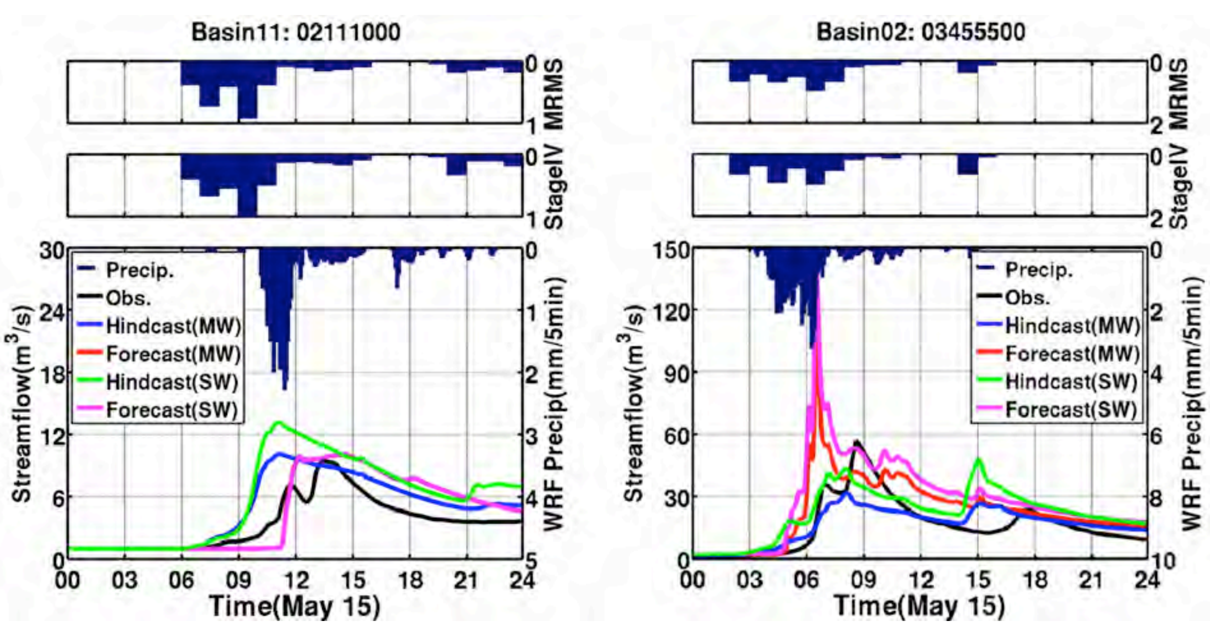

Figure 3. These two sets of plots show results from 24-hour streamflow forecasts and hindcasts during IPHEx using the new (uncalibrated) Duke Coupled Hydrology Model (DCHM)) at 250-m (820-ft) resolution for the Upper Yakin River [*left panel*] and the West Fork of the Pigeon River [*right panel*]. The two top plots in each panel represent the observed rainfall rate averaged over the catchment for each of the observational products, as indicated by the "y-axis label" on the right-hand side. In the bottom plot of each panel, the NU-WRF precipitation forecast averaged over the catchment is plotted along the top, with the amount of precipitation plotted down the right hand side. The streamflow forecasts and hindcasts are plotted along the bottom, with the flowrates plotted up the left-hand side. The pink lines are forecasts using NU-WRF precipitation and initial conditions from the hindcast for the previous day using Stage IV rainfall. The red lines are the same as the pink lines, but where the previous day hindcast was obtained using MRMS rainfall. The blue line is the hindcast for the present day, using MRMS rainfall at the end of the day. The green line is the same as the blue line, but using Stage IV rainfall. Please see text for definitions of acronyms used in graphs. **Image credit:** Jing Tao [Duke University]

excessively high, whereas the hindcast hydrographs are closer to the observations. The hindcast produced after blending the SW product with observations from additional rain gauges installed for IPHEx shows further improved streamflow simulations, thus indicating that the QPE has improved. Nevertheless, these results give a clear indication that the "true" rainfall is not known.

These examples, which were produced operationally during IPHEx proper, illustrate well the grand challenge of precipitation uncertainty for hydrological applications, and underscore the importance of GPM's contribution to the national observing system—which will be to fill current observational gaps in mountainous regions and complex terrain, broadly.

Severe Storm Precipitation Properties

Another example of the data collected during IPHEx—from May 23, 2014, illustrated in **Figures 4 – 8**—includes a small line of severe storms that formed and passed over the Piedmont. This dataset demonstrates the utility of synchronous ground-based observations and aircraft flights during a GPM Core Observatory overpass (2316 UTC). While severe storms are comparatively rare events when considered in the broader spectrum of precipitating cloud systems, they often produce rains that contribute significantly to local rainfall climatologies. Moreover, the deep columns of ice and liquid water found in these storms can pose special problems to GPM retrieval algorithms. For both these reasons, scientists are eager to learn more about the properties of precipitation produced by severe storms, and the opportunity to observe a line of storms as the GPM satellite passed over while simultaneously taking aircraft and ground-based observations was fortuitous.

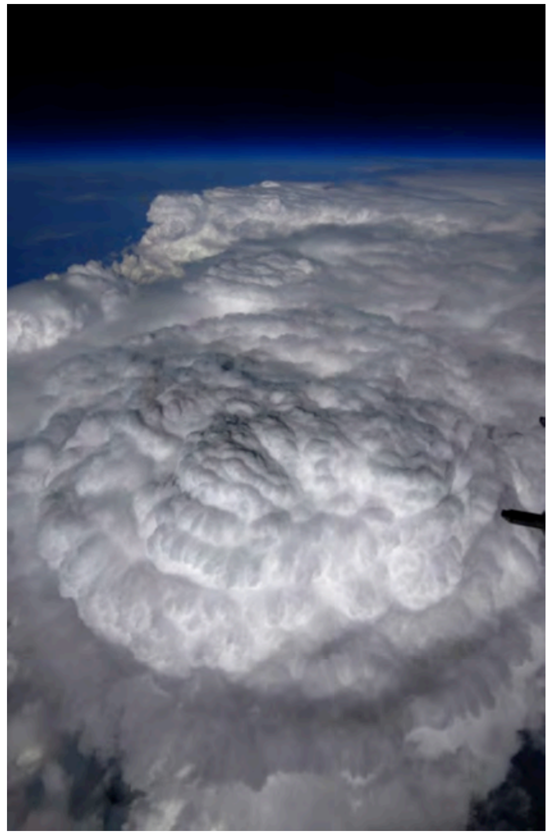

Figure 4. *The severe convective storm as seen from above.* The pilot of the ER-2 captured this photo of severe convection over the Piedmont of North Carolina on May 23, 2014—just prior to the GPM Core satellite overpass at 2316 UTC. **Image credit:** Donald "Stew" Broce [NASA's Armstrong Flight Research Center]

The storms sampled were located on the Piedmont approximately 80 to 150 km (50 to 190 mi) southeast of the NPOL radar, and even closer to the Greenville-Spartanburg, NC and Columbia, SC WSR-88D radars. **Figure 4** shows an example of what the event looked like when viewed from the cockpit of the high-flying ER-2.

The May 23 storm produced cloud tops greater than 50,000 ft (15 km), tennis ball-sized hail, and robust ice scattering signatures at even the lowest AMPR frequencies—see **Figure 5**. These measurements are consistent with the NPOL

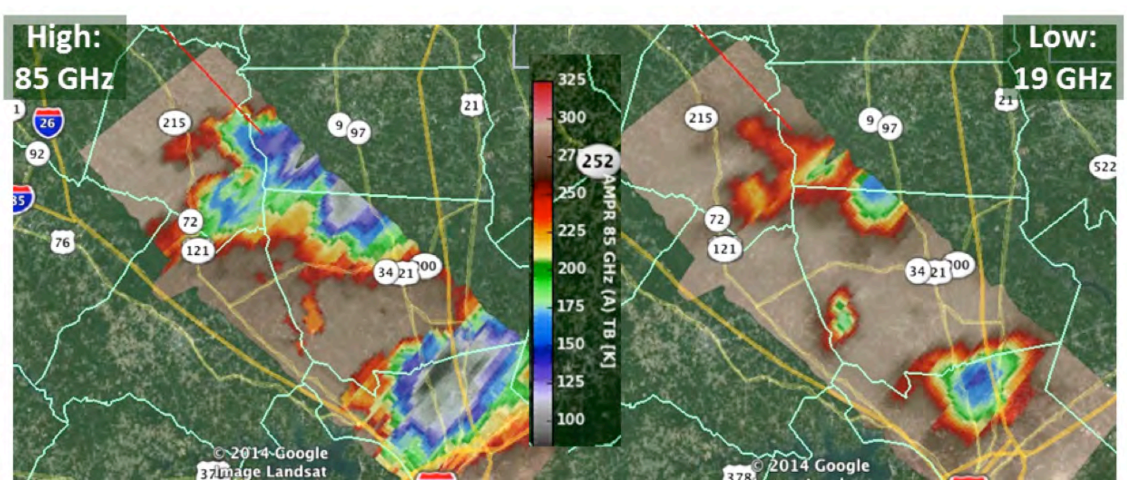

Figure 5. *Microwave brightness temperatures during severe storm convection.* These data—at high frequency [*left*] and low frequency [*right*]—in severe convection were observed by the AMPR radiometer aboard the ER-2 during a GPM Core satellite overpass at approximately 2316 UTC on May 23, 2014. Regions of increasing intensity are shown as nominally concentric color changes. **Image credit:** NASA

measurements—see **Figure 6**—and associated deep reflectivity structures in the airborne radar data—see **Figure 7**—with significant attenuation noted at the highest frequencies, which is to be expected in the presence of heavy precipitation.

The aircraft and ground-based data matched well with the satellite data—see **Figure 8**—although the more spatially coarse reflectivity data from GPM's Dual-frequency Precipitation Radar (DPR) exhibited relatively lower values than the ground-radar (see Figures 6 and 7). As in the case of the ER-2 AMPR data, the GPM Microwave Imager also observed cold brightness temperatures at 89 GHz that were indicative of ice scattering (cf., Figure 4). Relative to the importance of the ice scattering signature, note that the enhanced ice process aloft in this storm (and storms like it) is likely responsible for the production of a significant fraction of the heavy rainfall observed at the surface, with indications that large rain drops produced in heavy rainfall are associated with the melting of large ice particles such as hail (cf., Figure 5). (Indeed, this matches what was observed

The aircraft and ground-based data matched well with the satellite data although the more spatially-coarse reflectivity data from GPM's Dual-frequency Precipitation Radar (DPR) exhibited relatively lower values than the ground-radar.

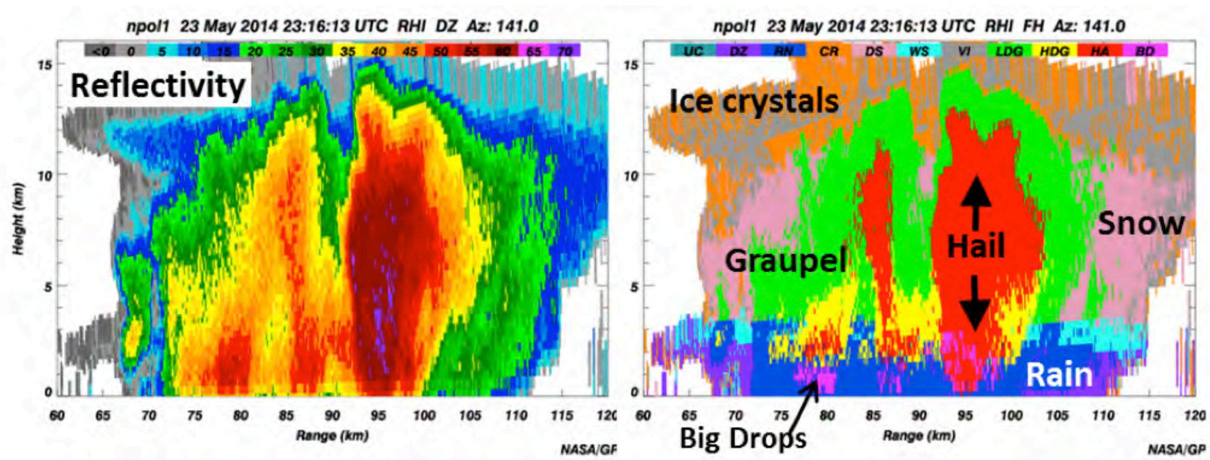

Figure 6. Cross-sections of radar scans obtained during a severe storm. NASA NPOL Radar range-height scan cross-sections cut through the severe storm sampled by the ER-2 and observed by the AMPR on May 23, 2014. The image on the left shows radar reflectivity, while the image on the right shows the derived precipitation types in the storm as estimated from polarimetric radar variables. Note the production of "big drops" underneath melting hail and large graupel. Increasing reflectivity is indicated by the gradations of color, with the highest reflectivity shown as purple. **Image credit:** David Wolff and Walt Petersen [both from NASA's Wallops Flight Facility]

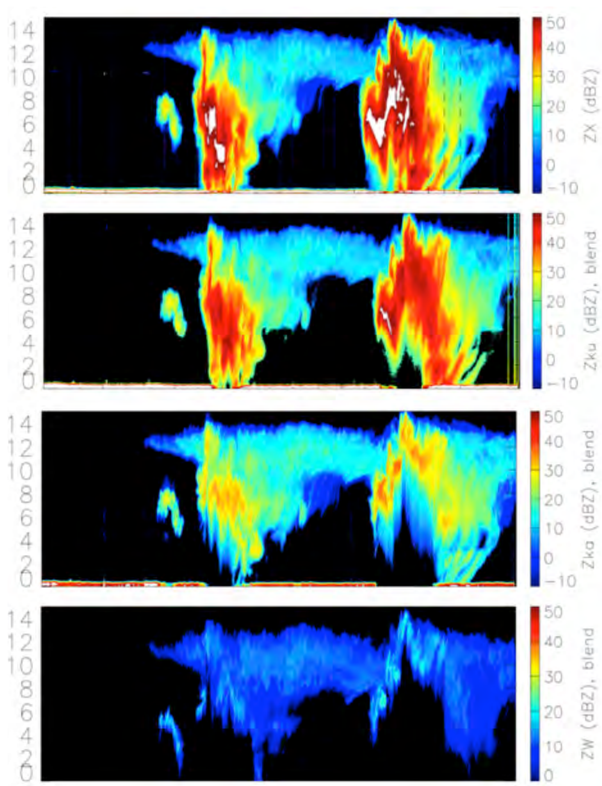

Figure 7. *Radar sampling of a severe storm from the ER-2.* Shown are radar reflectivity profiles from ER-2-based quad-frequency radar sampling of a severe convective storm, sampled on May 23, 2014. The data are a function of altitude along the ER-2 track at X, K_u, K_a, and W-bands [*top to bottom panel*], respectively. Increasing intensities are indicated by red and orange as the signals move toward the center of the cell. Note the progressively stronger attenuation and loss of signal in the higher K_u, K_a, and W-band frequencies as the radar beams propagate through the large hail and heavy rain at the storm's core. Also note the "notch" structure and weak radar echo region of the strong storm updraft near 2320 UTC. Radar reflectivity data as presented here are still preliminary and require final calibration. **Image credit:** Gerry Heymsfield [NASA's Goddard Space Flight Center]

For more detail to aid in interpreting the figures in this article, visit the full-color version at *eospso.nasa.gov/earth-observer-archive*.

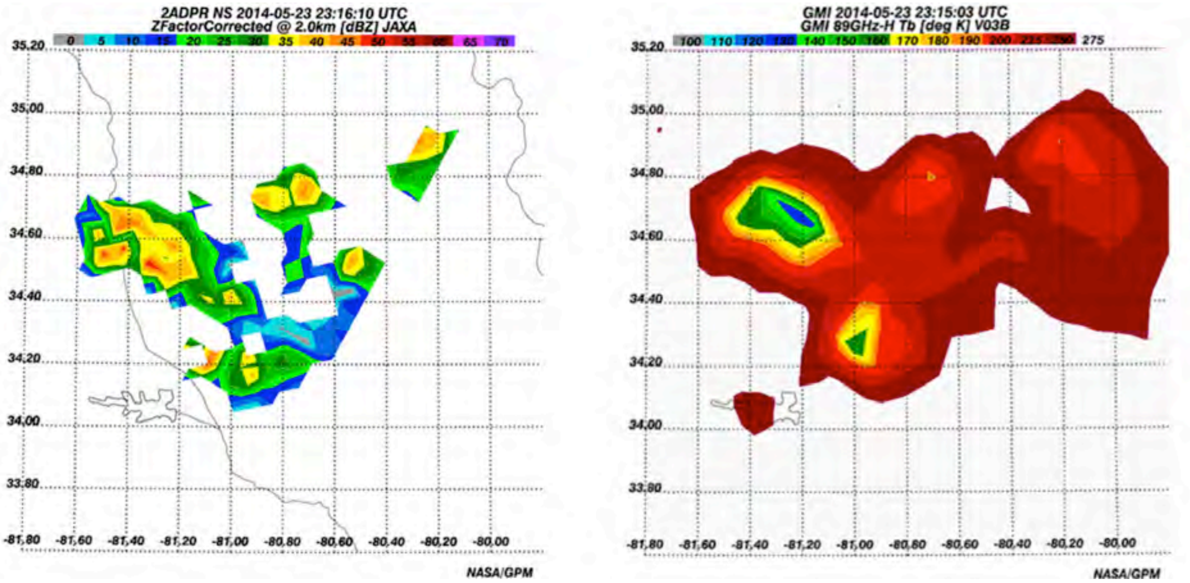

Figure 8. *GPM Core Satellite overpass image of severe storm convection.* These data were obtained over the Piedmont at 2316 UTC, May 23, 2014. Shown here are the dual-polarization radar reflectivities observed by the K_u-band channel at the 2-km (1.2 mi) height level [*left*] and GMI radiometer brightness temperatures (K) observed by the 89 GHz, horizontal polarization channel [*right*]. Note that the footprint for both GMI and the dual-polarization radar are approximately 5 km (3.1 mi), while the ER-2 and ground-based radar instruments collect at resolutions of 1-km (0.6-mi) to less than 1-km. Increasing intensities are indicated by brighter colors as the signals move toward the center of the cell. **Image credit:** David Marks [NASA's Wallops Flight Facility]

directly by ground-based disdrometers in another similar event during IPHEx.) The presence of even a few very large rain and/or hail particles can substantially impact signals observed at the higher GPM radar frequencies in a disproportionate fashion; hence understanding their formation and occurrence within individual storms is important.

Conclusion

As the examples in this article show, the early IPHEx results have already led to some exciting discoveries. With the comprehensive suite of results and datasets still to analyze, these preliminary results are expected to be just the first indicators of new information that scientists will use to address a wide and deep set of specific questions related to precipitation patterns over variable terrain. The results from IPHEx will not only have benefits to support GPM validation, but could also lead to longer-lasting studies of the effects of orography on precipitation phenomena. As with other such campaigns, the opportunities for science collaboration and participation amongst a wide range of interested organizations are manifold.

For more on IPHEx, visit *gpm.nsstc.nasa.gov/iphex* and *iphex.pratt.duke.edu*. ■

With the comprehensive suite of results and datasets still to analyze, these preliminary results are expected to be just the first indicators of new information that scientists will use to address a wide and deep set of specific questions related to precipitation patterns over variable terrain.

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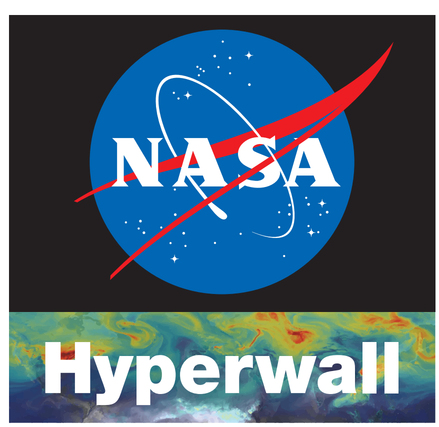

feature articles

NASA FIRMS Helps Fight Wildland Fires in Near Real-Time

Josh Blumenfeld, NASA's Goddard Space Flight Center/ADNET Systems, Inc., joshua.c.blumenfeld@nasa.gov

A key resource for wildland firefighters and managers around the world is NASA's Fire Information for Resource Management System (FIRMS), which is part of NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) in NASA's Earth Observing System Data and Information System (EOSDIS).

Introduction

Fahrenheit 572 is a critical value for wildland firefighters. This is the temperature at which wood releases hydrocarbon gases that mix with oxygen, ignite, and combust. With a source of fuel and air, along with enough heat to bring this volatile mixture to this ignition temperature, a wildland fire can become an uncontrolled, self-sustaining cataclysm.

Locating these fires rapidly is vital to managing and containing these natural and, in many cases, anthropogenic events. A key resource for wildland firefighters and managers around the world is NASA's Fire Information for Resource Management System (FIRMS), which is part of NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE[1]) in NASA's Earth Observing System Data and Information System (EOSDIS[2]).

The FIRMS Web Fire Mapper Tool and Applications

FIRMS delivers global fire locations in easy-to-use formats using data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Aqua and Terra Earth-observing satellites. Terra has a sun-synchronous daytime orbital path and crosses the equator from north to south at 10:30 AM local time (and again from south to north, 12 hours later); Aqua has a sun-synchronous orbit that crosses the equator from south to north at 1:30 PM local time (and again from north to south, 12 hours later). Global coverage is achieved every one to two days.

The University of Maryland developed FIRMS in 2007 with funds from NASA's Applied Sciences Program and the United Nations Food and Agriculture Organization (UNFAO). NASA began offering FIRMS data in 2007, and the UNFAO began offering FIRMS data in 2010 through its Global Fire Information Management System (GFIMS).

Diane Davies [NASA's Goddard Space Flight Center—*LANCE Operations Manager*] was part of the team that developed the Web Fire Mapper as an interactive system that allows users to see where wildland fires are occurring. Davies and her team soon discovered that there was a huge demand for fire data and a need to deliver this information rapidly. "We realized that there were a lot of users with very poor Internet access or in very remote areas," Davies says. "They said, 'well can you just send me a notification of when there is a fire occurring in my area of interest?' So we developed [an] email alert system." Davies notes that every day more than 2000 FIRMS email alerts are sent to users in over 120 countries.

