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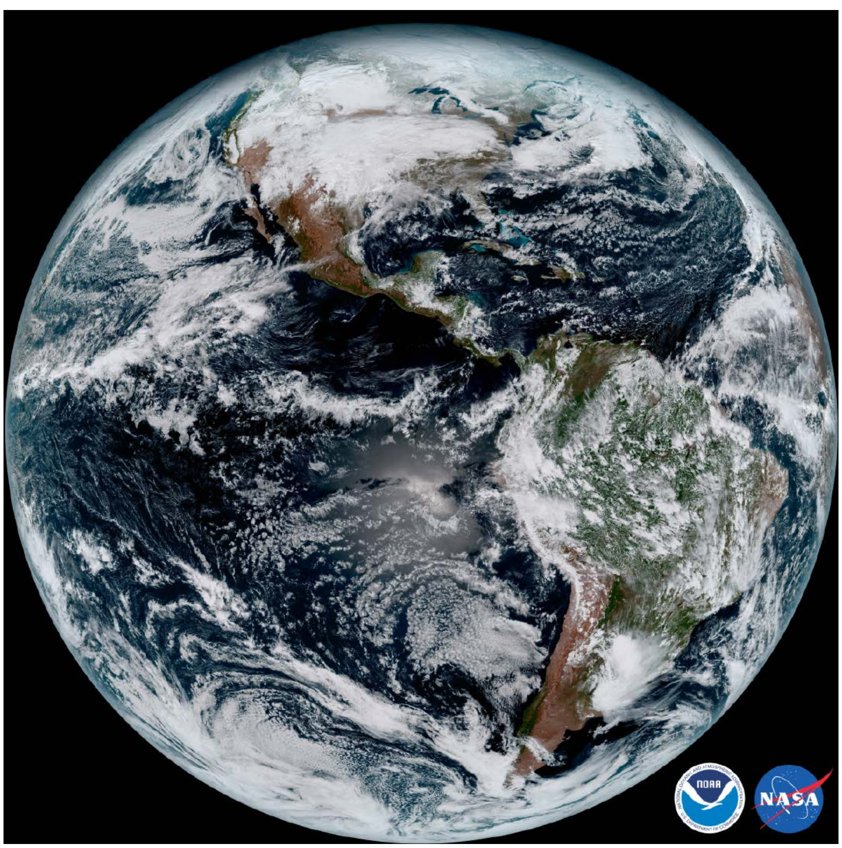
# the earth observer

## Editor's Corner

***Steve Platnick***
*EOS Senior Project Scientist*

I am very sad to report that **Piers Sellers** passed away on December 23, 2016 from pancreatic cancer at the age of 61. Piers, who often referred to himself as the "human satellite," came to GSFC in 1981 as a biospheric scientist and served as the first Project Scientist for the NASA Earth Observing System's Terra mission (then called AM-1). He was selected to join the NASA Astronaut Corps in 1996 and went on to fly in space three times—including six spacewalks. In 2011, after concluding his tour of duty as an Astronaut, Piers returned to GSFC where he served as the deputy director of the Sciences and Exploration Directorate and the director of the Earth Science Division. The perspective Piers gained by observing the Earth from the vantage point of space made him all the more excited to resume his original mission to understand Earth's climate—and to communicate the science to the public. In a *New York Times* opinion piece from January 2016 Piers wrote of his spaceflight experience: "From this God's-eye-view, I saw how fragile and infinitely precious the Earth is. I'm hopeful for its future." The passion Piers brought to his work—especially after his cancer diagnosis—was an inspiration to all who were fortunate enough to work with him over the years. His humor, optimism, intellect, and tireless energy will be sorely missed. My condolences to Piers' family, friends, and many colleagues around the world. Please turn to page 4 to read *In Memoriam,* describing Piers' distinguished career.

continued on page 2



Among the "first light" images released from GOES-R (GOES-16) was this full-disk visible image of the Western Hemisphere at 1:07 PM EST on January 15, 2017. It was created using several of the 16 spectral channels available on the satellite's sophisticated Advanced Baseline Imager. The image, taken from 22,300 mi (~33, 588 km) above the surface, shows North and South America and the surrounding ocean.

**Image credit:** NOAA and NASA

## In This Issue



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

Among his many accomplishments, Piers was one of the visionary leaders of FIFE and BOREAS—two of NASA's first field campaigns designed to improve our understanding of the biosphere in the Earth system. The year 2017 marks the 30th anniversary of the beginning of FIFE'87. On October 6-7, 2016, a "reunion meeting" took place at NASA's Goddard Space Flight Center (GSFC). Dubbed *How FIFE/BOREAS Changed the World*, the meeting agenda was designed to look back at what these two experiments accomplished—and in some cases are still providing—and to consider how they changed the world for Earth science studies. Please turn to page 6 of this issue to learn more about these two pioneering field experiments.

NASA ended 2016 on a high note, with the successful launch of the Cyclone Global Navigation Satellite System (CYGNSS)—described in detail in our previous issue.[1] The mission launched on December 15, 2016, at 8:37 AM Eastern Standard Time, from Cape Canaveral Air Force Base in Florida aboard a Pegasus-XL launch vehicle into a low-inclination, low-Earth orbit over the tropics. CYGNSS is the first Earth Venture Mission (EVM-1)[2] to launch, and features a constellation of eight small satellites that will receive both direct and reflected signals from Global Positioning System (GPS) satellites. The direct signals pinpoint CYGNSS observatory positions, while the reflected signals respond to ocean surface roughness, from which wind speed maps are created. Kudos to principal investigator **Christopher Ruf** [University of Michigan] and the entire CYGNSS Team. To learn more about the CYGNSS "first light" science data, see the News story on page 51 of this issue, or visit *http://cygnss-michigan.org*.

Previously we reported on the successful launch of GOES-R (now GOES-16) on November 19, 2016.[3] "First light" images from the Advanced Baseline Imager (ABI) were released on January 23. Included among them is a composite color full-disk visible image of the Western Hemisphere captured on January 15, 2017—see front cover.

[1] To learn more about CYGNSS, read "Eight Microsatellites, One Mission: CYGNSS" in the November-December 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 6**, pp. 4-13].

[2] Earth Venture class missions are broken down into Suborbital (EVS), Instrument (EVI), and Mission (EVM). Learn more about the three categories and see a list of missions at *https://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder*.

[3] See the Editorial of the November–December 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 6**, pp. 1-2].

Created using several of the ABI's 16 spectral channels, the full-disk image offers an example of the satellite's capability compared with previous GOES imagers. One ABI imaging mode provides a full-disk image every 15 minutes, a continental U.S. image every 5 minutes, and smaller mesoscale images every 30 seconds for one region or every minute for two regions. Another mode simply produces a full-disk image every 5 minutes. ABI spatial resolution ranges from 0.5 to 2 km at nadir (depending on spectral channel).

In May 2017 NOAA plans to announce the planned location for GOES-16, and by November 2017 GOES-16 is expected to be in either the GOES-East or GOES-West position. The next spacecraft in the series, GOES-S, is scheduled to launch in Spring 2018,[4] and is currently undergoing a full set of environmental, mechanical, and electromagnetic tests at Lockheed Martin's Littleton, CO facility. After initial on-orbit checkout GOES-S (GOES-17) will be moved into the operational position not occupied by GOES-16.

For more information refer to *https://www.nasa.gov/feature/goddard/2017/goes-16-sends-first-images-to-earth*. A gallery of other first light images can be found at *www.nesdis.noaa.gov/content/goes-16-image-gallery*.

Meanwhile, as EVM-1 (CYGNSS) prepared to launch this past year, 15 proposals submitted in response to the EVM-2 announcement were being reviewed. In early December, NASA HQ announced that the Geostationary Carbon Cycle Observatory (GeoCARB) was selected as the winner. The mission will monitor plant health and vegetation stress throughout the Americas, and probe the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

GeoCARB will launch on a commercial geosynchronous communications satellite. The intent is for GeoCARB to employ otherwise unused launch and spacecraft capacity to advance science and provide societal benefits. By demonstrating that it can be flown as a hosted payload on a commercial satellite, GeoCARB will strengthen NASA's partnerships with the commercial satellite industry and provide a model that can be adopted by NASA's international partners to expand these observations to other parts of the world.

The principal investigator for GeoCARB is **Berrien Moore** [University of Oklahoma]. Other mission partners include the Lockheed Martin Advanced Technology Center; SES Government Solutions Company; the Colorado State University; GSFC; ARC; and JPL. Congratulations to the GeoCARB team on being selected as NASA's newest Earth Venture mission. To learn more about GeoCARB see the News story on page 50 of this issue.

Finally, this issue includes details about NASA's recent outreach activities at the UNFCC's COP-22 meeting and the 2016 AGU Fall Meeting—see page 24 of this issue. These events, organized by the Science Communication Support Office, showcase NASA science plans and stories on the Hyperwall and Dynamic Planet (see photo on page 24). These two display technologies provide a unique means to communicate science face-to-face with colleagues, stakeholders, and the public. To see where NASA's Hyperwall is headed next, follow the team on Twitter *@NASAHyperwall*. ■

[4] There will be two more in the "GOES-R" series: GOES-T and GOES-U are planned for launch in 2019 and 2024, respectively.

### Undefined Acronyms Used in Editorial and Table of Contents

| | |
|---|---|
| ARC | NASA's Ames Research Center |
| AGU | American Geophysical Union |
| BOREAS | Boreal Ecosystem–Atmosphere Study |
| CERES | Clouds and Earth's Radiant Energy System |
| COP | Conference of Parties |
| FIFE | First ISLSCP Field Experiment |
| GOES | Geostationary Operational Environmental Satellite |
| GRACE | Gravity Recovery and Climate Experiment |
| GSFC | NASA's Goddard Space Flight Center |
| ISLSCP | International Satellite Land Surface Climatology Project |
| JPL | NASA/Jet Propulsion Laboratory |
| UNFCC | United Nations Framework Convention on Climate Change |

## In Memoriam

**Piers J. Sellers**, a renowned climate scientist and former NASA astronaut, passed away at age 61 on December 23, 2016, due to pancreatic cancer.

Piers J. Sellers **Photo credit:** NASA

Piers most recently served as the deputy director of the Sciences and Exploration Directorate at NASA Headquarters and acting director of the Earth Sciences Division at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. Piers arrived at GSFC in 1981 from his native Great Britain and dove into pioneering research on the use of satellites and computer models to study photosynthesis on a global scale. In the 1990s Piers served as the first project scientist for the Terra mission (then called AM-1), the first satellite in NASA's Earth Observing System and a "flagship" of the agency's Earth-observing fleet. After 14 years as an Earth-based NASA scientist, Piers changed course in 1996 when he joined the NASA astronaut corps with an eye toward working in space. His dreams were made real when he participated in missions to the International Space Station in 2002, 2006, and 2010, where he performed six spacewalks and various space station assembly tasks. In addition to helping build the space station, he gained a perspective on Earth that would infuse his talks to the public for the rest of his life. In 2011 Piers returned to GSFC where he provided leadership and guidance to the center's cadre of more than 2000 scientists. In this role, he once again took up his mission to study the changing climate and share his views with audiences worldwide.

Early in his career, Piers focused on the challenges of understanding and simulating the complex interactions between Earth's atmosphere and biosphere—the collection of the planet's plant life. In the mid-1980s he led the work that created the first realistic computer model of how the biosphere interacts with Earth's climate. He would go on to mine deeply this line of research, breaking new ground, and helping build the foundation for what the science community now understands.

Piers on one of his six spacewalks (STS-121, EV1). **Photo credit:** NASA

"It took years and years, but at the end of it we came up with a complete theoretical understanding of how it goes from a single leaf, with its little chloroplasts doing photosynthesis, to what that looks like from space, and then how to integrate the whole thing to find out the photosynthetic power of the planet," Piers said in a 2016 interview.

While Piers could dazzle a crowd with stories of seeing Earth from space as an astronaut, he was equally enthusiastic when discussing the excitement of scientific breakthrough. "It was enormous fun," he said. "It was the most fun I ever had. It was a huge scientific adventure."

Piers' five most impactful scientific journal articles—collectively outlining his Simple Biosphere Model (SiB), updates to it (SiB-2), and insights into how forest canopies conduct photosynthesis—have been cited in 7697 peer-reviewed papers. The work has had enormous impact on the current understanding not only of how the planet works, but also of how Earth will respond to rising carbon dioxide concentrations in its atmosphere.

"Piers did seminal work," said **Colleen Hartman** [GSFC—*Director of the Sciences and Exploration Directorate and Acting Center Director for Science at GSFC*]. "It completely changed the paradigm of how to use satellite data and made it so much more useful for applications in the real world and for understanding our changing climate. Purely on the science, he would be an icon."

After learning of his cancer diagnosis, Piers took on a much higher public profile when a January 2016 op-ed piece he wrote for *The New York Times* resonated deeply with people around the world. The piece described how his diagnosis affected his approach to examining our changing climate. It captured both the depth of his thinking on the topic and his pragmatic optimism.

"There is no convincing, demonstrated reason to believe that our evolving future will be worse than our present, assuming careful management of the challenges and risks," Piers wrote. "History is replete with examples of us humans getting out of tight spots. The winners tended to be realistic, pragmatic, and flexible; the losers were often in denial of the threat."

In the final year of his life, Piers gave dozens of interviews about his grounded yet hopeful perspective, culminating in an appearance in the documentary film, *Before the Flood*, released this fall. The message resonated, Hartman said, because of its authenticity.

On June 2, 2016, **NASA Administrator Charles Bolden** presented Piers with the *Distinguished Service Medal*—the highest honor the agency can bestow.

"When I was a kid, I watched the Apollo launches from across the ocean, and I thought NASA was the holy mountain," Piers said during his acceptance speech. "As soon as I could, I came over here to see if I could climb that mountain." And climb it he did, and then some. He accepted the award on behalf of everyone in attendance and all the people he has worked with throughout his 34-year career at NASA. "I owe this agency everything," he said.

Remembering Piers, Bolden said, "Piers devoted his life to saving the planet. As a climate scientist, his work in computer modeling of the climate system, satellite remote sensing studies, and field work using aircraft, satellites, and ground teams broke new ground in our understanding of Earth's systems. His legacy will be one not only of urgency that the climate is warming but also of hope that we can yet improve humanity's stewardship of this planet. His cancer diagnosis became a catalyst for him to work even harder on efforts to save the planet from global warming for the benefit of future generations. Piers was an eternal optimist whose positive energy inspired all those who had the good fortune to know him. His laughter, humor, and lighthearted spirit are as much a part of his legacy as his work."

Longtime friend and colleague Compton "Jim" Tucker spoke with Piers near the end. He said that Piers' final request was for "no moping" at events remembering him. Instead, he asked that we celebrate his life and accomplishments.

*The Earth Observer* staff would like to dedicate this issue to Piers who, among so many other accomplishments, led two groundbreaking field research campaigns—FIFE and BOREAS—described in great detail in the article on page 6 of this issue.

This *In Memoriam* drew information from several sources, including:

**NASA Administrator Remembers NASA Scientist, Astronaut Piers Sellers**

*https://www.nasa.gov/press-release/nasa-administrator-remembers-nasa-scientist-astronaut-piers-sellers*

**Piers Sellers: A Legacy of Science**

*https://www.nasa.gov/feature/goddard/2016/piers-sellers-a-legacy-of-science*

**Cancer and Climate Change (The New York Times):** *https://www.nytimes.com/2016/01/17/opinion/sunday/cancer-and-climate-change.html?_r=0*

**Sellers Awarded Distinguished Service Medal:** *https://www.nasa.gov/feature/goddard/2016/reaching-the-summit-at-nasa-piers-sellers-receives-distinguished-service-medal*

**Piers Sellers Media Resources:** *http://svs.gsfc.nasa.gov/12275*

**Image gallery:** *https://www.flickr.com/photos/nasa_goddard/sets/72157669808364751*

# Recollections of FIFE and BOREAS: Historical Perspective and Meeting Summary

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## Introduction

Field campaigns are a critical component of NASA's Earth Observing System (EOS). Such experiments are designed to test and evaluate various scientific hypotheses governing interactions between the Earth's surface and atmosphere, and form the basis of algorithms used in computer models that simulate Earth's weather and climate. Field experiments are thoughtfully designed and carefully planned to acquire data to test and evaluate hypotheses contained within these model's codes. This typically requires synchronous observations taking place at several-to-many locations, over a range of spatial scales, and at multiple levels of the atmosphere. The *in situ* measurements obtained include surface states as well as rates of energy, gas, and heat exchange within the atmosphere. Exchanges of carbon, water, and heat (or *fluxes*) are measured at a range of altitudes within the atmospheric boundary layer. For example, measurements of radiative energy exchange are required at scales of meters (feet) to kilometers (miles) from ground level to space—usually defined as 100 km (~62 mi). Geophysicists, meteorologists, and oceanographers have been doing field experiments since the International Geosphere Year (IGY) in 1957-'58; however, the biosphere was not included in this type of multisite strategic approach until just a few decades ago—in 1987.

The first field campaign to include the coupled biosphere–atmosphere as part of a coordinated measurement strategy was the First International Satellite Land Surface Climatology Project (ISLSCP) Field Experiment [FIFE], with deployments in 1987 and 1989 to the Konza Tallgrass Prairie near Manhattan, KS—see *The FIFE and BOREAS Study Areas* on pages 8–9—to measure surface properties (e.g., vegetation and vegetation status, soil moisture) and fluxes of heat, moisture, and trace species. The surface flux measurements were used as ground truth for the development and evaluation of algorithms to estimate fluxes from satellite observations. FIFE'87 had four, two-week deployments[2] involving 5 satellites, 10 aircraft, and some 150 people. Researchers returned to Kansas two years later for a second round of experimentation on the Konza Prairie—FIFE'89. Measurement approaches were refined based on the results of FIFE'87 so as to resolve scientific questions that arose during subsequent algorithm development to estimate fluxes from satellites.

The logos for FIFE and BOREAS. **Image credit:** NASA

Even as scientists analyzed data collected during FIFE, plans were underway for an even more ambitious (and better-funded) experiment: the joint U.S.-Canadian Boreal Ecosystem–Atmosphere Study (BOREAS),[3] with preparatory activities in 1993 and field deployments in 1994 and 1996. Whereas FIFE took place on the plains of Kansas, BOREAS was executed over the more-remote southern and northern extremes of north-central Canada—the boreal forests.

[1] Regrettably, Piers Sellers passed away on December 23, 2016, from pancreatic cancer. An *In Memoriam* for Sellers appears on page 4 of this issue.
[2] These deployments were timed so they captured different parts of the growing season.
[3] U.S. participants in BOREAS included NASA, the National Science Foundation (NSF), and the National Oceanic and Atmospheric Administration (NOAA); Canadian participants included the National Science and Environmental Research Council (NSERC), National Aeronautics Council (which provided the Twin Otter aircraft), and Agriculture and Agri-Food Canada.

The primary objectives of BOREAS were to determine how the boreal forest interacts with the atmosphere (via gas and energy fluxes), how much carbon is stored in the forest ecosystem, how climate change will affect the forest, and how changes in the forest affect weather and climate. BOREAS integrated ground, tower, airborne, and satellite measurements of the interactions between the forest ecosystem and the lower atmosphere. BOREAS moved beyond FIFE in two important ways. The FIFE ecosystem was relatively small and simple, and the physics of the remote sensing of the simple grassland was well understood. On the other hand, in addition to being a much larger region, the BOREAS ecosystem was far more complex and remote sensing of the complex forest canopy and undergrowth was much more difficult than that of the simple grassland of the Konza. There were two smaller study areas where observations took place, each further subdivided into observation sites—see *The FIFE and BOREAS Study Areas* on pages 8–9. Once the BOREAS experiment was completed, the Canadian government took over the infrastructure that had been built. The Boreal Ecosystem Research and Monitoring Sites (BERMS) study began in 1996, operated and funded by Environment Canada (EC). Some of the BOREAS sites are still in use today as part of Fluxnet-Canada, discussed later in this article.

FIFE and BOREAS helped to move scientific understanding of Earth's systems from a good idea to a concrete reality in the late 1980s, and further laid the groundwork for understanding how the individual components of Earth's systems (e.g., atmosphere, biosphere) work and interact with one another.

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The year 2016 marked the twenty-ninth anniversary of the beginning of FIFE'87 and the twentieth anniversary of the conclusion of BOREAS. On October 6-7, 2016, a gathering of interested parties convened for a reunion meeting at NASA's Goddard Space Flight Center (GSFC), called *How FIFE/BOREAS Changed the World.* The meeting agenda was designed to look back at what these two experiments accomplished—and in some cases are still providing—and to consider how they literally changed the world, as new perspectives on Earth system science (as it is now called) were developed.

If we are to understand how FIFE/BOREAS changed the world, however, we first need to get some sense of the world that existed before these experiments took place, particularly in the realm of NASA's biospheric science studies; we provide that perspective here. We also briefly summarize the history of FIFE and BOREAS, along with historic perspectives and anecdotal accounts from participants in FIFE and BOREAS, as shared during the GSFC meeting.[4]

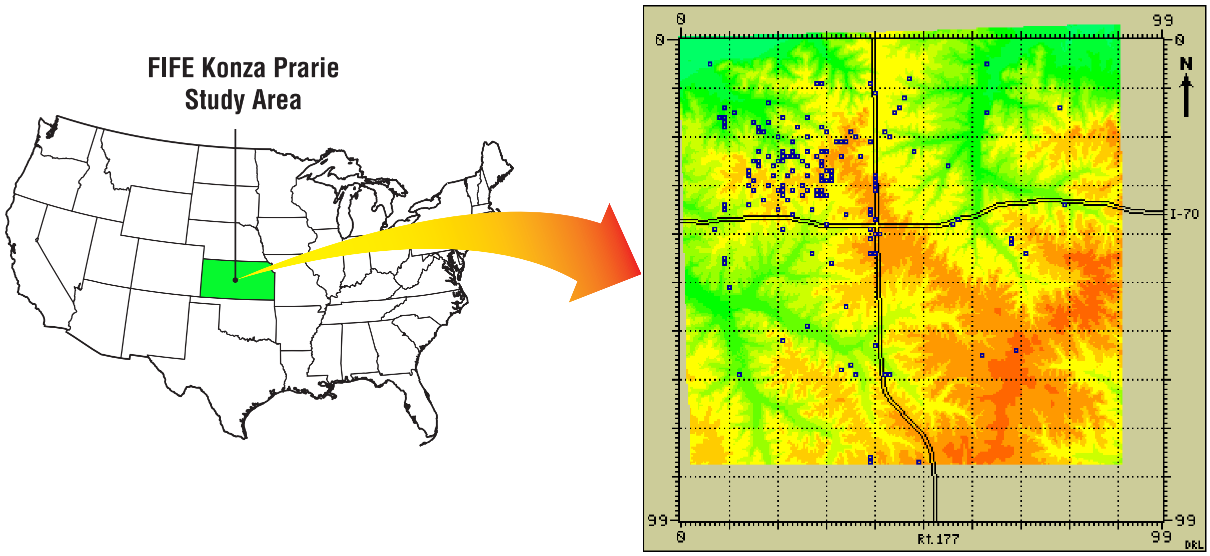
[4] All presentations from the meeting can be viewed and downloaded from *http://cce.nasa.gov/cce/boreas_fife/boreas_vids/BOREAS_Vids.html*.