FIRMS Data in Detail

The MODIS Thermal Anomalies and Fire Product is the data source for FIRMS products—see *Accessing FIRMS Data* below. The sensitivity of the MODIS instrument

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[1] LANCE provides more than 40 near-real-time data products from instruments aboard NASA's suite of Earth-observing satellites, and has been discussed in several previous articles in *The Earth Observer*, the most recent having been published in the November-December 2014 issue [**Volume 26**, **Issue 6**, pp. 37-40]. For more information, visit *earthdata.nasa.gov/data/near-real-time-data.*

[2] NASA's EOSDIS provides end-to-end capabilities for managing NASA's Earth science data from various sources such as satellites, aircraft, field measurements, and various other programs. Its history has been detailed previously in "The Earth Observing System Data and Information System: Where We Were and Where We Are, Parts I and II" in the July-August [**Volume 21, Issue 4,** pp. 4-11] and September-October 2009 [**Volume 21, Issue 5,** pp. 8-14] issues of *The Earth Observer.* For more information, visit *earthdata.nasa.gov.*

allows scientists and researchers to study our planet in minute detail and, in the case of wildland fires, helps identify areas that may need a closer look. MODIS uses a complex computer algorithm to identify the center of any 1-km^2 (0.4-mi^2) area, or *pixel*, where the instrument detects a *thermal anomaly*, which could indicate a wildfire or any significant heat source, such as an erupting volcano—see **Figure 1**. Knowing where these *hotspots* are located gives fire crews and wildland managers a "leg up" as they work to locate a potential wildland fire.

One critical benefit of FIRMS data is that—thanks to LANCE—they are generally available within three hours of a satellite overflight, making these near real-time (NRT) data a valuable tool to help first responders pinpoint the approximate location of a potential wildland fire (or hotspot) and to track the development of established fires—especially in remote or rugged areas.

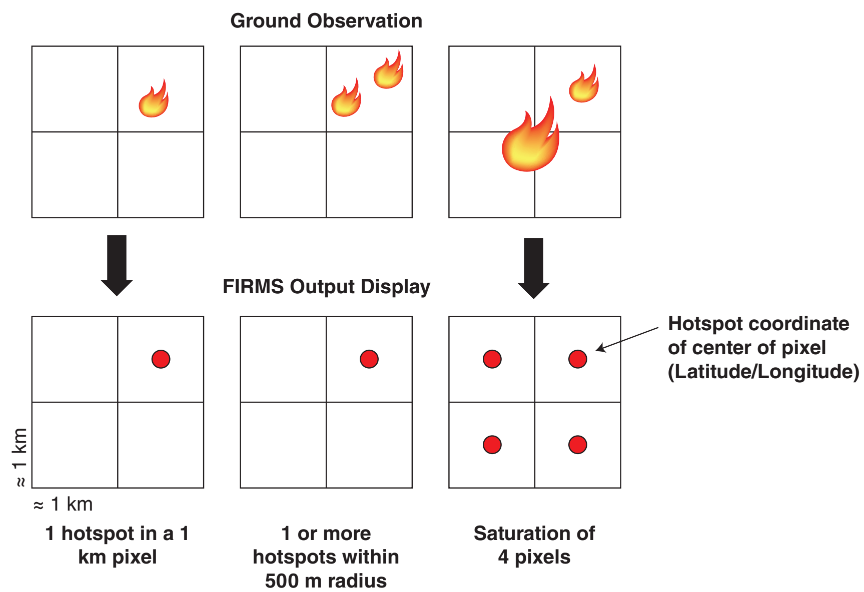

Figure 1: A MODIS-indicated hotspot represents the center of an approximately 1-km^2 (0.4-mi^2) pixel flagged as containing one or more thermal anomalies, which may indicate a fire. The hotspot "location" is the center point of the pixel, which is not necessarily the coordinates of the actual thermal anomaly. **Image credit:** NASA FIRMS

"We are an additional source for fire information," Davies says. "Quite often, [our email notification] might be the first time people have heard about a fire in their area, or they've heard about a fire and they didn't know where it was. So having the approximate coordinates [of the fire] gives them a good idea of where they should be looking."

Through FIRMS, users can interactively view and search fire/hotspot data for the past 24 to 48 hours, and for the past seven days (*earthdata.nasa.gov/data/near-real-time-data/firms*)—see **Figure 2**, next page. In addition, users can search the entire MODIS fire/hotspot data archive using the FIRMS MODIS Fire Archive Download tool (*earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data#tab-content-6*). The Fire Archive Download tool provides access to NRT data processed through LANCE and replaces this NRT data with data extracted from the standard MODIS fire products (these are science-quality products created using the best available ancillary, calibration, and ephemeris information) as they become available. Users also can sign up to receive automated *Fire Email Alerts* for their geographic areas of interest (*earthdata.nasa.gov/data/near-real-time-data/firms/fire-email-alerts*).

Accessing FIRMS Data

To start using MODIS fire data available through FIRMS, visit the Earthdata FIRMS NRT webpage at *earthdata.nasa.gov/firms*. From this webpage, users can:

- Download recent and historic global MODIS fire locations in a variety of file formats;
- sign up to receive FIRMS Fire Email Alerts;
- interactively browse daily global MODIS fire locations and monthly burned areas through Web Fire Mapper; and
- view and download global 10-day fire maps and monthly composite animations by year.

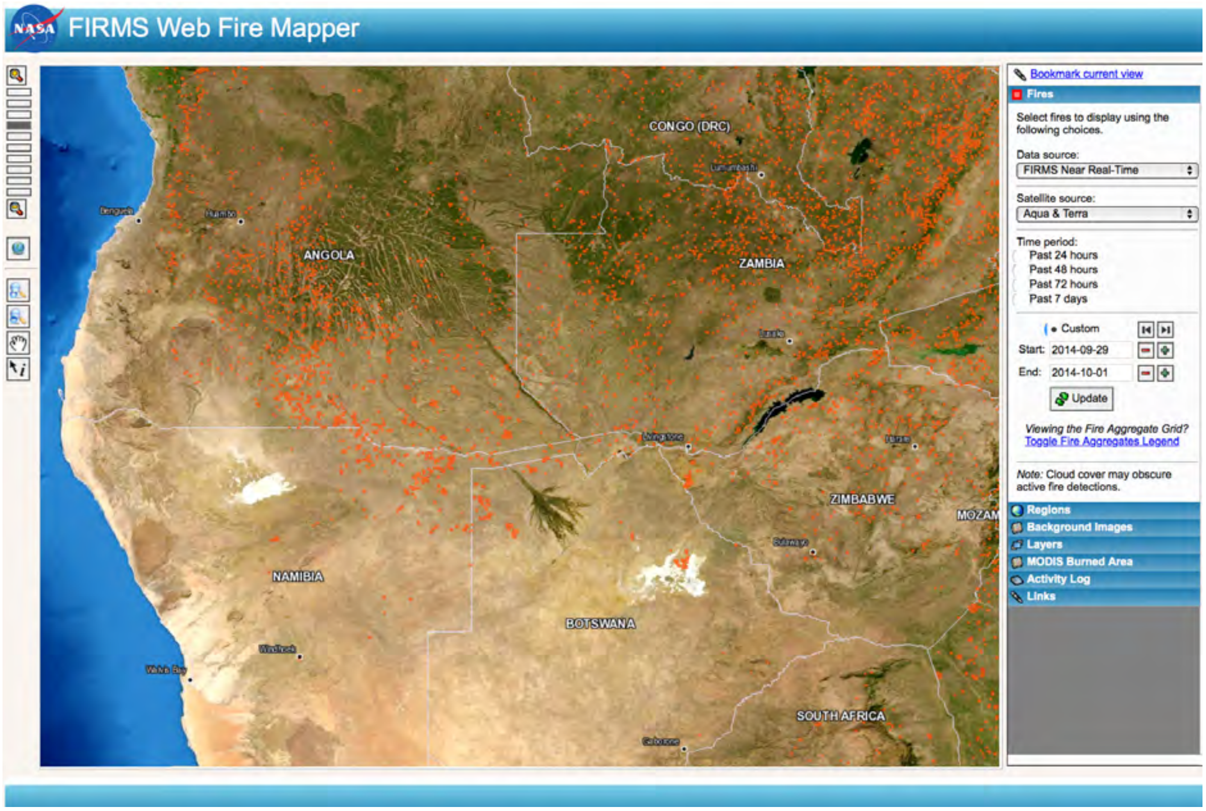

Figure 2: Each of the red dots scattered throughout Angola and Zambia and in northern Namibia and Botswana on this FIRMS Web Fire Mapper image indicates a hotspot or thermal anomaly detected by the MODIS instrument, which may be a wildland fire. **Image credit:** NASA LANCE

Along with MODIS, NRT products are available for the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) onboard Aura and for the Atmospheric Infrared Sounder (AIRS) onboard Aqua. New NRT products for the Advanced Microwave Scanning Radiometer 2 (AMSR2) instrument on the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission-Water (GCOM-W1) satellite soon will be added. The wealth of NRT data available through LANCE can be viewed as browse imagery using the NASA *Worldview* interactive interface (*earthdata.nasa.gov/worldview*) and downloaded after registering at the EOSDIS User Registration System (URS) website at *urs.earthdata.nasa.gov*. As part of NASA's Open Data Policy[3], LANCE data are available to users around the world.

Along with MODIS, NRT products are available for the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) onboard Aura and for the Atmospheric Infrared Sounder (AIRS) onboard Aqua.

It is important to note that NRT products are not intended to take the place of standard data products, and geolocation is based on predictive rather than definitive satellite orbit information. This, in turn, could lead to small differences—generally less than 100 m (328 ft)—between an indicated hotspot and its actual location on the ground. Davies notes that in some instances, such as during spacecraft maneuvers or space weather events, the differences between an indicated hotspot and its actual location can increase by several kilometers. Nevertheless, the benefits of having NRT data, especially for wildland managers, means that decisions also can be made in NRT.

"Using the MODIS imagery, you can pick out the area that is already burned, which helps because if you know what's burned, and you know where the hotspots are, and you have an idea of the wind direction, this helps with your strategic fire planning," Davies says. "It also helps because they might be able to see the smoke and estimate

[3] NASA promotes the full and open sharing of all data with the research and applications communities, the private sector, academia, and the general public. For more information, visit *science.nasa.gov/earth-science/earth-science-data/data-information-policy.*

the relative thickness of the smoke, which is helpful if they're trying to fly in or do aerial fire management." (See **Figure 3** for an illustration.)

Today, MODIS and FIRMS are being used to help manage wildland fires around the world. Along with their use by the UNFAO, the U.S. Forest Service uses MODIS fire detection data and maintains public archives of fire data dating back to 2001 through their Remote Sensing Applications Center. LANCE MODIS fire data also are a cornerstone of the Firecast system developed by Conservation International for detecting fires in Peru, Bolivia, Colombia, Madagascar, and Indonesia.

"We have lots of users who *broker* the FIRMS data—i.e., they take the data and add value to it," Davies says. "For example, in India, the Forest Departments in both the Uttar Pradesh and Madhya Pradesh take the data and create their own fire alerts, which they send to mobile phones and distribute via email. In Thailand, the Department of National Parks sends email alerts in Thai to managers at all forest parks. The Vietnam National University recently set up their own version of FIRMS, and the European Union's Joint Research Centre has created a Web client for fire monitoring in protected areas of Africa using data from FIRMS."

Summary

While wildland fires will continue to be an integral component of wildland development and evolution, the NRT MODIS data provided through LANCE coupled with FIRMS products makes it easier to manage these global events and give those living in fire-prone areas around the world more control over the chaos these events can bring. For Davies, FIRMS is a valuable addition to the global wildland fire management toolbox. "We couldn't do what we've done if we didn't have such good data. The demand for the data was there—people need fire information and they need it in real time." ■

While wildland fires will continue to be an integral component of wildland development and evolution, the NRT MODIS data provided through LANCE coupled with FIRMS products makes it easier to manage these global events and give those living in fire-prone areas around the world more control over the chaos these events can bring.

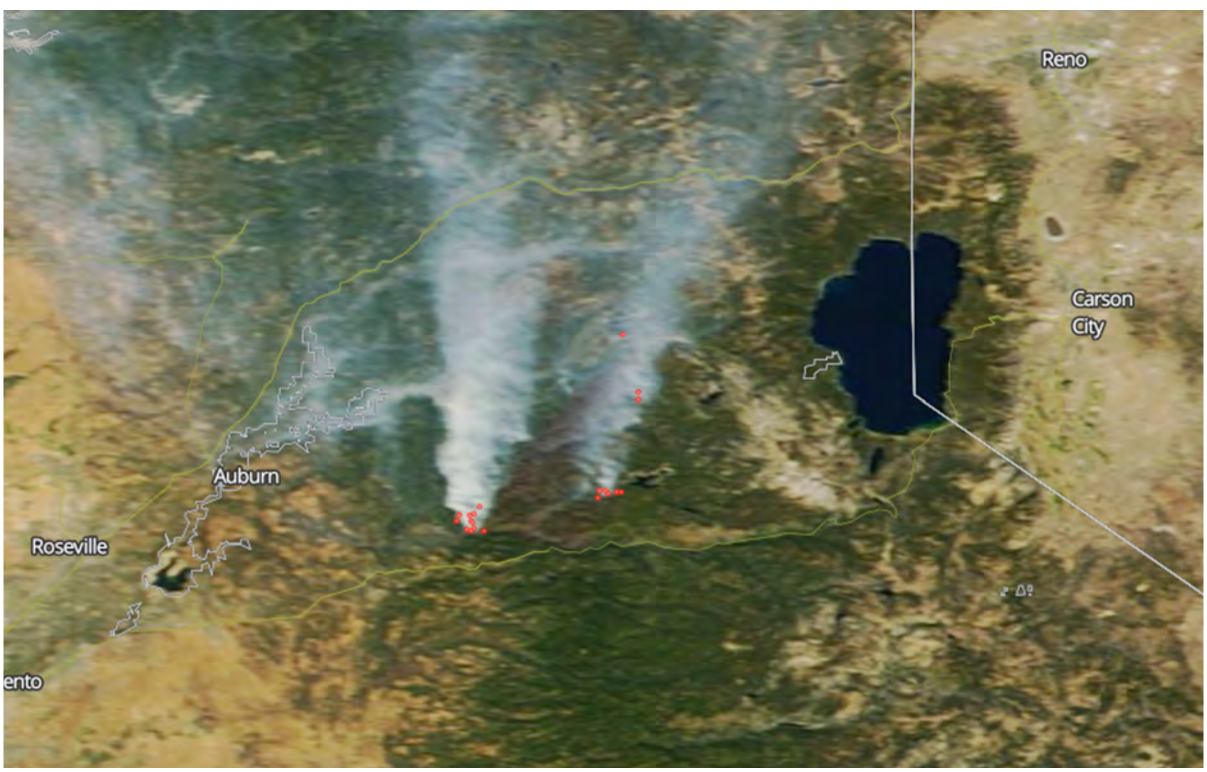

Figure 3: A MODIS image (Corrected Reflectance [*true color*], Terra/MODIS; Fire & Thermal Anomalies [*Day & Night*], Terra/MODIS) of the King Fire in California on September 24, 2014, from the Worldview interactive image browser. Red dots [*left of the center*] are hotspots detected by MODIS. White areas colocated with the hotspots and oriented south to north are smoke. Lake Tahoe is to the right. **Image credit:** NASA Worldview

Nimbus Celebrates Fifty Years

Alan Ward, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., alan.b.ward@nasa.gov

August 28, 2014, marked the fiftieth anniversary of the launch of the Nimbus-1 satellite. Nimbus-1 was the first of seven Earth-observing satellites in a series that spanned 30 years; Nimbus-7 ceased operations in 1995. On October 8, 2014, an event took place at the Visitor's Center of NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD, to commemorate that anniversary.

Introduction

NASA's Earth Observing System (EOS) recently celebrated its twenty-fifth anniversary[1]. For fifteen years, beginning with the launch of Terra[2] on December 18, 1999—the first of three EOS "flagship" missions—a fleet of EOS satellites has been keeping watch over our home planet, making observations of a variety of its characteristics in order to better understand the Earth as a system of interrelated systems. Viewing the situation from this later portion of the "EOS era," when satellite measurements are so commonplace, it is easy to forget that it was not that long ago that this was not the case at all.

One of the Earth-weather satellite programs that played a crucial role in developing many of the technologies that we now take for granted as part of EOS was *Nimbus*. In fact, many of the instruments that have flown or are flying on NASA, National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and other Earth-observing satellites can trace their origins to instruments developed and flown on one or more Nimbus missions.

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This article will summarize this meeting, but before doing so it would perhaps be helpful to reflect on where we were 50 years ago when Nimbus was first conceived.

NASA's Nimbus Program: From Cloud Pictures to Earth Remote Sensing

Nimbus—which in Latin, means "rain cloud"—was conceived as a satellite that would be used for research and development. But in 1960, spurred on by the intriguing images returned from the Television Infrared Observation Satellite (TIROS)—NASA's first step in Earth-examining satellites—there was considerable political pressure to develop a National Operational Meteorological System. John F. Kennedy's famous speech to Congress requesting funds for the Apollo program (May 25, 1961) also included a request for additional funding for the Environmental Satellite Service Administration (ESSA), a forerunner of NOAA, to develop an operational meteorological forecast system. NASA and the Department of Commerce (which included ESSA) subsequently signed an agreement to carry out this plan. For a host of reasons, the partnership lasted only eighteen months before ending. The separation was serendipitous however: As a result, the Nimbus program was eventually freed to pursue the instrument research and science that was originally envisioned for it[3], and ESSA (later NOAA) was free to develop a different operational system. Nimbus would go on to become NASA's experimental meteorological satellite program and the premier Earth research satellite of its era.

[1] The highlights of that history are presented in "The Earth Observer: 25 Years Telling NASA's Earth Science Story" in the March–April 2014 issue of *The Earth Observer* [**Volume 26**, **Issue 2**, pp. 4-13].
[2] To learn more, see "15@15: Fifteen Things Terra Has Taught Us in Its Fifteen Years in Orbit" in the January-February 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 1**, pp. 4-13].
[3] The program was so designated beginning with Nimbus-3 in 1969.

At a press conference held five days after that first Nimbus launch, **William Nordberg**[4] [*Project Scientist for Nimbus-1–3*] said:

> *"The future meteorological satellite programs will move from cloud mapping to measuring parameters of the atmosphere such as temperature profiles, pressure, and winds. We will put all these parameters into a model and run it in a huge computer to grind out the prediction of what the weather is going to be."*

Today, in light of the development of NASA's EOS and other Earth-observing missions, we look back on Nordberg's words as more than prophecy. He essentially outlined the general approach to satellite-based remote sensing—a model that we use today. However, in 1960 people genuinely did not know what was possible. There were many concepts about what might be done from space, but at that time, none of them had been implemented and tested; the ideas awaited development of the appropriate technologies to make them a reality. The Nimbus missions would provide that opportunity.

With many new ideas and innovations arising in this timeframe, only a few people "believed" at the beginning—the so-called *early adopters*; most people waited to see what happened before getting onboard. Such was the case with *satellite remote sensing*—inferring Earth's physical characteristics from the electromagnetic emissions from a planet's surface. In 1960 the technique had been used to study other planets, and a small number of scientists believed that these techniques could be used to study the Earth—but they were a distinct minority.

The Nimbus satellite missions became a testbed to test new technologies and develop satellite remote sensing techniques—see **Table 1** below for a list of Nimbus instruments. With each successive Nimbus launch, more capabilities were developed and Nordberg's prophecy began to be fulfilled—see **Table 2** on page 21.

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[4] Nordberg was a pioneer in satellite remote sensing, having worked on TIROS, and playing a role in the development of Nimbus and the Environmental Research Technology Satellite (ERTS), which became known as Landsat-1.

Table 1. Nimbus Program instrument complement, characteristics, and satellites on which each instrument flew.

Acronym	Instrument Name	Instrument Measurements/ Application	Nimbus
APT	Automatic Picture Taking	High-resolution visible pictures; slow readout	1, 2
AVCS	Advanced Vidicon Camera System	High-resolution visible pictures; full swath coverage	1, 2
BUV	Backscatter Ultraviolet Spectrometer	Atmospheric ozone profile measurements	4
CZCS	Coastal Zone Color Scanner	Ocean color measurements to determine oceanic constituents; ocean temperature; ocean productivity	7
ERB	Earth Radiation Budget	Incoming and outgoing radiation measurements for Earth energy balance studies	6, 7
ESMR	Electrically Scanning Microwave Radiometer	Microwave spectrum radiation measurements; global sea ice concentrations, snowcover, water vapor, and rainfall	5, 6

Table 1. Nimbus Program instrument complement, characteristics, and satellites on which each instrument flew (continued).

Acronym	Instrument Name	Instrument Measurements/ Application	Nimbus
FWS	Filter Wedge Spectrometer	Measure vertical distribution of water vapor and carbon dioxide	4
HIRS	High Resolution Infrared Spectrometer	Full-swath atmospheric temperature profiles	6
HRIR	High-Resolution Infrared Radiometer	Daytime/nighttime global cloud cover—full swath	1, 2, 3
IDCS	Image Dissector Camera System	Daytime cloud cover with slow readout capability	3, 4
IRIS	Infrared Interferometer Spectrometer	Vertical profiles of temperature, water vapor, ozone, and chemical species; interferograms/spectral measurements	3, 4
IRLS	Interrogation, Recording, Location System	Determines platform location, collects data	3, 4
ITPR	Infrared Temperature Profile Radiometer	Atmospheric vertical temperature profiles	5
LIMS	Limb Infrared Monitoring of the Stratosphere	Views Earth's limb; stratospheric temperature, ozone, water vapor, nitric oxide, nitrogen dioxide	7
LRIR	Limb Radiance Inversion Radiometer	Views Earth's limb; temperature, ozone, and water vapor profiles from lower atmosphere to stratosphere	6
MRIR	Medium-Resolution Infrared Radiometer	Measures Earth's reflected and emitted radiation	2, 3
MUSE	Monitor of Ultraviolet Solar Energy	Measures solar radiation not viewed from Earth	3, 4
NEMS	Nimbus Experiment Microwave Spectrometer	Atmospheric temperature profiles in the presence of clouds; multispectral observations producing oceanic humidity and cloud water, sea-ice age, snow depth, and snow accumulation rates over Antarctica.	5
PMR	Pressure Modulated Radiometer	Stratospheric temperature and chemical species	6
RMP	Rate Measuring Package	Demonstration of a gyroscope designed with air bearings	3
RTG	Radioisotope Thermoelectric Generator	Nuclear material electric power generation from nuclear material heat generation	3
SAM-II	Stratospheric Aerosol Measurement II	Map global concentrations of aerosols and optical properties in stratosphere and troposphere	7
SAMS	Stratospheric and Mesospheric Sounder	Gas concentrations and temperature profiles in the stratosphere and mesosphere	7

Table 1. Nimbus Program instrument complement, characteristics, and satellites on which each instrument flew (continued).

Acronym	Instrument Name	Instrument Measurements/ Application	Nimbus
SBUV	Solar/Backscatter Ultraviolet Spectrometer	Measures solar irradiance; ozone profile measurements in lower atmosphere	7
SCAMS	Scanning Microwave Spectrometer	Temperature profiles, oceanic humidity, and rain; global imagery characterizing fronts and hurricanes	6
SCMR	Surface Composition Mapping Radiometer	Earth mapping; identification of surface minerals	5
SCR	Selective Chopper Radiometer	Temperatures of six layers of the atmosphere	4, 5
SIRS	Satellite Infrared Radiometer Spectrometer	Atmospheric temperature profiles	3, 4
SMMR	Scanning Multi-channel Microwave Radiometer	Global sea-ice concentrations and type (age) and sea surface temperatures; sea surface winds; snowcover; soil moisture; atmospheric water vapor over oceans; and rainfall	7
T&DRE	Tracking and Data Relay Experiment	Data transmission from satellite to ground station through a geosynchronous satellite; develops satellite ephemeris through communication link range and range rate information	6
THIR	Temperature/Humidity Infrared Radiometer	Daytime/nighttime global cloud cover and water vapor mapping	4, 5, 6, 7
TOMS	Total Ozone Mapping Spectrometer	Maps of total ozone in the stratosphere and troposphere, sulfur dioxide, and aerosols; volcanic ash cloud tracking	7
TWERLE /RAMS	Tropical Wind Energy Level Conversion and Reference Level Experiment/Random Access Measurement System	Equatorial wind studies; animal tracking; platform locations; data collection; radio frequency reception from up to 200 platforms	6

Table 2. Number of experiments and spectral channels on each Nimbus satellite. Note the growth in the number of electromagnetic spectral regions from Nimbus-1 to Nimbus-7.

Spacecraft	N1	N2	N3	N4	N5	N6	N7
Number of Experiments	3	4	9	9	6	9	9
Number of Spectral Channels	3	8	28	43	34	62	79
Spectral Region:							
• Visible	x	x	x	x	x	x	x
• Infrared	x	x	x	x	x	x	x
• Far Infrared		x	x	x	x	x	x
• Ultraviolet			x	x			x
• Microwave					x	x	x

The unique vantage point of space allowed for continuous and comprehensive observations of the Earth system that were simply not possible without satellites. This clear value notwithstanding, measurements on the ground and *in situ* continue to be an important part of Earth science research to the present day. Satellite observations complement these other observations to give us a more complete picture of the Earth system than could be accomplished separately.

Much of the story of the development of Nimbus has been told in other documents[5] and will not be repeated herein. For 30 years, it was the country's primary remote-sensing research and development platform for Earth science—see *A Summary of Nimbus' Key Achievements* on page 23—and its legacy continues to the present day—see **Figure** on page 24. The multidecadal, multidisciplinary data archives it presaged have been—and continue to be—valuable for Earth science research.

The summary that follows presents highlights from the series of presentations given at the Fiftieth Anniversary Meeting held in October 2014, and is a fitting testament to the impact that Nimbus has had and continues to have on Earth system science as it exists today[6]. Recordings of most of the presentations can be found at *svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=10277*; e-mail *charles.e.cote@nasa.gov* to obtain *PowerPoint* presentations.

*The unique vantage point of space allowed for continuous and comprehensive observations of the Earth system that were simply not possible without satellites. This clear value notwithstanding, measurements on the ground and **in situ** continue to be an important part of Earth science research to the present day.*

Opening Remarks

The meeting opened with remarks by several representatives of organizations that have played major roles in the Nimbus story.

Chris Scolese [NASA's GSFC—*Center Director*] discussed how Nimbus set the stage for many of the Earth system science investigations and missions we know today. He noted that when he was in grade school, an issue of *Weekly Reader* had Nimbus-B on the cover, and as a self-described "space geek," he was captivated by that image. In this and in many other ways, said Scolese, the Nimbus legacy has lasted 50 years and likely will go on for another 50.

Ellen Stofan [NASA Headquarters (HQ)—*Chief Scientist*] reminded the attendees that Nimbus' impact was not limited to Earth science; she had a career as a planetary scientist and the Infrared Interferometer Spectrometer (IRIS) instrument that flew on Nimbus-3 and -4 was also used on seven planetary missions. She also reflected on how Earth science investigations using Nimbus data continue today in a wide range of science disciplines and with huge societal impact. The success of the program was—and is—a tribute to the leadership roles that both NASA and NOAA have played in studying our home planet.

Richard Spinrad [NOAA—*Chief Scientist*] reminded the audience that 50 years ago NOAA did not exist. Its forerunner agencies included the U.S. Weather Bureau and later ESSA. Like NOAA, these agencies worked closely with NASA, and Nimbus was an early shining example of this collaboration. Therefore, there is a long history of cooperation between NASA and NOAA. Indeed, NOAA operations are supported by much of NASA's research. Spinrad pointed out that cooperation continues—e.g., Jason-3[7], Suomi National Polar-orbiting Partnership (NPP), Deep Space Climate

[5] See, for instance, the *Nimbus Program History* (*NP-2014-10-188-GSFC*) written by **Ralph Shapiro** [*Mission Operations Manager for Nimbus 1–7*]. This reference was the basis for the history summarized in the opening section of this article.

[6] A similar event took place to commemorate the fortieth anniversary of Nimbus. The presentations given at that meeting became the basis for a "Nimbus: 40th Anniversary" article on *The Earth Observatory* website, written by **Rebecca Lindsey**. It can be found at *earthobservatory.nasa.gov/Features/Nimbus.*

[7] Jason-3 is a collaborative effort between NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), with contributions from NASA and the French Centre Nationale d'Études Spatiale (CNES). The mission is discussed in more detail in the "Ocean Surface Topography Science Team Summary" on page 41 of this issue.

A Summary of Nimbus' Key Achievements

One of the authorities on the history of Nimbus is **Ralph Shapiro**, who was the operations manager for the Nimbus Program from 1963 to 1981. He is author of the *Nimbus Program History* referred to in this article and has also written a book describing his experience*. When asked to comment on Nimbus for *The Earth Observer*, Shapiro listed some of Nimbus' science achievements. While not intended to be comprehensive, his list does give a sense of the wide range of science that Nimbus instruments were used to investigate. Specifically, Shapiro mentioned:

- Nimbus three-dimensional global datasets of diverse meteorological data, which, for the first time, enabled accurate two-to-three day global weather forecasts to become available, confirmed by the international yearlong First Global GARP** Experiment (FGGE) in 1978-79.
- The Total Ozone Mapping Spectrometer (TOMS) onboard Nimbus-7 validated the presence of a large ozone hole in the Antarctic stratosphere and raised awareness of this public health concern, leading to the Montreal Protocol that banned the use of chlorofluorocarbons (CFCs). This discovery was so significant to human health that a similar satellite ozone-measuring device has been flown continuously on several platforms ever since.
- The ability to locate a device anywhere on Earth using Nimbus instruments demonstrated the efficacy of satellite-based location software that led to the satellite Global Positioning System (GPS) and the ongoing international COSPAS-SARSAT*** satellite system that is used to locate missing boats and downed small aircraft—credited with saving the lives of several hundred people, annually.
- Nimbus instruments provided the initial climatology data for measuring global energy balance that subsequent missions have continued to build upon to the present day.
- Nimbus measured oceanographic characteristics and terrestrial resources, and conducted land mapping, rain, stratospheric chemistry, and polar ice measurements. These data provided many commercial benefits and led to many NASA follow-on satellite programs—see Figure on page 24.

In addition to the science achievements, Shapiro discussed societal benefits deriving from Nimbus. For example, the Nimbus High Resolution Infrared Radiometer (HRIR) provided the first nighttime cloud pictures from space, which enabled alerts about hurricanes developing in the Pacific—at a time when there was no other warning system. Nimbus 1, 2, and 3 carried a high-resolution daytime camera system that downloaded the pictures at a low data rate, which enabled local TV stations to show real-time, high-quality pictures of local overhead clouds and storms—a major public treat at that time.

He also reflected on how Nimbus satellites carried several new technologies that were transferred to later applications. The Radioisotope Thermoelectric Generator (RTG) was the power source for later missions to the planets. The Rate Measuring Package (RMP) was an air-bearing gyroscope used in later space applications requiring low-noise gyroscopes. The Tracking and Data Relay Experiment (T&DRE) instrument was a demonstration of the upcoming system of collecting satellite data by sending the satellite data up to a geostationary satellite that routed the data back down to a NASA data collection site. Versions of the Nimbus-3 and -4 Infrared Interferometer Spectrometer (IRIS) instrument design that measured the Earth's atmospheric temperature, chemical species, and water vapor, later flew on planetary missions: Voyager (to the outer planets—and beyond), Mariner 9 (to Mars), and Cassini (to Saturn).

*The book is titled *From NYC Lower East Side To NASA Satellite Operations Manager* (2012).

**The Global Atmospheric Research Program (GARP) was a fifteen-year international research program that began in 1967 and organized several important field experiments, including the First Global GARP Experiment (FGGE), which later became known as the Global Weather Experiment. Data from these experiments led to significant advances in the field of numerical weather prediction.

***COSPAS is a Russian acronym: Cosmicheskaya Sistema Poiska Avariynyh Sudov, which translates to Space System for the Search of Vessels in Distress; SARSAT stands for Search and Rescue Satellite Aided Tracking.

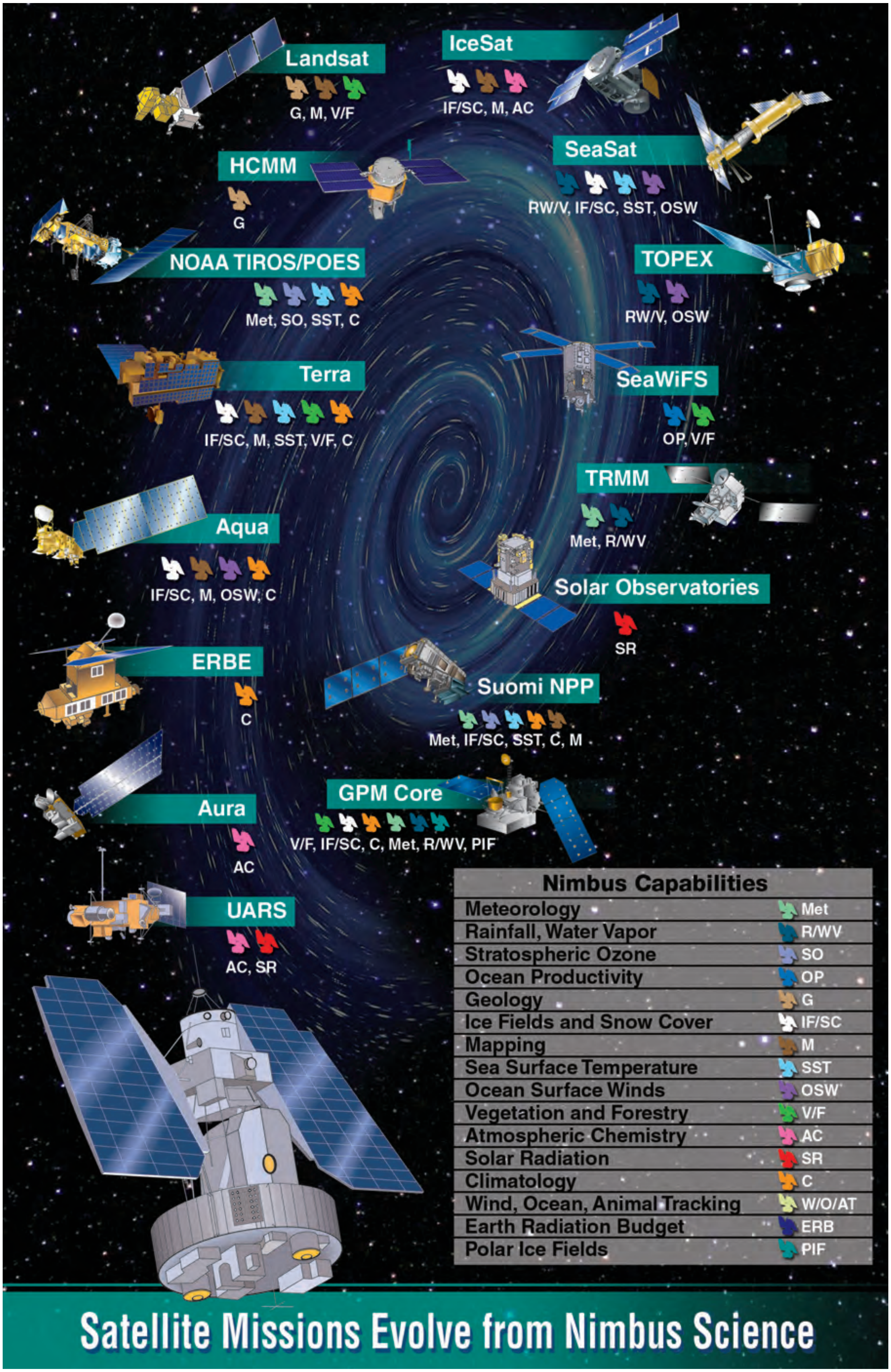

Figure. This graphic gives an idea of some of the many satellite missions, past and present, that can trace their heritage to instruments that flew as part of the Nimbus program. **Image credit**: NASA/Mike Marosy and Jay O'Leary

Observatory (DSCOVR), and the Joint Polar Satellite System (JPSS)—and said that NOAA looks forward to the next 50 years of cooperation with NASA.

Rick Obenschain [GSFC—*Deputy Director*] reflected on his time with the Nimbus Program. He stated that the Nimbus scientists and engineers with whom he worked were true pioneers in remote sensing. When working on Nimbus, he said that, "Each day was an adventure." Obenschain also recognized **Leonard Jaffe** [*Former Associate Administrator for Space Applications at NASA HQ*] who was a strong supporter of Nimbus. Jaffe was not able to attend the meeting, but sent some reflections in a letter that Obenschain summarized. Jaffe, who was responsible for managing the development of many "Applications of Space," credited the Nimbus Program for "…blazing the trail for the GPS satellite and weather forecasting while providing invaluable scientific research in the areas of radiation, ozone, sea ice, and more." He also added that, "People, businesses, and countries that are seeking to develop new technologies or implement technically difficult programs should take time to learn from the experience—and extraordinary success—of early programs like Nimbus."

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*—**Leonard Jaffe** [Former Associate Administrator for Space Applications at NASA HQ]*

Review of Nimbus Firsts and Contributions to Society

After the introductions, **Charles Cote** [GSFC—*Former Associate Chief of the Laboratory for Atmospheres*], who was a principal investigator (PI) for Nimbus-3 and -4 and a co-investigator for Nimbus-6, reviewed the accomplishments of the Nimbus Program, which flew 33 instruments over 7 missions, spanning about 30 years, with each satellite in the series being larger and progressively more sophisticated than the previous one. Cote cited the prophetic words of William Nordberg that appear on page 19. He also spoke about the key role that **Harry Press** [*Project Manager for Nimbus 1–3*] played in advocating to continue the Nimbus Program in the early days, and preserving it as a meteorological satellite program after ESSA dropped out of its short-lived partnership with NASA. Nimbus' multispectral coverage—and microwave observations, in particular—helped scientists track water vapor in the atmosphere even when there was cloud cover, and for the first time made accurate three-to-five day weather forecasts possible.

To illustrate the broad range of Nimbus-based measurements, Cote showed a diagram of the spectral range of each of the instruments on Nimbus-7. He summarized the "Nimbus firsts[8]"—i.e., things achieved for the first time with each successive mission in the series; he also showed a list of societal benefits deriving from Nimbus observations.

Cote also recognized the *Nimbus Program History* document, referenced above, is an excellent source for program history[9], and concluded by recognizing the former Nimbus scientists and support staff who were present at the meeting.

Historical Perspective

Building on Cote's comments, the presentations that follow highlight some of the firsts and benefits he had earlier summarized.

Ron Browning [GSFC—*Goddard Retirement and Alumni Association*] was a project manager for Nimbus-7 from 1976 to 1979; his duties included mission operations and data dissemination for Nimbus-4, -5, and -6, as well as integration, testing, launch, and operations of Nimbus-7. He gave an historical overview of the development of the Nimbus Program, and also noted (as Charles Cote had earlier illustrated) that Nimbus-7 was the first platform to be designated as an environmental monitoring satellite. He then talked about the team that worked on designing Nimbus[10]. Noteworthy names include William Stroud, Rudolf Stampfl, John Licht, Rudolf

[8] Refer to p. 7 and p.16 of the *Nimbus Program History* for lists of these landmark achievements.
[9] Another excellent reference is *Atmospheric Science at NASA: A History* by **Erik J. Conway**, a historian at NASA/Jet Propulsion Laboratory. Chapters 2–3 in particular focus on the development of Nimbus.
[10] This group originally worked together at Fort Monmouth, NJ; they later came to GSFC in 1959 to work on TIROS, and then worked on the "follow-on" mission—Nimbus.

Hanel, William Bandeen, and William Nordberg. Each of these people would go on to play important roles in the development of Nimbus and/or its instruments.

Browning praised the Nimbus Program for having what he described as a very competent team, comprised of representatives from government, industry, and academia, who worked together to design, develop, launch, and operate Nimbus, and release timely data products.

NASA HQ Perspective

Jack Kaye [NASA HQ—*Associate Director for Research of the Earth Science Division*] focused on: *What did Nimbus do for us?* He noted that for the most part, the results equaled—or exceeded—what was planned. Nimbus observations thus provided a path to the future. As the presentation summaries that follow demonstrate, the heritage of EOS instruments—and others outside the aegis of EOS—can be traced back to Nimbus. For many of the now-classic trend observations (e.g., ozone), Nimbus is where it started.

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Kaye also mentioned that, as with most science missions, there were also serendipitous discoveries from Nimbus, and that researchers were able to develop data products that they had not originally anticipated. There were also *combined observations*—where a Nimbus observation was combined with data from another source—which is a key technique to Earth system science observations.

Kaye went on to note that before Nimbus, Earth science disciplines acted largely independently; but after Nimbus things started to become more interdisciplinary. As Nimbus progressed, thanks to significant investments in calibration/validation and focused research efforts by the science community, confidence in the results from satellite observations increased. Because of this work, said Kaye, "We could be sure that if we got the right result from a satellite measurement, it was for the right reason." He also pointed out that the new observing capabilities allowed scientists to begin to "think in three dimensions." In this way, Nimbus set the stage for Earth system science to emerge in the 1980s and laid the groundwork for EOS observations that are being made today. Kaye then went on to discuss a few of the Nimbus instruments not detailed in other presentations, including the Limb Infrared Monitoring of the Stratosphere (LIMS), Stratospheric and Mesospheric Sounder (SAMS), and Stratospheric Aerosol Measurement (SAM-2) instruments on Nimbus-7, and described some of their data products.

In discussing some of his personal involvement with Nimbus, Kaye recalled using Nimbus-7 data to initialize three-dimensional chemical modeling when he first arrived at GSFC in 1983. Later in his career, when he moved to NASA HQ to manage the Atmospheric Chemistry, Modeling and Analysis Program, he recalled receiving a number of proposals to reprocess Nimbus observations, collected years earlier, and study them in more detail. Thus, said Kaye, "I was a Nimbus user and Nimbus enabler."

Weather Forecasting Methodology is Revolutionized

William "Bill" Smith [University of Wisconsin, Madison—*Professor Emeritus*; Hampton University—*Distinguished Professor*] was a former Nimbus PI, whose PhD research advisor was the late Verner Suomi, a scientist who was instrumental in establishing remote sensing by satellites in polar orbit, and for whom the Suomi NPP, launched in 2011, was named. Smith reviewed a list of satellite sounding milestones and listed Nimbus atmospheric sounding pioneers.

He stated that the earliest sounders flew in 1969; these spectral radiometers (or *spectrometers*) took measurements in the infrared region of the spectrum. For the first time, it was possible to produce vertical profiles of atmospheric parameters such as temperature and pressure. Smith mentioned the roles that **Rudolf Hanel** [GSFC] and **David Wark** [NOAA] played in developing IRIS, mentioned earlier, and the Satellite

Infrared Radiometer Spectrometer (SIRS) respectively, both of which flew onboard Nimbus-3 and -4. He showed an example of how SIRS data helped improve weather analysis over the Pacific Ocean: Using the new data for wind forecasts, pilots could minimize fuel consumption when they made trans-Pacific flights.

Smith noted that the earliest spectrometers (i.e., IRIS and SIRS) did not deal well with clouds, so Nimbus-5 and -6 flew *multispectral* radiometers that had very high horizontal resolution, and were able to better discriminate clouds, compared to instruments on earlier satellites. They also added microwave sounders—although these still lacked vertical resolution. Newer instruments (AIRS, AMSU, CrIS, IASI[11]) have moved toward *hyperspectral* measurements—employing thousands of channels. The information content of hyperspectral instruments is three-to-four times greater than that of multispectral measurements. Smith stated that these advances improved weather forecasting to a degree that was almost on par with the invention of the radiosonde.