FIFE - BOREAS Reunion Meeting particpants at GSFC on October 6, 2016. **Photo credit:** Bill Hrybyk [GSFC]

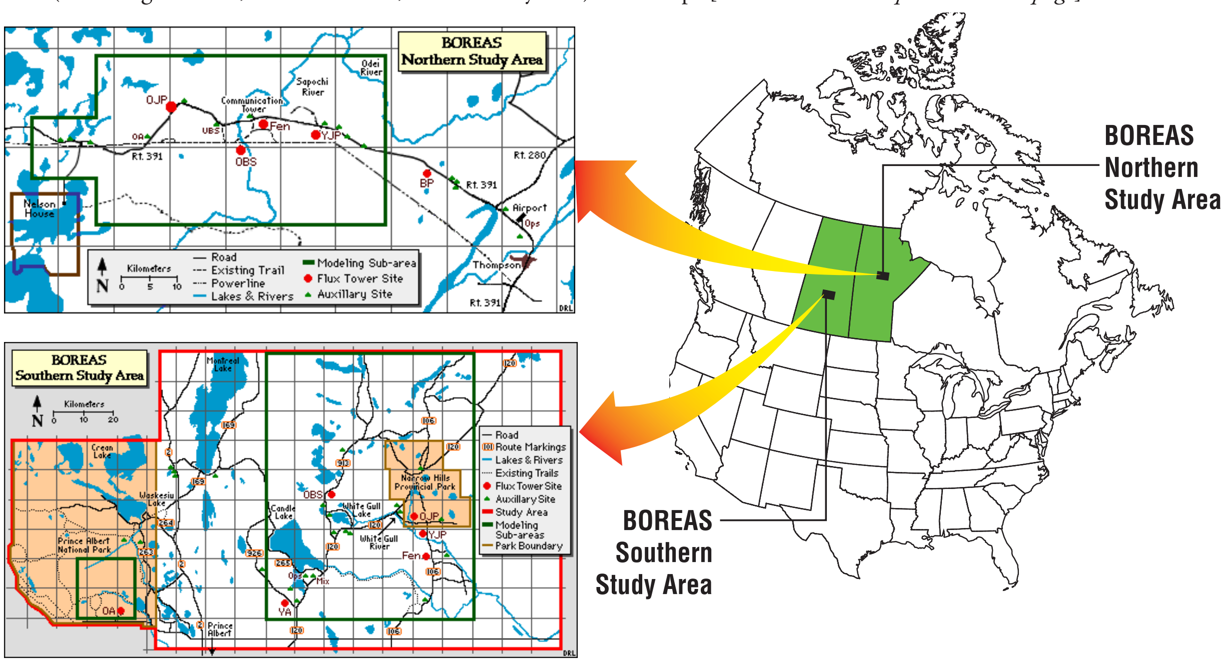
## The FIFE and BOREAS Study Areas*

The goals of FIFE and BOREAS were to develop and test methods for upscaling biophysical understanding from meter scales to geographic scales—where carbon, climate, and weather models operate. They were also to develop and test satellite remote sensing algorithms for inferring the surface drivers of these models—e.g., albedo, temperature, soil moisture, and vegetation type. The specific objectives of the field phases of FIFE and BOREAS followed directly from those goals. The challenge was to design feasible experiments.

FIFE focused on the Konza Prairie study area, a 15 x 15-km (~9 x 9-mi) inhomogeneous rolling terrain site of the Konza Preserve near Manhattan, KS—see map [*below*]. The area was small enough to sample with existing resources, but large enough to acquire sufficient samples of satellite data and sample the turbulent structure of the planetary boundary layer with aircraft. It also had convenient access to aircraft (Fort Riley) and logistical support (Kansas State University in Manhattan).




BOREAS was more ambitious, with observations taking place over a larger 1000 x 1000-km (~621 x 621-mi) region with two distinct study areas in northern Canada—the **Northern Study Area** and the **Southern Study Area**—each with multiple sites (modeling subareas, flux tower sites, and auxillary sites)—see maps [*below—with descriptions on next page*].



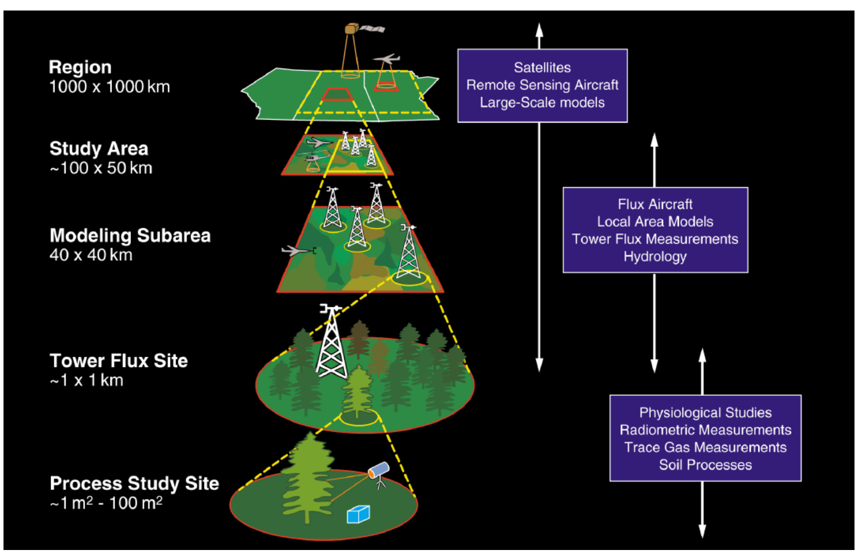
The **Northern Study Area** (NSA) was a 100-km x 80-km (~62-mi x 50-mi) area around Thompson, Manitoba. The NSA had five main sites and several auxiliary sites. They were:

- Beaver Pond (NSA-BP)—*flux tower*† on a small lake;
- Fen (NSA-Fen)—flux tower in a swampy wetland area;
- Old Black Spruce (NSA-OBS)—flux tower in an area of old growth black spruce (wet soil);
- Old Jack Pine (NSA-OJP)—flux tower in an area of old Jack Pine (dry soil);
- Young Jack Pine (NSA-YJP)—flux tower in an area of young Jack Pine (dry soil);
- BOREAS Operations (NSA-Ops)—BOREAS Ops center, Thompson Airport;
- Upland Black Spruce (NSA-UBS)—canopy access tower in a small stand of spruce (auxiliary);
- Old Aspen (NSA-OA)—canopy access tower in a large stand of old Aspen trees (auxiliary).

The BOREAS **Southern Study Area** (SSA) was a 130-km x 90-km (~81-mi x 56-mi) area around Prince Albert, Saskatchewan—about 780 km (~485 mi) from the NSA. The SSA had six main sites and several auxillary sites in and around the Prince Albert National Park (PANP) and Narrow Hills Provincial Forest. They were:

- Fen (SSA-Fen)—flux tower in a swampy wetland area;
- Old Aspen (SSA-OA)—flux tower in an area of old growth aspen trees;
- Old Black Spruce (SSA-OBS)—flux tower in an area of old growth black spruce (wet soil);
- Old Jack Pine (SSA-OJP)—flux tower in an area of old Jack Pine (dry soil);
- Young Aspen (SSA-YA)—flux tower in an area of young aspen trees;
- Young Jack Pine (SSA-YJP)—flux tower in an area of young Jack Pine (dry soil);
- BOREAS Operations (SSA-Ops)—BOREAS Ops center, Snodrifters Lodge, Candle Lake;
- Southern Airport—Prince Albert Airport; and
- Mixed Growth Site (SSA-Mix)—Terrestrial Ecology (TE) canopy tower in a mixed forest (auxillary).

The diagram [*below*] illustrates the multiscale measurement strategy used during FIFE and BOREAS with measurements going on from synoptic (regional) scales down to the level of individual trees and leaves (i.e., at the process level).




* To learn more details about these study areas and see some images and pictures, visit *https://daac.ornl.gov/FIFE/FIFE_Location.html*, *https://daac.ornl.gov/BOREAS/bhs/Sites/SSA.html*, and *https://daac.ornl.gov/BOREAS/bhs/Sites/NSA.html*.

† Flux towers monitor physical and chemical properties of atmosphere-related processes, such as humidity, wind, and reactive nitrogen at several levels. They also measure *net ecosystem exchange*—the amount of gas that is exchanged between the atmosphere and the ecosystem.

### The World before FIFE[5]

As intimated earlier, Earth system science did not spring full-blown into existence. The steps to organizing this literally global enterprise were small and somewhat hesitating—droplets of discovery slowly coming together throughout the 1960s and 1970s to form separate streams of scientific endeavor that, in the early 1980s, began to coalesce into the Earth-spanning interdisciplinary effort we know today. At that time there were a number of NASA workshops initiated to "address the feasibility of developing a major NASA research initiative to document, to understand, and if possible, to predict long-term (i.e., between 5 and 50 years duration) global changes that can affect the habitability of Earth."[6] The consensus arising from these workshops was that while this would be a worthwhile endeavor, there would be significant knowledge gaps that would need to be closed before proceeding—in particular, with regard to interactions between the atmosphere and Earth's surface, about which virtually nothing was known. Models at the time were at the "hand-waving stage"[7] when it came to their representation of many parameters crucial to understanding Earth's climate, e.g., radiative energy, water vapor, and carbon fluxes; surface albedo; atmospheric water content; and the roles of clouds—all highlighted as necessary foci to understand Earth's systems and climate.

**How FIFE and BOREAS Changed the World**

*Then*

*Now*

Logo for *How FIFE/BOREAS Changed the World* meeting. **Image credit:** NASA (concept by Piers Sellers).

As all this played out (in the early 1980s), it became increasingly apparent that biology (not just physics) played a key role in regulating the Earth system. (In fact, biology controls about one-third of the energy exchanges between the land surface and the atmosphere.) At that time, AgRISTARS (defined in the *Timeline* on page 13), a large interagency program using empirical techniques to monitor agricultural productivity, was coming to a close, and a small portion of those resources, together with some of the scientific leadership, became available for "reprogramming." Additional intellectual vigor entered through the National Research Council's new Post-Doctoral program and from other existing NASA programs (e.g., the Earth Resources Branch at GSFC) and the Biospheric Sciences program was born. Research initially focused on the role of biologic processes on climate models and later expanded to include carbon flux measurements.

### Harbingers of FIFE and BOREAS: ISLSCP and HAPEX-MoBilHY

By the early 1980s, a programmatic framework for global biospheric studies was in place. Now, all that was needed was a mechanism to make it all happen, and the International Satellite Land Surface Climatology Project (ISLSCP—the "I" in FIFE) would provide that mechanism. Conceived of in 1983, the idea behind this large-scale program was to study the land biosphere in terms of its relevance to Earth's climate. This would require a series of field experiments to develop and improve general circulation models (GCMs) and to develop satellite-based methods to initialize and validate these models on regional and global scales to answer increasingly interesting and important Earth-system science questions. ISLSCP provided a practical framework to do this. The field studies and model development being proposed under ISLSCP provided the opportunity for biospheric sciences to become an essential part of NASA's climate program. ISLSCP held its first meeting in 1984, and planning for FIFE began. The French Centre National de Recherche Meteorologique (CNRM) was also involved in ISLSCP and invited NASA to participate in the HAPEX-MoBilHy[8]

[5] While many specific details could not be preserved due to editorial requirements, the presentations given by **Bob Murphy**, **Piers Sellers**, **Forrest Hall**, and **Joe Berry** at the *How FIFE/BOREAS Changed the World* meeting and additional information provided by co-authors Hall and Murphy form the basis for this introductory material. Some material in those presentations has therefore been omitted from the summaries, provided here.

[6] This quote is an amalgamation from two sources: *Global Change Impacts on Habitability*, NASA/Jet Propulsion Laboratory D-95 (1982); and *Earth Observations from Space: History, Promise, and Reality,* National Academy of Science (1995).

[7] See Piers Sellers's "Reflections on the Early Days of EOS: A Biased and Unexpurgated History" in the January-February 2009 issue of *The Earth Observer* [**Volume 21**, **Issue 1**, pp. 4-8].

[8] HAPEX-MoBilHy stood for Hydrologic Atmospheric Pilot EXperiment–Modelisation du Bilan Hydrique. The campaign's goal was to measure the hydrological budget and evaporation flux at a resolution of 10 $km^2$ (~4 $mi^2$)—i.e., the scale of a general circulation model grid square at the time. A follow-on experiment was HAPEX-Sahel, which was undertaken in western Niger, in the west African Sahel region from 1990 to 1992, and sought to understand how interannual changes to the land surface of that region impacted the general circulation in general—and on drought in particular.

field experiment—an activity of the World Climate Research Programme (WCRP)—which took place in 1986 over a 100-km x 100-km area near Toulouse. The NASA team had only a small remote sensing component during HAPEX-MoBilHy, nevertheless they learned much from participating in development of ground measurement strategies that they would use during FIFE. For example, one effective observational strategy used during HAPEX–MoBilHy was the implementation of a *special observing period (SOP)*, or alternatively *intensive observing period (IOP)*, during which researchers obtained detailed measurements of atmospheric fluxes and remote sensing observations of Earth's surface properties using instrumented aircraft. This was the basis for FIFE and BOREAS later implementing a similar intensive field campaign (IFC) measurement strategy—see **Figure 1**.

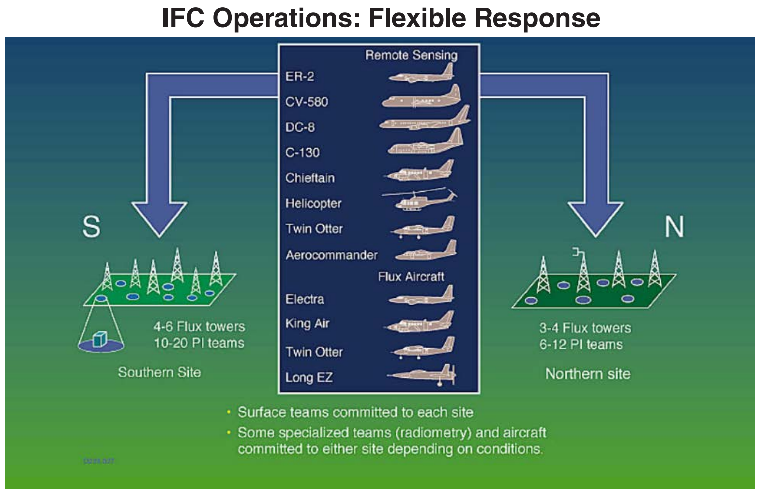



**Figure 1.** An illustration of how the Intensive Field Campaign (IFC) was implemented during BOREAS, with observations going on simultaneously at the Northern and Southern Study Areas. **Image credit:** NASA

## FIFE, BOREAS, and NASA's EOS

There was synergy and excitement at early planning meetings for FIFE as this great concept came together, along with the availability of talented individuals who could make it happen. FIFE was to be a multiscale experiment that would take measurements from the small scale (where biologists understood plant behavior) to the large scale (where remote sensing specialists could describe the aggregate result of the those small-scale processes). The idea was to both *upscale* knowledge from the leaf to satellite levels for prediction, and *downscale* from satellite maps of area to leaf level for validation—see **Figure 2**. Such an enterprise required careful planning and execution. The organizers (primarily **Piers Sellers** and **Forrest Hall,** both from GSFC) worked with the newly selected science team drawn from universities, NASA field centers, government laboratories, and the private sector to develop a detailed *FIFE Science Plan* and *FIFE Experiment Plan* that provided detailed guidance for accomplishment—see **Figure 3**. A similar plan would guide BOREAS.

Around the same time FIFE was underway, the concept for NASA's Earth Observing System (EOS) began to take shape; the first EOS Announcement of Opportunity was published the same year that FIFE'89 took place. The tumultuous and inspiring tale of its evolution has been told in bits and pieces in other places and will not be recounted

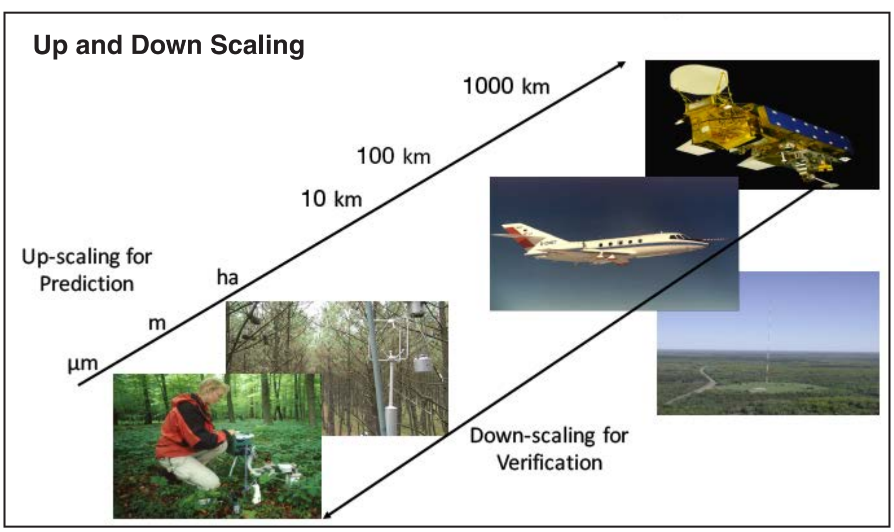
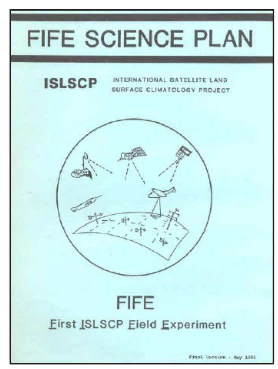



**Figure 2.** Diagram showing the upscaling (for prediction) and downscaling (for validation) done during FIFE and BOREAS. **Image credit:** Forrest Hall



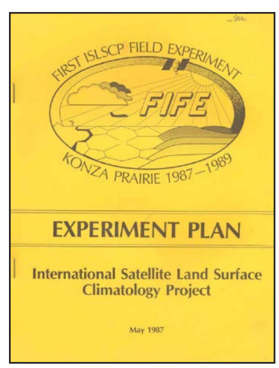




**Figure 3.** Covers for the *FIFE Science Plan* and *FIFE Experiment Plan*. A similar set of documents guided BOREAS. **Image credit:** NASA (covers hand-drawn by Piers Sellers)

here;[9] in this context, it suffices to say that EOS went through a series of revisions to the design of the proposed spacecraft during the early-to-mid 1990s—just as BOREAS was being planned and implemented.

As the following summary of the meeting held this past October at GSFC makes evident, FIFE and BOREAS were truly interdisciplinary studies that required the insights and participation of ecologists, soil scientists, boundary-layer meteorologists, and weather and climate modelers—and thus the research projects conducted were perfectly suited to be conducted as EOS investigations, which emphasized interdisciplinary science. The FIFE/BOREAS community (i.e., the ISLSCP community) provided 8 of the 31 original EOS Interdisciplinary Scientists—the most prestigious and well-funded positions in the early days of that program. This was quite a remarkable achievement for a discipline that did not exist in the early 1980s!

*"In retrospect, it's clear that the years of hard and painstaking work by the FIFE and BOREAS teams were absolutely critical in getting the Earth Observing System started, designed, and launched—and how remarkable and rare a success the EOS project was. Dixon Butler, Berrien Moore, Francis Bretherton, Shelby Tilford, Ghassem Asrar, Chris Scolese, Michael King, Diane Wickland, and Piers Sellers—as well as many others—deserve enormous credit for making EOS a reality."*

**—Forrest Hall**

With this as background, we will now move into summaries of the meeting presentations, emphasizing the seminal changes that so significantly contributed to our current understanding of Earth system science and—as a result—how we view our home planet. Please note that the presentations given at the meeting were individual reminiscences of each speaker's experience during FIFE and/or BOREAS, and thus what appears in this summary is not a chronological account of these events. The *Timeline of Key Events Related to FIFE and BOREAS* on page 13 may be helpful to refer to while reading.

**EDITORIAL ACKNOWLEDGMENT:** Every speaker at the *How FIFE/BOREAS Changed the World* meeting reviewed a draft summary of their presentation, which resulted in a very detailed account of the meeting. The authors wish to thank all participants for contributing those detailed reviews. Unfortunately, in order to fit within page limits in *The Earth Observer*, some of that information had to be shortened or eliminated—including many entertaining and enlightening anecdotal accounts. We hope that what we have preserved conveys the fact that, in addition to being pioneering scientific endeavors, FIFE and BOREAS were intensely personal experiences. Those interested in reading the unabridged summaries should contact the first author of this article.

## Meeting Presentation Summaries

### *Thursday, October 6*

### Opening Remarks: Changing the World

**Piers Sellers** [GSFC—*Deputy Director of the Earth Sciences and Exploration Directorate*[10]] welcomed everyone to the meeting and set the scene as July 20, 1994, as the team awaited the nightly BOREAS Operations briefing at a location near Candle Lake, Saskatchewan, Canada. The teams were preparing for IFC operations first at the Southern Study Area on July 21, 1994, then two days later at the Northern Study Area. He showed operational documents such as an Aircraft Flight Plan, a daily Team Participation Schedule, and a list of issues from the Mission Manager (Sellers) and Study Area Manager (Carla Evans). These documents gave a sense of the immense amount of logistical planning that was required to make this IFC happen.

Sellers proceeded to give what he called a "revisionist history" of FIFE and BOREAS and ways in which they changed the world and, in particular, how they served as impetus to move interdisciplinary Earth system science from the realm of possibility to the realm of reality. He ended with a discussion of the results of these two campaigns, which led to large integrated datasets (i.e., measurement from subsoil to

[9] *The Earth Observer* has done many previous articles chronicling the history of the EOS Program. One of the most comprehensive summaries is "The Earth Observer: 25 Years Telling NASA's Earth Science Story" in the March–April 2014 (25th anniversary) issue of *The Earth Observer* [**Volume 26**, **Issue 2**, pp. 4-13]. This article references a number of articles in the *"Perspectives on EOS"* series that ran from 2008 to 2011, which have been compiled into *The Earth Observer Perspectives on EOS Special Edition*, and can be downloaded at *http://eospso.nasa.gov/sites/default/files/eo_pdfs/Perspectives_EOS.pdf*.

[10] Please note that, unless otherwise specified all affiliations listed in brackets are the speaker's current (or most recent if retired or deceased) affiliation and, if applicable, title.

orbit), available on CD-ROMS (some of which are still being used today), and an abundance of publications, both discipline-specific and—later—interdisciplinary. These themes were repeated in many of the presentations that followed.

**Remote Sensing During FIFE and BOREAS**

**Forrest Hall** [GSFC, *retired*] recalled the humble beginnings of what led to FIFE, beginning with closet-like office space and simplistic computing capabilities. Hall led the remote sensing part of FIFE/BOREAS because—as he put it—"Piers headed up pretty much everything else." Hall traced how remote sensing capabilities evolved from the time he moved from NASA's Johnson Space Center (where he had worked on LACIE and AgRISTARS—defined on timeline, *right*) to GSFC in 1985 throughout FIFE and BOREAS. He discussed plans for FIFE, including a diagram of the scenario that Piers conceived for choosing *golden days* and *silver days* (used during FIFE and BOREAS) to prioritize measurements for data analysis.[11]

Hall summarized results obtained during FIFE'87 showing Normalized Difference Vegetation Index (NDVI) maps of the region and describing efforts to measure sensible heat. He and his colleagues developed remote sensing algorithms using data from FIFE to produce seasonal, annual, and decadal maps of vegetation type and biophysical properties at regional and global scales. They also developed a quantitative methodology for using vegetation indices to monitor surface energy, water, and carbon fluxes, as well as a physical understanding of what vegetation indices were measuring and their dependence on extraneous effects such as atmospheric and sun angle variations—all foundational approaches to interdisciplinary, multiscale, Earth system science.