Smith finished his remarks by showing a diagram of the percent contribution of different observations to forecast error, and explained that the phenomenal five-day accuracy of Hurricane Sandy forecasts in 2012 can be attributed to the use of satellite sounding data. If the information from infrared sounders is left out, the forecast of Sandy's track compared to what came to pass is dramatically different—the storm does not even make landfall. Smith concluded by emphasizing that the Nimbus Program initiated many of the revolutionary advances achieved in weather forecasting during the past 45 years.

Ozone measurements began with the Nimbus-4 Backscatter Ultraviolet Instrument (BUV), but became famous when the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) confirmed large ozone losses over the Antarctic—the so-called ozone hole.

Nimbus and TV Weather

Joe Witte [GSFC/ADNET—*Meteorologist*] spoke about the evolving role of television weather forecasters as more and more satellite information becomes available for use. Informal science education and public awareness of science were both significantly enhanced as a result of Nimbus. Where once the weather report routinely consisted of plastic wall hangings on a magnetic board (he showed a video from a weather broadcast given just after Hurricane Camille in 1969), it now routinely uses satellite images with graphics superimposed upon them. Satellite images too have come a long way; Witte showed an example that was aired on *The Weather Channel* in 1982 and then some examples of what we can do today—e.g., presenting and describing many Earth system components, among them sea ice, sea surface temperature and height, salinity, and ozone. With such information at hand, today's TV weatherperson is also truly a climate educator. Witte stressed that "show me" is a crucial part of informal education, and television weather forecasts can do just that by providing a capability to take people to places they could not otherwise visit—by using satellite imagery. He illustrated this point by showing a recent video of meteorologist **Mike Favetta** of *News12* in the Bronx of New York, NY. Favetta used some NASA images as part of his weather segment, and ended by pointing out to his viewers that, "…education can in fact be inspirational."

Educating the World about Ozone Depletion

Paul Newman [GSFC—*Chief Scientist for Atmospheric Sciences*] is a former Nimbus investigator. He began with a short history of the events leading up to the discovery of the ozone hole. Ozone measurements began with the Nimbus-4 Backscatter Ultraviolet Instrument (BUV), but became famous when the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) confirmed large ozone losses over the Antarctic — the so-called *ozone hole*. A dramatic image was included in the three-volume set, *Atmospheric Ozone: 1985*, that formed the science basis for the Montreal Protocol,

[11] These acronyms respectively stand for: Atmospheric Infrared Sounder (AIRS) and Advanced Microwave Sounding Unit (AMSU) onboard Aqua; Cross-track Infrared Sounder (CrIS) onboard Suomi NPP and planned for the Joint Polar Satellite System (JPSS) series of satellites; and Infrared Atmospheric Sounding Interferometer (IASI) on the European Space Agency's operational meteorology (METOP) series of satellites.

enacted in 1987, whereby signatories committed to eliminating ozone-destroying chemicals—e.g., CFCs.

Newman then went on to discuss the "world avoided" because we enacted the Montreal Protocol. Although Antarctic ozone loss continues and atmospheric concentrations of ozone depleting substances (ODSs) remain high, had we not taken action to ban these substances, two-thirds of the ozone layer would have been destroyed by 2065. He presented some encouraging signs that the protocol is working, as the Antarctic ozone layer appears to now be slowly recovering. Newman ended by stressing the key role of observations from Nimbus-4 and -7 in influencing both the scientific community and the general public, which provided an impetus to take action to ban ODSs.

Today, SARSAT beacons are commonplace—with over 17,000 lives having been saved as a result of this system.

Location and Data Collection Systems

Chuck Cote began by discussing the Interrogation, Recording, and Location System (IRLS), which flew onboard Nimbus-3 and -4. This was long before GPS satellites existed, so there was no real-time capability. He described the IRLS Balloon Interrogation Package (BIP) that was designed to locate and collect data from free-floating, constant-level balloons. Addresses of platforms were programmed into the satellite on an orbit-by-orbit basis from the central ground station, and interrogation commands were transmitted to platforms throughout the orbit. Sensory data could then be transmitted to the satellite for storage and subsequent retrieval from balloon interrogation units, buoys, and other platforms. Position location coordinates were computed for each platform following data readout from each orbit.

Cote then discussed some of the early experiments that were precursors to search and rescue as we know it today, including the Tropical Wind Energy Conversion and Reference Level Experiment (TWERLE) onboard Nimbus-6[12]. TWERLE used randomly transmitted signals from several hundred high-altitude instrumented balloon platforms and thus did not require interrogation commands, thereby reducing the size, weight, and power of platform electronics. He described how TWERLE worked, and showed examples of how it was used to track balloons, animals, and even an aircraft, and showed photos of the equipment. He described a search and rescue operation in which data from TWERLE were used to track and save the lives of three balloonists.

TWERLE was a precursor to the development of a later system, Argos, which Cote explained was developed in 1978 as a partnership between NASA, NOAA, and CNES. Argos also utilizes the random access technique to conveniently locate and deliver data from the most remote platforms to the user's desktop—often in near-real-time. An international operational Search and Rescue (SAR) System evolved between the U.S., France, Russia, and Canada, based on the Argos system. He ended showing a bumper sticker they made with the slogan: *"Support Search and Rescue. Get lost."*

Search and Rescue Satellite Aided Tracking (SARSAT)

Following on Cote's presentation on Nimbus search and rescue activities, **Tim Sinquefield** [NOAA—*SAR Satellite Aided Tracking (SARSAT) Operations Officer*] discussed the current operational SARSAT. Today, SARSAT beacons are commonplace—with over 17,000 lives having been saved as a result of this system. In addition to polar-orbiting satellites, NOAA's Geostationary Operational Environmental Satellites (GOES) now incorporate SARSAT. This gives SARSAT a much larger footprint over Earth and has made response time faster—clearly a benefit to those who need this service! Sinquefield also discussed International Search and Rescue planning, which has grown from the original short list of participants to cover most of

[12] TWERLE was also used for environmental monitoring and was closely associated with the objectives of the GARP and FGGE. To learn more, visit *nssdc.gsfc.nasa.gov/nmc/experimentDisplay.do?id=1975-052A-01*.

the nations of the world. He also described SARSAT's role in national search and rescue programs.

Sinquefield cited a case study of *S/V Wild Eyes*, in which a teenager tried to be the youngest person to circumnavigate the globe in a small sailing vessel. The boat was damaged severely in a bad storm in the remote Indian Ocean, and was about as far from civilization as one could possibly be, with no means of communication other than a distress beacon designed to contact SARSAT—and it worked perfectly!

Sinquefield said that NOAA's weather satellites are now moving beyond their expected service life. A new generation of Medium Earth Orbit Search and Rescue (MEOSAR) receivers are now being deployed on U.S. (GPS), Russian (GLONASS), and European (GALILEO) navigation satellites. Once operational, the new system will have improved accuracy—expected to be within a few meters—and location times that will be shorter than what is possible with the current SARSAT system.

Advancing Understanding of Earth's Fundamental Energy Budget

Herb Jacobowitz [Montgomery College—*Former Chief of Atmospheric Sciences Branch at NOAA*] was PI for the Earth Radiation Budget (ERB) instrument that flew on Nimbus-6 and -7. He began with a discussion of the Earth's radiation budget and the key role it plays in regulating Earth's climate. Early measurements (e.g., from TIROS) provided a low-resolution view of the Earth's radiation budget and intrigued scientists with what might be possible; Nimbus provided the opportunity to test those ideas.

The Medium Resolution Infrared Radiometer (MRIR), on Nimbus-2 and -3, confirmed the early results and greatly expanded our knowledge of Earth's radiation budget. Scientists explored regional Earth radiation budget features—e.g., major deserts, Amazonia, the Sahel, seasonal variations over continents, stratus clouds over the ocean, and differences in radiation budget between the Arctic and Antarctic. While this was a radiometer with five spectral bands that could estimate IR and reflected solar energy, it could not directly measure solar irradiance.

The ERB, which flew on Nimbus-6 and -7, was a more complete Earth radiation budget measurement package that included low-spatial resolution, fixed-position radiometers, and higher-resolution scanning radiometers for measuring Earth radiance, as well as 10 spectral bands for measuring solar irradiance. With these capabilities, ERB made the first high-precision measurements of the direct solar irradiance reaching Earth. Furthermore, the variations (i.e., the standard deviation) in the outgoing infrared radiation estimates used in climate models at the time were found to be twice as high as the values Nimbus-7 ERB was measuring. Based on these findings, models were considerably revised—and their accuracy greatly improved. These results would provide the baseline for the ongoing monitoring of Earth's climate from space; the Earth Radiation Budget Experiments (ERBEs) and Clouds and Earth's Radiant Energy System (CERES) have continued the measurements that ERB initiated[13]. ERB results would also guide development of broader international climate experiments (e.g., the Global Energy and Water Exchanges Project).

Forty Years of Satellite Precipitation Estimates: From Nimbus to GPM

Gail Skofronick–Jackson [GSFC—*Chief of Laboratory for Mesoscale Atmospheric Processes, Global Precipitation Measurement Mission (PMM) Project Scientist*] called Nimbus the "granddaddy" of precipitation measurements. The Nimbus-E Microwave Spectrometer (NEMS), the first microwave-sounding device in 1969, and the Scanning Microwave Spectrometer (SCAMS) on Nimbus-6 in 1975, which provided the first imagery characterizing fronts and hurricanes, were "pioneers" in measuring

The Nimbus-E Microwave Spectrometer (NEMS), the first microwave-sounding device in 1969, and the Scanning Microwave Spectrometer (SCAMS) on Nimbus-6 in 1975, which provided the first imagery characterizing fronts and hurricanes, were "pioneers" in measuring precipitation from space.

[13] The ERBE satellite was launched from the Space Shuttle Challenger in 1984, and separate ERBEs were launched on NOAA-9 in 1984 and on NOAA-10 in 1986. CERES has flown onboard the Tropical Rainfall Measuring Mission (TRMM), now flies onboard Terra and Aqua, and will fly onboard JPSS-1.

precipitation from space. The most recent related launch was the Global Precipitation Measurement (GPM) Core Observatory, launched in 2014, with the GPM Microwave Imager (GMI) and Dual-frequency Precipitation Radar (DPR) onboard. Skofronick-Jackson drew an analogy to medical science, comparing GMI to an X-ray, which covers a swath across the surface, and DPR to a CAT scan, which looks down through layers of atmosphere. She illustrated how the capabilities of microwave radiometers have evolved, by showing that SCAMS had three channels as compared with today's typical radiometer [e.g., on the Tropical Rainfall Measuring Mission (TRMM)], with five channels. The GPM instrumentation adds three more channels, which enhances its observational capabilities considerably over its predecessors.

The Coastal Zone Color Scanner (CZCS) onboard Nimbus-7 was NASA's "proof–of-concept" instrument for studying living marine resources "remotely"—i.e., via satellite…The data changed scientists' perceptions of the ocean, revealing the first-ever global picture of the distribution of marine phytoplankton and ocean productivity.

Skofronick–Jackson ended by showing a photograph from a SCAMS Science Team Meeting in 1977, which showed a group of 22 people, including a number of well-known individuals in the field of satellite remote sensing—including Bill Smith, who spoke earlier. She also showed the first SCAMS images of water vapor and cloud liquid water. (This image was on the cover of *Science* magazine on September 2, 1977.) For contrast, she then showed a photo from the most recent Precipitation Measurement Mission Science Team Meeting (from August 2014), which included 200 scientists, followed by an image showing TRMM mean precipitation averages from 1998 to 2011. Her point was to illustrate how measurement capabilities have dramatically improved in the last 40 years and to show that, particularly with the launch of GPM, precipitation measurement has truly become a global endeavor.

The Oceans and Our Changing Climate

Jeremy Werdell [GSFC—*Research Oceanographer in the Ocean Ecology Laboratory*] described the importance of phytoplankton, the first link in the marine food chain and a key player in the ecology of all marine ecosystems. He emphasized that prior to Nimbus-7, studying global distributions of phytoplankton was highly impractical. In essence, one had to go where the phytoplankton was to study it—which usually meant getting on a ship, with all that that entails. The Coastal Zone Color Scanner (CZCS) onboard Nimbus-7 was NASA's "proof–of-concept" instrument for studying living marine resources "remotely"—i.e., via satellite. There was some resistance in the scientific community because they viewed it as "pretty picture" science, but it became so much more than that; in fact, said Werdell, data records from the CZCS revolutionized oceanography as we know it. The data changed scientists' perceptions of the ocean, revealing the first-ever global picture of the distribution of marine phytoplankton and ocean productivity.

The pioneering work of CZCS enabled much of the ocean color research that continues today. Werdell said that because of the measurements made by CZCS and its successors (SeaWiFS, MODIS, MERIS, VIIRS, and eventually PACE[14]), oceanographers like him can complement their detailed ship-based research with daily, global views of the world's oceans. SeaWiFS, for example, provided unprecedented imagery for studying the transitions between El Niño and La Niña conditions. Furthermore, SeaWiFS demonstrated that it was not only possible to study the ocean using ocean-color satellite instruments, but also land vegetation. MODIS and VIIRS are currently used to continue these studies, and the upcoming PACE mission will enable even more detailed studies of the ocean.

Werdell ended with two examples of how ocean-color satellites are being used to study research topics that are "in the news." First, these satellites have demonstrated how the so-called *ocean deserts*—the least productive regions of the open ocean—appear to

[14] These acronyms respectively stand for: Sea-viewing Wide Field-of-view Sensor that flew onboard GeoEye's OrbView satellite; Moderate Resolution Imaging Spectroradiometer that flies onboard Terra and Aqua; Medium-spectral Resolution, Imaging Spectrometer that flew onboard ESA's Enivsat satellite; Visible–Infrared Imaging Radiometer Suite on Suomi NPP and planned for JPSS; and Pre-Aerosol-Clouds and Ecosystems mission, proposed to fly in the next decade.

be growing in concert with our changing climate. Second, ocean-color satellites have provided invaluable information about the response of the Chesapeake Bay to human activities and natural events. Satellite-based estimates of phytoplankton stocks and community structure have been highly beneficial in these studies.

Closing Remarks

Charles Cote shared the following remarks, prepared by **Ralph Shapiro**.

As I reflect on this occasion celebrating the fiftieth anniversary of the launch of Nimbus-1, I feel blessed to have had the opportunity to be involved with Nimbus for so many years, and contribute to the successful operations that resulted in so many benefits to society. Nimbus set the pathway for NASA, NOAA, and international operational satellite instrumentation that has extended those benefits well beyond what the early "pioneers" that designed Nimbus ever imagined.

The Nimbus Program accomplishments came as a result of those visionaries who conceived the basic Nimbus spacecraft design and of the later scientists who conceived the later Nimbus satellite scientific objectives. The Nimbus Program achievements arose as a result of the Nimbus Team's activities, a dedicated, capable Nimbus Project staff to oversee Nimbus satellite developments, the very competent industry and university team that built the spacecraft and instruments, and the scientists who collaborated to creatively apply the Nimbus instrument data to achieve the many benefits described today.

Cote concluded by thanking everyone who participated in the day's meeting. He thanked the speakers and especially those that helped organize the gathering, including: **Ralph Shapiro**, **Cynthia O'Carroll** and **Trusilla Steele** [GSFC, Office of Communications]; **Mike Marosy**, **Rob Kilgore**, and **Bob Stratzel** [GSFC, Technical Information and Management Services (TIMS)]; **William Hrybyk** [TRAX International]; and **Jay O'Leary** [GSFC—Scientific Visualization Studio (SVS)]. The outstanding efforts of all these people contributed greatly to the success of the celebration. ■

Nimbus set the pathway for NASA, NOAA, and international operational satellite instrumentation that has extended those benefits well beyond what the early "pioneers" that designed Nimbus ever imagined.

HyspIRI Science and Applications Workshop Summary

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Introduction

NASA's Hyperspectral Infrared Imager (HyspIRI), a mission first identified by the National Research Council's Decadal Survey[1] in 2007 as a *Tier 2* priority[2], is being developed to address a specific set of scientific challenges and societal needs as outlined by the intergovernmental Group on Earth Observations (GEO[3]). These needs, which span the role of Earth observations in responding to natural disasters (e.g., volcanoes, wildfires, and drought), water resources management and sustainable development, and public health and biodiversity, grow increasingly critical—particularly under the stresses of a changing global climate. Our understanding of the impacts of climate change and our ability to adapt to these changes can be greatly advanced through data from missions such as HyspIRI, which can support both Earth systems science research and applications.

To address the objectives identified for the mission[4], the HyspIRI community continues to establish, demonstrate, and document a diverse array of capabilities, scientific and instrumentation advances, calibration/validation exercises, and applications development through acquiring and studying *HyspIRI-like* datasets, such as those from airborne instruments: HyTES, PHyTIR, AVIRIS, and MASTER[5]. These datasets simulate data that will be acquired from HyspIRI's two instruments: a visible-to-short-wave-infrared imaging spectrometer (VSWIR), which has 10-nm contiguous bands from 380 to 2500 nm, and a multispectral thermal infrared imager (TIR), which has 8 discrete bands ranging from 3 to 12 µm. The VSWIR and TIR instruments will have a spatial resolution of 60 m (197 ft) at nadir, with a revisit time of 19 days for VSWIR imagery and 5 days for TIR imagery. The HyspIRI mission also includes an Intelligent Payload Module (IPM) that will enable access to a subset of this information for near-real-time applications and needs. In addition, the HyspIRI concept team is engaging with NASA's Sustainable Land Imaging efforts to explore technologies relevant to the future of land imaging.

Meeting Overview

Hosted by NASA/Jet Propulsion Laboratory (JPL), the 2014 HyspIRI Science and Applications Workshop was held October 14-16, 2014, at the Beckman Institute, California Institute of Technology (Caltech), in Pasadena. Approximately 112 people were in attendance, representing a diverse community of research and applications experts, as well as Earth Science Division (ESD) leadership from **Lawrence Friedl** [NASA Headquarters (HQ)—*Director of the Applied Sciences Program (ASP)*]. The presentations from the workshop are available at *hyspiri.jpl.nasa.gov*, and are summarized here.

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

[2] The 2007 Decadal Survey identified three levels, or *tiers*, of priorities for missions. HyspIRI was placed in the second level of priority.

[3] For more information about GEO, visit *www.earthobservations.org*.

[4] These objectives, as well as additional information on the mission,may be found at *hyspiri.jpl.nasa.gov*.

[5] HyTES stands for HyspIRI Thermal Emission Spectrometer (HyTES); PHyTIR stands for Prototype HyspIRI Thermal Infared Radiometer (PHyTIR); AVIRIS stands for the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS); MASTER stands for the Moderate Resolution Imaging Spectroradiometer (MODIS)/Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) airborne simulator.

HyspIRI science and applications meeting participants. **Photo credit:** Scott Nolte

Tuesday, October 14, 2014

Lawrence Friedl and **Woody Turner** [NASA HQ—*Program Manager for Ecological Forecasting and Biological Diversity*] provided a programmatic overview and agency perspective of HyspIRI in the context of research and applications beneficial to society. In addition to discussing the HyspIRI mission, Friedl also discussed the upcoming 2017 Decadal Survey and ways in which HyspIRI can continue to demonstrate its potential for societal benefit and groundbreaking science. Turner also set the tone for the workshop as an opportunity to review HyspIRI activities over the past year, discuss collaborations for 2015, and make preparations for the 2017 Decadal Survey.

Robert Green [JPL]**, Simon Hook** [JPL]**,** and **Betsy Middleton** [NASA's Goddard Space Flight Center (GSFC)] provided technical overviews of the current status of the HyspIRI mission concept (in preformulation).

Michael Mercury [JPL] and **Ernie Diaz** [JPL] were among those who shared results from studies conducted in an effort to simulate or generate HyspIRI-like products, such as the smallsat VSWIR study. This evaluation identified a viable low-cost option for launching a VSWIR instrument into orbit, using the Pegasus *XL* launch vehicle; furthermore, this study found that the smallsat VSWIR could achieve a 30-m (98-ft) spatial resolution with a 16-day revisit.

Other presentations demonstrated the utility of hyperspectral data in investigating pressing global and regional systems topics. **Philip Dennison** [University of Utah] and **Dar Roberts** [University of California, Santa Barbara (UCSB)] discussed the utility of HyspIRI-like data in studying the longterm drought in the Western U.S. **Ryan Pavlik** [Caltech] discussed modeling global plant functional diversity. **Tom Painter** [JPL] described how hyperspectral data can be used to study how black carbon and dust in snow and ice may alter or increase the rate of melting. **Kevin Turpie** [University of Maryland Baltimore County] discussed the use of hyperspectral products in aquatic remote sensing.

Wednesday, October 15, 2014

The second day of the meeting began with a special session on the ECOsystem Spaceborne Thermal Radiometer on the Space Station (ECOSTRESS) mission, which was one of two instruments recently selected through the NASA Earth Venture call[6]. This session included presentations from **Simon Hook**, who will be principal investigator for ECOSTRESS, **Joshua Fisher** [JPL], **Glynn Hulley** [JPL], **Ernie Diaz**, and **Pierre Guellivic** [JPL], and covered topics such as the planned Level 1 and 2 ECOSTRESS data products. These presentations also described the different approaches that will be used to derive evapotranspiration from ECOSTRESS data and how ECOSTRESS can be used for diurnal monitoring of plant stress.

There was also a poster session on the second day, together with additional science presentations. **Ian McCubbin** [Desert Research Institute (DRI)] gave an update on the HyspIRI Airborne Preparatory Campaign. **Meryl McDowell** [Scitor Corporation] and **Fred Kruse** [Horizon GeoImaging] described the use of data from the AVIRIS and MASTER airborne sensors to map surface composition. **Vincent Realmuto** [JPL], **Alexander Berk** [Spectral Sciences, Inc. (SSI)] and **Chona Guiang** [SSI] discussed using TIR data to track volcanic plumes. At the end of the day, Berk and Guiang gave a demonstration of the plume tracker tool described during their presentation.

Thursday, October 16, 2014

The third day of the meeting featured a series of presentations on aquatic remote sensing applications. **Tom Bell** [UCSB], **Joe Ortiz** [Kent State University], and **Eric Hochberg** [University of Hawaii] dicussed assessing kelp biomass, algal blooms, and coral reefs, respectively. **Dar Roberts** also described the status of a special issue of *Remote Sensing of Environment* that focuses on HyspIRI.

Other presentations on the third day discussed the use of HyspIRI-like data for terrestrial applications. **Phil Townsend, Eric Kruger**, **Andrew Jablonski**, **Sean DuBois**, and **Ankur Desai** [all from University of Wisconsin-Madison (UW)], and **Shawn Serbin** [Brookhaven National Laboratory] discussed using hyperspectral observations to study various aspects of ecosystem physiology. **Paul Moorcroft**, **Alex Antonarakis, Stacy Bogan**, and **Paige Kouba** [all from Harvard University] described efforts to link terrestrial biosphere models with spectrometer imagery of ecosystem composition.

The day's afternoon session consisted of presentations describing applications using HyspIRI-like data from AVIRIS and MASTER for wildfire applications. **Natasha Stavros** [JPL] described using hyperspectral data to evaluate megafires[7]; **Sander Veraverbeke** [JPL] discussed using HyspIRI-like data for post-fire environment assessment.

[6] ECOSTRESS was chosen, along with the Global Ecosystems Dynamics Investigation (GEDI), as the winning proposals to the Earth Venture Instrument (EVI-2) solicitation. These two complementary Earth-observing instruments are scheduled to fly on the International Space Station (scheduled for launch in 2018 and 2019, respectively), and will help scientists better understand how forests and ecosystems globally are affected by changes in climate and land-use change.

[7] Megafires occur when multiple fire spots and individual fronts merge and have the following characteristics: very high fire-line intensity, long duration, and large burn area.

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meeting summaries

The South Central and Eastern European Regional Information Network

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Introduction

The South Central and Eastern European Regional Information Network (SCERIN) is an established network of the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) project of the Global Terrestrial Observation System (GTOS). The regional networks perform an essential cross-cutting role in the implementation and integration of GOFC-GOLD's objectives and provide a link between the national/regional agencies and the global user/producer community. The SCERIN network has strong linkages with the Northern Eurasia Earth Science Partnership Initiative (NEESPI), and is well positioned to contribute to the emerging Northern Eurasia's Future Initiative (NEFI) under the auspices of the Future Earth program. The need to establish SCERIN was identified at the 2010 Joint NASA Land-Cover and Land-Use Change (LCLUC) Science Team Meeting and the Northern Eurasia Regional Information Network (NERIN) Workshop, held in Tartu, Estonia. SCERIN was established in 2012, as a sub-network for NERIN, based on existing professional contacts of regional participants, joint research projects, and existing regional networks, including Science for the Carpathians (S4C), EnviroGRIDS, and Food Consumer Science in the Balkans (FOCUS-BALKANS).

The geographic domain of SCERIN encompasses a large region of South Central and Eastern Europe (SCEE), including the Danube, Dnepr, Dniester, Odra, and Vistula watersheds, and the western and southern Black Sea coast—see **Figure 1**. SCERIN strives to ensure continuity of remote sensing data products through collaboration between the scientists, professionals, and existing remote sensing networks in the region. Currently, SCERIN includes scientists and professionals from academia, research and operational agencies, and from observational networks throughout SCEE, including representatives from Bulgaria, Czech Republic, Hungary, Moldova, Macedonia, Poland, Romania, Serbia, Slovakia, Slovenia, Turkey, and Ukraine.

SCERIN Regional Specifics and Goals

The extreme diversity of land forms and environmental conditions typical for the SCERIN region has produced a unique richness and diversity of species that are highly sensitive and vulnerable to climate change. Currently, mainstream research and the established European mitigation policies view the effects of land-use and land-cover changes in parts of the region as low priority and of marginal importance. However, climatic predictions for the SCEE region show higher uncertainties and processes and trends that differ significantly from climatic forecasts for Western or Northern Europe. The decline of vitality and stability of the ecosystems, especially forests, in the SCEE region may trigger extreme events (e.g., droughts, flooding, wildfires) and result in ecological degradation such as soil erosion and aridification, constraints and pressure on sustainable ecological diversity, and extinction of endangered species. Ecosystem degradation also has the potential to negatively impact carbon sequestration and storage processes across the region, diminishing biomass yield and threatening food, fiber, and agricultural production.

Most of SCEE has undergone extensive land-use practices, which have rendered many of the natural processes of adaptation unsustainable. This opens the possibility—and the responsibility—of applying planned, large scale measures (i.e., human initiatives) to support and enhance the natural processes. Extensive land-use changes across SCEE, caused by industrial and mining

Figure 1. Map of the area encompassed by SCERIN. **Image credit:** SCERIN

activities, have been a source of air pollution and acid rain for vast areas of Europe. The air pollution loads, and the associated forest decline, have been especially high in the so called "Black Triangle," encompassing the border regions of Western Czech Republic, Southwestern Poland, and Eastern Germany—see **Figure 2**. During the twentieth century, the region was exposed to two world wars and a "Cold War," during which the ruling governments neglected environmental issues. In compliance with European Union standards, at the end of the twentieth century the pollution loads in SCEE were lowered. As a result, the forest ecosystems are recovering from the effects of acid pollution, thus providing a model area for studying forest growth, decline, and recovery. In addition, the SCEE region is densely populated, and ever-growing urbanization plays an important role in food production and industrial activities. The economic and social restructuring following the political transition since the end of the twentieth century has not reached a stable phase yet, thus considerably intensifying the socioeconomic consequences of land-cover change.

The goals of SCERIN, are to improve cooperation in developing methods for monitoring the dynamics, stability, and vulnerability of the major regional ecosystems of SCEE for future effective sustainable management and preservation, not only on the local but also regional and pan-European levels. SCERIN promotes the production and provision of land surface observations for the satellite data user communities in SCEE. In particular, by working with the regional forest and land management agencies, the group aims to ensure continuous high quality observations and facilitate sustainable natural resources management.

SCERIN has identified the following regional cross-cutting LCLUC thematic areas and priority remote sensing research applications:

- monitoring the effects of drought and other stress factors (e.g., pollution) on vegetation for ecological stability;
- maintaining food, fiber, and agricultural production and security;
- indentifying forest change processes and natural, environmental, and social driving forces; and
- assessing the environmental consequences of urbanization.

To facilitate exchange of data, analytical tools, experience, and ideas, SCERIN initiated regional activities as described in the next section.

SCERIN Workshops and Coordinated Training Initiatives

To date, SCERIN has conducted three workshops to help address regional issues of common interest: the SCERIN Formulation Workshop in 2012, and SCERIN-1 and -2 Meetings in 2013 and 2014, respectively. As a result, a strong SCERIN group has been established, consisting of regional researchers, remote-sensing experts, and professionals from operational agencies. The goals, priorities, and achievements that SCERIN participants outlined during the meetings are described hereafter.

SCERIN Formulation Workshop (2012)

The SCERIN Formulation Workshop took place April 17, 2012, in Sofia, Bulgaria, in conjunction

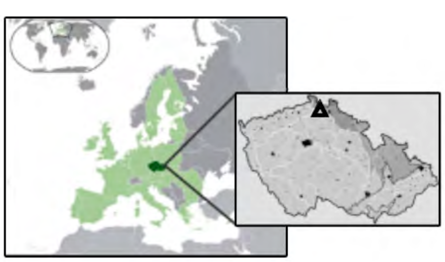

Figure 2: This image pair shows the amount of forest degradation that took place in the Jizera Mountains (Jizerské hory) in the Czech Republic between 1974 and 1992. As the inset maps indicate, this region is located in the so-called "Black Triangle" area of SCERIN, and the damage can largely be attributed to air pollution**. Image credit**: Jana Albrechtova [CU]

with the Annual Meeting of EnviroGRIDS project (*www.envirogrids.net*). The National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences (NIMH-BAS) and its Director General, **Georgi Kortchev**, hosted the workshop. The event was held under the auspices of the GOFC–GOLD program and the SysTem for Analysis, Research and Training (START) program. Forty one participants from Bulgaria, Czech Republic, Germany, Hungary, Macedonia, Poland, Romania, Slovakia, Switzerland, Netherlands, Turkey, Ukraine, and the U.S. presented their current research; discussed the availability of satellite data, products, and approaches for land-cover monitoring in SCEE; and outlined the requirements for land-cover and land-use characterization in the SCEE region. The orignal intent was to form a Southeastern European Network (SEERIN); however, the regional participants at the formulation workshop expressed strong interest in forming a regional network that would include both Southeastern and Central Europe. As a result, the acronym was changed to SCERIN to reflect the expanded geographic coverage of the network.

At this initial workshop, **Petya Campbell** [University of Maryland Baltimore County/NASA], **Jana Albrechtova**, and **Lucie Kupkova** [both from Charles University (CU), Prague, Czech Republic] agreed to coordinate activities for SCERIN.

Finally, regional experts and representatives outlined the following priority objectives for SCEE:

- improve land-cover diversity maps to adequately represent the specific issues and interests for the SCEE region;
- investigate and identify main drivers of land-cover change; and
- monitor vegetation productivity and condition in connection with pollution load, carbon sequestration, and climate change.

For more information about the Formulation Workshop, visit *www.fao.org/gtos/gofc-gold/net-SEERIN_Meetings_Sofia.html*.

SCERIN-1 Meeting (2013)

The first SCERIN meeting (SCERIN-1) took place at Charles University (CU), Faculty of Science, in Prague, Czech Republic, June 17-19, 2013. **Jana Albrechtova**, **Lucie Kupkova,** and **Premysl Stych** [CU] hosted the three-day meeting with the overarching theme "The Current Status of LCLUC Science, Regional Issues, and Future Directions in the SCERIN Region." Forty-three experts from Bulgaria, Czech Republic, Greece, Germany, Hungary, Italy, Norway, Poland, Romania, Turkey, Ukraine, and the U.S. participated in the workshop—supported by START.

The meeting agenda included 32 presentations and discussion topics, organized into five sessions: SCERIN goals and plenary; forest conditions, disturbances, and biomass; land-cover changes; special topics; and organization and formation of two SCERIN focus groups (FG-1 and FG-2, respectively). FG1 would focus on forest monitoring, disturbances, health, and biomass, while FG2 would focus on land-cover changes, agricultural land abandonment, and urban expansion. Specific science questions, formulated by SCERIN's FGs, include:

- What were the land-change effects of institutional change during socialist planning and European Union planning and policies?
- How effective are protected areas at preserving species and biodiversity?
- How have peri-urban areas changed in the post-socialist epoch with regard to issues such as repurposing of industrialized and worker residential areas and sprawl versus intensification?

The goals of the focus groups, as defined at SCERIN-1, are to collaborate on joint projects, review and share the available satellite and *in situ* data and products, and compare the effectiveness of different approaches for land-cover monitoring in SCEE. The conclusions of the workshop included the need to strengthen collaboration and exchange of information on LCLUC and remote sensing research in the region.

The SCERIN-1 workshop also offered a two-day training on "Advanced Classification Methods in Land-Use/Land-Cover Change." Twenty SCERIN students, post-graduates, and early-career scientists attended the training sessions.

For more information about SCERIN-1, visit *csebr.cz/scerin/index.html*.

SCERIN-2 Meeting (2014)

The SCERIN-2 meeting was held June 9-10, 2014 at the Jagiellonian University in Krakow, Poland—supported by START. **Katarzyna Ostapowicz** and **Jacek Kozak** [both from Jagiellonian University, Institute of Geography and Spatial Management] hosted the meeting—see **Photo**. At this regional conference, 51 participants from SCEE and observers from Armenia, Georgia, and Belarus, came together to discuss regional and local issues related to satellite data products, methodologies, and end users. The theme of the meeting was "Current LCLUC Challenges in SCERIN: Addressing Ecosystem Function and Processes," with goals to:

- provide opportunities for the SCERIN FGs to resolve specific issues and actions as requested by the community;

- review the availability of satellite data, products, and approaches for land-cover monitoring in SCEE;
- outline the specific land-cover and land-use change research, applications, and development needs in SCEE; and
- inform participants about ongoing major scientific efforts and projects, with possible contributions and follow-up activities.

The meeting included 36 presentations and discussions led by the participants, and was organized in five sessions that covered: LCLUC in SCEE and ecosystem landscape assessments of grasslands, forests, agriculture, urban landscape, river deltas, and inland wetlands.

In addition to the existing two focus groups, a third focus group (FG3) was established to address validation and verification efforts for current and future NASA missions, e.g., the Hyperspectral Infrared Imager (HyspIRI), Landsat and the Sustainable Land Imaging programs, as well as ESA's Sentinel and Copernicus programs.

The following activities were identified high priority for SCERIN:

- forming new collaborative research projects; and
- further developing regional applications and capacity building.

The capacity-building activities, currently targeted by SCERIN, include regional level comparison and validation of the standard land-cover classification products at moderate (e.g., Landsat, Sentinel-2) and coarse (e.g., MERIS, MODIS, VIIRS[1], and Sentinel-3) resolutions. They also include establishing a regional network of product validation sites and establishing a regional database relating land-cover characterization with spectral and spatial diversity.

For more information about the SCERIN-2 workshop, visit *www.csebr.cz/scerin2014*.

Future Activities and Directions

The SCERIN-3 workshop will be held at Transylvania University of Brasov in Romania, July 13-15, 2015, hosted by **Ioan Abrudan** [Transylvania University of Brasov]. It will be the first SCERIN Capacity Building Workshop (CBW) designed to facilitate discussions between the three SCERIN focus groups.

The objectives of the SCERIN CBW will be to:

- provide a forum for the SCERIN focus groups to resolve specific issues and actions as requested by the community and to enhance capacity building in the region;

[1] MERIS stands for Medium Resolution Imaging Spectrometer, which flew onboard ESA's Envisat satellite; MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies onboard NASA's Terra and Aqua satellites; VIIRS stands for Visible Infrared Imaging Radiometer Suite, which flies onboard the joint NASA-NOAA Suomi National Polar-orbiting Partnership (NPP) satellite.

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Photo. SCERIN-2 meeting participants June 9-10, 2014, Jagiellonian University, Krakow, Poland. **Photo credit:** Jagiellonian University

NASA Earth Science Technology Forum 2014

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Introduction

NASA's Earth Science Technology Office (ESTO)[1] convened the tenth Earth Science Technology Forum (ESTF) at the National Conference Center in Leesburg, VA, October 28-30, 2014. The forum provided principal investigators (PIs) the opportunity to present their work; network with engineers, technologists, and software developers from across the country; and learn about the future needs, development, and infusion opportunities available to the emerging technologies of NASA's Earth Science Division (ESD).

Over 135 attendees from NASA centers, other federal agencies, industry, and academia participated in the two-and-a-half day event to discuss ongoing projects. Each project team was offered the chance to submit an abstract and present their work to the larger community, which included representatives from NASA, the National Oceanic and Atmospheric Administration (NOAA), and private industry interested in the ongoing work of ESTO.

The schedule was organized around various themes in two parallel tracks: instruments and components, and information systems. In total, 70 presentations were given during the conference.

Day One

The ESTF kickoff began with a plenary presentation from **Jack Kaye** [NASA Headquarters (HQ)—*Associate Director for Research*] titled "The Role of Space Observations in Earth System Science: Then, Now, and Later." His talk introduced the forum to NASA's important role of studying the Earth from space in what Kaye referred to as, "the golden age of Earth observation."

Kaye discussed the ESD's guiding documents: the 2007 National Research Council's Decadal Survey[2] and the 2010 *Responding to the Challenge of Climate and Environmental Change: NASA's Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space*[3]. Together, these documents help to delineate the technology needs for future Earth observations—an area where ESTO investments are already making an impact, as became clear during the meeting.

Jack Kaye gives the ESTF kickoff plenary presentation the first morning of the forum. **Photo credit:** Philip Larkin, NASA/ESTO

The data that NASA has collected over the past several decades have led to important research results in various long-term trends and short-term extreme event observations that can be—and are being—used for societally beneficial applications, globally. The work done by NASA-funded technologists and researchers "[helps to enable] a better future for ourselves and the people around the world," said Kaye.

Next, Kaye discussed future needs and opportunities. He encouraged PIs to seek new ways to move their work into a space-based perspective. In particular, he mentioned that Earth Venture missions—such as Cyclone Global Navigation Satellite System (CYGNSS) and Tropospheric Emissions: Monitoring of Pollution (TEMPO)—can provide Earth-observation measurements in less time than the development of a more-typical, at- or near-surface-based NASA Earth Science mission. He also said that there are opportunities to utilize the International Space Station (ISS) as a science platform, and cited the recently launched ISS-Cloud-Aerosol Transport System (CATS) mission as an excellent example of extending ISS-based capabilities.

[1] More about ESTO can be found in "ESTO: Benefiting Earth Science through Technology" in the May–June 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 3**, pp. 22-29]

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

[3] This document is available online at *go.nasa.gov/1uP3RlV.*

Kaye also stressed that as important as such capabilities are, it's not all about satellites and space. Ground-based systems and airborne missions can be used to measure the changing planet in many ways. New and evolving data systems can improve the accessibility, use, application, and visualization of NASA acquired data—areas of importance to ESTO.

Kaye discussed his view of the future (e.g., 15 years from now), and what the needs could be. He sees importance in higher temporal sampling, improved spectral information, increased real- and near-real-time data availability, and increased capabilities in data modeling and visualization. In Kaye's view, despite (or because of) their long history we will still need several things to face the science challenges of the future, e.g., a growing need for access to fresh water; increased partnerships (public and private), data availability, a diverse workforce, and increased citizen science will help to make them possible. Technology can play a large role in addressing these science challenges. Kaye closed by reminding the attendees, "We create our own future. You do that."

After the Forum kickoff and plenary session, the attendees split up to discuss their specific tracks. In the *Instrument and Components* track, sessions were divided into three topics: Clouds, Aerosols, and Precipitation; Temperature, Humidity, and Radiation; and Snow, Ice, and Soil Moisture. In all, 16 presentations were given on the components and instruments under development that could provide data to address these topics.

The *Information Systems* track was divided into two sessions: Data Collection and Handling and Emerging Information Systems Technology Applications I and II. ESTO Advanced Information Systems Technology (AIST) PIs, co-Is, and their partners gave 10 presentations during these sessions.

Day Two

The second day began with one session in each of the tracks. The Instruments and Components track held a session on the topic of Earth Surface and Vegetation, with seven presentations, while the Information Systems track convened a four-presentation session on Data Exploitation and Information Production. After these sessions, there was a mid-morning plenary session, which involved the entire forum.

ESTO projects often test and validate their technologies on aircraft. To help the forum better understand the various airborne platforms available to NASA investigators, **Jeffrey Myers** [NASA's Ames Research Center—*Manager of the Airborne Sensor Facility*] discussed the current capabilities of the Airborne Science Program. Plenary session attendees received an overview of many available platforms, the engineering and payload integration information, and the required administrative details such as flight request procedures and flight readiness reviews. Myers also explained the services that the Program offers, e.g., the use of airborne data networks.

Myers went on to highlight 16 of the available airborne platforms NASA investigators could use, ranging from small, low-altitude, unmanned aircraft like the Sensor Integrated Environmental Remote Research Aircraft (SIERRA), which can carry a 10-lb (4.5 kg) payload, to the large DC-8 that can fly a payload up to 30,000 lbs (13,600 kg). Indeed, NASA has access to aircraft of various sizes capable of flying at many altitudes up to 70,000 ft (21 km) to test new technologies over real-world scenes covering areas of interest such as large lakes, tall columns of air, or carbon-rich environments. In addition to the many aircraft platforms available, the Airborne Sciences Program also has facility systems, such as tracking cameras and precision altitude references, available on loan for approved flights.

Myers detailed the requirements for mounting structures on their aircraft and structural stress analysis. He explained that project teams must work with the aircraft provider to ensure that all NASA airworthiness standards are met. His presentation covered important administrative details on the process of requesting a flight and the procedural requirements throughout the integration and flight process, including flight readiness review outlines and airworthiness review boards. Meyers used a recent ESTO-funded instrument, called the High-frequency Airborne Microwave and Millimeter-wave Radiometer (HAMMR) that flew on a Twin Otter aircraft to detail the process.

The sessions reconvened in the afternoon. The Information Systems track sessions consisted of presentations related to search, access, analysis, and display, while the Instruments and Components group discussed oceans and winds. A total of 17 presentations were given during the afternoon.

A conference-wide Town Hall event was held the evening of day two. **George Komar** [HQ—*ESTO Program Director*] gave an informal talk about ESTO and how the organization fits into NASA's ESD, and the future of technology for better and increased Earth observations.

Komar began his presentation by highlighting one of the priorities of the ESD strategy, to "develop and demonstrate technologies for the next generation of measurements." Before moving on to what technologies are to come, Komar looked at the current Earth-observing missions and the measurements called for in the *2007 Decadal Survey*. He also explained the structure of ESTO and the current budget of the program.

Because the majority of the Town Hall attendees were ESTO-funded PIs, Komar also highlighted how ESTO tracks metrics and successes, so that development teams could better understand the requirements set by program management.

Even with ESTO and ESD successes, there are still challenges that remain. Komar outlined four areas of technology that could improve science measurements in the coming years:

- Active remote sensing technologies to enable atmospheric, cryospheric, and Earth surface measurements;
- deployable instruments (e.g., concept shown in Figure) and components that could enable future weather, climate, and natural hazards measurements;
- intelligent distributed systems using advanced communication, onboard processing, autonomous network control, data compression, and high-density storage; and
- information knowledge captured through three-dimensional visualizations, holographic memory, and seamlessly linked models.

After showing the short video, "NASA Earth Science at 2030: A Vision of the Future," that details the various possible ways Earth science technology could shape the future of scientific discovery, especially related to the four challenges he listed earlier, Komar took questions from the audience. The informal discussion allowed attendees to discuss ways that the two tracks could more closely work together on shared goals to meet NASA's technology needs.