Hall next mentioned some of the lessons learned during aircraft experiments during FIFE and BOREAS and how they laid the foundation for EOS data product algorithms and influenced Decadal Survey[12] and Venture Class[13] mission concepts. The data collected revealed, for example, that three-dimensional vegetation structure could be inferred using lidar (GEDI), radar, and passive optical remote sensing (MODIS), and that hyperspectral imagers can map vegetation, photosynthetic, and non-photosynthetic structure (HyspIRI).[14] These investigations also laid groundwork for future field campaigns [e.g., BERMS, LBA,[15] and Arctic Boreal Vulnerability Experiment (ABoVE)[16]].

**Impacts on Numerical Weather Forecasting**

**Alan Betts** [Atmospheric Research] worked on analyzing aircraft data during FIFE (obtained mostly by instruments on the de Havilland Canada DH-6 Twin Otter aircraft)

Timeline of Key Events Related to FIFE and BOREAS

**1972**
*- First "remote sensing" experiments with Landsat-1 data*

**1974**
*- Large Area Crop Inventory Experiment (LACIE)* ***1974-1978***

**1978**

**1979**
*- Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS)* ***1979-1985***

**1983**
*- ISLSCP Conceived*

**1984**
*- First ISLSCP Meeting*
*- Biospheric Sciences Branch created at GSFC*

**1986**
*- HAPEX-MoBilHy*

**1987**
***- FIFE'87***

**1988**
*- KUREX'88*

**1989**
***- FIFE'89****; -EOS AO*

**1990**
*- HAPEX-Sahel* ***1990-1992***

**1991**
*- KUREX'91*

**1992**

**1993**
***- BOREAS preparatory***

**1994**
***- BOREAS***

**1995**
*- LBA begins* ***1995-2005***

**1996**
***- BOREAS***
*- BERMS*

**1999**
*- Launch of first EOS "flagship" mission—Terra*

[11] At the end of FIFE'87, the participating scientists reviewed the preliminary datasets and mission logs and identified the best day in each IFC as a *golden day*, assigning it the highest priority for data processing and submission. Other days known to have good datasets were identified as *silver days* and given slightly lower priority for data processing. The process was repeated after FIFE'89 and the BOREAS field deployments.

[12] The National Academy of Science's 2007 Earth Science Decadal Survey was the first-ever comprehensive study of the Earth sciences that could benefit from spaceborne observations; it identified science priorities and a proposed time sequence of missions: Tier 1, Tier 2, and Tier 3. To learn more, visit *https://decadal.gsfc.nasa.gov/about.html*. A 2017 Decadal Survey is presently in formulation—see *http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm*.

[13] Earth Venture class missions are broken down into Suborbital (EVS), Instrument (EVI), and Mission (EVM). For more about the three categories and a list of missions, see *https://science.nasa.gov/about-us/smd-programs/earth-system-science-pathfinder*.

[14] GEDI stands for Global Ecosystem Dynamics Investigation Lidar, an Earth Venture Instrument mission planned for launch in 2020; MODIS stands for Moderate Resolution Imaging Spectroradiometer on NASA's Terra and Aqua satellites; and HyspIRI stands for Hyperspectral Infrared Imager, a Tier 2 Decadal Survey mission currently in formulation.

[15] The Largescale Biosphere–Atmosphere Experiment in Amazonia (LBA) took place from 1995 to 2005 and was led by Brazil. While the timeframe is mostly beyond the scope of this article, LBA can essentially be thought of as a follow-on to BOREAS, this time focusing on tropical forests.

[16] NASA's Terrestrial Ecology Program is conducting ABoVE, a major field campaign in Alaska and western Canada, for 8 to 10 years, starting in 2015. ABoVE seeks a better understanding of the vulnerability and resilience of ecosystems and society to the changing environment.

and realized they could be used to evaluate the European Centre for Medium Range Weather Forecasts' (ECMWF) weather forecast model. Betts was delighted to receive enthusiastic support from Tony Hollingsworth, then Director of Research at ECMWF. The timing was fortuitous for ECMWF: The improved version of the land-surface model went into testing in July 1993 and hit "pay dirt" immediately as it greatly improved forecast skill for the historic flooding that took place in the Midwest U.S. that summer.

The improved ECMWF model was used for daily forecasts for BOREAS, and BOREAS data were subsequently used to correct forest snow albedo in Canada and Eurasia. Data from both BOREAS and BERMS later played a big role in improving ECMWF's 45-year reanalysis of global atmosphere and surface conditions that ran until August 2002. Betts said that FIFE and BOREAS were transformative for modeling, and provided significant ground truth for evaluating forecast models; he noted that the FIFE dataset was used to test every land surface model for a decade. In summary, BOREAS/BERMS led to new forest models and several generations of snow models—information still being transferred into Earth-science models today.

*FIFE and BOREAS were transformative for modeling, and provided significant ground truth for evaluating forecast models; the FIFE dataset was used to test every land surface model for a decade.*

**Physiology: Leaf to Orbit**

**Joe Berry** [Carnegie Institution for Science] described a series of scientific investigations that took place around the same time FIFE was under way. He began by describing the pioneering work of Compton "Jim" Tucker at GSFC, who developed NDVI using AVHRR[17] data in 1979, and Inez Fung, then at NASA/Jet Propulsion Laboratory (JPL), who studied global atmospheric carbon dioxide ($CO_2$) concentrations. Berry showed the iconic "flying carpet plots," (from a 1986 article in *Nature* that Tucker, Fung, and others, co-authored) that show how $CO_2$ and NDVI varied over space and time. Around the same time as Tucker and Fung's research, Sellers was working to incorporate his Simple Biosphere (SiB) land-surface parameterization into a GCM. Berry began an effort to improve the SiB model's representation of evapotranspiration, based on an earlier model of photosynthesis developed by Graham Farquhar and Susanne von Caemmerer, who were both at the Australian National University. Berry and Tim Ball, Berry's graduate student at Colorado State University (CSU), used that model to predict the stomatal response, later used by Sellers and his GSFC colleague, Jim Collatz, in an improved version of the canopy model: the Simple Biosphere Model-II (SiB-II).

Ultimately, all these areas of study came into play when two of the original EOS Interdisciplinary Science Projects merged to form *The Greening of the Colorado State University GCM*, which was discussed in a 1996 issue of *Journal of Climate*. This was the first time models of larger-scale processes were coupled with models of smaller-scale process. The project took place in parallel with FIFE and BOREAS, which meant there were plenty of new field data to test the updated models.

**Aircraft Flux Measurements during FIFE and BOREAS**

**Raymond Desjardins** [Agriculture and Agri-Food Canada, Science and Technology Branch] showed how FIFE and BOREAS aircraft observations contributed to improving flux-measuring systems. These experiments improved our understanding of mass and energy fluxes between Earth's surface and its atmosphere. He demonstrated how the data collected by flying long [30-m (~98-ft)] transects over the boreal forest helped quantify the contribution of mesoscale transfer to the lack of energy budget closure on flux measurements.

Desjardins described several key measurement techniques that were new at the time, and also showed how integrated observations are essential for understanding land-atmosphere interactions. He stated that additional information will be extracted from these data. He noted that if he were to do an experiment like FIFE or BOREAS today, he would recommend fewer tower/aircraft comparisons, more focus on budget studies, and taking measurements over long transects.

[17] AVHRR stands for Advanced Very High Resolution Radiometer, which has flown on NOAA's Polar Orbiting Environmental Satellite series.

**FIFE and BOREAS Soil/Atmosphere Flux Models**

**Dave Schimel** [JPL] noted the irony in Piers Sellers asking him to discuss modeling. He noted that he always thought of FIFE as "scaling from chiggers to C-130s"—chiggers being a key operational issue in those days.[18] He invited participants to step into "the modeling Wayback Machine" by describing the now-dated technology used at the time, and then focused in on the state of the art of models prior to FIFE. In the mid-1980s it was accepted that "you could not scale from leaf to canopy" because there was no scaling rule to simplify modeling each leaf, and there was no way to choose between alternate scaling theories. Testing scaling theories and models required measuring photosynthesis or respiration at large scales and—until FIFE—this had never been done.

Early empirical field observations over the Konza Prairie led to the discovery of a relationship between light interception and nitrogen limitation, which led to emergence of a scaling rule that related light absorption, canopy nitrogen, and photosynthetic capacity—the first step to scaling from leaf to canopy. That rule was immediately incorporated into the nascent SiB-II. However, the basic assumptions still needed verification. The pioneering sustained eddy covariance measurements taking during FIFE led to the answer—i.e., canopy-scale flux measurements. While now routine, work done on the Konza Prairie established biophysical and biogeochemical linkages that are still being absorbed into models.

**Flux Observations at the BOREAS Northern Study Area Old Black Spruce (NSA-OBS) Site**

**Steve Wofsy** [Harvard University] was introduced to models of the global carbon cycle through Inez Fung's work, discussed previously. He described how he thought Sellers and Hall had a "beautiful" concept for a campaign, and noted that Diane Wickland, in her roles as HQ program scientist and program monitor for FIFE and BOREAS, was willing to push the envelope beyond the norm at NASA, taking a risk in funding their concept. History has shown that her risk has more than paid off.

Wofsy showed pictures of the NSA-OBS site—see *The FIFE/BOREAS Study Areas* on pages 8-9 for context—and the people involved, noting the ground-level temporal and spatial variability in the boreal forest. Wofsy also connected the BOREAS study to the recent EVS-1 study, Carbon in the Arctic Reservoirs Vulnerability Experiment (CARVE), yet another "grandchild" of BOREAS—see *https://carve.jpl.nasa.gov* to learn more. Three years of aircraft flights over Alaska (2012–2014) resulted in hundreds of vertical atmospheric profiles, giving results that were foreshadowed by BOREAS. BOREAS provided the remote sensing context to link ecosystem scale observations to the global carbon cycle. BOREAS results also showed the critical importance of year-round monitoring of the *shoulder seasons* in between peak activity to understand the soil-climate-carbon nexus—and how to model it.

*BOREAS results also showed the critical importance of year-round monitoring of the shoulder seasons in between peak activity to understand the soil-climate-carbon nexus—and how to model it.*

**Follow the (Surface) Water**

**Richard Cuenca** [Oregon State University, Corvallis] gave a detailed description of the routine used to make soil moisture measurements during the first BOREAS campaign (1994) using a neutron probe. He also discussed visualization of soil water dynamics during BOREAS, using neutron probe data and then using continuous-recording dielectric probe data. He also described infiltration tests to parameterize soil water dynamics, describing winter operations under trying conditions to maintain and prepare the sites for summer campaigns.

[18] *Chigger* is one nickname for a class of arachnids called *trombiculid mites*; they are commonly found in moist grassy areas like fields and forests (which pretty much covers the terrain of FIFE and BOREAS). Adult chiggers don't bite but their larvae do. They can latch onto pants and shirts and seek out and attach to exposed skin. The bites, which can be very itchy, would most often be found in clusters around the waist or lower legs.

Cuenca went on to discuss the Airborne Microwave Observatory of Subcanopy and Subsurface Mission (AirMOSS) campaign (see *http://airbornescience.jpl.nasa.gov/campaign/airmoss*), which involved Mahta Moghaddam from the University of Southern California and Sassan Saatchi from JPL, who also worked together during BOREAS—see presentation below. He showed the AirMOSS sites, noting that some were used during BOREAS. He ended by commending Sellers and Hall for their vision and pioneering work to make these field campaigns a reality.

**Follow the Carbon**

**David Fitzjarrald** [State University of New York (SUNY) Albany, Arctic Slope Research Corporation] was fresh from the NASA Atmospheric Boundary Layer Experiment (ABLE), with projects in the Amazon forest, the Alaskan tundra, and Quebec boreal forest and fen, when he met Sellers and Hall in 1992. Sellers called this flux work "Boy Scout science," with defined steps and mid- and endpoints, whereas BOREAS was to be the "real science." Fitzjarrald demurred at this assessment, and felt his approach was more *aleatoric*, that is, prizing the serendipitous discovery common in field research.

*Spirited but civil debate—a notable feature of BOREAS—led the very same FIFE people who early on argued against long-term flux measurements to lead the development of FLUXNET, a large international flux tower network.*

BOREAS was structured to have the former ABLE participants and new Canadian colleagues in the NSA and FIFE veterans participate in a more-elaborate field operation in Saskatchewan. Fitzjarrald stated that among the durable results from BOREAS was recognition that long-term eddy flux measurements are required, supplanting the FIFE template of a series of short-term intensive field periods. Spirited but civil debate—a notable feature of BOREAS—led the very same FIFE people who early on argued against long-term flux measurements to lead the development of FLUXNET, a large international flux tower network.

**Follow the Photons**

**Jing Chen** [University of Toronto] began working on BOREAS as a postdoc. He described how photons in leaves can go to three different interrelated processes: non-photochemical quenching, chlorophyll fluorescence, and photochemical quenching—the main interest for his work. The *one big leaf* model for photon pathways gives a fair estimate of Net Primary Productivity, but work by John Norman, moving to two leaves (a sunlit leaf and a shaded leaf), improved results considerably. According to the fraction of vegetation photosynthesis model, discussed previously, photons are "more welcome" in shaded leaves. During and after BOREAS, researchers started "following the photons" in various ways and learned that the mechanistic photosynthesis model developed by Graham Farquhar and Susanne von Caemmerer (described previously) requires us to follow photons to both the sunlit and shaded leaves. Chen then proceeded to show how gaps in canopies are as important as gaps between measurement sites, and that remote sensing has a major role to play in filling both gaps.

**Radar Derived Forest Biomass and Canopy and Soil Moisture in BOREAS**

**Sassan Saatchi** [JPL] started his remote sensing work during FIFE'89, and got to know Sellers and Hall when he worked at GSFC from 1989 to 1991. Prior to BOREAS, vegetation canopy radar observations from space were conceived of but there was very little to connect them to the ground. Saatchi was part of the Airborne Synthetic Aperture Radar (AirSAR) team when they prepared to head to Canada in 1993, and described how the three-frequency microwave measurements provided information about soil and vegetation over the BOREAS study sites. Saatchi discussed the theoretical basis for the biomass algorithm developed during the experiment and how results and concepts were later incorporated into space missions—e.g., NASA's Soil Moisture Active/Passive (SMAP) mission, the joint NASA–ISRO[19] Synthetic Aperture Radar Mission (NISAR), and the AirMOSS.

[19] ISRO stands for the Indian Space Research Organization.

*Friday, October 7*

**New Understanding of Atmospheric Turbulent Mixing**

**Jielun Sun** [University Corporation for Atmospheric Research] described the pioneering work that she and her colleagues did during BOREAS to investigate the role of the $CO_2$ advection in explaining the "missing" nighttime $CO_2$.[20] Since then, many field campaigns have been conducted to study this effect. She went on to describe the only nighttime flight of the Twin Otter and the *ad hoc* boat measurements to try to measure the *chimney effect*[21] over Candle Lake. The data Sun's team collected during BOREAS also revealed significant differences between surface radiation temperature and aerodynamic temperature—differences that are important to understand in order to parameterize turbulent heat transfer from air–land interactions in models.

Sun demonstrated how BOREAS facilitated interdisciplinary work, which included both designed and *ad hoc* experiments. She concluded by showing some more-recent research into understanding turbulent mixing in air–land interactions that builds upon the knowledge gained during BOREAS.

*Large-scale experiments like BOREAS are not just about scientific achievements but also about human synergy; twenty years later, the people involved in FIFE and/or BOREAS are still a community.*

**Flux Tower Measurements during BOREAS**

**Elizabeth Pattey** [Agriculture and Agri-Food Canada] reported on how studying unmanaged forest and managed agroecosystems provide insight on atmospheric biogeosciences, thus supporting aircraft teams, atmospheric chemists, and Earth-observation scientists. She described how FIFE and BOREAS initiatives helped the micrometeorological community improve their flux measuring methodology and better understand and interpret their flux measurement datasets. The OBS site data, obtained used two tunable diode lasers for methane and nitrous oxide fluxes and a relaxed eddy accumulation system for measuring isoprene emissions, revealed that boreal forests—and OBS in particular—behave like an arid ecosystem, as they are very conservative in resource management. Other phenomena from these early studies presaged increased tower- and aircraft-based trace gas flux experiments. Researchers experimented with new ways to assimilate such data into vegetation models. Pattey reflected sentiments similar to those of previous speakers: Large-scale experiments like BOREAS are not just about scientific achievements but also about human synergy: She noted that twenty years later, the people involved are still a community.

**Learning Ecosystem Atmosphere Studies from BOREAS**

**Ken Davis** [Pennsylvania State University] was a physics undergraduate student when FIFE took place, and was a postdoc at the National Center for Atmospheric Research (NCAR) during BOREAS. He described his experiment [Airborne Fluxes and Meteorology (AFM)-13] on the NCAR Electra aircraft based in Saskatoon, Saskatchewan Province, Canada, with activities to "tie together" the BOREAS northern and southern study areas. Davis noted that point measurements (e.g., from flux towers) and global measurements are not sufficient, and that intensive campaigns that oversample ecosystem variability in important regions of the Earth system are necessary. Davis also called for renewed engagement between the climate modeling community and the field research community.

**Capturing and Cataloguing Data: FIS and BORIS**

**Don Strebel** [Versar, Inc.], speaking on behalf of co-authors **Fred Huemmrich** [University of Maryland, Baltimore County] and **David Landis** [Global Science & Technology, Inc.],

[20] In ecological studies, the "missing $CO_2$" refers to the mismatch between the known reasonable amount of $CO_2$ respiration from the ground and ecosystem at night and the relatively small $CO_2$ flux measured at towers. Because of the stable boundary layer developed at night, which reduces turbulent mixing, a significant amount of the $CO_2$ is transported horizontally and never reaches to the tower sensors.

[21] The *chimney effect* refers to cold air drainage flow over Candle Lake that carries nighttime respirated $CO_2$ from soil/canopies over the warmer lake water surface. The convective buoyancy then transports air with high $CO_2$ concentrations upward over the lake by turbulent mixing, forming a $CO_2$ transporting mechanism, or *chimney*, over the area.

The FIFE datasets were made widely available on CD-ROM, which at the time was state of the art technology. **Photo credit:** Don Strebel

described the pioneering information systems that connected investigators with data—essential to the success of FIFE and BOREAS. He described the creation and accomplishments of the FIFE Information System (FIS), with tools that are the functional equivalents of what we commonly use today, but were not then available.

FIS grew into NASA's first working interactive online data system, which successfully supported FIFE, formed the basis for the BOREAS Information System (BORIS), and reinvigorated a later version of NASA's Pilot Land Data System (PLDS).[22] In addition to the FIS staff, the collaborative effort drew upon the talents of many NASA scientists, contract support scientists, Konza Prairie Longterm Ecological Research (LTER) scientists, and the FIFE investigator teams.

The FIS Staff, ca.1988. [Standing, *left to right*] Scott Goetz, Gail Beckman, Babu Banerjee, Forrest Hall, David Landis, Jeff Newcomer, Rich Irish,Tom Eck. [Seated, *left to right*] Ned Horning, Ruth Kennard, Jaime Nickeson, Don Strebel. Others *not pictured* included Diana Van Elburg–Obler, Fred Huemmrich, Jim Ormsby, Steve Ungar, Jim McManus, Bob Lutz, Alan Nelson, Patrick Agbu, and Blanche Meeson, along with several interns. **Photo credit:** Don Strebel

In sum, FIS personnel (see photo above) built the Internet's first interactive scientific database, established the first practical data documentation standards, and published the first digital scientific data collection to meet the "20-year test" by publishing the FIFE data on CD Roms—see photo [*upper left*]. Still in use today and described as "the longest running FIFE experiment," this effort showed that formal data publication could preserve for at least 20 years data for access and use by a scientist unfamiliar with the datasets or their collection.

*In sum, FIS personnel built the Internet's first interactive scientific database, established the first practical data documentation standards, and published the first digital scientific data collection to meet the "20-year" test by publishing the FIFE data on CD-ROMs.*

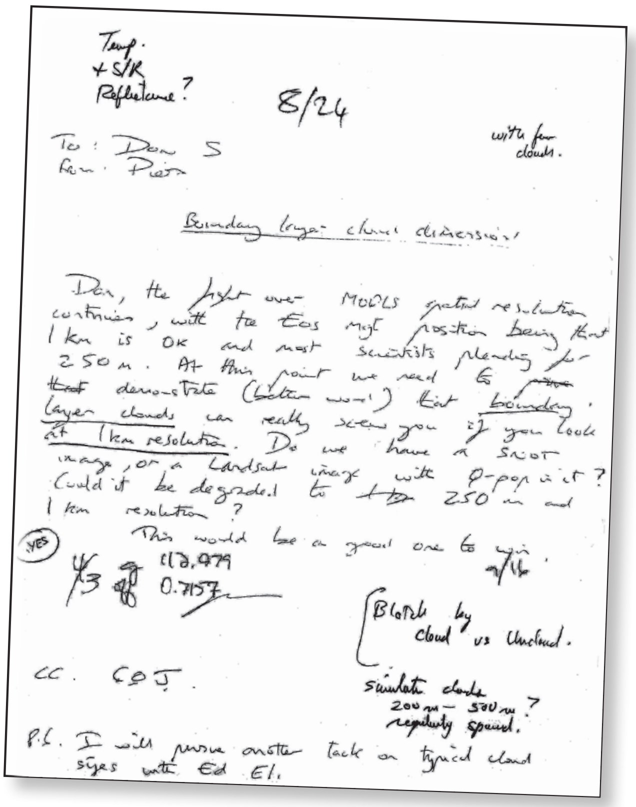
**Planning and Implementing FIFE and BOREAS (a.k.a. *Herding Cats*)**

**Jaime Nickeson** [GSFC/Science Systems and Applications, Inc.] recalled some of her experiences at GSFC during FIFE and BOREAS, spending most of her FIFE years in the laboratory processing satellite data and working to radiometrically rectify the satellite datasets. She did much more field work during BOREAS, however, from early information gathering and data processing to field reconnaissance, to identify and locate tower and auxiliary sites. She discussed how Sellers and Hall worked with GSFC staff to compile the Experiment Plan: three volumes dictating what would be done where and when, and appendices A through P, containing things such as flight plans, procedures, satellite overpass schedules, customs, and shipping. Key to the success of the experiments were planning (laid out in the Experiment Plans), excellent leadership (from both Hall and Sellers), and assigning staff to each of the science disciplines with subsequent building of relationships. Years later, Nickeson found a handwritten memo from Sellers. It was titled *Boundary Layer Cloud Dimension*, and it described the battle Sellers had been waging within EOS over the resolution of the MODIS sensor—see *How FIFE Changed MODIS* on the next page.

[22] PLDS was the data system that NASA HQ was working in the years leading up to FIFE. Strebel and his associates quickly came to the conclusion that PLDS, as it existed at the time, would not be flexible enough for use in FIFE, which led them to develop a separate FIS. This, in turn, fed back into the evolution of the PLDS.

## How FIFE Changed MODIS

NASA's Earth Observing System (EOS) was being conceived in the mid-to-late 1980s, right around the same time FIFE was being planned and executed, and the concept continued to evolve as BOREAS unfolded in the mid-1990s. While FIFE/BOREAS data and personnel influenced the design of EOS in many ways, one development was particularly noteworthy: A hotly debated issue at the time was the utility of including a couple of 250-m-resolution bands on the two Moderate Resolution Imaging Spectroradiometer (MODIS) instruments that were being designed and would eventually fly on the EOS Terra (1999) and Aqua (2002) flagship missions.



Temp.
+ S/R
Reflectance?

8/24

with few clouds.

To: Don S
From: Piers

Boundary layer cloud dimensions

Don, the fight over MODIS spatial resolution continues, with the EOS mgt position being that 1 km is OK and most scientists pleading for 250 m. At this point we need to ~~that~~ demonstrate (better word) that boundary layer clouds can really screw you if you look at 1 km resolution. Do we have a SPOT image, or a Landsat image with Q-pop in it? Could it be degraded to ~~the~~ 250 m and 1 km resolution?

YES

This would be a good one to win.

9/16

113,979
0.7157

Blotch by cloud vs Uncloud.

simulate clouds 200 m – 500 m? regularly spaced.

cc. COJ.

P.S. I will pursue another tack on typical cloud sizes with Ed El.

A hand-written Memo from **Piers Sellers** to **Don Strebel** and cc'ing **Chris Justice** [University of Maryland, College Park] (circa 1991-92) asking if the FIFE Team could provide some data that would help him in his effort to convince decision makers at NASA HQ that the proposed 250-m MODIS bands were essential to include. **Image credit:** Jaime Nickeson

At the end of her presentation at the meeting, **Jaime Nickeson** produced a handwritten memo that Piers Sellers had sent to Don Strebel *circa* 1991–1992. Sellers was trying to make the case that "boundary layer clouds can really screw you if look at them at 1-km resolution," and wanted imagery to back up his claim—adding, "this would be a good one to win." Strebel shared the memo with Nickeson, who dug into the FIFE satellite archive that contained plenty of imagery with "popcorn" clouds. She resampled some 20-m SPOT* imagery to the 250-m resolution they were proposing for MODIS, and then also resampled to 500 m and 1 km. They found that many of the small boundary layer clouds, clearly visible in photos from FIFE and higher-resolution images, tended to disappear at lower resolutions. This information helped convince **Dixon Butler** and other decision makers at NASA HQ that including the 250-m MODIS bands was essential. Relying on the poorer temporal coverage of higher-resolution sensors (e.g., Landsat, SPOT) simply would not suffice for global biosphere studies.

Today, MODIS is arguably the workhorse of the EOS satellite fleet, as it provides data for many applications and has been cited in many papers in science journals. How different the world of EOS (and thereafter) would have been had Sellers not prevailed in this argument.

* SPOT stands for Satellite Pour l'Observation de la Terre; it is a commercial, high-resolution, optical-imaging, Earth-observation satellite system run by the French company Spot Image, based in Toulouse.

## "I Was There!": Some Personal Views of FIFE and BOREAS

On the afternoon of the first day, the focus of the meeting shifted away from science and more to personal anecdotes and memories of the FIFE and/or BOREAS experience from several individuals who were there, walking on or flying over the prairies of Kansas and/or the boreal forests of Canada. The short summaries we use in this article do not do these reports justice, so we highly recommend watching the online videos of these presentations—and perhaps reading the unabridged presentation summaries.

**Willie Dykes** [WBOC TV, Salisbury, MD] captured the crowd's imagination as he described the exploits of the helicopter remote sensing team at NASA's Wallops Flight Facility (WFF)—"The Troponauts." He explained that helicopters are ideal for testing new experiments since they are able to hover over a target and take continuous measurements. Dykes concluded by noting that "During BOREAS we learned the troposphere is not just a layer of gas—it's Earth's breath."

The Troponauts helicopter remote sensing team during BOREAS. [*Left to right.*] **Igor Gorankov** [visiting Russian scientist], **Charlie Walthall**, **James Ampe** [University of Kansas (KU)—*Graduate Student of Prasad Gogineni*], **Charles "Smitty" Smith** [*Mechanic*], **Willie Dykes**, and another of Gogineni's grad students at KU. **Photo credit:** Rick Huey [WFF]

**Charlie Walthall** [U.S. Department of Agriculture, ARS—*National Program Leader*] also went to WFF to test the feasibility of using a helicopter [*top photo*] to acquire detailed spectra of terrestrial surfaces. He described his experiences working with "The Troponauts" and experimenting with a number of different remote sensing instruments.

**Ian MacPherson** [National Research Council of Canada, *retired*] explained that FIFE and BOREAS put the Twin Otter aircraft [*bottom photo*] "on the map," as they were the first experiments to make extensive use of the aircraft in the flux-measuring role. He shared some of his more memorable experiences while flying, including the largest wind gust ever encountered by the Twin Otter as well as a break fire during takeoff—see related poem on page 21.

The Twin Otter crew during one of the FIFE'87 Intensive Field Campaigns. [*Left to right.*] **Ray Desjardins**, **Peter Schuepp** [McGill University], **John Croll** [*Pilot*], **Chuck Taylor** [*Instrument Technician*], **Ben McLeod** [*Aircraft Maintenance*], and **Ian MacPherson**. **Photo credit:** Ian MacPherson

**Christopher Pali** [NASA/Dyncorp] showed a *NASA 427* model of NASA's Wallops Flight Facility's C-130 *Hercules*—"The Cutie"—which he piloted for BOREAS during January and July 1996. He shared fond memories from his time in Canada and reflected on the friendship he had with Sellers, who left BOREAS in 1996 to join the NASA astronaut corps.

**Steve Ungar** [GSFC, *retired*] explained the three roles he had during FIFE: project scientist for FIS; MODIS Airborne Simulator (MAS) instrument scientist during FIFE (which flew on the C-130); and Soil Moisture Measurement principal investigator. He described how his experiences in FIFE, the Kursk 1991 Experiment (KUREX'91) in Streletskaya, Russia (where they studied global climate processes in steppe vegetation), and BOREAS, all helped prepare him for his later role as project scientist for the Earth Observing-1 mission.

**Paula Pacholek** [Canadian Wildlife Service] discussed Canadian concerns of a NASA invasion that would impact vegetation, wildlife, and/or the experience of the Prince Albert National Park visitor. Such fears were proved unfounded, however, and the BOREAS scientific activities were welcomed and enjoyed, as NASA demonstrated ability to live under local conditions.

**Scott Goetz's** [Northern Arizona University] initial involvement was in selecting flux tower and other sites for BOREAS. He now leads the Arctic Boreal Vulnerability Experiment (ABoVE), the next generation NASA-led field campaign.

**John Norman** [University of Wisconsin, Madison, *retired*] described how FIFE led to better models for satellite mapping. The key lesson was that the canopy must be represented as two or more layers—because soil behaves much differently than leaves.

### ISLSCP I and II

**Forrest Hall** described how Piers Sellers was the perfect person to organize large-scale experiments like FIFE and BOREAS, and ISLSCP. He talked about a workshop at GSFC in 1992, convened to assess the current state and direction of biosphere–atmosphere model development, data needs for models, current satellite data algorithms, and other global datasets. This meeting served as an impetus for the ISLSCP-Initiative I data collection, which was a two-year effort (1987 and 1988) and which resulted in a variety of datasets mapped to a common 1° x 1° equal-angle grid, and made available on CD-ROMS. An article describing ISLSCP-I datasets appeared in the *Bulletin of the American Meteorology Society* in 1996.

As noted earlier, Sellers went on to astronaut training in 1996 and Hall took the lead on ISLSCP-Initiative II, which expanded upon ISLSCP I collection—with increased spatial (¼° x ¼°, ½° x ½°, and 1° x 1° grids) and temporal resolution (10 years, from 1986 to 1995, as opposed to 2 years for ISLSCP-I) and added carbon datasets (ISLSCP-I had primarily focused on water). Hall showed a slide that gave an idea of the many organizations involved in ISLSCP-II and also showed an impressive list of publications that site ISLSCP-II. The ISLSCP-II datasets were published in a *Journal of Geophysical Research* article in 2006. The most common uses of the data were for model intercomparisons and for studies of global runoff, global forests, global fire emissions, and global carbon distribution.

### Perspectives from NASA HQ

Two presentations were provided by individuals who played prominent programmatic roles in the years leading up to and during FIFE and BOREAS.

**Bob Murphy** [NASA HQ, *retired*] shared his perspective as one who participated in the birth of FIFE and BOREAS both at GSFC and NASA HQ, noting the early lack of any biospheric science at NASA in 1977 and the activities that led to formation of the Biospheric Branch at GSFC, which subsequently organized FIFE. He ended his reflections by asking: "Did FIFE/BOREAS change the world?", and answered his own question with an enthusiastic, "You bet!" As a result of these campaigns, many scientific findings have been brought into practical use in forecast models and continue to feed our understanding of crucial environmental problems. Of particular note is that a scientific discipline and community of researchers have been formed that did not exist 35 years ago.

**Diane Wickland** [NASA HQ, *retired*] called the event being reported on here a "lovely trip down memory lane." She particularly liked hearing perspectives on FIFE that were different from what she experienced as a NASA program manager—see *"I Was There!": Some Personal Views of FIFE and BOREAS* on page 20. She commended Murphy's role in actively pursuing the resources to do FIFE, which provided the budgetary foundation for future field campaigns. Wickland also commended Sellers and Hall for "figuring out" the logistics of how to organize and implement a large-scale experiment the likes of which NASA had never done before. She expressed great pride in the accomplishments of the FIFE–BOREAS community.

*Eyeball-to-eyeball with the tree*
*flies Aiken John—so low that he*
*is wont to say when crewmen squeal,*
*"that's how I like to spin the wheel".*
*And much desired photo-ops*
*are when he shaves the black-spruce tops.*
*The camera in Raymond's hand*
*spasmodically scans the land*
*a flash of Otter, blue and white,*
*a drunken hurtling out of sight,*
*a hint of sky, a blur of tree,*
*that's what you might or might not see.*

***—Peter Schuepp***

### FIFE, BOREAS, and EOS: Precursor and Consequent

**Piers Sellers** provided some remarks connecting the FIFE/BOREAS story to the broader story of EOS, describing how he was enjoying life as a young scientist at GSFC in the mid-1980s, working on FIFE with Hall and others when EOS began to take shape. He eventually became deputy to Gerry Soffen [the first EOS Project Scientist (PS)], served on the EOS Review Group (ERG), and then was dismissed as EOS Deputy PS after sharing the conclusions of the ERG, returned happily to FIFE, but then was summoned back to EOS within 18 months to become the first AM-1 PS.[23]

[23] Sellers recounts more details of this tale in his "Perspectives on EOS" article, previously referenced.

Sellers described three areas where results from FIFE/BOREAS and the people who developed them impacted the design of EOS. These included:

1. Selection of the equator crossing time for AM-1 (which later became Terra)—choosing a morning orbit (1030 local Equator crossing time) as opposed to afternoon (1330);
2. the design of MODIS (see *How FIFE Changed MODIS* on page 19*)*; and
3. FIS, the forerunner of what became the EOS Data and Information System (EOSDIS).

In each case, Sellers shared personal anecdotes of his experiences in the field and his contributions to these discussions. One noteworthy observation was his thinking that the early EOS Data System as being developed at Raytheon would not work. To some extent he was correct, although elements of the original concept were incorporated into the final system.[24]

*Fluxnet-Canada built on the success of BOREAS to make high-quality field measurements of biosphere–atmosphere fluxes, which were combined with remote sensing data and used to help develop and test predictive models of northern forests and peatlands.*

**Long-Term Influence of BOREAS on Carbon Cycle and Ecosystem Research in Canada**

**Hank Margolis** [NASA HQ—*Program Manager of Terrestrial Ecology*[25]] shared his BOREAS journey, and then discussed Fluxnet-Canada, which built on the success of BOREAS to make high-quality field measurements of biosphere–atmosphere fluxes, which were combined with remote sensing data and used to help develop and test predictive models of northern forests and peatlands.

Margolis described the archived dataset, which he called Fluxnet-Canada's "major legacy." They have amassed 185 site-years of flux data from 34 sites through 2011; they also have basic ecological data for nearly all sites. Some 932 users from 51 countries downloaded data between 2012 and 2014 from the Oak Ridge National Laboratory Distributed Active Archive Center (DAAC) and the Ameriflux database, which are used extensively for regional and global analyses.

Margolis presented some data from the Gravity Recovery and Climate Experiment (GRACE) that shows a gravity anomaly (attributed to groundwater) over White Gull Creek—which just happens to be centered exactly where Sellers and Hall chose to locate BOREAS more than two decades ago (because early models suggested climate change would be significant in this area) and which served as the basis for the longer-term BERMS studies. He showed how *in situ* BOREAS results validate the GRACE results. Work that began in BOREAS and continued with Fluxnet-Canada has laid groundwork for the current ABoVE campaign.

**Concluding Remarks by the Organizers**

To start a general conversation, **Piers Sellers** asked: *What did we do in FIFE and BOREAS and why does it matter?* As the presentations at the meeting made clear,

[24] Rama Ramaprayin tells the story of the progress, perils, and pitfalls along the way to developing the EOS Data and Information System (EOSDIS) in his two-part article "EOS Data and Information System, Where We Were and Where We Are" in the July–August 2009 and September–October 2009 issues of *The Earth Observer* [**Volume 21**, **Issue 4**, pp. 4-10 and **Volume 21**, **Issue 5**, pp. 8-15].

[25] Margolis replaced Diane Wickland in this role in 2015; prior to that he was at Université Laval, Québec City, Canada.

prior to FIFE non-credible models were used to make predictions of significant societal importance. For example, in 1988, when Jim Hansen, then at NASA's Goddard Institute of Space Studies (GISS), testified before the U.S. Senate on June 23, 1988, stating his opinion that, "the greenhouse effect has been detected, and its changing our climate now," his conclusions were based on the unreliable models created in the 1970s and 1980s.[26] It is noteworthy that at the end of his remarks Hansen said to the Senators, "I would like to stress that there is a need for improving these global climate models, and there is a need for global observations if we're going to obtain a full understanding of these phenomena.

Hansen's words read like a harbinger of FIFE (which was already underway in 1988), BOREAS, and EOS. Indeed FIFE and BOREAS contributed to the improvement of models that Hansen had asked for in his testimony. In essence, data from these field experiments "broke" the old models, but also provided the information needed to "fix" them, which in turn led to the development of much-improved versions of these models. And the models have kept on improving since then.

*Improved models are needed now more than ever as we try and tackle the underpinnings and consequences of climate change—and to convince the world of the seriousness of related issues. While there has been significant progress in this area since 1987, there is still much work to be done.*

Sellers emphasized that improved models are needed now more than ever as we try and tackle the underpinnings and consequences of climate change—and to convince the world of the seriousness of related issues. While there has been significant progress in this area since 1987, there is still much work to be done. The scientific community created by FIFE/BOREAS continues to play a crucial role in studying such global issues and communicating the results of their findings. What was shared during this meeting shows the many ways in which these experiments changed the world—or at least, our understanding of it. Such contributions are indeed foundational and formative to the present and future of Earth system science.

**Forrest Hall** also offered some concluding words. He thanked everyone who participated, and particularly those who presented both data and information and their personal views of the activities. He specifically thanked Carla Evans, who works at the NASA Carbon Cycle and Ecosystems Office for Science Systems and Application Inc.—and herself a FIFE/BOREAS veteran—for the logistical work she did to make this meeting possible.

**Summary**

Overall, FIFE and BOREAS arrived at an opportune time for the emerging field of Earth system science—just in time for the concepts for EOS to emerge and to take shape. The campaigns accelerated collaboration between previously discrete scientific communities, and moved interdisciplinary science from theory to reality. They also accelerated development and validation of GCMs and served as a pathfinder for scientific and organizational work done by EOS. Also, a new generation of now-experienced and motivated students participated in these two experiments, subsequently completing their studies, with many acquiring doctoral degrees using FIFE and BOREAS datasets. They also forged lasting friendships and work relationships, without which ongoing important scientific work could not be done. With FIFE and BOREAS as the basis for early work, there are many scientists that are leaders in the field today, pushing our understanding of Earth system science into new and deeper realms. ■

[26] Hansen's findings were based on a 1988 publication in the *Journal of Geophysical Research* that described his work using the GISS model (developed in the 1970s).

# NASA's Outreach Activities at COP-22 and the 2016 AGU Fall Meeting

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

## Introduction

The NASA Science Communication Support Office (SCSO), previously called the Science Program Support Office,[1] is the primary point of contact for NASA's Science Mission Directorate and Earth Science Division for science exhibit outreach and product development. During fiscal year 2016,[2] the office supported activities at 25 domestic and international science conferences and public events by providing an inspiring and interactive communications venue and using a unique storytelling approach. This allows a variety of audiences worldwide to connect with and understand NASA's science activities.[3]

During the final months of 2016 the SCSO supported the twenty-second Conference of Parties (COP-22) to the United Nations Framework Convention on Climate Change and the forty-ninth annual American Geophysical Union (AGU) Fall Meeting. To view photos from these and other events, visit *https://www.flickr.com/photos/eospso/albums*.

## COP-22

COP-22 took place in Marrakech, Morocco, November 7-18. The U.S. Department of State hosted the U.S. Center at COP-22, where the SCSO supported the NASA Hyperwall and Dynamic Planet display[4]—see **Photo 1**. As has been the standard for past COP meetings, representatives from NASA were present in the U.S. Center to highlight key climate programs and relevant scientific research. The Hyperwall was used for 30-minute, single-presenter talks and side-event presentations—i.e., 60-90-minute discussions generally provided by a small panel. **Ali Omar** [NASA's Langley Research Center—*Research Scientist*], **John Reager** [NASA/Jet Propulsion Laboratory (JPL)—*Research Scientist*], **Lesley Ott** [NASA's Goddard Space Flight Center (GSFC)—*Research Scientist*], and **Dan Irwin** [NASA's Marshall Space Flight Center—*SERVIR*[5] *Director and Research Scientist*] traveled to Morocco to participate in the two-week event by delivering a variety of Hyperwall and side-event presentations—see **Photos 2-4**. The

**Photo 1.** The NASA Hyperwall and Dynamic Planet were located inside the U.S. Center at COP-22. Pictured here, **Ali Omar** described how NASA's satellites observe Earth's climate from space; the current Earth-science satellite fleet is also shown on the Hyperwall. The Dynamic Planet is pictured in the foreground. **Photo credit:** NASA


**Photo 2. John Reager** discussed some of the dynamic changes in Earth's gravity field that NASA is able to observe from space using the Gravity Recovery and Climate Experiment (GRACE) satellites. **Photo credit:** NASA


**Photo 3.** Using the Hyperwall, **Dan Irwin** provided a unique perspective on how NASA connects "space to village" by empowering decision-makers with tools, data products, and services so they can act locally on climate-sensitive issues such as disasters, agriculture, water issues, ecosystems, and land use. **Photo credit:** NASA

[1] To read about other outreach activities previously reported on in *The Earth Observer*, see "Delivering NASA Science Face-to-Face to the World" [**Volume 28, Issue 1,** pp. 20-22].

[2] The U.S. federal government's fiscal year begins on October 1 of the previous calendar year and ends on September 30 of the year with which it is numbered.

[3] The SCSO's 2016 Annual Report provides a broad overview of these activities, along with details about new Hyperwall stories, publications, social media, key partnerships, and more. To read the full report, visit *https://eospso.nasa.gov/sites/default/files/publications/AnnualReport2016_508.pdf*.

[4] NASA's *Dynamic Planet* is a 48-inch spherical display system that provides a unique and vibrant global perspective on Earth, our sun, various planetary bodies in our solar system, and the universe to increase and improve scientific understanding.

[5] SERVIR, which means "to serve" in Spanish, is a joint venture between NASA and the U.S. Agency for International Development, that provides state-of-the-art, satellite-based, Earth-monitoring data, geospatial information, and tools to help improve environmental decision-making among developing nations in Eastern and Southern Africa, the Hindu Kush and Himalaya regions, and the Mekong River Basin in Southeast Asia.

**Photo 4. Lesley Ott** used the Hyperwall to discuss atmospheric composition and aerosols, as well as how human activities impact Earth's climate. **Photo credit:** NASA

Hyperwall presentations were well attended, with over 40 guests from around the world listening at any given time. Reager reported that the Hyperwall "…literally made passersby stop in their tracks and stare in amazement." To add to their amazement, Omar and technical staff members **Eric Sokolowsky** [GSFC] and **Mark Malanoski** [GSFC] conceived of a game where the audience would look at zoomed-in regional images of Earth at night, and ask attendees to guess the location based on lighting patterns. Once the guests had submitted their guesses, Omar would reveal the location by zooming out. The Dynamic Planet was also a showstopper, providing opportunities for attendees to discuss various datasets and science results in a one-on-one fashion with NASA's scientists and other personnel—see **Photo 5**. Reager stated that overall, "…it was great to see how NASA data—and seeing the world from space—really inspire people's creativity and imaginations." A brochure containing the science stories that were shown on the Hyperwall and Dynamic Planet is available online at *https://eospso.gsfc.nasa.gov/sites/default/files/publications/NASA_COP22_Hyperwall%20Brochure%202016.pdf*.

**Photo 5. Mark Malanoski** and **Hamdan bin Mohammed bin Rashid Al Maktoum** [United Emirates Crown Prince] examined the Arabian Peninsula on NASA's Dynamic Planet. **Photo credit:** NASA

### AGU Fall Meeting

The AGU Fall Meeting took place in San Francisco, CA, December 12-16. Prior to the meeting, the SCSO organized the 2016 Annual Communications Meeting, where NASA employees, who contribute to the agency's communications activities, convened to shape outreach communications strategies and guide the workflow for the coming year—see *2016 Annual Communications Meeting* [*above, right*].

### 2016 Annual Communications Meeting

The 2016 Annual Communications Meeting was held at the Marriott Union Square in San Francisco, CA, Sunday, December 11. More than 100 NASA employees attended the daylong event. The attendees heard from **Kristen Erickson** [NASA Headquarters (HQ)—*Director of Science Engagement and Partnerships*], **Sandra Smalley** [HQ—*Director of Joint Agency Satellite Director*], and each of the four Science Mission Directorate (SMD) division heads—**Paul Hertz** [HQ—*Director of Astrophysics*], **Michael Freilich** [HQ—*Director of Earth Science*], **Jim Green** [HQ—*Director of Planetary Science*], and **Steven Clarke** [HQ—*Director of Heliophysics*]. In addition, **Alex Young** [HQ—*Associate Director of Heliophysics*] spoke about the 2017 total solar eclipse event and **Jason Townsend** [HQ—*Deputy Social Media Manager*] spoke about the agency's social media efforts and future plans. Following the lunch social and SMD breakout sessions, **Thomas Zurbuchen** [HQ—*NASA Associate Administrator for SMD*] shared his thoughts on communicating science to the larger audience and fielded various questions from the attendees, talking with the group for over an hour. Participants left well informed about NASA's wide range of communications activities.