Day Three

The final day of the conference consisted of three sessions: Two Instrument and Component sessions were held, addressing atmospheric composition (consisting of 10 presentations), and a joint Information and Instruments session addressing the importance of enabling synthetic aperture radar (SAR) measurements. This unique session looked at new instrument and information systems technologies that could improve measurements useful for tracking change, such as changes caused by earthquakes.

Summary

Now that ESTF2014 has ended and feedback has been received, enthusiasm is building for the eleventh such event, the ESTF2015 forum. The forum is tentatively scheduled for June 23-25, 2015, at the Beckman Institute at the California Institute of Technology, in Pasadena, CA.

For more information on ESTF2014 and to view all the presentations from the conference sessions, the plenary sessions, and Town Hall events, visit *esto.nasa.gov/forum/estf2014/index.html.* ■

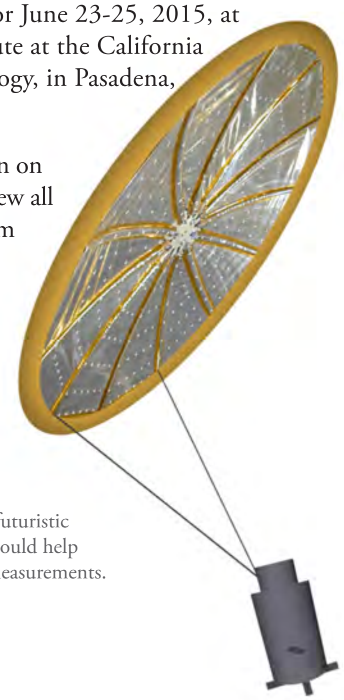

Figure. A rendering of a futuristic deployable antenna that could help collect Earth-observing measurements. **Image credit:** NASA

HyspIRI Science and Applications Workshop Summary

continued from page 33

William Johnson [JPL] showed results PHyTIR, which was designed and developed to support HyspIRI risk-reduction activities.

Daniel Mandl [GSFC] gave a presentation on the status of the IPM. **Byron van Gorp** [JPL]**, Pantazis Mouroulis** [JPL], and **Robert Green** described a new concept for a VSWIR Dyson spectrometer, a novel design based on the use of a plano-convex lens and a concave mirror.

To wrap up the workshop, **Woody Turner**, **Robert Green**, and **Simon Hook** led a discussion about the status of HyspIRI requirements and possible inputs for the 2017 Decadal Survey.

Summary

The workshop demonstrated the utility and diversity of HyspIRI-like datasets to address key Earth systems research and applications topics such as: climate; ecosystems (e.g., global biodiversity, land-use/land-cover change); wildfire impacts and recovery; coastal habitats (e.g., coral reef composition and status); volcanoes; and geology and natural resources. Workshop attendees noted that the unique aspect of a mission such as HyspIRI is its potential widespread utility to address multiple science questions and societal needs. Furthermore, there are numerous research and applications communities that are skilled in working with HyspIRI-like data and able to take advantage of the datasets accessible through such a mission. ■

Ocean Surface Topography Science Team Meeting

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Introduction

The 2014 Ocean Surface Topography Science Team (OSTST) Meeting was held at Lake Constance, Germany, October 28-31. The meeting took place in conjunction with the International Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS[1]) [IDS] and SARAL/AltiKa[2] workshops; all three events were part of the "New Frontiers of Altimetry" congress. The Eighth Coastal Altimetry Workshop (CAW) was held the week before (October 23-24), in the same location.

The primary objectives of the OSTST Meeting were to provide updates on the status of Ocean Surface Topography Mission (OSTM)/Jason-2 (hereafter, Jason-2[3]); conduct splinter sessions on various corrections and altimetry data products; and discuss the science requirements for future altimetry missions. The meeting lasted three-and-a-half days, to accommodate discussions during dedicated roundtables for each splinter session. This report, along with all of the presentations from the plenary, splinter, and poster sessions, are available on the Archiving, Validation and Interpretation of Satellite Oceanographic data (AVISO) website: *www.aviso.altimetry.fr/en/user-corner/science-teams/ostst-swt-science-team/ostst-2014-lake-constance.html*.

Update on Current and Future Ocean Surface Topography Missions

Jason-2 was launched in June 2008 to cover the former ground track of Jason-1 and the Ocean Topography Experiment (TOPEX)/Poseidon mission. All systems on Jason-2 are in good condition and the satellite is operating nominally after six years in orbit. CNES and EUMETSAT have approved the mission to be extended up to 2017 and it is anticipated that NASA will give similar approval during the 2015 Earth Science Senior Review, which should conclude this summer. No major events occurred this year on the platform. Furthermore, the instances when Jason-2 entered *safe hold mode* during 2013 have been better understood, and software patches have been successfully developed and uploaded to avoid similar situations in the future.

There was a major payload event this year, when the Global Positioning Satellite Payload (GPSP)-A[4] experienced an anomaly, which required switching to GPSP-B on September 8, 2014. Some degradation of the GPS performance has been identified from the GPSP-B instrument, which is currently being investigated. However, from a global point of view, Jason-2 continues to collect data that meet all mission and Level-1 science requirements.

Although Jason-2 is performing well, the project requested consideration of an *Extension of Life* (EOL) phase when the risk of losing control of the satellite becomes high. This was one of the key points considered during splinter sessions (as described later), which gave participants the opportunity to express their scientific and/or operational needs.

Jason-3 continues to make progress toward launch. The instruments have been integrated on the Jason-3 spacecraft and the ground system is ready. Development is nominal at satellite, instruments, and ground levels, and the integration is completed. Next steps are the Satellite Qualification Review in November 2014 and satellite final preparation before shipment to Vandenberg Air Force Base (VAFB) in February 2015. At the time of the meeting, the planned launch date remained set for March 31, 2015. However, there were still uncertainties about the NOAA funding needed for the launch (pending enactment of the 2015 Continuing Resolution from Congress)[5]. Since that time, NOAA's funding issues have been resolved and launch is now scheduled for July 22, 2015.

[1] DORIS is a French satellite system used to determine satellite orbits and for positioning. DORIS is onboard Jason-2 (and other satellites), and will be onboard Jason-3 and Sentinel 6/Jason-CS.

[2] The SARAL/AltiKa project is a collaboration between the French Centre National d'Études Spatiales (CNES) and the Indian Space Research Organization (ISRO). SARAL stands for Satellite with Argos and AltiKa. Argos is a satellite-based system that collects, processes and disseminates environmental data from fixed and mobile platforms worldwide that can locate the source of the data anywhere on Earth (*www.argos-system.org/?nocache=0.10773899871855974).* AltiKa is an innovative K_a-band altimeter that flies onboard SARAL.

[3] Jason-2 is a joint mission involving NASA, the U.S. National Oceanic and Atmospheric Administration (NOAA), French Centre National d'Études Spatiales (CNES), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

[4] Like many satellite instruments, GPSP has redundant electronics. There is an "A-Side" and "B-Side."

[5] **UPDATE**: Since the OSTST meeting, NOAA announced that the March 31 launch date could not be met due to budget constraints and issues involving production and qualification of the new SpaceX launch vehicle by NASA, and that the Jason-3 launch would slip until at least the summer of 2015. At the end of 2014, President Obama signed the FY15 omnibus appropriations bill into law, so Jason-3 now has the funding needed to launch in 2015. The project teams are working hard to resolve the remaining launch vehicle issues, but it is a very positive development that the mission has secured funding.

Jason-CS has been renamed Sentinel6/Jason-CS (following a request of the European Commission) and will continue the Jason series of research and operational oceanography missions. This mission will have a new K_u/C-band radar altimeter, a K/K_a-band passive microwave radiometer, Global Navigation Satellite System (GNSS) equipment, and DORIS as part of its payload. Progress on planning and development of Jason-CS is ongoing. As recommended by the OSTST in previous meetings, an interleaved altimeter mode is now the baseline for the mission, which will simultaneously provide both low-resolution mode (LRM) and high-resolution synthetic aperture radar mode (SARM) data. In addition, implementation of a radiometer with long-term stability (likely to be maintained with an onboard calibrator) is now also included in the baseline mission, as recommended by the OSTST. The OSTST expressed its appreciation for the responsiveness of the Jason-CS project in all of these instances. Securing funding for Jason-CS remains a significant hurdle and is now driving the schedule—with launch unlikely before 2020.

Highlights from Opening Plenary Session

At the beginning of the session, **Lofti Aouf** [Météo-France] made a dedication to his former colleague **Jean-Michel Lefevre** [Météo-France], who passed away on April 5, 2014. Lefevre was a great scientist with exceptional communicative good humor. He was among the first in the adventure of altimetry and its application for wave studies. His death is a great loss to the oceanographic community and in particular for the waves research community.

There were five keynote presentations given during the Opening Plenary Session.

The first two keynote presentations addressed sea level initiatives for both NASA and the European Space Agency (ESA). **Steve Nerem** [University of Colorado, Boulder] gave an overview of the activities of the NASA Sea Level Change Team (N-SLCT), and **Benoit Meyssignac** [Laboratoire d'Études en Géophysique et Océanographie Spatiales (LEGOS)], reported on behalf of **Gilles Larnicol** [Collecte Localisation Satellites (CLS)], on two decades of global and regional sea level observations from ESA's Climate Change Initiative Sea Level Project. The three other keynotes served as introductions to the three *Science Results from Satellite Altimetry* splinter sessions: **Dean Roemmich** [Scripps Institution of Oceanography] reported on the development of the Deep Argo Program; **Ruoying He** [North Carolina State University] described the impact of mesoscale eddies on the Gulf Stream and shelf ecosystem in the southeastern U.S.; and **Stephane Calmant** [LEGOS] discussed using satellite altimetry over rivers (from data processing to thematic applications—with focus on the Amazon basin).

In addition to the five keynotes, **Lee-Lueng Fu** [NASA/Jet Propulsion Laboratory (JPL)] presented a progress report on the Surface Water and Ocean Topography (SWOT)[6] mission, highlighting some of the challenges to be addressed by the OSTST community through creative modeling and analysis. SWOT will observe ocean surface topography at unprecedented spatial resolution with moderate temporal resolution. The science requirement of the mission has been developed by its Science Definition Team, of which the successor is to be formed in the near future to support the mission through its planned launch in 2020.

Highlights from Splinter Sessions

Following the opening plenary session, focused splinter sessions were held on the following topics:

- Precise Orbit Determination;
- Near-Real-Time Products and Applications and Multi-Mission, Multi-Sensor Observations;
- Tides, Internal Tides, and High-Frequency Processes;
- Regional and Global Calibration/Validation for Assembling a Climate Data Record;
- Science Results from Satellite Altimetry;
- Instrument Processing;
- Outreach, Education, and Altimetric Data Services;
- The Geoid, Mean Sea Surfaces, and Mean Dynamic Topography; and
- Quantifying Errors and Uncertainties in Altimetry Data.

In a manner similar to what was done with Jason-1 and -2 after the Jason-2 launch in 2008, Jason-3 will fly in formation with Jason-2 along the same ground track, within about 60 seconds of each other. This will allow biases between the missions to be carefully measured and understood, preserving the integrity of the long-term sea-level record. There was a good deal of discussion about what the duration of this *cross-calibration* mission should be. **Eric Leuliette** [NOAA's Satellite Oceanography and Climatology Division] gave a presentation in the *Quantifying Errors and Uncertainties*

[6] SWOT was identified as a *Tier 2* mission in the National Research Council's 2007 Earth Science Decadal Survey, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, which provided the basis for the future direction of NASA's space-based Earth observation system. The mission brings together two traditional separate research areas to develop a better understanding of the world's oceans, it terrrestrial surface waters, and the interplay between them.

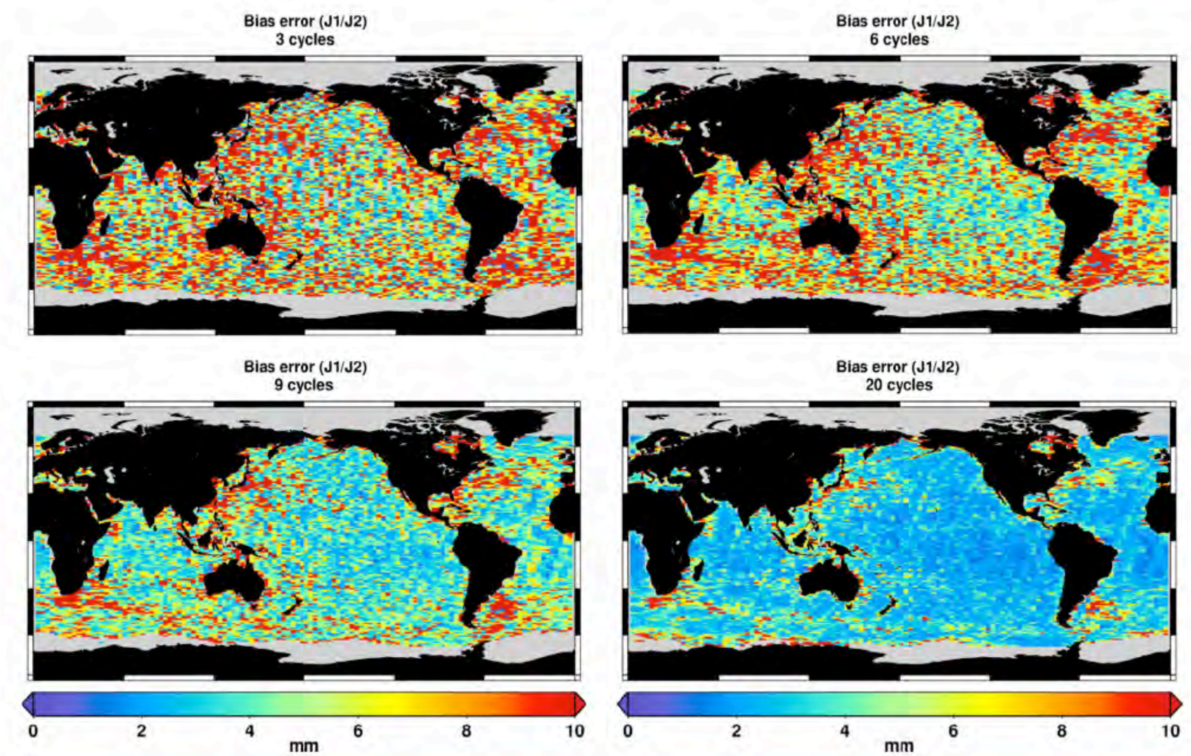

Figure 1. Local bias errors between Jason-1 and OSTM (Jason-2) after 30 days [*upper left*], 60 days [*upper right*], 90 days [*lower left*], and 200 days [*lower right*]. Only after six months was it possible to reduce the bias to approximately 2 mm (0.1 in). **Image credit:** Eric Leuliette

in Altimetry Data session, during which he suggested that in order to remove geographically correlated errors, the cross-calibration mission needs to last at least six months—as was the case with Jason-1 and -2 (see **Figure 1**).

In the *Science Results from Satellite Altimetry* splinter, several of the results presented focused on global sea level rise and ocean warming. **William Llovel** [JPL[7]] presented results based on a combination of satellite altimetry observations, ocean mass changes from the twin Gravity Recovery and Climate Experiment (GRACE) satellites, and warming in the upper ocean, as observed by the Argo Array of profiling floats. Subtracting these three, Llovel and his colleagues found that little to no sea level rise could be attributed to warming in the deep ocean, below 2000 m (1.2 mi)—see **Figure 2**.

Also in the same splinter session, **Ben Hamlington** [Old Dominion University] presented results obtained using altimeter data to separate out the portion of regional sea level rise over the past 20 years that can be attributed to human activities from those that can be attributed to natural variations. Hamlington found

[7] Llovel is no longer at JPL, but he was at the time of this meeting.

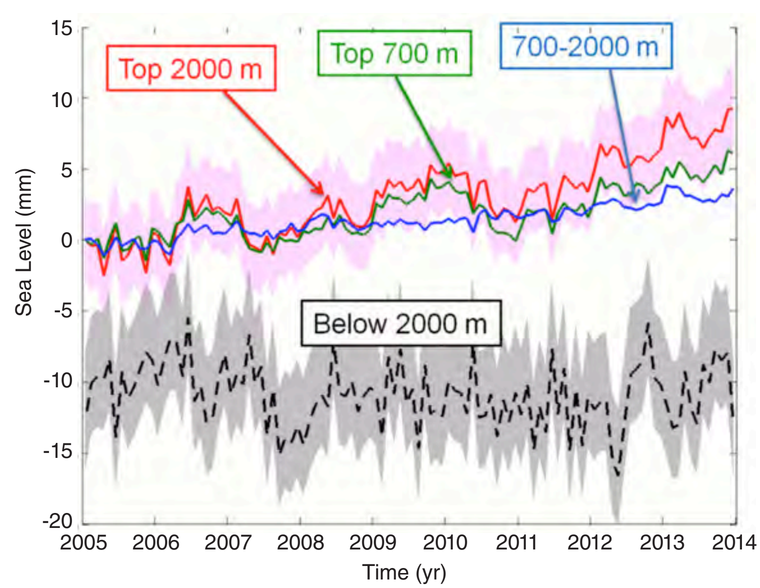

Figure 2. Global sea level rise due to thermal expansion in different layers of the ocean (red: top 2000 m (1.2 mi); green: top 700 m (0.4 mi); blue: 700 to 2000 m (0.4 to 1.2 mi); dashed black: 2000 m (1.2 mi) to bottom). Pink and medium gray bands represent uncertainty. Note that the deep ocean shows little to no long-term trending, suggesting that modern day deep warming contributes almost nothing to global sea level rise. **Image credit**: William Llovel and colleagues

that after removing changes in Pacific sea level variability that could be attributed to the slowly changing Pacific Decadal Oscillation (PDO), a significant amount of regional sea level rise in the western Pacific still remained. A comparison with a simulation using the NASA Seasonal-to-Interannual Prediction Project (NSIPP) Atmospheric General Circulation Model (AGCM), a climate model, suggested that this pattern of sea level rise might be linked to human activities—see **Figure 3**.

Highlights from the Closing Plenary Session

There were two keynote presentations during the closing plenary session, given by groups of new, emerging scientists. In the framework of the CNES Argonautica project (*www.cnes.fr/web/CNES-fr/7161-argonautica.php*) two groups of students were selected to present their results. The first group, representing **Collége Esquinance**, a middle school in Réole, France, discussed "The Plastic Islands in the Atlantic Ocean." They described their analysis of the trajectory of buoys to help find the main sites of aggregation of marine debris in the Atlantic. The second group was from **Lycée Alexis Monteil**, a high school in Rodez, France; they discussed their "Théthys Investigation in the Mediterranean Sea." Théthys is the third satellite-driven buoy that these students have created to help them study the Ligure current[8].

In addition to the two keynote presentations, participants heard summaries of each of the splinter sessions and of the two other meetings mentioned in the introduction to this report. **Paolo Cipollini** [National Oceanography Centre—U.K.] reported on the Eighth Coastal Altimetry workshop, and **Jacques Verron** [Laboratoire de Glaciologie et Géophysique de l'Environnement—France] gave a summary of the SARAL/AltiKa workshop, which took place concurrently with the OSTST Meeting.

The meeting ended with an update on the status of reprocessing. **Phil Callahan** [JPL] discussed the TOPEX Reprocessing and update to geophysical data record[9] (GDR)-C standards. The current plan is to generate a new retracked GDR, consistent with GDR-C processing, which should become available in early 2015. **Nicolas Picot** [CNES] discussed the current GDR status for Jason-1 and -2. Plans to reprocess Jason-1 and -2 data to a new GDR-E standard are underway, and Jason-1 reprocessing will start in early 2015. An upgrade for SARAL/AltiKa products is also foreseen in 2015. For the calibration/validation phase, Jason-3 will be based on GDR-D standard with orbit in GDR-E, fully inline with Jason-2 standard. The next product version will be defined after the calibration/validation phase.

It was also noted during the closing plenary session that the ongoing accuracy of globally averaged sea level as observed by the Jason series of altimeters is partly maintained and verified by the global tide gauge network. This had been a point of discussion during the *Regional and Global Calibration/Validation for Assembling a Climate Data Record* splinter session—and the science

[8] The Ligure Current is located in the Mediterranean Sea between the Italian Rivera and the island of Corsica.

[9] A geophysical data record (GDR) refers to a fully validated data product that uses a precise orbit and the best environmental/geophysical corrections. The -C, -D, and -E, refer to different releases, each using more updated processing techniques than the previous, to make the datasets more consistent.

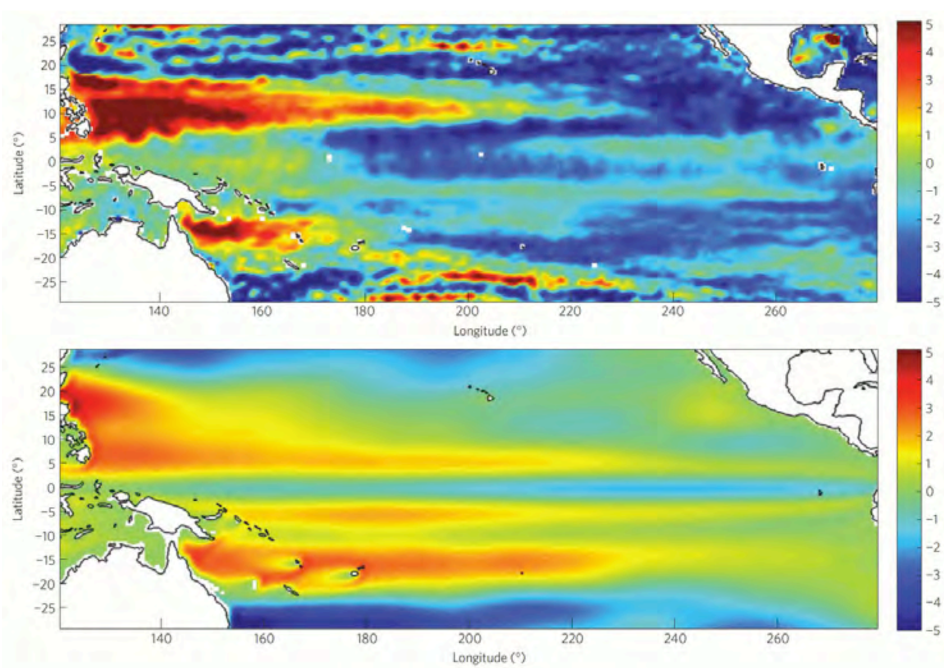

Figure 3. Sea level trends in mm/yr with natural decadal variability (i.e., the Pacific Decadal Oscillation) removed. The top panel shows observed trends; the bottom panel shows modeled trends. Note the rapid rise near the equator in the Western Tropical Pacific. This analysis suggests this rise is related to human-caused contributions to climate change. **Image credit:** Ben Hamlington and colleagues

team noted that cross-agency efforts are needed to maintain the global tide gauge network, and to colocate GPS stations to detect ground motion at many key tide gauge locations.