**Photo 6.** Pictured here are some of the staff members who helped staff the NASA booth at AGU. **Photo credit:** NASA

As has been the case for more than 10 years, the SCSO organized and supported the NASA exhibit at the AGU Fall Meeting. With help from the NASA outreach community (most of whom attended the Annual Communications Meeting)—see **Photo 6**—the exhibit clearly represented the depth and breadth of NASA's science activities across several disciplines, including Earth science, planetary science, and heliophysics. The booth featured the Hyperwall, various kiosks showcasing NASA's websites and applications, and—new this year—a hands-on demonstration area. Throughout the week there were a total of 69

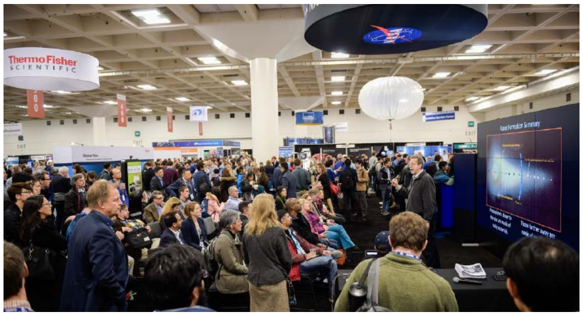



**Photo 7.** Hyperwall and Flash Talk presentations always attracted large crowds. **Photo credit:** NASA

**Photo 8.** Hyperwall and Flash Talk presenters answered several great questions after their talks. **Photo credit:** NASA

**Photo 9.** At the hands-on demonstration area in the booth, attendees had an opportunity to visualize climate data using virtual-reality goggles. **Photo credit:** NASA

Hyperwall presentations, 35 Flash Talks,[6] and 25 hands-on demonstrations; the full schedule of events is provided at *go.nasa.gov/2hnmNDf*. These presentations and demonstrations continuously attracted large crowds and generated lots of questions and healthy discussions among attendees—see **Photos 7-9**.

There was also an *Ocean Worlds* display where attendees were invited to write and pin comments and questions about ocean science, and several information tables where attendees could collect resources and talk one-on-one with NASA personnel about specific topics—see **Photos 10-12**. The NASA Science calendar was one of the many resources that attracted attendees to the NASA booth—see **Photo 13**. Also new this year, six winners of the *2016 AGU Data Visualization and Storytelling Competition* presented their winning

[6] Flash Talks also took place on the Hyperwall but were quick seven-minute presentations. Hyperwall presentations were 15 minutes in length.

**Photo 10.** Attendees were asked to write their responses to a variety of questions about ocean science that were then attached to the *Ocean Worlds* display at the booth. The attendees were eager to write their thoughts and appreciated the opportunity to get involved. **Photo credit:** NASA


**Photo 11.** [*Left to right*] NASA personnel **Enrico Piazza** [JPL], **Winnie Humberson** [GSFC—*SCSO Task Lead*], and **Heather Hanson** [GSFC] posed for a photograph in front of the *Ocean Worlds* display. By the third day of the exhibit, the display had filled up with hundreds of responses. The fish were left on display for attendees to read for the remainder of the week. **Photo credit:** NASA

**Photo 12. Holli Riebeek Kohl** [GSFC] talked to attendees about how to observe clouds with the new *GLOBE Observer* mobile app—a citizen scientist opportunity released by the GLOBE Program.

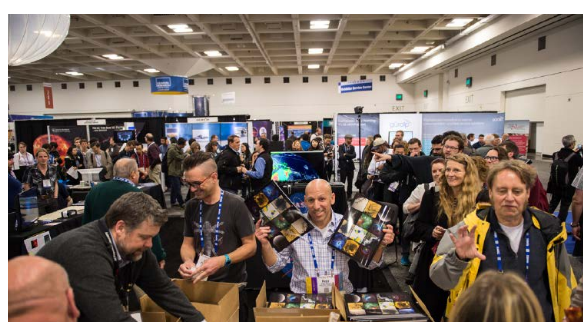


**Photo 13.** [*Center*] **Peter Falcon** [JPL; *center*] helped distribute NASA Science calendars. The line of attendees hoping to snag one of the agency's popular calendars stretched around the NASA booth during the opening reception. **Photo credit:** NASA

## Special Hyperwall Presentations

In 2016, AGU launched the *AGU Data Visualization and Storytelling Competition*, a contest open to undergraduate and graduate students that focuses on innovation and creativity in presenting data to a larger audience in new, more easily accessible ways. The competition was funded by a grant from NASA. The winners had the opportunity to present their visual stories on the NASA Hyperwall in the exhibit hall at the AGU Fall Meeting. It was the first time NASA opened its Hyperwall up to student presentations. All five of the Grand Prize winners and one of the five Runner-Up winners presented their efforts on the Hyperwall on Tuesday, December 13, and Wednesday, December 14, during the lunchtime hour.

On Tuesday **Mejs Hasan** [University of North Carolina, Chapel Hill] showed the effects of war and drought on water supplies in the Middle East; **Matthew Ross** [Duke University] presented the impacts of mountaintop mining on the environment; and **John Granholm*** [Appalachian State University] showed how virtual reality enables a greater understanding of Earth's tectonic processes.

On Wednesday **Allison Daniel** [University of Alabama, Huntsville] showed how she used NASA's Earth-observations data to enhance drought-management decisions within the Mekong River Basin's agricultural fields; **Kaytan Kelkar** [Texas A&M University] shared his three-dimensional mapping approach to explore susceptibility to mass movement in the Western San Juan Mountains in Colorado; and **Sara Lubkin** [Northern Virginia Community College] showed how she decoded spectral signatures of harmful algal blooms in the Chesapeake Bay.

For more information on the AGU competition and to see a full list of the winners, visit *https://education.agu.org/grants/data-visualization-storytelling-competition/award-information*.

*John Granholm was the only Runner-Up winner to present. The others were Grand Prize winners.

[*Left to right*] **Christine McEntee** [AGU—*Executive Director and Chief Executive Officer*] introduced and congratulated Storytelling Competition winners **Allison Daniel**, **Kaytan Kelkar**, and **Sara Lubkin**. **Photo credit:** NASA

[*Left to right*] **Steve Platnick** [NASA's Goddard Space Flight Center—*Deputy Director for Atmospheres and EOS Senior Project Scientist*] congratulated winners **Matthew Ross**, **John Granholm**, and **Mejs Hasan** on their successful use of NASA data to visualize scientific concepts. **Photo credit:** NASA

visualizations on the Hyperwall—see *Special Hyperwall Presentations* [*above*]. A time-lapse video of activities at the NASA booth—in particular, the Hyperwall area—provides a glimpse of the many thousands of attendees that stopped by to learn about science at NASA. To watch the video, visit *https://www.flickr.com/photos/eospso/32066123426/in/photostream*.

### Conclusion

Outreach exhibits allow the agency to represent NASA's science activities, including Earth science, in a single setting, often reaching thousands of people over a very short time. Currently, the Hyperwall and Dynamic Planet provide revolutionary platforms for NASA to communicate its science activities face-to-face with individuals, in a manner unlike that of any other space agency in the world. Looking ahead, the SCSO remains committed to implementing next-generation communication platforms as they become available. To see where the Hyperwall is headed next, follow *@NASAHyperwall* on Twitter. ■

# 2016 Precipitation Measurement Missions Science Team Meeting Summary

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## Introduction

The Precipitation Measurement Missions (PMM) Science Team Meeting (STM) took place in Houston, TX, October 24-27, 2016. The PMM program supports scientific research, algorithm development, and ground-based validation activities for the Tropical Rainfall Measuring Mission (TRMM)[1] and Global Precipitation Measurement (GPM) Mission—including the GPM Core Observatory.[2] The 155 attendees came from NASA, the Japan Aerospace Exploration Agency (JAXA), the U.S. National Oceanic and Atmospheric Administration (NOAA), universities, and other partner agencies, including 15 attendees from 7 additional countries.

There were 53 oral presentations across 11 sessions as well as 100 posters across 2 sessions. The presentation and poster topics ranged from basic science analysis for algorithm development to use of the datasets for science and societal benefit areas, algorithm updates, and mission activities. There were also 11 breakout meetings on specialty topics, and meetings of the Joint PMM Science Team,[3] and of the Committee on Earth Observation Satellites (CEOS) Precipitation Virtual Constellation (P-VC).[4] The highlights of the meeting are summarized in this report. For more information about GPM data products, science team activities, and future updates, visit *https://pmm.nasa.gov*.

## Programmatic Updates and TRMM and GPM Status Reports

**Ramesh Kakar** [NASA Headquarters (HQ)—*GPM Program Manager*] discussed the state of NASA's current and upcoming Earth Science missions. In particular, he mentioned the Cyclone Global Navigation Satellite System (CYGNSS) mission, scheduled for launch in December 2016,[5] and a Lightning Image Sensor (LIS) onboard the International Space Station (ISS) that will provide new insight into surface wind speeds and lightning.[6] He introduced the new PMM Science Team that was selected last fall, which includes 14 new principal investigators and a total of 60 projects. Kakar also informed the attendees that the GPM mission will go through the NASA Senior Review process in spring 2017.

**Scott Braun** [NASA's Goddard Space Flight Center (GSFC)—*TRMM Project Scientist*] announced that TRMM was selected for the prestigious Pecora Team Award,[7] a joint NASA–U.S. Geological Survey award that is presented annually to recognize outstanding contributions to understanding the Earth by means of remote sensing.

**Gail Skofronick-Jackson** [GSFC—*GPM Project Scientist*] discussed the current status of the GPM Core Observatory, launched on February 27, 2014. The satellite has a mission lifetime of 3 years, but the current fuel projection appears to be sufficient to last between 18 to 33 years (through 2032 and 2047, respectively)—an estimate that includes enough fuel for a controlled reentry. The satellite is returning excellent data and is meeting its Level 1 science requirements. GPM project management is preparing for two NASA HQ reviews in the spring of 2017: the End-of-Prime Mission Review and the Earth Science Senior Review for extended operations.

**Erich Stocker** [GSFC—*GPM Deputy Project Scientist for Data*] discussed the status of GPM data products. GPM Core and constellation data products are provided through the Precipitation Processing System (PPS) STORM[8] system free after registration. Products range from near-real-time data from individual sensors to the Integrated Multi-satellitE Retrievals (IMERG) for GPM

[1] While TRMM mission ended in 2015, data processing is ongoing.
[2] TRMM and GPM are partnerships between NASA and the Japan Aerospace Exploration Agency (JAXA), with more than 20 additional international partners. To learn more about GPM, read a recent journal article titled "The Global Precipitation Measurement (GPM) Mission for Science and Society," published by the American Meteorological Society at *http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-15-00306.1* or see "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].
[3] The purpose of NASA's PMM Science Team and JAXA's Science Team leadership board was to schedule and approve joint TRMM and GPM mission activities and data products.
[4] The CEOS P-VC works to sustain and enhance a systematic capability to observe and measure global precipitation, *http://ceos.org/ourwork/virtual-constellations/p-vc*.
[5] **UPDATE**: CYGNSS was successfully launched on December 15, 2016. To learn more please see "Eight Microsatellites, One Mission: CYGNSS" in the November–December 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 6**, pp. 4-13]. There is also a News story on the release of "first light" data from CYGNSS on page 51 of this issue.
[6] To learn more about LIS, see "LIS on ISS: Expanded Global Coverage and Enhanced Application" in the May–June 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 3**, pp. 4-14].
[7] ***Kudos*** for this achievement, as well as the individual award winner, appears in the November–December 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 6**, p.50].
[8] STORM is a publicly available web-based data access interface for the GPM Mission's Precipitation Processing System (PPS). See *https://storm.pps.eosdis.nasa.gov* for more details.

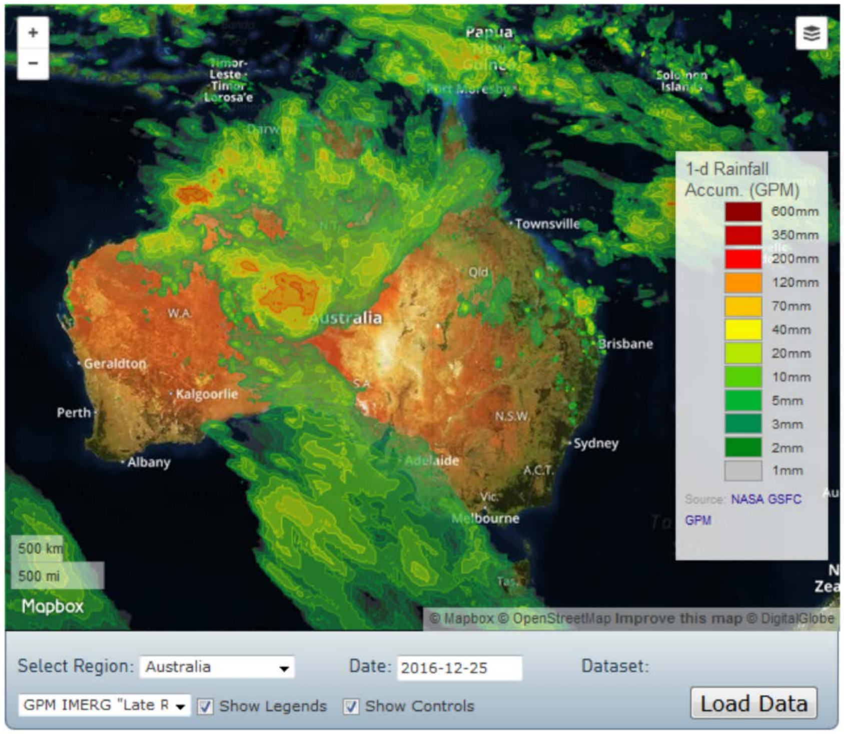


**Figure.** The Precipitation and Applications Viewer app allows users to access 30-minute, 3-hour, and 1-, 3-, and 7-day rainfall accumulations from IMERG. Shown here is 1-day IMERG "Late" rainfall accumulation over Australia. The interface allows users to interactively view rainfall, landslide, and flood products as well as use the advanced tools to access these products via an applications programming interface (API).

product that combines data from GPM with partner satellite data. All products have been reprocessed to Version 04 except IMERG products, which should be updated to Version 04 in early 2017.[9] All GPM products are expected to be released in Version 05 between spring and mid-autumn of 2017. TRMM products will be updated to Version 08 (TRMM-tailored versions of the GPM algorithms) in October 2017. The PPS at GSFC is meeting its latency requirements for the datasets.

**Dalia Kirschbaum** [GSFC—*GPM Associate Deputy Project Scientist for Applications*] discussed GPM applications activities. She explained that highlights over the past year included four online training sessions, a new applications-focused paper that was accepted in the *Bulletin of the American Meteorological Society*, and new visualization and data access tools designed for a range of end users. The last topic includes an applications programming interface (API) for accessing IMERG, landslide, and flood data that is available at *https://pmm.nasa.gov/precip-apps*—see **Figure**. Other outreach activities from the GPM team include new videos and visualizations, new hard-copy materials, and media campaigns—including significant media engagement for covering Hurricane Matthew in October 2016.

Next, Japanese partners provided updates. **Riko Oki** [JAXA—*GPM Program Scientist*] gave an overview of JAXA's program status, including the selection of a new science team as of April 2016, with 41 proposals submitted, 30 funded, and 13 at no-cost or from international partners. She also provided the status of Dual-frequency Precipitation Radar (DPR)[10] algorithm development and evaluation of DPR performance. **Yukari Takayabu** [University of Tokyo—*GPM Project Scientist*], and **Toshio Iguchi** [National Institute of Information and Communications Technology] gave status updates for GPM Science and the DPR algorithm status, showing findings related to global precipitation characteristics in the tropics and mid-latitudes, and lake-effect snow observations. **Takuji Kubota** [JAXA—*TRMM Project Scientist*] provided examples of how the JAXA multisatellite algorithm, Global Satellite Mapping of Precipitation (GSMaP),[11] is being used across several different sectors, including flood prediction in Pakistan, Bangladesh, and the Philippines; landslide warnings in the Philippines; drought monitoring in Indonesia; and Japanese agriculture insurance.

## Algorithm Status

**Wes Berg** [Colorado State University (CSU)], **Bob Meneghini** [GSFC], **Bill Olsen** [University of Maryland, Baltimore County/GSFC], **Chris Kummerow** [CSU], and **George Huffman** [GSFC] all presented material on various aspects of the GPM algorithms, including discussions of intercalibration of the GPM Microwave Radiometer Constellation (XCAL) and plans for GPM Version 05 and TRMM Version 08 reprocessing, along with Version 04 and 05 status and plans for DPR, combined GMI and DPR, Goddard Profiling Algorithm (GPROF), and IMERG, respectively. Development of all the algorithms is progressing well, despite delays in the rollout of the Version 04 products. The Version 05 release is scheduled to begin in the spring of 2017.

[9] This was the planned schedule at the time this article was prepared.
[10] DPR is one of the instruments on GPM; the other is the GPM Microwave Radiometer (GMI).

[11] GSMaP is recommend changing this to: GSMaP is the Japanese multi-satellite product similar in concept to IMERG

## Ground Validation

**Walt Petersen** [NASA's Marshall Space Flight Center—*GPM Deputy Project Scientist for Ground Validation*] summarized GPM's ground validation (GV) efforts, including current activities related to GPM science requirements verification and the Olympic Mountain Experiment (OLYMPEX) that took place in fall and winter of 2015-16 on the Olympic Peninsula in Washington. He also summarized the set of GPM GV field campaigns that have taken place in the last six years, reemphasizing the need to use field campaign data to physically connect precipitation processes occurring in the atmospheric column to the remote sensing algorithms used by GPM sensors. Lastly, Petersen summarized an upcoming GV field campaign led by the Korea Meteorological Administration, called the International Collaborative Experiments of PyeongChang Olympics and Paralympics (ICE-POP). ICE-POP is planned for winter 2018 during the PyeongChang Winter Olympics in South Korea; it is designed to examine snowfall processes over complex terrain and to test numerical weather prediction for heavy winter storms. GPM GV will contribute its Dual-Frequency Dual-Polarimetric Doppler Radar (D3R) and supporting snowfall measurement instrumentation.

**Lynn McMurdie** [University of Washington—*OLYMPEX Project Manager and Operations Director*] outlined the field campaign instrumentation and showed some of the unique observations that the campaign was able to make of the extreme rainfall that occurred. OLYMPEX observations documented precipitation enhancement over complex terrain: Rainfall from November through May ranged from 68 in (~173 cm) along the coast to over 192 in (~488 cm) in the mountains. One phenomenon observed was that small droplets accounted for up to half of the total precipitation in very warm atmospheric-river-type storms.

Over 15 representatives from the international community participated in the STM, contributing a variety of GPM validation efforts as no-cost team members. Two international contributions are mentioned here. **Geun-Hyeok Ryu** [National Meteorological Satellite Center/Korea Meteorological Administration] provided an overview of the GPM ground-validation activities over Korea and additional information on ICE-POP. **Francisco Tapiador** [University of Castilla-La Mancha (UCLM), Spain] showed results of a unique experiment in which 16 Parsivel disdrometers[12] were deployed in an array to measure rain properties over an area of ~4-5 $m^2$ (~43-54 $ft^2$). The experiment demonstrated that measurement bias and uncertainty for rain properties such as median and maximum diameter and radar reflectivity were ~15% for a single Parsivel disdrometer, and that the error asymptotically reduced to a minimum when at least 7 Parsivel disdrometers were used.[13]

[12] A disdrometer measures the drop size distribution and velocity of falling precipitation. The Parsivel disdrometer can distinguish between precipitation types.

## Science and Applications

Several themes emerged among the science reports. These included evaluation and improved approaches to GPM algorithm retrievals of rain and snow, studies of the precipitation processes that improve parameterization for GPM algorithms, longer-term global studies of convection, GPM-related modeling, and applied research. The **Table** beginning on page 31 shows the full list of science reports.

One theme that was emphasized was the comparison and evaluation of GPM products across a variety of spatial and temporal scales against ground-based observations, global modeling products, and other satellite data. Science topics highlighted the expanded science that can be carried out with the nearly 20 years (and continuing) of precipitation data, first from TRMM and now from GPM.

**Shuyi Chen** [University of Miami] compared the evolution of the Madden Julian Oscillation (MJO) from the TRMM precipitation data features. **Robert Adler** [UMD/Earth System Science Interdisciplinary Center (ESSIC)] compared global characteristics of the precipitation products from TRMM, GPM, the Global Precipitation Climatology Project (GPCP),[14] and CloudSat[15] across different latitudes, finding comparable results in the tropics and improved performance of the GPM DPR radar compared to TRMM Precipitation Radar (PR), but underestimation of mean precipitation at higher latitudes. **Catherine Naud** [Columbia University/NASA's Goddard Institute for Space Sciences (GISS)] and **Jimmy Booth** [City College of the City University of New York] evaluated the performance of GPM Level-2 data for extratropical systems, comparing against Modern Era Retrospective Analysis (MERRA-2)[16] and Next Generation Radar (NEXRAD)[17] ground-based data, respectively.

Another topic covered was how GPM data can be used to better characterize microphysical properties and modeling for raindrops, ice particles, and surface emissivities. **Steven Rutledge** [CSU] presented new results

[13] These results have been accepted for publication in the American Meteorological Society Journal of Hydrometeorology.

[14] To learn more, visit *http://gpcp.umd.edu* or *https://www.ncdc.noaa.gov/wdcmet/data-access-search-viewer-tools/global-precipitation-climatology-project-gpcp-clearinghouse*.

[15] To learn more about CloudSat, see "A Useful Pursuit of Shadows: CloudSat and CALIPSO Celebrate Ten Years of Observing Clouds and Aerosols" in the July–August 2016 issue of *The Earth Observer* [**Volume 28, Issue 4,** pp. 4-15].

[16] For more information about MERRA-2, visit *https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2*.

[17] Next-Generation Radar (NEXRAD) is a network of 160 weather radars operated by the National Weather Service over the United States.

text continued on page 32

**Table 1**. Science reports from the PMM Science Team Meeting.

| Presenter | Affiliation | Title |
|---|---|---|
| Robert Adler | UMD/Earth System Science Interdisciplinary Center (ESSIC) and NASA's Goddard Space Flight Center (GSFC) | Global Precipitation (Means and Variations): GPM, TRMM, and GPCP |
| Alessandro Battaglia | University of Leicester, U.K. | Multiple Scattering in Observations of the GPM Dual-frequency Precipitation Radar: Evidence and Ways Forward |
| Alexis Berne | École Polytechnique Fédérale de Lausanne, France | GPM in Complex Terrain: Evaluation in the Swiss Alps |
| Raphael Bras | Georgia Institute of Technology | Assimilation of Satellite Precipitation and Soil Moisture Data into the Weather Research and Forecasting-Noah Model |
| Shuyi Chen | University of Miami, Rosenstiel School of Marine and Atmospheric Science | Large-scale Precipitation Tracking using TRMM-GPM Data for MJO Convective Initiation and Eastward Propagation |
| Brian Colle | Stony Brook University | Warm Frontal Snowband Evolution and Microphysical Validation During GPM Cold Season Precipitation Experiment (GCPEx) |
| Anthony Del Genio | NASA's Goddard Institute for Space Studies (GISS) | Toward the Parameterization of Organized Convection in GCMs |
| Robert Field | Columbia University and GISS | Integrating Satellite Precipitation Estimates into the Global Fire Weather Database |
| Ziad Haddad | NASA/Jet Propulsion Laboratory (JPL)/ California Institute of Technology | Interpreting MM-Wave Sounder Observations Over Deep Convection |
| Robert Houze | University of Washington | GPM Characterization of Convection over South America and the U.S. |
| Christopher Kidd | UMD/ESSIC | The Activities of the International Precipitation Working Group |
| Hyungjun Kim | Institute of Industrial Science and The University of Tokyo, Japan | Dynamical Downscaling Application for Off-line Forcing Generation for Hyper-Resolution Land Surface Modeling |
| Kwo-Sen Kuo | UMD/ESSIC and GSFC | Plans For the Next Version of OpenSSP: More, Larger, and Better! |
| William Lau | UMD/ESSIC | What Would Happen to Superstorm Sandy in a Warmer Climate? |
| Xiaowen Li | Morgan State University and GSFC | Ice-Phase Particle Size Distributions in May 20 MC3E Convective System |
| Gerald (Jay) Mace | University of Utah | The Information Content in Dual-Frequency Radar Measurements in the Face of Realistic Uncertainties in Ice Crystal Scattering Properties |
| Joe Munchak | GSFC | Active/Passive Surface Characteristics from GPM: Physical Insights and Algorithm Applications |
| Catherine Naud | Columbia University and GISS | GPM Precipitation in Extratropical Cyclones |
| Branislav Notaros | Colorado State University | Advanced Observations for Microphysics Scheme Evaluation, Using GCPEx Data and Beyond |
| Sungmin O | University of Graz, Austria | Evaluation of GPM IMERG Early, Late, and Final Rainfall Estimates with WegenerNet Gauge Data in Southeast Austria |

**Table 1**. Science reports from the PMM Science Team Meeting. (cont.)

| Presenter | Affiliation | Title |
|---|---|---|
| Christa Peters-Lidard | GSFC | Dynamic Emissivity Estimates to Support Physical Precipitation Retrievals for GPM |
| Silvia Puca | Dipartimento della Protezione Civile, Italy | Ground-Calibration of DPR Precipitation Rate Over Italy |
| Geun-Hyeok Ryu | National Meteorological Satellite Center/Korea Meteorological Administration | The GPM Validation Activity Over Korea and ICE-POP 2018 |
| Carl Schreck | Cooperative Institute for Climate Studies | Kelvin Waves and Tropical Cyclogenesis in a Lagrangian Framework |
| Marshall Shepherd | University of Georgia | Precipitation Metrics and the Energy-Food-Water Nexus: Challenges and Opportunities |
| Francisco Tapiador | University of Castilla-La Mancha (UCLM) | The Large-Disdrometer Experiment (LDE) and UCLM's S-Band Radar (T-REX) Status |
| Huan Wu | UMD/ESSIC | Initial Results in Global Flood Monitoring Using GPM Data |
| Manuel Zuluaga | Universidad Nacional de Colombia | Synergistic Research Collaboration Between NAS PMM and Sistema de Alerta Temprana del valle de Aburrá (SIATA) Medellin, Colombia: From Data Validation to Risk Management Applications in Tropical South America |

on regional raindrop size-distribution regimes, and **Branislov Notaros** [CSU] discussed applications of new imaging technologies and scattering models used to describe falling snow and ice crystals. **Kuo-Sen Kuo** [UMD, ESSIC/GSFC] highlighted the advances in modeling ice particle shapes, riming, and aggregation while talks by **Ziad Haddad** [NASA/Jet Propulsion Laboratory] and **Jay Mace** [University of Utah] focused on the proper representation of ice particles in retrievals of both high-frequency microwave channels and multifrequency radars. **Joe Munchak** and **Christa Peters-Lidard** [both from GSFC] focused on surface emissivity, highlighting recent advances to unify emissivity estimates from radiometers and radars.

Science reports also covered topics relating to how GPM satellite retrievals and NASA ground-validation observations can be used to improve model parameterizations. The scale of processes ranged from interaction of ice crystals to the role of convection in global climate models (GCMs). On small scales, **Xiaowen Li** [Morgan State University/GSFC] discussed ice-collection efficiencies for simulations of a stratiform rain event observed during the Midlatitude Continental Convective Clouds Experiment (MC3E), held in central Oklahoma in May 2011. On large scales, **Anthony Del Genio** [GISS] described convective cloud parameterizations in the GISS GCM. **William Lau** [UMD] compared storm tracks of Superstorm Sandy simulated in NU-WRF[18] using current climatological sea-surface temperatures (SSTs) and estimates of warmer future SSTs.

Several presentations described hydrometeorological studies over land using TRMM and GPM precipitation products. Key issues highlighted by the speakers included the accuracy of precipitation retrievals over land and the value of GPM's enhanced resolution products for predicting critical hydrologic variables such as soil moisture, runoff, and evapotranspiration. **Huan Wu** [UMD/ESSIC] showed that the Global Flood Monitoring System can readily transition from TRMM-era to GPM-era precipitation products, with streamflow and inundation data that are provided in a *GeoTIFF* format for rapid uptake by the emergency response communities. **Robert Field** [Columbia University/GISS] found that GPM-era products enable more-accurate monitoring of fire susceptibility; he showed some results from recent fire seasons in Washington State and Southeast Asia.

## Closing

**Ramesh Kakar** and **Gail Skofronick-Jackson** closed the meeting, announcing that GPM will have a special collection of papers published across many different journals of the American Meteorological Society. They also highlighted important directions for future science investigations, including snowfall retrievals, high-latitude precipitation retrievals, long-term science and applications investigations using IMERG reprocessed to the beginning of the TRMM era, and precipitation observations for future Earth Venture and Decadal Survey missions. ■

[18] The NASA-Unified Weather Research and Forecasting (NU-WRF) model is an observation-driven regional Earth system modeling and assimilation system at satellite-resolvable scale, *https://nuwrf.gsfc.nasa.gov*.

# Summary of Air Quality and Health Showcase

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## Introduction

The Air Quality and Health Showcase took place November 17, 2016, at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. The Showcase brought together approximately 75 professionals, mostly from the Washington, DC, area. Attendees included NASA scientists and program managers, as well as 40 external researchers, decision makers, and end users of NASA data products. The objectives of the event were to:

- increase the visibility of NASA's air-quality-related data products and training resources;
- identify cases where NASA data products are being used to support decision making;
- identify stakeholder needs in terms of data products and scientific support; and
- enhance the network of air quality and health professionals in the Washington, DC, area.

## Workshop Summary

The day began with remarks by **Steve Platnick** [GSFC—*Deputy Director for Atmospheres, Earth Science Division*] and **John Haynes** [NASA Headquarters (HQ)—*Program Manager for the Weather, Public Health, and Air Quality Applied Sciences Themes*] (see **Photo 1**), both of whom noted the power of NASA's fleet of Earth science satellites—the largest-ever civilian constellation—to address societal issues such as air pollution and public health. Platnick and Haynes emphasized that this event was an opportunity to connect NASA's atmospheric science expertise with the environmental health community. **Maggie Hurwitz** [GSFC—*Deputy Applied Sciences Manager*] and **Dalia Kirschbaum** [GSFC—*GPM Associate Deputy Project Scientist for Applications*] introduced the event and explained how the Showcase fit into the larger portfolio of applied sciences at GSFC.


**Photo 1**. **John Haynes** delivered remarks on NASA's extensive remote sensing satellite constellation and the potential utility of its data for air quality and health applications. **Photo credit**: Dalia Kirschbaum

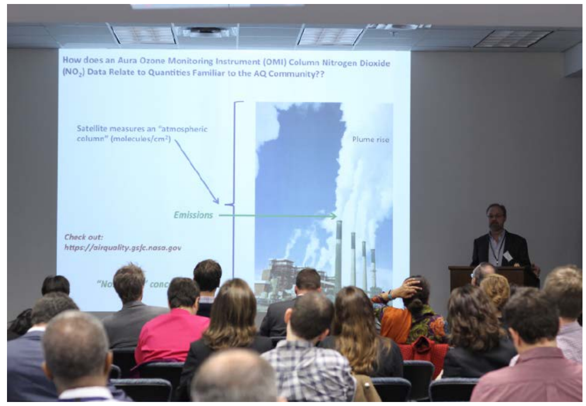



**Photo 2**. **Bryan Duncan** discussed the value of NASA's remote sensing products to monitor air quality. **Photo credit***:* Shobhana Gupta

The morning sessions featured 10 brief presentations from a mix of NASA scientists, academic researchers (i.e., those who use NASA data products to study topics such as the link between pollution and asthma), and stakeholders (i.e., those who use data products to make decisions, monitor conditions, and evaluate policies). The first set of presentations highlighted NASA's air quality capabilities and links to aircraft and ground-based observational platforms. **Bryan Duncan** [GSFC—*Aura Deputy Project Scientist*] summarized the structure and successes of NASA's Air Quality Applied Science Team (AQAST), as well as the challenges and opportunities of the newly-formed Health and Air Quality Applied Science Team (HAQAST), for which he is a principal investigator—see **Photo 2**. **Ana Prados** [GSFC—*NASA Applied Remote Sensing Training (ARSET) Project Manager*] presented the ARSET program's capabilities—particularly in the air-quality area—and encouraged end users to participate in ARSET's online training webinars. ARSET will provide a training course on Sustainable Development Goal (SDG) indicators related to $PM_{2.5}$[1] in March 2017. **Steven Pawson** [GSFC—*Chief of the Global Modeling and Assimilation Office (GMAO)*] gave an overview of the GMAO's capabilities in modeling global climate, atmospheric chemistry, and aerosols. The latest generation of high-resolution model products combines information from multiple sources and "demonstrate[s] the value of NASA data in real time." Additional NASA air-quality products were

[1] $PM_{2.5}$ refers to fine atmospheric particulates with diameter equal to or greater than 2.5 μm.

highlighted during break times on a NASA Hyperwall display,[2] including a new presentation on sulfur plumes from a fire near Mosul, Iraq.

**Russ Dickerson** [University of Maryland, College Park (UMD)] showed the value of combining satellite, aircraft, and ground-based measurements of atmospheric pollutants to inform and monitor air-quality policies. He highlighted a new NASA Atmospheric Infrared Sounder (AIRS)[3] product that can detect ammonia emissions—which mainly come from agricultural sources. **Olaf Veerman** [Development Seed][4] described the OpenAQ platform, which incorporates ground-based air-quality measurements from stations worldwide in a consistent format, and provides social media and data analysis tools for researchers. While OpenAQ is currently limited to ground-based $PM_{2.5}$ measurements, it may soon expand to other pollutants (such as ground-level ozone) and to airborne and remote sensing datasets. **Ken Pickering** [GSFC] led a discussion session during which participants reiterated the power of remote sensing instruments to observe air quality in regions where ground stations are sparse. In response, participants noted the need for political sensitivity when reporting on air quality extreme events and trends in other countries.

The second set of presentations provided perspectives from a variety of end users and stakeholders. **Jason Jabbour** [United Nations Environmental Programme (UNEP) Regional Office for North America] outlined UNEP's air quality program, including its network of low-cost air quality monitoring stations. He highlighted an example of how air quality monitoring stations have been installed at a group of schools in Nairobi, Kenya. The measurements made at the schools will be incorporated into the city of Nairobi's decision-making processes. This is just one example of how air quality observations are being made at the neighborhood scale and used at larger scales. **Sergio Sanchez** [Clean Air Institute] highlighted the scale of Latin America's air pollution issue: 150 million people live in cities where the World Health Organisation's (WHO) air quality guidelines are exceeded on a chronic basis. He emphasized the value of simple visualizations of NASA datasets and simulations to inform Latin American air quality policy and regional planning. **Helaina Matza** [U.S. Department of State] outlined the State Department's Air Quality Monitoring program, which supports ground-based, reference-quality air quality stations at U.S. diplomatic posts worldwide. She emphasized the need to align air quality and health messaging with the Environmental Protection Agency (EPA)'s guidelines, as well as the need to solicit technical advice from atmospheric scientists.

**Meredith McCormack** [Johns Hopkins University] and **Urvashi Narain** [World Bank] provided examples of how air quality datasets are being used to quantify the health impacts of air pollution. McCormack mentioned a recent study that linked $PM_{2.5}$ data to hospitalization rates, illustrating how satellite data can provide more information about potential health exposures in rural areas, where ground-based coverage is poor. Narain discussed a World Bank report that used satellite data to show that "air pollution is a major health risk, and a drag on development." She reiterated Sanchez's statement that much of the world's population lives in areas where $PM_{2.5}$ chronically exceeds WHO guidelines; in fact, 1 in 10 deaths globally can be attributed to indoor and outdoor air pollution.

**Pawan Gupta** and **Ana Prados** [both from GSFC] chaired a discussion session that focused on connections between various stakeholder organizations. For example, connecting low-cost monitoring programs (e.g., that from UNEP, as described by Jason Jabbour) with ground monitoring networks (e.g., the State Department's program that monitors U.S. diplomatic posts, as described by Helaina Matza). Another discussion topic was the value of open data platforms such as OpenAQ (as described earlier by Olaf Veerman). Also, participants expressed the need to monitor air pollution and its impacts at the city level; related to this discussion was Bryan Duncan's summary of his recent study of nitrogen dioxide trends in cities, worldwide.

## The Way Forward: Forging Lasting Connections with NASA

Meeting new people and creating new relationships were important components of the Showcase—see **Photo 3**. Participants debated policy and data-related issues during the formal discussion sessions and continued the discussions in informal exchanges throughout the day, including several groups in active partnerships with NASA.

**Photo 3**. Showcase participants were very attentive, made new contacts, and networked with colleagues during the event. **Photo credit**: Shobhana Gupta.

[2] A NASA Hyperwall is a 9- or 12-screen display system capable of displaying high-definition images and video. A Hyperwall is located at GSFC in the same building that the meeting was held.

[3] AIRS, developed at NASA/JPL, flies on NASA's Aura satellite.

[4] Development Seed provides an open-source infrastructure for citizen use of governmentally supplied data. OpenAQ is an open-source platform to address inequalities in air quality, worldwide. Visit *https://developmentseed.org/projects/openaq* for more information.

Nearly half of the Showcase participants completed a post-event survey. Overwhelmingly, the respondents said that the Showcase increased their understanding of NASA's remote sensing data products, and that it provided a good opportunity to make new contacts in the air-quality and health community. As one visitor to GSFC stated, "… we are already connecting with a number of NASA researchers to understand how we can use the data for our in-country policy dialogues." There was also enthusiasm for a follow-up event, which would strengthen partnerships between NASA and stakeholders, and provide further discussion of NASA's data products and the best practices for incorporating these products into environmental health monitoring and decision-making activities. ■

## Congratulations PECASE Award Winners!

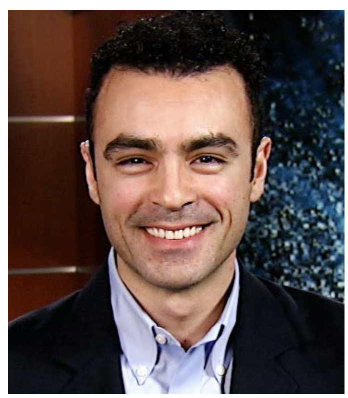
Congratulations to **Dalia Kirschbaum** [NASA's Goddard Space Flight Center (GSFC)—*GPM Associate Deputy Project Scientist for Applications*] and **Miguel Roman** [GSFC—*Research Physical Scientist*] for winning the remarkably competitive Presidential Early Career Awards for Scientists and Engineers (PECASE), the highest honor bestowed by the U.S. government on science and engineering professionals in the early stages of their independent research careers. These two awardees—named by **President Obama** on January 9, 2017—were selected for their pursuit of innovative research at the frontiers of science and technology and their commitment to community service as demonstrated through scientific leadership, public education, or community outreach.

"I congratulate these outstanding scientists and engineers on their impactful work," **President Obama** said. "These innovators are working to help keep the United States on the cutting edge, showing that federal investments in science lead to advancements that expand our knowledge of the world around us and contribute to our economy."

Dalia and Miguel join a group of 102 scientists and researchers who received the PECASE award this year. The full announcement may be found at *https://obamawhitehouse.archives.gov/the-press-office/2017/01/09/president-obama-honors-federally-funded-early-career-scientists.*

Please join us in congratulating Dalia and Miguel on this achievement.

Dalia Kirschbaum



Miguel Roman

meeting summaries

# 2016 Sounder Science Team Meeting Summary

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## Introduction

The NASA Sounder Science Team Meeting (STM) was held September 13-16, 2016, at the Greenbelt Marriott Hotel in Greenbelt, MD, where a total of 79 presentations were given during 5 themed sessions. The meeting focused on science using atmospheric sounder observations, with most presentations describing results from hyperspectral infrared instruments and companion microwave sounders. The hyperspectral infrared instruments included the Atmospheric Infrared Sounder (AIRS) on NASA's Aqua satellite, launched in 2002; the Tropospheric Emission Spectrometer (TES) on the Aura Satellite, launched in 2004; two Infrared Atmospheric Sounding Interferometer (IASI) instruments on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Metop-A and Metop-B satellites, launched in 2006 and 2012, respectively; and the Cross-track Infrared Spectrometer (CrIS) on the joint NASA-National Oceanic and Atmospheric Administration (NOAA) Suomi National Polar-orbiting Partnership (NPP) satellite, launched in 2011.

This report highlights some of the key results presented at the meeting. The meeting agenda is available at *http://airs.jpl.nasa.gov/events/37*.

## Highlights

Most of the presentations from this and earlier meetings can be downloaded from *http://airs.jpl.nasa.gov/resources/presentations*. After an *Introductory Session*, sessions included *Weather and Climate; Atmospheric Composition and Aerosols;* and *Sounder Products and Applications*. There was also a special session devoted to results from five years of Suomi NPP sounding observations—see *Special Session on Suomi NPP Sounders,* on page 38.

### *Introductory Session*

The meeting began with a series of three related opening presentations, intended to review the status of the current operational hyperspectral satellite sounding instruments mentioned above. **Claire Parkinson** [NASA's Goddard Space Flight Center (GSFC)—*Aqua Project Scientist*] described the current status of the Aqua spacecraft, which includes the AIRS and AMSU[1] sounding instruments. She noted that Aqua and AIRS are expected to continue operating into the early 2020s. **Mitch Goldberg** [NOAA] provided some perspective on how NOAA uses hyperspectral sounding data, and plans for future Joint Polar Satellite System (JPSS) hyperspectral instruments that will serve as follow-ons to instruments on Suomi NPP. **Thomas August** [EUMETSAT] described the status and use of the IASI Level-2 products at EUMETSAT, and described planned future instruments. These plans for IASI and CrIS instruments extend into the mid-2030s, with overlap in time coverage planned for successive instruments.

**Will McCarty** [GSFC] described current data assimilation efforts and plans for similar future activities. He noted the challenges in assimilating radiances from cloudy and precipitating scenes. While of limited success to date, the use of cloud-affected radiances offers the potential of full utilization of all satellite radiances by data assimilation systems.

### *Weather and Climate*

This was the largest session at the meeting, with over 30 presentations. **Lazaros Oreopoulos** [GSFC] began the session, describing results of a combined analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) and AIRS data on Aqua. He showed that clouds observed by MODIS can have a significant effect on the spectrally resolved outgoing longwave radiation measured by AIRS.

Three related presentations addressed several phenomenological changes taking place in the Arctic. **Richard Cullather** [University of Maryland] showed that the significantly reduced Arctic ice cover seen during winter 2015-16 was related to warm, moist conditions in the near-surface atmosphere—confirmed by AIRS observations validated in earlier studies. Using similar data, **Linette Boisvert** [GSFC] related the area of greatest ice loss over northern Eurasia during winter 2015-16 to cyclonic systems in the northeast Atlantic that carried warm air northward. **Abhay Devasthalhe** [Swedish Meteorological and Hydrological Institute] showed the importance of AIRS near-surface humidity

[1] **UPDATE**: The AMSU-A2 instrument on Aqua ceased operating on September 24, 2016, shortly after the Sounder Science Team Meeting. It remains turned off as of December 2016. AIRS and AMSU-A1 continue operating normally.

in modulating the surface energy balance of the Arctic. Meteorological events that carry increased moisture over the Arctic from lower latitudes can lead to significant warming during both summer and winter.

Several speakers took advantage the long-term records becoming available from hyperspectral sounders. **Jie Gong** [GSFC] showed long-term variability in gravity wave activity in radiances measured from space, while **Jianglei Huang** [University of Michigan] showed that AIRS and AMSU radiances can reveal decadal-scale variations in the stratosphere.

**Oreste Reale** [GSFC] explained the effects of assimilating both clear-sky and cloud-cleared radiances from CrIS, AIRS, and IASI. He showed that the greatest challenges remain with utilization of cloud-cleared radiances.

*Atmospheric Composition and Aerosols*

The atmospheric composition session included 11 presentations describing updates to the operational atmospheric composition products from AIRS and CrIS. Topics included progress in new algorithm development and validation that could enable Earth Observing System (EOS) data continuity, the use of atmospheric composition data in climate science, and development of new science applications.

**Edward Olsen** [JPL] introduced the AIRS Version 6 tropospheric carbon dioxide ($CO_2$) retrieval algorithm, quality-control filtering criteria, and validation against airborne *in situ* data and Orbiting Carbon Observatory-2 operational data. He also reviewed some key publications using AIRS Version 5 $CO_2$ data. In a related presentation, **Xun Jiang** [University of Houston] described the variability of AIRS-observed $CO_2$, with lower concentrations of $CO_2$ observed over the Southern Atlantic Ocean. She related this to the sinking branch of the Atlantic Walker Circulation bringing $CO_2$-poor upper-tropospheric air into the middle troposphere, where AIRS takes measurements. Jiang also showed that during Stratospheric Sudden Warming events, Arctic mid-tropospheric $CO_2$ concentrations decrease, which she attributes to subsidence of $CO_2$-poor air from the stratosphere. She also showed that AIRS $CO_2$ concentrations are high over the Southwest U.S. during drier summer months, and showed results that linked increased $CO_2$ during droughts to increased biomass burning from wildfires, decreased uptake of $CO_2$ by plants, and more rising $CO_2$-rich air.

A series of three presentations described trace-gas observations from multiple sensors. **Nick Nalli** [NOAA] described evaluation and validation activities for the AIRS and CrIS atmospheric profiles of ozone ($O_3$), carbon monoxide (CO), methane ($CH_4$), and $CO_2$. He showed broad agreement in CO, $CH_4$, and $CO_2$ from the two instruments and from *in situ* observations. The JPSS results are close to pre-launch requirements. In the second presentation, **Dejian Fu** [JPL] illustrated the characteristics of a retrieval algorithm performing joint AIRS/OMI, TES/OMI, CrIS/OMPS, and CrIS/TROPOMI[2] retrievals for $O_3$, $CH_4$, CO profiles, and single-instrument retrievals for a suite of trace gases important to climate and air quality. These high-spatial-resolution retrievals could help in distinguishing the local and nonlocal emission of pollutants—useful information in science applications for air quality and ecosystem health. Finally, **Vivienne Payne** [JPL] described the latest science community efforts to expand the suite of composition products using NASA's thermal infrared sounders. She pointed out that measurements of multiple trace gases over global scales are needed to provide constraints on chemistry-transport models. Thermal infrared sounder data have not yet been fully exploited. Much potential remains for development, especially of new products when combined with rigorous error analysis.

**Le Kuai** [JPL and University of California, Los Angeles] presented a study of hydrological controls on ozone and its greenhouse effect using Aura/TES data. Relative humidity (RH) is a useful quantity to help characterize the large-scale circulation, which is the primary driver that determines water vapor, temperature and cloud distributions. Kuai's study provided an outlook on future Hadley cell expansion, habitability of the Middle East, and strength of the Asian monsoon. She discussed the feasibility of using AIRS/CrIS/IASI data in this research to improve spatiotemporal coverage and resolution.

*Sounder Products and Applications*

The first part of this session covered retrievals and radiative transfer algorithms (RTAs) for generating data products from the sounders. Presentations addressed retrievals from the operational algorithms by **Tim Hultberg** [EUMETSAT] for IASI; **Joel Susskind** [GSFC] for AIRS; and **Christopher Grassotti** [NOAA] for ATMS. In addition to these, there were several other presentations on AIRS retrievals and RTAs. Expected future improvements include increased accuracy for temperature, water vapor, and ozone profiles, single-footprint retrievals in cloudy regions, and improved spectroscopy.