During the closing plenary session, the OSTST adopted the following recommendations and expressed its appreciation for the following accomplishments:

- Approval of extended funding for Jason-2 up to 2017;
- SARAL/AltiKa fast delivery of high-quality data products to the community; and
- recognition by the agencies of the ongoing need to continue processing Jason-1 and TOPEX/Poseidon data.

To close, the OSTST made the following recommendations:

- A Jason-2 Extension of Life Working Group should be re-established to consider different options for science given operational limitations, which must be provided by the agencies.
- Continuity being of the utmost importance, the participating space agencies should strive to maintain the current launch date of Jason-3.
- The participating space agencies should strive to avoid further slippage of the Jason-CS launch date to ensure that there is overlap with the expected five-year lifetime of Jason-3.
- Move Jason-2 to an interleaved orbit with five-day delay (as for Jason-1) after six months of formation flight with Jason-3.

Conclusion

Overall, the meeting fulfilled all of its objectives, providing a forum for an update on the status of Jason-2 and other relevant missions and programs, along with detailed analyses of the observations by the splinter groups. The OSTST looks forward to a successful launch of Jason-3 in 2015 and will reconvene the week of October 19-23, likely somewhere in the vicinity of Washington, DC. ■

The South Central and Eastern European Regional Information Network

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- address SCEE priority topics, focusing on remote sensing in forest management and administration, monitoring of protected areas, and assessment of forest disturbance;
- review the requirements and availability of satellite data, products, and approaches for land-cover monitoring in SCEE;
- outline the specific land-cover and land-use change research, applications, and development needs in SCEE; and
- inform participants about ongoing major scientific efforts and projects, with possible contributions and follow-up activities for SCERIN participants.

Specific research topics of high regional interest to be discussed at the SCERIN CBW include forest dynamics and tree line evolution in pasture lands, based on Landsat archives, and forest insects attacks detection and monitoring, which is of increasing importance in the context of climate change.

The SCERIN-3 CBW will include a day of training for graduate students and early-career professionals.

Conclusion

The SCERIN framework provides a platform for collaboration among remote sensing experts working on different projects in SCEE. This collaboration is particularly important since it facilitates the progress and consistent implementation of remote sensing and LCLUC methodology in the region. SCERIN activities promote the exchange of multidisciplinary regional expertise from the fields of geographic information systems (GIS), remote sensing, ecology, and ecosystem and plant biology, all needed to study ecosystem processes and LCLUC on local, regional, and continental scales.

There is a need for continued development and support of international collaborations in remote sensing and LCLUC scientific research. SCERIN activities and meetings offer a valid, functional platform for developing professional collaborations and advancing regional remote sensing and LCLUC science. With technological advances in global remote sensing, the need for regional networks, such as SCERIN, will not diminish but, on the contrary, will increase, for regional validation of global remote sensing products and providing feedback to the sattelite agencies and information providers. ■

NASA Satellite Reveals How Much Saharan Dust Feeds Amazon's Plants

Ellen Gray, NASA's Goddard Space Flight Center, ellen.t.gray@nasa.gov

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

What connects Earth's largest, hottest desert to its largest tropical rain forest?

The Sahara Desert is a near-uninterrupted brown band of sand and scrub across the northern third of Africa. The Amazon rain forest is a dense green mass of humid jungle that covers northeast South America. But after strong winds sweep across the Sahara, a tan cloud rises in the air, stretches between the continents, and ties together the desert and the jungle. It's dust. And lots of it.

For the first time, a NASA satellite has quantified in three dimensions how much dust makes this trans-Atlantic journey. Scientists have not only measured the volume of dust, they have also calculated how much phosphorus—remnant in Saharan sands from part of the desert's past as a lake bed—gets carried across the ocean from one of the planet's most desolate places to one of its most fertile.

A new paper published February 24 in *Geophysical Research Letters,* a journal of the American Geophysical Union, provides the first satellite-based estimate of this phosphorus transport over multiple years, said lead author **Hongbin Yu** [University of Maryland, Earth System Science Interdisciplinary Center]. A complementary paper published online by Yu and colleagues in the January 8 issue of *Remote Sensing of the Environment* provided the first multiyear satellite estimate of overall dust transport from the Sahara to the Amazon.

This transcontinental journey of dust is important because of what is *in* the dust, Yu said. Specifically the dust picked up from the Bodélé Depression in Chad,

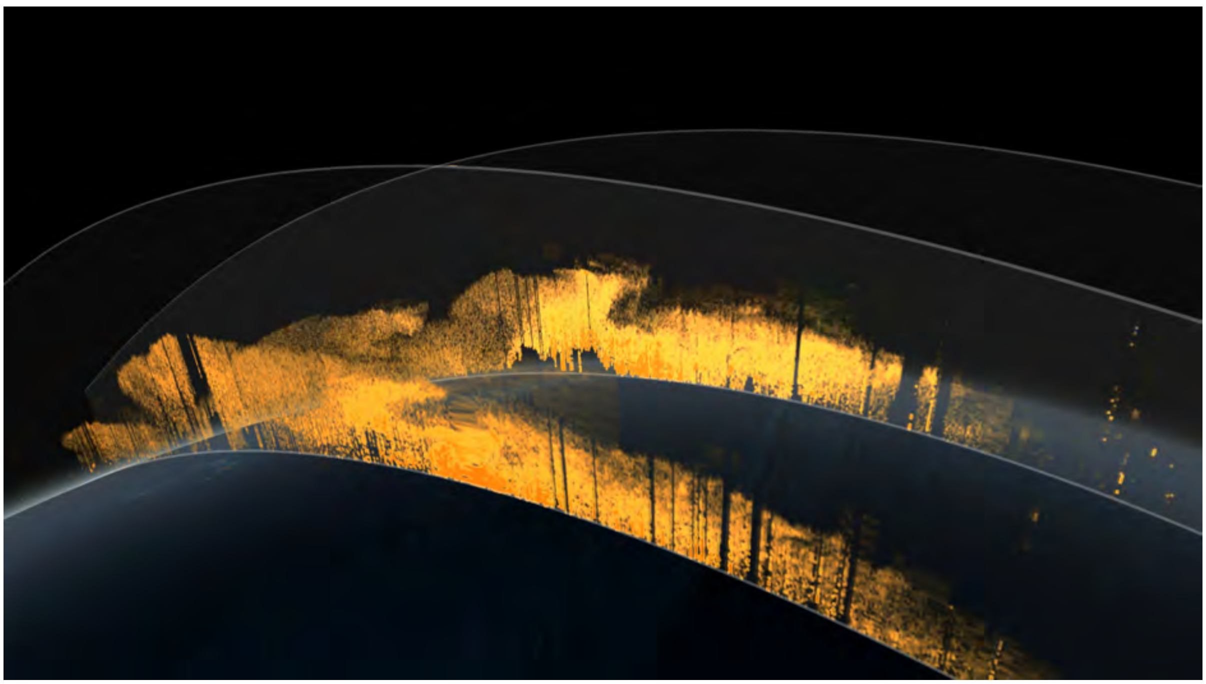

Figure. Shown here is an example of a cross-section, or "curtain," of data from the CALIOP instrument aboard the CALIPSO satellite, which sends out pulses of light that bounce off particles in the atmosphere and back to the satellite. CALIOP can distinguish dust from other particles based on optical properties. **Image credit**: NASA's Scientific Visualization Studio

an ancient lakebed where rock minerals composed of dead microorganisms are loaded with phosphorus. Phosphorus is an essential nutrient for plant proteins and growth, which the Amazon rain forest depends on in order to flourish.

Nutrients (the same ones found in commercial fertilizers) are in short supply in Amazonian soils. Instead they are locked up in the plants themselves. Fallen, decomposing leaves and organic matter provide the majority of nutrients, which are rapidly absorbed by plants and trees after entering the soil. But some nutrients, including phosphorus, are washed away by rainfall into streams and rivers, draining from the Amazon basin like a slowly leaking bathtub.

The phosphorus that reaches Amazon soils from Saharan dust—an estimated 22,000 tons per year—is about the same amount as that lost from rain and flooding, Yu said. The finding is part of a bigger research effort to understand the role of dust and aerosols in the environment and on local and global climate.

Dust in the Wind

"We know that dust is very important in many ways. It is an essential component of the Earth system. Dust will affect climate and, at the same time, climate change will affect dust," said Yu. To understand what those effects may be, "First we have to try to answer two basic questions. How much dust is transported? And what is the relationship between the amount of dust transport and climate indicators?"

The new dust transport estimates were derived from data collected from 2007 to 2013 by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), an instrument on NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite.

NASA recently produced an animation (*svs.gsfc.nasa.gov/goto?11775*) showing that wind and weather pick up on average 182 million tons of dust each year and carry it past the western edge of the Sahara (at 15° W longitude). (This volume is the equivalent of 689,290 semi trucks filled with dust.) The dust then travels 1600 mi (2500 km) across the Atlantic Ocean, though some drops to the surface or is flushed from the sky by rain. Near the eastern coast of South America (at 35° W longitude) 132 million tons remain in the air, and 27.7 million tons (enough to fill 104,908 semi trucks) fall to the surface over the Amazon basin. About 43 million tons of dust travel farther to settle out over the Caribbean Sea (past 75° W longitude).

Yu and colleagues focused on the Saharan dust transport across the Atlantic Ocean to South America and to the Caribbean Sea because it is the largest transport of dust on the planet.

Dust collected from the Bodélé Depression and from ground stations on the island of Barbados and in Miami, FL, give scientists an estimate of the proportion of phosphorus in Saharan dust. This estimate is used to calculate how much phosphorus gets deposited in the Amazon basin from this dust transport.

The seven-year data record, while too short for looking at long-term trends, is nevertheless very important for understanding how dust and other aerosols behave as they move across the ocean, said **Chip Trepte** [NASA's Langley Research Center—*CALIPSO Project Scientist*], who was not involved in either study.

"We need a record of measurements to understand whether or not there is a fairly robust, fairly consistent pattern to this aerosol transport," Trepte said.

Looking at the data year by year shows that that pattern is actually highly variable. There was an 86% change between the highest amount of dust transported in 2007 and the lowest in 2011, Yu said.

Why so much variation? Scientists believe it has to do with the conditions in the Sahel—the long strip of semi-arid land on the southern border of the Sahara. After comparing the changes in dust transport to a variety of climate factors, the one Yu and his colleagues found a correlation to was the previous year's Sahel rainfall. When Sahel rainfall increased, the next year's dust transport was lower.

The mechanism behind the correlation is unknown, Yu said. One possibility is that increased rainfall means more vegetation and less soil exposed to wind erosion in the Sahel. A second, more likely explanation is that the amount of rainfall is related to the circulation of winds, which are what ultimately sweep dust from both the Sahel and Sahara into the upper atmosphere where it can survive the long journey across the ocean.

CALIPSO collects "curtains" of data (see **Figure)** that show valuable information about the altitude of dust layers in the atmosphere. Knowing the height at which dust travels is important for understanding, and eventually using computers to model, where that dust will go and how the dust will interact with Earth's heat balance and clouds, now and in future climate scenarios.

"Wind currents are different at different altitudes," said Trepte. "This is a step forward in providing the understanding of what dust transport looks like in three dimensions, and then comparing with these models that are being used for climate studies."

Climate studies range in scope from global to regional changes, such as those that may occur in the Amazon in coming years. In addition to dust, the Amazon is home to many other types of aerosols like smoke from fires and biological particles, such as bacteria, fungi, pollen, and spores released by the plants themselves. In the future, Yu and his colleagues plan to explore the effects of those aerosols on local clouds—and how they are influenced by dust from Africa.

"This is a small world," Yu said, "and we're all connected together." ■

NASA Science Leads New York City Climate Change 2015 Report

Michael Cabbage, NASA's Goddard Institute for Space Studies, mcabbage@nasa.gov
Leslie McCarthy, NASA's Goddard Institute for Space Studies, leslie.m.mccarthy@nasa.gov

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

The New York City Panel on Climate Change (NPCC) 2015—co-chaired by **Cynthia Rosenzweig** [NASA's Goddard Institute for Space Studies (GISS)]—published its latest report, which details significant future increases in temperature, precipitation, and sea level in New York, NY. The report, titled *Building the Knowledge Base for Climate Resiliency*, can be found online at *onlinelibrary.wiley.com/doi/10.1111/nyas.2015.1336.issue-1/issuetoc*.

The report aims to increase current and future resiliency of the communities, citywide systems, and infrastructure in the New York metropolitan region to a range of climate risks.

The NPCC was founded in 2008 to study the effects of climate change on New York City's five boroughs and surrounding region. As some of the leading Earth scientists in the metropolitan New York area, GISS researchers have been involved in the panel's work since the beginning. The GISS climate model was used in climate projections, and scientists at GISS led the technical team, which analyzed the scientific data and developed the projections.

"The NPCC is a prototype for how federal government scientists and municipal policymakers can work together," said Rosenzweig, who also is affiliated with the Center for Climate Systems Research at Columbia University's Earth Institute, New York. "This collaboration will help ensure that climate science developed for the New York metropolitan region informs and draws from the best available information, positioning residents and planners to confront expected future changes in the most effective way possible."

Increasing temperature and heavier precipitation events, along with sea level rise, are projected by the report to accelerate in the coming decades, increasing risks for the people, economy, and infrastructure of New York City.

Specific report findings about local New York observations and projections include:

- Mean annual temperature has increased a total of 3.4 °F (1.9 °C) from 1900 to 2013 (see **Figure 1**). Future mean annual temperatures are projected to increase between 4.1 and 5.7 °F (2.3 and 3.2 °C) by the 2050s (see **Figure 2**) and between 5.3 and 8.8 °F (2.9 and 4.9 °C) by the 2080s—relative to the 1980s base period.
- The frequency of heat waves is projected to increase from two per year in the 1980s to roughly six per year by the 2080s.
- Mean annual precipitation has increased by a total of 8 in (20 cm) from 1900 to 2013. Future mean annual precipitation is projected to increase between 4 and 11% by the 2050s and between 5 and 13% by the 2080s—relative to the 1980s base period.

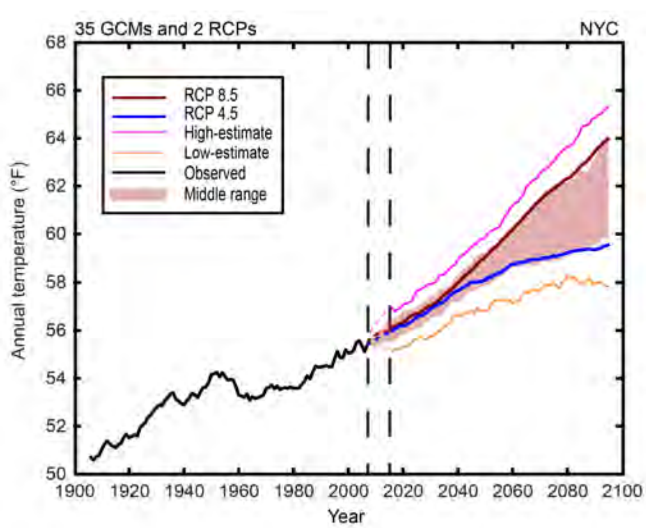

Figure 1. This graph shows the observed and projected temperature in New York, NY, based on the outputs of 32 different global climate models run under two different Representative Concentration Pathways (RCPs). RCPs are four greenhouse gas concentration (not emissions) trajectories adopted for use by the Intergovernmental Panel on Climate Change for use as emission scenarios in its fifth Assessment Report (AR5) in 2014. The four RCPs are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively). **Image credit**: NPCC, 2015

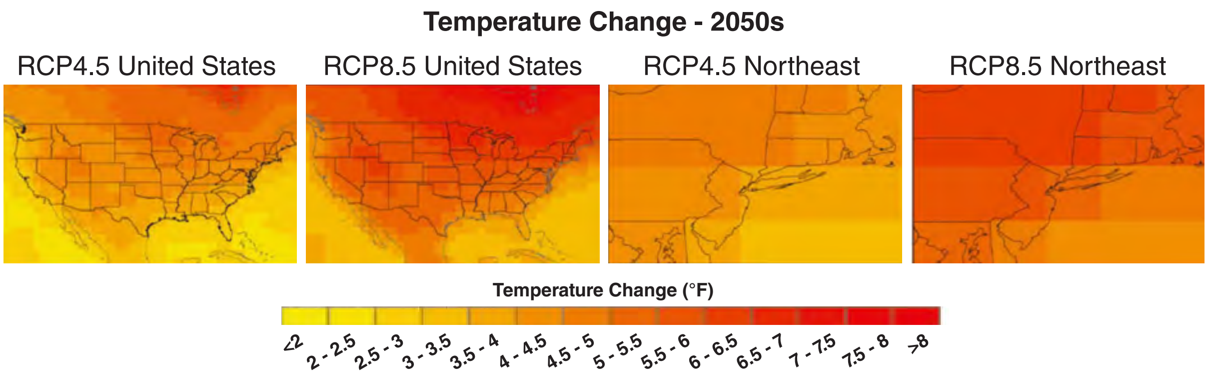

Figure 2. Map of annual temperature changes predicted for the U.S. and for the Northeast U.S. in 2050 for RCP 4.5 and 8.5. **Image credit:** NPCC, 2015

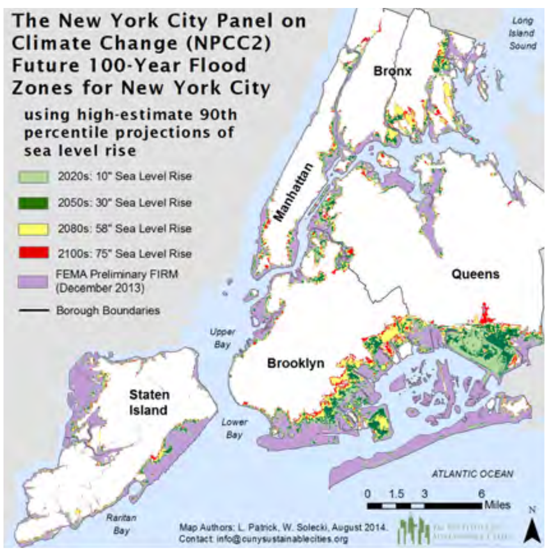

Figure 3. This map shows potential areas that could be impacted by the 100-year flood in the 2020s, 2050s, 2080s, and 2100, in New York, NY, based on the high-estimate 90th percentile NPCC2 sea level rise scenario. **Image credit**: NPCC, 2015

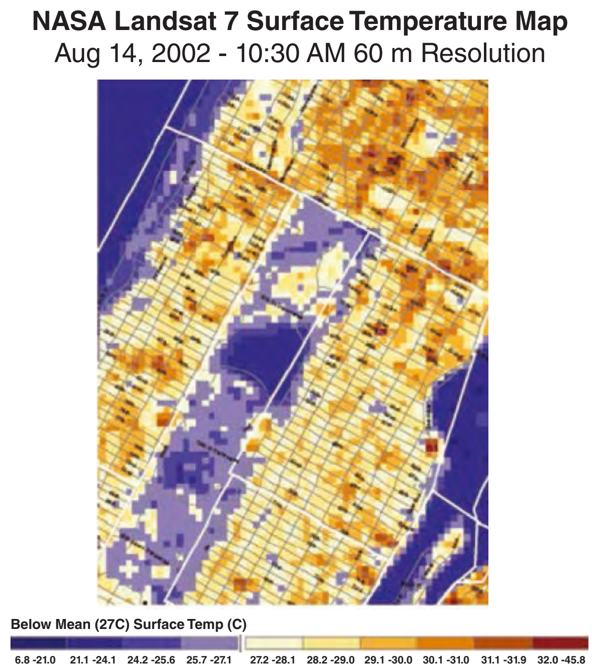

Figure 4. This map, created with data from Landsat-7, shows surface temperatures across upper Manhattan, New York, NY from August 14, 2002 at 10:30 local time. **Image credit:** NPCC, 2015

- Sea levels have risen 1.1 ft (30 cm) in New York City since 1900—i.e., 115 years. That is almost twice the observed global rate of between 0.5 and 0.7 in (1.3 and 1.8 cm) per decade over a similar time period. Projections for sea level rise in New York City increase from 11 in (28 cm) to 21 in (53 cm) by the 2050s, 18 in (46 cm) to 39 in (99 cm) by the 2080s, and, 22 in (56 cm) to 50 in (127 cm), with the worst case of up to 6 ft (2 m), by 2100. Sea level rise projections (see **Figure 3**) are relative to the 2000 to 2004 base period.

"Climate change research isn't just something for the future," said Rosenzweig. "It's affecting how key policy decisions are being made now. NASA is proud to work with New York City and other intergovernmental entities to provide world-class science."

The report also uses NASA Landsat 7 data to map the surface temperature of mid-town Manhattan and show the cooling effect of Central Park (see **Figure 4**). The Climate Impacts Group at GISS, led by Rosenzweig, provided technical support for the report.