[2] Acronyms on this line not previously defined in order of occurrence are: OMI—Ozone Monitoring Instrument (on Aura); OMPS—Ozone Mapping and Profiler Suite (on Suomi NPP and planned for JPSS); and TROPOMI—TROPOspheric Monitoring Instrument (planned for the European Space Agency's Sentinel-5P mission).

## Special Session on Suomi NPP Sounders

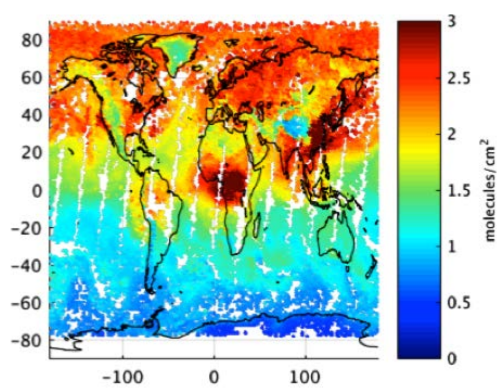
The Suomi National Polar-orbiting Partnership (NPP) recently celebrated the fifth anniversary of its launch. Suomi NPP is a bridge to NOAA's next-generation Joint Polar Satellite System (JPSS) weather satellites, with the JPSS-1 satellite scheduled for launch in 2017. Suomi NPP extends the measurement records for environmental variables made by the research instruments aboard the core NASA Earth Observing System (EOS) missions (i.e., Terra, Aqua, and Aura) since their respective launches in 1999, 2002, and 2004, as well as measurements from earlier NOAA operational platforms and pre-EOS NASA research satellites to help create multi-decadal environmental records. Among the instruments on Suomi NPP are two sounders: CrIS and the Advanced Technology Microwave Sounder (ATMS).

This session provided an opportunity for national and international Sounder Science Team Meeting partners to learn about the recent activities by the Suomi NPP Science Team, and for discussions on future directions in algorithm improvements and the successful transition to operations. A total of 17 presentations were presented in this session; however, only highlights of a few presentations are provided here.

**Chris Barnet** [Science and Technology Corp. (STC)—*Suomi NPP CrIS and ATMS Discipline Lead*] opened the session with an overview of the current goals and topics of discussion within the Suomi NPP Science Team. He summarized the Sounder Science Investigator-led Processing Systems (SIPS) calibration efforts aimed at producing CrIS and ATMS data files that will have the same look and feel of current AIRS and AMSU products that NASA currently produces and archives. He also reported on three different retrieval algorithms currently under development. One of them (called NUCAPS)* was developed by Barnet's group at STC (see example below); another was developed at GSFC and is based on the operational AIRS algorithm. He also described a third algorithm being developed by a research group at Atmospheric and Environmental Research. The main highlight of this presentation was the synergistic nature of the Suomi NPP Science Team (currently funded by both NASA and NOAA) in embracing broader collaborative efforts.

Two invited speakers, **Eva Borbas** [University of Wisconsin, Madison] and **Glynn Hulley** [NASA/Jet Propulsion Laboratory (JPL)] provided an overview of the NASA MEaSUREs†-supported Combined ASTER-MODIS Emissivity over Land (CAMEL)‡ dataset surface temperature and emissivity database. Its high spatial resolution and well-characterized uncertainties are intended to serve the needs of a broad scientific community, with the goal of supporting development of long-term and well-characterized multisensor data records of environmental variables. This is a key priority for the Suomi NPP Science Team.

**Van Dang** [JPL] described a comparison study between the GSFC and NUCAPS temperature and water vapor retrievals, using both AIRS/AMSU and CrIS/ATMS data colocated with European Centre for Medium-Range Weather Forecasts (ECMWF) reanalyses. Her analysis indicates that the presence of high clouds reduces the information content in the satellite temperature and water vapor retrievals and is ultimately responsible for a warm temperature bias with respect to ECMWF. All three retrieval algorithms (i.e., GSFC using CrIS, NUCAPS using CrIS, and GSFC using AIRS) show dependency on cloud height when compared to reanalysis data. The study showed strong evidence that the lack of low clouds in ECMWF retrievals might be contributing to a wet bias in both GSFC and NUCAPS water vapor retrievals.




Carbon monoxide determined using the NUCAPS retrieval algorithm for descending orbits on February 17, 2015. **Image credit**: Nick Nalli, NOAA.

This session showed that significant progess has been made in developing retrieval algorithms for sounders. The challenge remains to reconcile the geophysical quantities produced by these algorithms and combine them in a scientifically useful way. The presentation of results from this effort can be expected in future sounder team meetings.

* NUCAPS stands for NOAA Unique CrIS/ATMS Processing System.

† MEaSUREs is a NASA program called Making Earth System Data Records for Use in Research Environments (*https://earthdata.nasa.gov/community/community-data-system-programs/measures-projects*).

‡ CAMEL is a compound acronym that contains ASTER—the Advanced Spaceborne Thermal Emission and Reflection Radiometer (on Terra)—and MODIS (on Terra and Aqua).

Other presentations described the use of sounder data in applications, which include drought prediction, volcanic ash dispersal prediction, and the monitoring of intrusions of ozone-rich stratospheric air to near the surface. **Emily Berndt** [NASA's Marshall Space Flight Center] presented recent work to develop and transition ozone products to centers. Information about stratospheric intrusion can help to forecast rapid cyclogenesis and hurricane-force wind events, and is important in air quality monitoring. These products are derived from AIRS, IASI, and CrIS/ATMS retrievals and are publicly available from NASA. **Thomas Hearty** [GSFC] described data services at the Goddard Earth Sciences Data and Information Services Center (GES DISC), a major repository for NASA sounder data.[3]

Several presentations described the calibration of AIRS, IASI, CrIS, and the Microwave Humidity Sounders—flying on the MetOp series of satellites. The radiometric calibration among the infrared sounders is good to better than 0.2 K and improvements are underway to reduce that to 0.1 K. The record of hyperspectral infrared sounders covers nearly 15 years to date—and is expected to cover over 40 years with planned operational sounders. A high level of accuracy and stability of radiances and retrieved geophysical products is necessary to make these data useful for climate process investigations, model validation, and climate prediction.

**Conclusion**

Four hyperspectral infrared sounders are currently being operated routinely by NASA, NOAA, and EUMETSAT.[4] These and other agencies also operate several satellite-based lower-spectral-resolution infrared and microwave sounders. Additional sounding instruments are carried on aircraft. Observations from operating sounding instruments have led to significant weather forecast improvements. In addition to providing up-to-the-minute forecast information, data from the operational sounders have already produced a detailed record of weather and climate phenomena for some 15 years. More satellite-borne instruments are either planned or proposed that will extend the hyperspectral sounder record for twenty or more years into the future. Many of the weather and climate phenomena being observed are not yet fully represented in weather and climate models, which means that current data assimilation systems are challenged to utilize radiances affected by clouds and precipitation. Since these affected radiances comprise the vast majority of observations, the sounder record will offer both important scientific insights and considerable challenges in the coming decades. Communicating these results and challenges is the major goal of the Sounder Science Team Meetings.

The next Sounder STM is planned for April 17-18, 2017, in Pasadena, CA—just before the Third A-Train Symposium[5] planned for April 19-21, also in Pasadena—and will concentrate on highlighting results from AIRS. ■

[3] For more information on GES DISC, visit *https://daac.gsfc.nasa.gov*.

[4] TES flying on Aura is no longer "routinely" operating.

[5] See *https://atrain2017.org* for more information on the Third A-Train Symposium.

# 2016 GRACE Science Team Meeting Summary

*Carmen Boening, NASA/Jet Propulsion Laboratory, carmen.boening@jpl.nasa.gov*

The Gravity Recovery and Climate Experiment (GRACE) mission is now in its fifteenth year of operations—long beyond its planned 5-year mission. A joint endeavor of NASA and the Deutsches Zentrum für Luft-und Raumfahrt (DLR) [German Aerospace Center], the twin GRACE satellites continue to improve our understanding of Earth's dynamical nature, making precise measurements of changes in the gravity signals associated with exchange of mass between several Earth system components. The 2016 GRACE Science Team Meeting (GSTM) took place October 5-7, 2016, at the GeoForschungszentrum (GFZ), in Potsdam, Germany. More than 100 scientists and engineers attended the meeting, which consisted of 55 oral presentations and additional posters distributed across the 8 science sessions. What follows is a summary of the content of each session; readers are directed to *http://www.gfz-potsdam.de/en/section/global-geomonitoring-and-gravity-field/topics/development-operation-and-analysis-of-gravity-field-satellite-missions/grace/gstm/gstm-2016/proceedings* to view the full presentations.

## Opening Remarks and Programmatic Updates

After host **Frank Flechter** [GFZ—*GRACE Co-Principal Investigator*] welcomed the participants, **Byron Tapley** [University of Texas/Center for Space Research (UT/CSR), University of Texas (UT) at Austin—*GRACE Principal Investigator*] began with a formal presentation on the status of and prospects for the GRACE mission. The mission has produced 156 *Release-05* (RL05) monthly measurements of Earth's gravity field (out of a maximum possible 174)[1] that are improved by approximately a factor of two over the previous RL04 product. Tapley highlighted that operations focus on extending mission life for overlap with the GRACE Follow-On (GRACE-FO) mission, scheduled to launch in 2017.

Several programmatic presentations came next:

- **Mona Witkowski** [NASA/Jet Propulsion Laboratory (JPL)] reviewed GRACE flight operations and satellite health. In particular, she mentioned that the spacecraft battery operations require regular monitoring and management, to maximize the satellite's lifetime.

- **Gerhard Kruizinga** [JPL] reviewed the status of GRACE Level-1 processing at JPL.

[1] To save energy, the instruments onboard the GRACE satellites are regularly and cyclically turned off and on. This leads to data gaps, and hence there are only usable data for 156 out of the 174 possible months that GRACE has been in orbit. The improvements are a natural evolution of satellite data releases and mainly due to improvements in background models.

- **Srinivas Bettadpur** [UT/CSR], **David Wiese** [JPL], and **Christoph Dahle** [GeoForschungsZentrum (GFZ)] reviewed the status of the latest Level-2 products produced by UT/CSR, GFZ, and JPL, respectively.

- **Himanshu Save** [UT/CSR—*GRACE Assistant Science Operations Manager*] gave an overview of the satellite's various systems' health and current operations.

- **Inga Bergmann-Wolf** [GFZ] presented the status of the GRACE dealiasing product *AODB1* RL05 and plans for RL06.

## Science Sessions

The remainder of the meeting comprised seven science sessions, addressing the following topics:

- GRACE-FO and Next-Generation Gravity Missions (NGGM);
- Multidisciplinary Science;
- GRACE Analysis Techniques and Intercomparisons;
- Applications;
- Oceanography;
- Solid Earth Science;
- Cryosphere; and
- Hydrology.

Each session included a series of invited and contributed presentations and a closing period for questions and answers. In addition, there were posters relevant to each topic on display throughout the meeting and informal discussions went on throughout the three days (e.g., during breaks).

### *GRACE-FO and NGGM*

The session began with an overview of the GRACE-FO project including reviews of the status of the flight system, payload, and ground system. The expected launch date of GRACE-FO is in early- to mid-FY18. The ensuing presentations in this session alluded to the expected performances of key GRACE, GRACE-FO, and future concepts for NGGM missions, including accelerometer and laser interferometry instrumentation. In the following, some new results that come from combining GRACE data with those from Swarm[2] and global positioning satellite system (GPS) data were presented, showing promising ways to enhance gravity-field recovery. The last presentation was an overview of a recently proposed mission to continue gravity-field recovery after GRACE and GRACE-FO. The proposal highlighted the importance of measuring gravity for understanding several ever-changing Earth system phenomena (and particularly the global water cycle) and emphasized applications to societally relevant themes such as water resource characterization and management and sea level change and its effects.

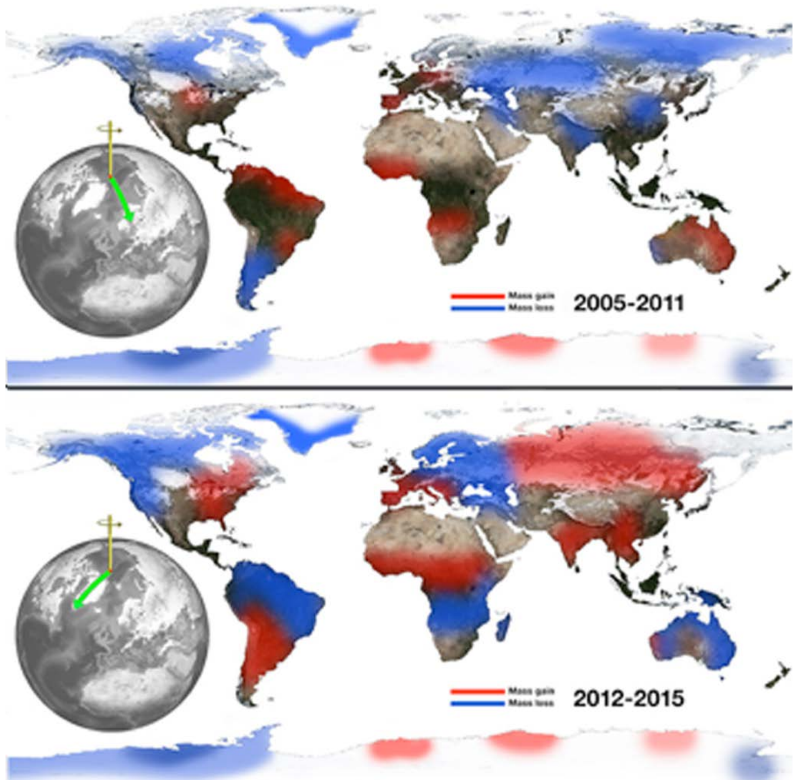



**Figure.** This figure depicts the relationship between continental water mass and the east-west wobble in Earth's spin axis. Losses of water in Eurasia from 2005-2011 correspond to eastward swings in the general direction of the spin axis [*top*], whereas water gains in Eurasia from 2012-2015 push the spin axis westward [*bottom*]. **Image credit:** Surendra Adhikari [JPL]

*Multidisciplinary Science*

The multidisciplinary session mainly addressed signatures in low-degree spherical harmonic coefficients—e.g., Earth's rotation, length of day, and geocenter variations—and their relationships to changes in climate. The session opened with a discussion the role of GRACE-derived interannual hydrospheric and cryospheric mass budgets in modeling Earth's rotation. The study answered the long-debated topic of a shift in direction of polar motion. While previous work hypothesized that this shift is due to changes in Earth's ice sheet due to increased melt, the current study adds that hydrologic changes play a significant role in explaining the current signature in the data, which exhibits an amplitude of (83 ± 23%) and mean directional shift (within 5.9° ± 7.6°) in polar motion—see **Figure**.

*GRACE Analysis Techniques and Intercomparisons*

This session addressed new developments in alternative GRACE gravity field solutions as provided, for example, by the University of Graz, Austria; the French Centre National d'Études Spatiales's Groupe de Recherche de Geodesie Spatiale; and NASA's Goddard Space Flight Center. Additional presentations during this session addressed analyses of the impacts of calibration, as well as the analyses of inherent noise in some GRACE instrument data. These analyses are necessary in order to reduce errors and improve future solutions. Other presentations elaborated on various filtering approaches to improving the time-variable and static gravity field derived from GRACE data.

*Applications*

During the applications session, several of the presentations focused on efforts to directly use GRACE data to study water resource management applications—the latter due to increased signal-to-noise ratios achieved through improved processing used on the current GRACE gravity products. European and U.S. centers summarized their current progress and how plans have evolved over the years of GRACE operations. The session went on to describe some current research into additional techniques including adding information from GPS data to the analysis that will further strengthen the link between GRACE data and these applications.

*Oceanography*

The oceanography session covered global and regional sea level budgets; barotropic and baroclinic ocean motions, tides, and currents; and implications of using GRACE data to improve knowledge of ocean circulation, generally. Presentations during this session addressed the sensitivity of the sea level budget to land masks used to distinguish between ocean and land data. In particular, the focus was on how these masking effects change the contribution of the postglacial rebound correction, which needs to be considered in determining

[2] Swarm is one of the European Space Agency's Earth Explorer Missions, dedicated to unraveling one of the most mysterious aspects of our planet: the magnetic field. (*http://www.esa.int/Our_Activities/Observing_the_Earth/Swarm/Introducing_Swarm*).

Group photo of 2016 GSTM attendees.

the mass contribution from GRACE. Another topic discussed was the use of GRACE data to determine tide model errors and improve tide model solutions using GRACE data. In particular at high latitudes, where observations from altimetry are lacking, integrating GRACE data shows significant improvements over other approaches that do not use GRACE data.

*Solid Earth Science*

This session addressed several new uses of solid Earth data and models to add to and improve the information that GRACE provides. Combinations of GPS displacements with GRACE data have led to promising results that will improve water storage change estimates. New glacial isostatic adjustment (GIA) models have been developed; one presentation during this session assessed the potential impact of the new models on GRACE and altimetry data. Another presentation showed a revised GIA prediction using GNET[3] GPS data over Greenland.

*Cryosphere*

The cryosphere session included presentations that addressed improvements in techniques for deriving ice mass trends (and accelerations) from the ice sheets, glaciers, and ice caps, and their error estimates. One presentation explored the utility of combining GRACE and GNET data over Greenland to get a better estimate of the ice sheet mass balance. The last presentation in the session discussed how atmospheric errors impact GRACE-derived ice sheet mass-loss solutions.

*Hydrology*

The hydrology session focused on advances in hydrology applications of GRACE data products, including signal interpretation, model assimilation, hydrological trends, long-term water storage variations, and terrestrial water balance decomposition. The session opened with a broad overview of GRACE record length land hydrology trends. The presentations that followed described novel applications for flood and drought forecasting and near-real-time applications of GRACE data for flood and drought monitoring. They also focused on using a multi-sensor assimilation approach to specifically improve estimates of terrestrial water storage. Examples of satellite data that will be used include data from GRACE/GRACE-FO, the Advanced Microwave Scanning Radiometer (AMSR)-E/AMSR-2 instruments, the Soil Moisture Active Passive (SMAP) mission, and the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite. There was also a discussion about the potential of using GRACE data to evaluate precipitation amounts over Earth's cold regions. While several precipitation sensors struggle to measure precipitation amounts—particularly under cold conditions—GRACE can provide valuable constraints on these estimates. Other presentations focused on the use of GRACE data to better evaluate groundwater budgets and utility in remote areas of the world.

**Conclusion**

Even though GRACE has long since exceeded its design lifetime, the mission continues to deliver extended data records of global mass redistribution for continued use in all Earth-science disciplines. The multinational mission operations team—made up of the German Space Operations Centre (GSOC), GFZ, JPL, and UT/CSR, together with industry support—continues to work to minimize the data gap that may occur before GRACE-FO continues these measurements into the next decade. The next GSTM will be held October 10-12, 2017 in Austin, TX. Look for details at the website mentioned earlier as the date approaches. ■

[3] There are 56 GPS stations located along the Greenland ice sheet; together they constitute the Greenland GPS Network, or GNET.

# CERES Science Team Meeting Summary

*Walter Miller, NASA's Langley Research Center/Science Systems and Applications, Inc., walter.f.miler@nasa.gov*

## Overview

On October 18-21, 2016, the Clouds and the Earth's Radiant Energy System (CERES), Geostationary Earth Radiation Budget (GERB), and Scanner for Radiation Budget (ScaRaB) science teams convened a joint Earth Radiation Budget (ERB) workshop in Reading, England. The GERB science team hosted the workshop, which was facilitated by the European Centre for Medium-Range Weather Forecasts (ECMWF). The GERB mission is a European consortium led by the United Kingdom (U.K.) that consists of a series of instruments in geostationary orbit to measure reflected sunlight and thermal emissions of Earth to study daily variations and long-term climate changes. ScaRaB is a joint project of France and India providing ERB data over the tropics from a low-inclination orbit aboard the Megha-Tropiques satellite, a joint Indian Space Research Organization (ISRO) and Centre National d'Études Spatiales (CNES)[French space agency] mission. The satellite was designed to study convective systems, focusing on the analysis of the water cycle and energy exchanges.

The workshop was comprised of technical sessions from each of the instrument groups. There were 29 science team presentations, followed by 36 additional science presentations from invited speakers and workshop participants. Workshop speakers described progress on algorithm development, validation, and instrument calibration. Highlights from the workshop included presentations focusing on intercalibration activities to cross-calibrate the CERES, GERB, and ScaRaB data records, and the use of GERB and ScaRaB to validate CERES Temporal Interpolation and Spatial Averaging (TISA) algorithms. Participants came from organizations across the U.K. and Europe, including Imperial College, London, University of Reading, U.K. Met Office (UKMO), ECMWF, Royal Meteorological Institute of Belgium (RMIB), CNES, and the Centre National de la Recherche Scientifique (CNRS) [French National Center for Scientifice Research]. Science presentations addressed various ERB-related topics that included climate modeling challenges, climate response, clouds and aerosols, surface radiation, and incoming solar radiation. The workshop also included a working session focused on the development of requirements for future ERB observations.

Selected highlights from the presentations given at the workshop are summarized in this article. Most of the presentations are available online at *https://ceres.larc.nasa.gov/science-team-meetings2.php*.

## Programmatic and Technical Presentations

During the first day-and-a-half of the workshop, the three instrument groups provided overviews of the programmatic and technical presentations that would occur during their periodic science team meetings.

**Helen Brindley** [Imperial College London] provided the current status of the three operational GERB instruments that fly on the European Organization for the Exploitation of Meteorological Satellite (EUMETSAT)'s METEOSAT Second Generation (MSG) series of geostationary satellites.[1] She explained that each GERB instrument provides measurements every 15 minutes over the same area of the Earth capturing the diurnal variations in the ERB.[2] GERB-3 and -4, located at 0° longitude, and GERB-2, having just recently arrived at 41.5° E longitude, provide data over Europe and Africa. Brindley stated that the GERB-4 commissioning effort was completed in December 2015, but the instrument is not expected to be used operationally until February 2018. She concluded that the Edition 1 filled data products—High Resolution (HR) and Binned Averaged Rectified Geolocated (BARG) radiances and fluxes—are pending final validation before being released.

**Jacqui Russel** [Imperial College London] described the approach used to intercalibrate the GERB instruments with CERES, explaining that measurements from the GERB-2 and -3 instruments are much closer together than GERB-1. Russel added that after corrections to GERB-1 based on CERES Flight Model (FM) 1 and correcting an offset issue on GERB-3, all three instruments agree within 3 to 5%.

**Alexandro Ipe** [RMIB] discussed improvements in Edition 2 products, including improved calibration, imager cloud properties, and Angular Distribution Model (ADM) candidate algorithms, concluding that the candidate fluxes compare favorably with CERES Edition 4 Single Scanner Footprint (SSF) data.

[1] There have been four MSG satellites launched (MSG-1, -2, -3, and -4), the most recent having been launched in 2015. MSG-1, -2, -3, and -4 have been renamed Meteosat-8, -9, -10, and –11, respectively. The GERB instruments were not flown in order, so GERB-2 is on MSG-1 and GERB-1 on MSG-2; GERB-3 and -4 are on MSG-3, and -4, respectively. All these satellites have at least one operating instruments, but GERB-1 is no longer operational on MSG-2.