NASA has a Climate Adaptation Science Investigator (CASI) program that is geared toward evaluating the risks facing NASA facilities due to climate change. The GISS Climate Impacts Group is using processes and lessons learned during its work with the NPCC to support the CASI program. And CASI research focusing on the advance of key NASA products related to climate adaptation could also have future applications benefiting New York City. In addition, the proposed *Climate Change Resilience Indicators and Monitoring System* will utilize NASA data observations and measurements to help the city manage climate risk. ■

New NASA Earth Science Missions Expand View of Our Home Planet

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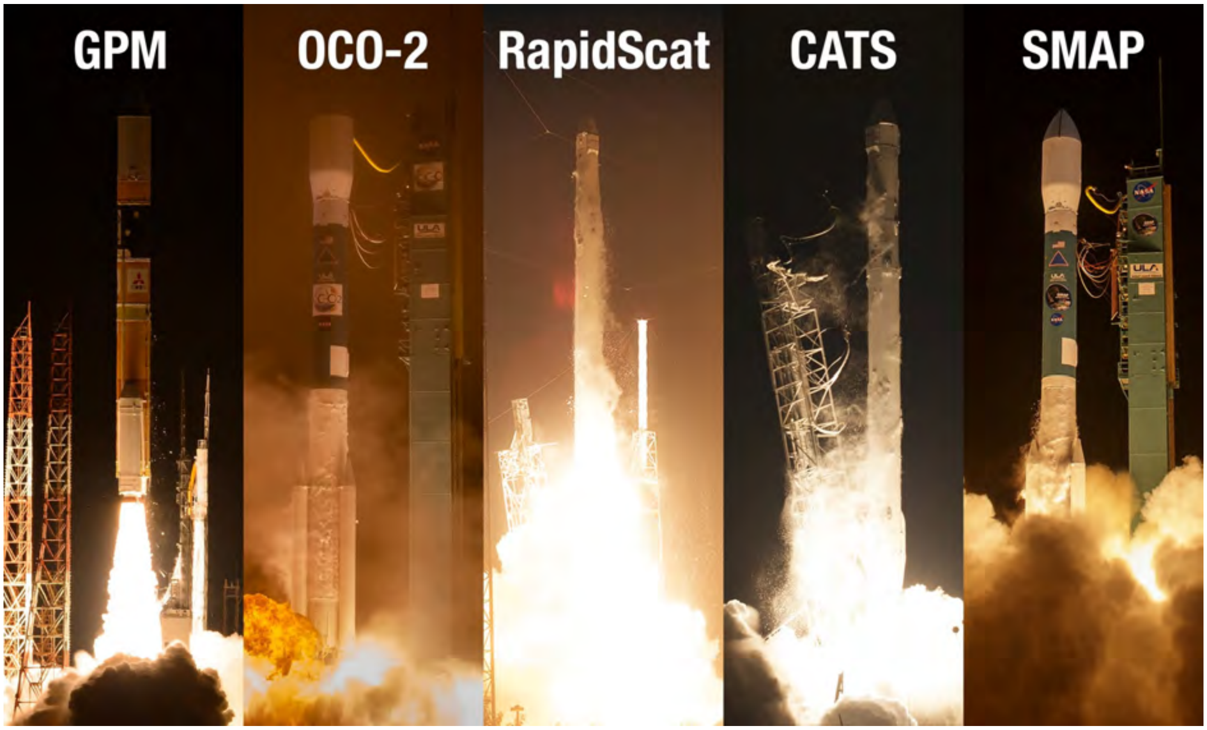
EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.



Over the past 12 months NASA has added five missions to its orbiting Earth-observing fleet—the biggest one-year increase in more than a decade. **Image credit:** NASA

Four new NASA Earth-observing missions are collecting data from space—with a fifth newly in orbit—after the busiest year of NASA Earth science launches in more than a decade.

On February 27, 2014, NASA and the Japan Aerospace Exploration Agency (JAXA) launched the Global Precipitation Measurement (GPM) Core Observatory into space from Japan. Data from the GPM Core and the other three missions are providing scientists with new insights into global rain and snowfall, atmospheric carbon dioxide, ocean winds, clouds, and tiny airborne particles called aerosols.

"This has been a phenomenally productive year for NASA in our mission to explore our complex planet from the unique vantage point of space," said **John Grunsfeld** [NASA Headquarters (HQ)—*Associate Administrator of the Science Mission Directorate*]. "Combined with data from our other Earth-observing spacecraft, these new missions will give us new insights into how Earth works as a system."

With these missions, including two instruments mounted on the exterior of the International Space Station, NASA now has 20 Earth-observing space missions in operation. Observations from these missions, like all NASA data, will be freely available to the international scientific community and decision makers in the U.S. and abroad.

"The highly accurate measurements from these new missions will help scientists around the world tackle some of the biggest questions about how our planet is changing," said **Peg Luce** [NASA HQ—*Deputy Director of the Earth Science Division*]. "These new capabilities will also be put to work to help improve lives here on Earth and support informed decision-making by citizens and communities."

Last month, NASA released the agency's most comprehensive global rain and snowfall product to date from the GPM mission made with data from a network of 12 international satellites including the GPM Core Observatory. The Core Observatory acts as a "tuner" to bring together measurements of other satellites, providing a nearly global picture of rain and snow called the Integrated Multi-satellite Retrievals for GPM (IMERG) product. The first global visualization of the initial IMERG data can be downloaded from NASA's Scientific Visualization Studio at *svs.gsfc.nasa.gov/goto?11784*.

"The IMERG data give us an unprecedented view of global precipitation every 30 minutes," said **Gail Skofronick-Jackson** [NASA's Goddard Space Flight Center(GSFC)—*GPM Project Scientist*]. "Knowing where, when, and how much it rains and snows is vital to understanding Earth's water cycle."

The Orbiting Carbon Observatory-2 (OCO-2), launched on July 2, 2014, is providing preliminary global maps of carbon dioxide concentrations and a related phenomenon known as solar-induced chlorophyll fluorescence[1]. OCO-2 data will let scientists better understand how carbon dioxide is distributed around the globe and changes with the seasons. The data will be used to identify the sources and storage places, or sinks, of carbon dioxide—the most significant human-produced greenhouse gas driving global climate change.

A preliminary global map based on observations from November and December 2014 shows carbon dioxide ... levels unprecedented in recorded history, according to **Ralph Basilio** [NASA/Jet Propulsion Laboratory (JPL)—*OCO-2 Project Manager*].

"The ultimate goal is to collect data to advance carbon cycle science, improve understanding of the global climate change process, and make better-informed decisions," Basilio said.

In addition to these two free-flying satellite missions, NASA deployed two Earth-observing instruments to the International Space Station (ISS): ISS-RapidScat, a scatterometer that measures wind speeds and direction over the ocean, and the Cloud-Aerosol Transport System (CATS), a lidar that measures the altitude of clouds and airborne particles.

[1] To learn more about the release of these products from OCO-2, see "NASA's Spaceborne Carbon Counter Maps New Details" in the January–February 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 1**, pp. 42-43].

Launched September 21, 2014, ISS-RapidScat's ocean wind measurements continue observations made by the agency's Quick Scatterometer (QuikSCAT) satellite. These measurements already are being used in weather forecast models used by the U.S. Navy, the National Oceanic and Atmospheric Administration, and by European and Indian scientists. The ISS-RapidScat team also is using the wind measurements to better understand how ocean winds differ, on average, during the day and night.

CATS, which was launched to the space station on January 10, has released its first data image: a slice of the atmosphere over Africa showing clouds and dust particles on February 11—see image on front cover of this issue. Clouds and aerosols remain two of the biggest question marks in terms of impact on future potential climate change. CATS was built by a team at GSFC as a way to demonstrate new lidar technology capable of accurate cloud and aerosol measurements, according to **Matt McGill** [GSFC—*CATS Principal Investigator*].

NASA's newest Earth-observing satellite, the Soil Moisture Active Passive (SMAP), was launched January 31 to begin its mission to map global soil moisture and detect whether soils are frozen or thawed. Currently in its checkout phase, the observatory completed a key milestone on February 24 with the deployment of its 20-ft-wide (6-m) reflector antenna, which by about March 24 will begin rotating at approximately 15 revolutions per minute. The antenna will produce a 620-mi-wide (1000-km) measurement swath, mapping the entire globe every two to three days.

Video and images of the new NASA data products discussed in this article are available online at *go.nasa.gov/newearthviews*. For more information about NASA's Earth science activities, visit *www.nasa.gov/earthrightnow*. ■

NASA Earth Science in the News

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

Rivers are Rapidly Draining Greenland, New NASA-UCLA Study Shows, January 13; *BoingBoing.net*. Researchers at the University of California, Los Angeles (UCLA), and NASA say rivers of melting glacier ice that flow over Greenland's frozen surface may be contributing as much to global sea level rise as all other processes that drain water from the melting ice sheet, combined. The new paper by lead author **Laurence Smith** [UCLA], **Alberto Behar** [NASA/Jet Propulsion Laboratory (JPL)], and nine other investigators, is based on research that they conducted on the ice sheet itself in July 2012. The researchers traveled by helicopter to map the network of rivers and streams over about 2000 mi^2 (5200 km^2) of Greenland. They were especially interested in learning how much of the meltwater remained within the ice sheet and how much drained to the ocean. The researchers found that virtually all of the flowing water drains directly to the ocean through sinkholes.

L.A. Basin Methane Emissions Found up to 61% Higher than Estimates, January 15; *Los Angeles Times*. A new study that used a mountaintop sensor to measure air pollution in the Los Angeles (L.A.) Basin found that emissions of methane, a potent greenhouse gas, are up to 61% higher than state government estimates. The study is the latest to reveal official emissions inventories that underestimate the amount of the planet-warming pollutant being released into the atmosphere. "This is a tremendous result from a scientific experiment," said **Charles Miller** [JPL], coauthor of the study. "For the first time, we have the capability of making maps, or images, of the distribution of methane across the L.A. basin." Government and university scientists measured emissions from September 2011 to October 2013 using a remote sensor on Mount Wilson, about 5700 ft (1737 m) high in the San Gabriel Mountains. They estimated that more than 430,000 tons of methane are released each year across the region, more than would be expected by adding up emissions from all sources inventoried by the California Air Resources Board.

Peering Inside Greenland's Ice Sheet, in 3D, February 3; *Scientific American*. Want to know what the inside of an ice sheet looks like? A new three-dimensional (3D) map and animation of the Greenland ice sheet—based on data from NASA's Operation IceBridge—lets researchers peer into the layers of ice that have accumulated over millennia. They can now see how the sheets have been warped over time as they flow and are put under pressure as newer layers accumulate above. This will help them better understand how Greenland—which holds enough ice to raise global sea levels by 20 ft (6 m)—will respond to current climate change by showing how it responded to similar changes in the past. One particular surprise was the amount of ice lost during the Eemian period of Earth history, which lasted from 130,000 to 115,000 years ago. Glaciologists are particularly interested in that period "…because it tells us about climate during a period of warmth similar to the present," said **Joe MacGregor** [University of Texas], though the buildup of warmth then was slower than it is today.

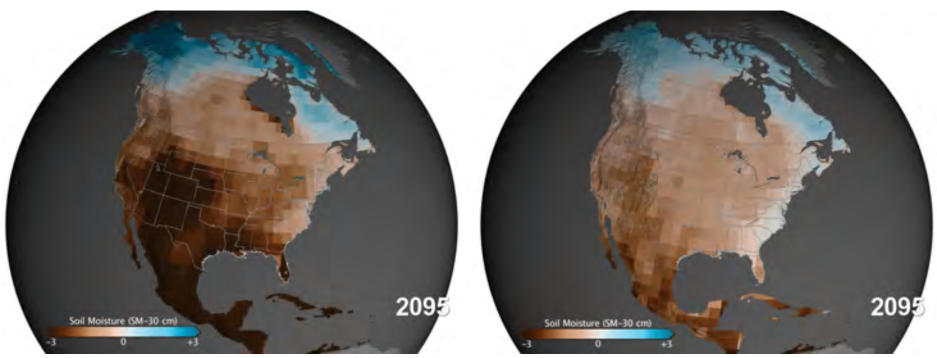


Figure 1. These images compare soil moisture projected through 2100, 30 cm (1 ft) below ground for high-emissions scenario *representative concentration pathways* (RCP) 8.5 [*left*] and moderate-emissions scenario RCP 4.5 [*right*]. The soil moisture data are standardized to the Palmer Drought Severity Index and deviations are from the twentieth century average. **Image credit:** NASA's Scientific Visualization Studio

Antarctic Sea Ice Gains Do Not "Cancel Out" Arctic Sea Ice Losses, NASA Finds, February 11; *Washington Post*. You may have heard Antarctic sea ice has recently set new records for extent, offsetting the dramatic loss in Arctic sea ice in recent decades. The first part of that statement is true, but NASA reports the second part is not. In fact, the huge decline in Arctic sea ice since the late 1970s swamps the small gains in Antarctic sea ice. As a result, global sea ice extent has shrunk over time and at an accelerating pace. "When I give public lectures or talk with random people interested in the topic, often somebody will say something on the order of 'well, the ice is decreasing in the Arctic but it's increasing in the Antarctic, so don't they cancel out?'" said **Claire Parkinson** [NASA's Goddard Space Flight Center (GSFC)—*Climate Change Senior Scientist*]. "The answer is no, they don't cancel out." To draw this conclusion, Parkinson analyzed trends in Arctic and Antarctic sea ice from satellite data and published her results in the December 2014 edition of the *Journal of Climate*. The study reports the Earth, as a whole, has been losing sea ice at annual rate of 13,500 mi^2 (35,000 km^2) per year, an area roughly the size of the State of Maryland.

Megadrought May Plague Parts of U.S., February 12; *USA Today*. The intense drought in California is only an appetizer compared with what may be coming this century across much of the western and central U.S., according to a new NASA-led modeling study. During the years 2050 to 2100, the Southwest and Great Plains will face a persistent *megadrought*—a drought lasting decades or longer, worse than anything seen in the past 1000 years—and the dry conditions will be "driven primarily" by human-induced global warming, scientists said—see **Figure 1**. There is at least an 80% chance of a megadrought in these regions if climate change continues unabated. A megadrought is defined as a drought that lasts for three decades or longer, such as those that scorched portions of the U.S. West in the twelfth and thirteenth centuries (as discerned through analysis of tree rings). "Natural droughts like the 1930s Dust Bowl and the current drought in the Southwest have historically lasted maybe a decade or a little less," said lead author of the study **Ben Cook** [GISS]. "What these results are saying is we're going to get a drought similar to those events, but it is probably going to last at least 30 to 35 years."

***How Sahara Dust Sustains the Amazon Rainforest, in 3D,** February 25; *ClimateCentral.com*. New research uses satellite data to create the first 3D look at how dust makes its way across the Atlantic. The findings provide researchers with another clue about how the fate of one of the wettest places on the planet is tied to that of one of the driest. Winds whipping across the Sahara Desert and surrounding semi-arid areas kick dust high into the atmosphere for the start of a 6000-mi (970- km) trip to the Amazon Basin every year. The new research uses data covering the period from 2007 to 2013—from NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite—to show just how massive the dust plume is. The biggest pulses of dust come in winter and fall, when an estimated 27.7 teragrams of dust make the Atlantic crossing. Teragrams not your thing? That's 182 million tons—or the equivalent of 498 Empire State Buildings in the estimation of **Hongbin Yu** [GSFC], lead author of the new study. Of that, nearly 28 million tons (or 75 Empire State Buildings, if you will) land in the Amazon. Why so much ado about dust in the wind? Because it contains phosphorus, a crucial nutrient that plants need to grow. Amazon soils run a phosphorus deficit as high as 90%, with rainfall and rivers washing it out to sea regularly. Decomposing leaves and plants help recycle some of the phosphorus already in the Amazon, but dust provides a key outside source of the nutrient.

***NASA Satellites Start Tracking Down the Sources of Climate Change,** February 27; *NBCNews.com*. NASA scientists are showing off some of the first results from a fresh crop of satellites and space station sensors—GPM, OCO-2, ISS-Rapidscat, and CATS[1]—designed to track the factors behind climate change and extreme weather on a near-real-time basis. "We're really looking forward to the contributions that these new missions will make to science and to life on Earth," said **Peg Luce** [NASA Headquarters—*Deputy Director of the Earth Science Division*]. The GPM mission released its first global time-lapse precipitation maps, showing the patterns of rainfall and snowfall during northern summer, as clouds swept from west to east in higher latitudes and marched from east to west near the equator. The readings from GPM and ISS-RapidScat are being factored into storm forecasts, including the outlook for hurricanes and other types of tropical cyclones. OCO-2 is focusing on a key factor behind potential climate shifts: the patterns behind emission of carbon dioxide into—and its removal from—the atmosphere. Carbon dioxide is produced through natural processes as well as industrial processes, and it is typically removed through photosynthesis and other natural "sinks." The scientists behind the CATS mission released their first public image, showing clouds and particulates on February 11 in a cross-section of the atmosphere over Africa. In the northern part of the continent, the dominant signature was dust from the Sahara Desert. Over central Africa, CATS registered cirrus clouds rising to a height of about 10 mi (16 km). CATS also tracked the smoke rising from fires in Zimbabwe in southern Africa.

[1] GPM stands for Global Precipitation Measurement; OCO-2 stands for second Orbiting Carbon Observatory; ISS-RapidScat stands for International Space Station Rapid Scatterometer; CATS stands for Cloud-Aerosol Transport System.

NASA Satellite Will Improve Drought Forecasting—With a Little Help From Texas, February 2; *State Impact (National Public Radio).* A satellite launched by NASA could help people around the world tackle the challenges of drought. Researchers at the University of Texas will play a part in that mission that could also help forecast flooding and allow officials to better manage reservoir water supplies. The Soil Moisture Active Passive (SMAP) satellite that launched on January 31, 2015, carries two sensors (a radiometer and a radar) that will collect data that scientists will use to help them track drought. Researchers say that by using the two different technologies, they will get a clearer understanding of where the soil is parched and where it is saturated around the globe. This new information from SMAP will be used to complement data gathered by soil moisture monitors, some of them installed around the Texas Hill Country by the university's Bureau of Economic Geology. According to **Nerendra Das** [JPL], these on-the-ground sensors will be used to help validate and improve the satellite's readings. "These local measurements are very important. We may not be able to resolve many issues using satellite data, said Das."

*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
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45th Earth Day: Celebrate with NASA

National Mall (Washington Monument)—April 17, 10:00 AM – 2:00 PM; April 18, 12:00 PM – 5:00 PM

Union Station (Main Hall)—April 21-22; 10:00 AM – 5:00 PM both days

In commemoration of the forty-fifth anniversary of Earth Day, NASA is teaming with Earth Day Network to share stories with the public about how the agency uses the vantage point of space to achieve a deep scientific understanding of our home planet, the sun and its effects on the solar system, other planets and solar system bodies, the interplanetary environment, and the universe beyond.

Events will take place in Washington, DC at the National Mall, April 17–18, and at Union Station, April 21–22. NASA's *Science Gallery* and a variety of hands-on demonstrations and activities will be offered at both venues.

On the official Earth Day (April 22) there will be several live presentations in front of NASA's Hyperwall—a nine-screen video wall capable of displaying multiple high-definition data visualizations and/or images simultaneously. Also on April 22, a NASA astronaut will sign autographs and answer questions about what it was like to view Earth from space.

We hope to see you in Washington, DC, to celebrate Earth Day!

Soil Moisture Quiz from NASA's *Know Your Earth Project* Is Now Live

The new quiz called "Soil Moisture" from NASA's *Know Your Earth Project* is now available online at *climate.nasa.gov/quizzes/soilmoisture-quiz*. The Know Your Earth Project aligns with the larger NASA Earth Right Now Campaign through quizzes related to NASA's Earth science activities; to date, nine quizzes have been released. The results of each quiz can be shared on social media pages.

To view the complete collection of quizzes visit *www.nasa.gov/content/know-your-earth-2014/#.VFubIr5UGA0*.

NASA Postdoctoral Fellowships

Deadline—July 1

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

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

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

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

Editor's Corner

continued from page 2

This fiftieth anniversary was recognized on October 8, 2014, at GSFC's Visitor's Center. The afternoon was an opportunity to reflect on the significant contributions that the Nimbus Program made to satellite-based Earth remote sensing as it exists today and its benefits to society. Turn to page 18 of this issue to read a summary of the Program's contribution to Earth Science, including the presentations given at the fiftieth anniversary event.

Finally, I would like to point out that several of the Science Program Support Office's most recent products are now available for download as *iBooks*, with additional "electronic publication" formats and platforms planned. Also, NASA's Hyperwall can now be followed on *Twitter*, **@NASAHyperwall**. This is another means to keep up with where NASA's video wall is headed, what stories are being told, and by whom. Please see the Announcements about the Hyperwall on Twitter and iBooks on pages 13 and 31, respectively. ■

EOS Science Calendar

May 5–7, 2015
CERES Science Team, Hampton, VA.
ceres.larc.nasa.gov/science-team-meetings2.php

May 19–22, 2015
Combined MODIS/VIIRS Science Team Meeting, Silver Spring, MD.
modis.gsfc.nasa.gov/sci_team/meetings

June 9–10, 2015
GPM Applications Workshop, College Park, MD.
pmm.nasa.gov/node/1261

June 23–25, 2015
Earth Science Technology Forum 2015, Pasadena, CA.

July 13–17, 2015
Precipitation Measurement Mission Science Team Meeting, Baltimore, MD.
By invitation only (Contact *Lisa.A.Nalborczyk@nasa.gov*)

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

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

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

Global Change Calendar

June 22–July 2, 2015
26th International Union of Geodesy and Geophysics, Prague, Czech Republic.
www.iugg2015prague.com

July 13-15, 2015
3rd South Central and Eastern European Regional Information Network (SCERIN) Workshop, Transylvania, Bulgaria.

July 20–24, 2015
19th GLOBE Annual Partner Meeting, Los Angeles, CA.
www.globe.gov/events/eventsdetail/globe/19th-annual-globe-partner-meeting

July 26–31, 2015
IEEE International Geoscience and Remote Sensing Symposium, Milan, Italy.
www.igarss2015.org

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

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

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

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

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

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

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