[2] The MSG satellites are operated as a two-satellite system that continually return detailed imagery of Europe, Africa, and parts of the Atlantic and Indian Ocean every 15 minutes for operational use by meteorologists.

**Thierry Tremas** [CNES] provided the current status of ScaRaB, stating that the third instrument in the series[3] is on the CNES-Indian Space Research Organization's Megha-Tropiques satellite. Tremas repoted that the instrument continues to operate well and is meeting stability requirements.

**Patrick Raberanto** [CNRS, Laboratory of Meteorological Dynamics (LMD)] described the ScaRaB algorithms and resultant data products, explaining that the ScaRaB ERBE-like (SEL) Level-2 flux product is equivalent to the CERES ERBE-like instantaneous products that use a Maximum Likelihood Estimation (MLE) approach to determine the scene and the Suttles' Angular Radiation Models.[4] Raberanto also described how they also produced the ScaRaB Artificial Neural Network (SANN) products stating that SANN1 uses all four of the instrument's spectral channels [short wave (SW), total, visible, and infrared window] as input, whereas SANN2 uses only the two broadband channels. Later he stated that comparison with CERES SSF data showed bias in longwave (LW) fluxes of 0.3% and in SW of about 4%.

**Olivier Chomette** [LMD] reported on the results from the periodic CERES and ScaRaB comparison campaigns, explaining that the CERES instrument can be positioned to scan in nearly the same direction of ScaRaB, so all the angles are similar when their orbits cross. He stated that the comparison during these campaigns showed that the radiances are within 2.5% of each other in the SW region, concluding that since these instruments have different designs, these comparisons provide checks on each other.

**Norman Loeb** [NASA's Langley Research Center (LaRC)] reported on the current status of CERES, stating that there has been no change in the health of the five CERES instruments currently in orbit. The instrument planned for the first Joint Polar Satellite System satellite (JPSS-1) passed observatory-level environmental testing this fall. Loeb also highlighted a negative global energy balanced and filled (EBAF) top-of-atmosphere (TOA) clear-sky SW flux anomaly during the spring of 2016. Loeb revealed how zonal data showed that it was occurring over the North Pole—see **Figure 1**—concluding that the amount of sea ice and snow over land set new record lows for those months, based on satellite-based snow and ice observations.

**Pat Minnis** [LaRC] discussed the plans to transition from Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 5 to Collection 6. He announced that the MODIS Science Team will cease processing Collection 5 data at the end of December 2016. He confirmed that the calibration between the two editions has been compared and a strategy developed to ensure consistency in the cloud properties produced. Minnis also discussed plans to bring in Suomi National Polar-orbiting Partnership (NPP) Cross-track Infrared Sounder (CrIS) data to provide infrared information that the Visible Infrared Imaging Radiometer Suite (VIIRS) misses as compared with MODIS.

**Seiji Kato** [LaRC] compared over 10 years of CERES Edition 3 and Edition 4 Synoptic One Degree (SYN1deg) surface fluxes, showing that the surface downward LW flux has increased by 5.2 W/m$^2$ and downward SW flux has decreased by 3.9 W/m$^2$ between the two Editions—due to increased cloud fraction

[3] The previous two ScaRaB instruments flew onboard Russian satellites. ScaRaB-1 flew on METEOR 3/7 from 1994 to 1995; ScaRaB-2 flew on RESURS 01/4 from 1998 to 1999.
[4] The original Earth Radiation Budget Experiment used MLE an angular radiation model that Tim Suttles [NASA HQ, *retired*] developed to determine fluxes from TOA radiances. CERES has continued this approach in their ERBE-like product and this forms the basis for one of the ScaRaB products.

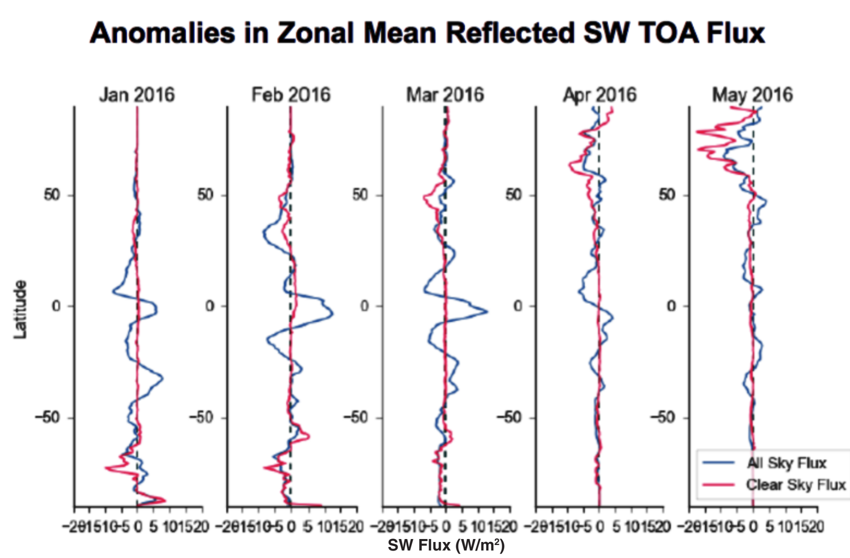



**Figure 1**. Zonal all sky (blue line) and clear sky (red line) reflected SW TOA flux anomalies from monthly means for the first five months of 2016. The data shown are from EBAF-TOA Version 2.8. The large negative anomalies poleward of 60° N latitude are caused by low snow and ice coverage. **Image credit:** Norman Loeb

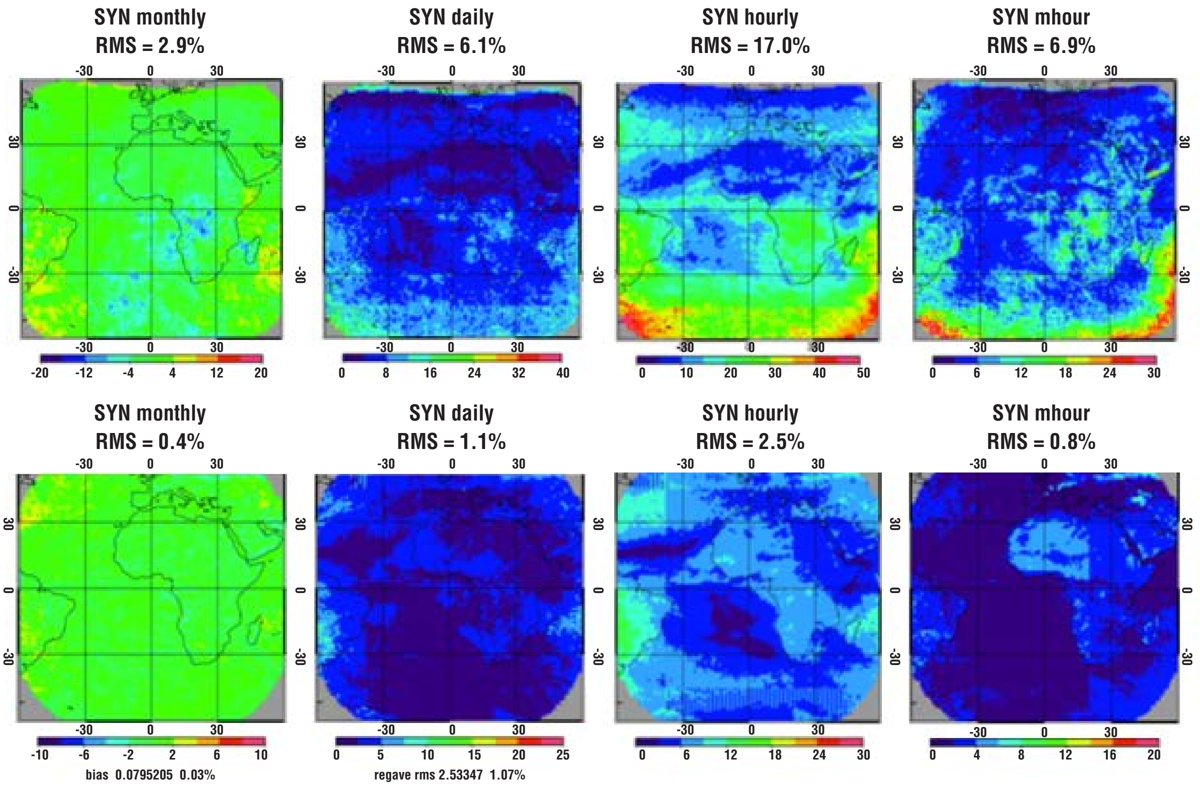



**Figure 2**. A comparison of CERES Edition 4 Synoptic One-degree products with GERB for January 2010. The top row shows SW TOA Fluxes; the bottom row shows LW TOA Fluxes. The four frames [*left to right across each row*] are monthly, daily, hourly, and monthly hourly regional values. **Image credit**: Dave Doelling

(especially at low levels of the atmosphere) along with higher surface temperatures. Based on these changes, Kato stated that the surface net irradiance increased by 2 W/m$^2$ over Edition 3 values. He pointed out that one significant improvement was the removal of the Edition 3 discontinuity that was caused by the change in meteorological inputs that occurred at the end of 2007.

**Dave Doelling** [LaRC] showed how the Edition 4 SYN1deg product was validated with GERB data for January 2010—see **Figure 2**—stating that the SYN1deg product uses hourly geostationary imagery data to provide diurnal information that CERES observations cannot supply. He concluded that the 15-minute GERB sampling captures these diurnal changes well.

**Norman Loeb** presented data from the Edition 4 EBAF-TOA candidate product that incorporates the many improvements that are included in the Edition 4 suite of CERES data products. He stated that the all-sky TOA fluxes have minor changes; the clear-sky TOA fluxes, however, are markedly higher than the earlier version at 0.8 W/m$^2$ and 2.5 W/m$^2$ for SW and LW, respectively. He explained that the Edition 4 flux trends are within 0.3 W/m$^2$ per decade of those in Edition 2.8. Loeb concluded by stating that modelers are most interested in the flux trends in identifying climate change and the EBAF trend changes are within the confidence intervals of the earlier values, or statisticaly, either could be determine correct.

## Earth Radiation Budget Observing Requirements

This session featured a discussion of ERB observing requirements. **Helen Brindley** presented material from the UKMO, explaining that the Global Climate Observing System (GCOS) recently completed their Implementation Plan (IP). She stated that the global mean TOA upwelling irradiance requirements are 1 W/m$^2$ with a 0.2 W/m$^2$ per decade stability in both SW and LW fluxes with 100-km (~62-mi) resolution; the surface upwelling irradiance had the same requirements. However, Brindley stated that it is unclear how the values chosen are related to understanding specific radiation processes. She suggested that one context to define it is the stated goal of observationally closing the carbon, water, and energy cycles to within 0.1 W/m$^2$.

**Norman Loeb** contended that a holistic view of the ERB observing system would consider collective strengths and weakness of satellite and *in situ* observations, stating that, clearly, no one individual observation type can provide all the required data. He explained that since climate time scales exceed the length of typical satellite missions, continuity is the most important requirement. Then he assessed the CERES accuracy for TOA irradiance as 4 W/m$^2$ and 2 W/m$^2$ at one standard deviation (1$\sigma$) for SW and LW fluxes, respectively. He noted that the stability of the current observations is close to the requirement in the GCOS IP.

**Highlights from Invited Science Presentations**

The remaining three days of the meeting were dedicated to science presentations, broken down into various subject areas with a poster session on Wednesday evening. All but one of these were invited presentations; the one non-invited presentation describes an effort to bring a new ERB instrument online.

**Jonathan Gregory** [University of Reading, U.K.] presented the first invited presentation in the section on climate response, which covered the inconstancy of transient climate response. To address this, he added a time-varying ocean heat term to the standard Equilibrium Climate Sensitivity (ECS) radiative forcing and feedback equation to handle the nonequilibrium stages that can occur. He showed that under the 1% carbon dioxide ($CO_2$) increase per year model results, the Transient Climate Response Parameter (TCRP) increases by about 20% over 140 years, owing to a decline in ocean heat uptake efficiency and a decrease in climate feedback mechanisms over time.

**Simon Tett** [University of Edinburgh] also gave an invited climate response presentation during which he discussed his approach for constraining climate sensitivity in a model with CERES TOA radiation measurements. He generated atmospheric model parameters that would match observed global-mean radiation measurements. He stated that the Hadley Center Atmosphere Model version 3 (HadAM3) could be automatically tuned to fit these TOA radiation observations, explaining that a range of values around the observations constrained by their uncertainty resulted in a broad set of observations. Tett ran 16 optimization cases, which were then combined with uncertainty analysis from the 14,000 *climateprediction.net* model experiments to produce probabilistic estimates of climate sensitivity.[5] His analysis showed a range of ECS values of between 2.7 and 4.2 K. The use of ERBE data in the analysis increased the upper limit to 5.6 K.

**Alejandro Bodas–Salcedo** [UKMO] started the session on cloud and aerosol effects with his invited presentation. He discussed how he investigated the large negative SW flux biases over the Southern Ocean in the Coupled Model Intercomparison Project (CMIP)[6] phase 3 results as compared to CERES data. He explained that the Southern Ocean is an area of strong negative SW flux cloud feedback, and the model dynamics could not account for the difference. Bodas–Salcedo described how he then looked at cloud structure and discovered that low- to mid-level clouds on the cold-air side of cyclones contribute most of the bias. He concluded that these supercooled liquid clouds are overestimated by the models, thereby increasing the intensity of the negative cloud feedback.

**Robin Hogan** [ECMWF] started the session on radiative considerations with an invited presentation on the impact of three-dimensional (3D) radiative effects on the global radiation budget. Hogan stated that using ECMWF model output and MODIS observations, the model cloud cover and Liquid Water Path (LWP) are too low and should result in less SW reflectivity, yet the SW Cloud Radiative Effect is also too low implying higher reflectivity. Hogan stated that the standard plane-parallel models do not account for side illumination, side escape, and in-region transport of radiation within clouds, adding that the Speedy Algorithm for Radiative Transfer through Cloud Sides (SPARTACUS) adds terms to account for these additional gains and losses of radiation that do not add large computational loads. Hogan concluded that the inclusion of 3D calculations in the ECMWF model suggest a 4 W/m$^2$ net flux change at both the surface and TOA and possibly explains the cold bias now seen in the model.

**Martin Wild** [Eidgenössische Technische Hochschule Zürich (ETH-Z)[7], Switzerland] provided an invited presentation to open the surface section. He noted that there is still a broad range of values for components of the surface energy budget derived from models and observations: There is a difference of more than 40 W/m$^2$ in the land downward solar radiation between the two. He stated that the CMIP Phase 5 (CMIP5) models tend to overestimate downward SW flux and underestimate downward LW flux—though not as badly as earlier model generations provided. Wild also stated that there is increased confidence in recent estimates of the global surface radiation budget, as independent surface- and satellite-based approaches converge to within a few W/m$^2$ of each other. He also showed that the surface energy budget has been changing with time, stating that the observations indicate that downward LW flux has increased by 2 W/m$^2$ per decade, which is consistent with CMIP5 simulations and an increasing greenhouse effect. Wild closed by stating that surface SW radiation also undergoes strong decadal changes—but that these are not represented in CMIP5 models. The SW changes are likely linked to changes in clouds and aerosols that are currently parameterized in climate models.

[5] *Climateprediction.net* has nonspecialist users run a a climate model with a double $CO_2$ scenario for 20 years with parameters set at high, medium, or low resulting in 14,000 different solutions.

[6] To learn more about CMIP in general, visit *https://climatedataguide.ucar.edu/climate-model-evaluation/cmip-climate-model-intercomparison-project-overview*.

[7] This is the Swiss Federal Institute of Technology in Zurich.

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# Lights in the Darkness

*Michael Carlowicz, NASA's Earth Observatory, michael.j.carlowicz@nasa.gov*

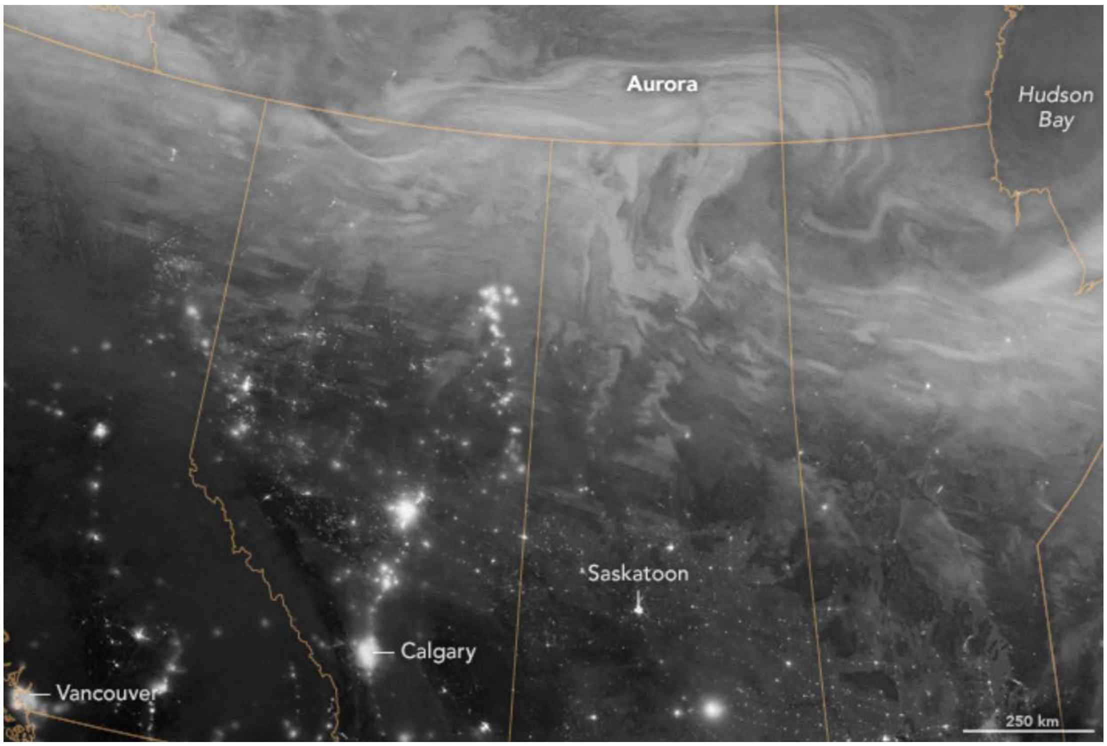


**Figure**. This image, created using data from the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (NPP) satellite, shows an aurora across northern Canada on December 22, 2016. **Image credit:** NASA's Earth Observatory

Just hours after the winter solstice, a mass of energetic particles from the Sun smashed into the magnetic field around Earth. The strong solar wind stream stirred up a display of northern lights over northern Canada—see **Figure**. With the "day-night band" (DNB) of the Visible Infrared Imaging Radiometer Suite (VIIRS), the Suomi National Polar-orbiting Partnership (NPP) satellite acquired this view of the aurora borealis on December 22, 2016. The northern lights stretched across British Columbia, Alberta, Saskatchewan, Manitoba, Nunavut, and Northwest Territories—areas that often fall under the auroral oval.

The DNB detects dim light signals such as auroras, airglow, gas flares, and reflected moonlight. In the case of the image *above*, the sensor detected the visible light emissions as energetic particles rained down from Earth's magnetosphere and into the gases of the upper atmosphere. The collision of solar particles and pressure into our planet's magnetosphere accelerates particles trapped in the space around Earth—such as in the radiation belts.[1] Those particles are sent crashing down into Earth's upper atmosphere—at altitudes of 100 to 400 km (60 to 250 mi)—where they excite oxygen and nitrogen molecules and release photons of light. The results are rays, sheets, and curtains of dancing light in the sky.

[1] To learn more about Earth's radiation belts, visit *http://earthobservatory.nasa.gov/IOTD/view.php?id=78985*.

# Space Laser Reveals Boom-and-Bust Cycle of Polar Ocean Plants

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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.

A new study using a NASA satellite instrument orbiting Earth has found that small environmental changes in polar food webs significantly influence the boom-and-bust, or peak and decline, cycles of phytoplankton. These findings will supply important data for ecosystem management, commercial fisheries, and our understanding of the interactions between Earth's climate and key ocean ecosystems.

"It's really important for us to understand what controls these boom-and-bust cycles, and how they might change in the future so we can better evaluate the implications on all other parts of the food web," said marine plankton expert **Michael Behrenfeld** [Oregon State University in Corvallis].

Phytoplankton also influence Earth's carbon cycle. Through photosynthesis, they absorb a great deal of the carbon dioxide ($CO_2$) dissolved in the upper ocean and produce oxygen, which is vital for life on Earth. This reduces the amount of $CO_2$ in the atmosphere.

Behrenfeld, along with scientists from NASA's Langley Research Center (LaRC) and several other institutions collaborated on the study. The findings were published Monday, December 19, 2016, in *Nature Geoscience*.[1]

Coastal economies and wildlife depend on what happens to tiny green plants, or phytoplankton, at the base of the ocean food chain. Commercial fisheries, marine mammals, and birds all depend on phytoplankton blooms. The new study shows that accelerations in growth rate cause blooms by allowing phytoplankton to outgrow the animals that prey on them. When this happens, the phytoplankton populations rapidly increase.

However, as soon as that acceleration in growth stops, the predatory animals catch up by eating the ocean plants and the bloom ends. This new understanding goes against traditional theories that blooms only occur when phytoplankton growth rates exceed a specific threshold of fast growth and that they end when these growth rates fall below that threshold again.

Behrenfeld compares the new idea to two rubber balls connected by a rubber band.

"A green ball represents the phytoplankton. A red one represents all the things that eat or kill the phytoplankton," he said. "Take the green ball and whack it with a paddle. As long as that green ball accelerates, the rubber band will stretch and the red ball won't catch the green ball. As soon as the green ball stops accelerating, the tension in the rubber band will pull that red ball up to it and the red ball will catch the green ball."

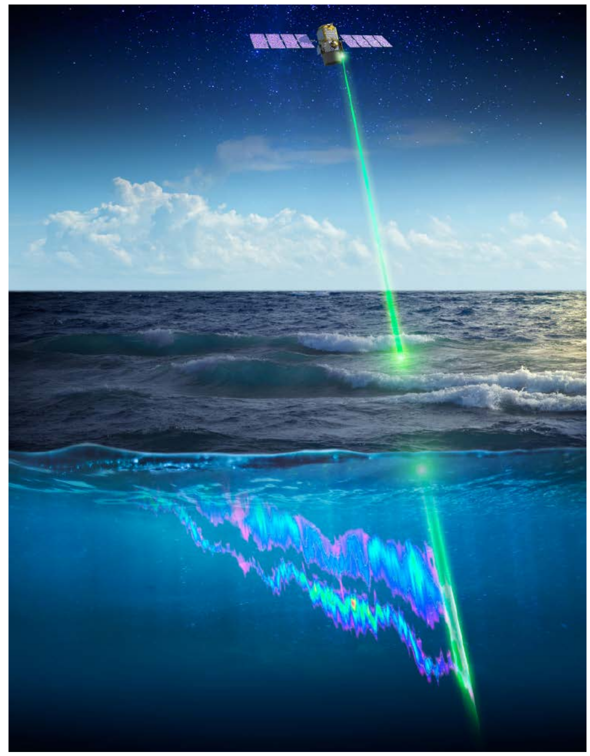

**Figure 1.** NASA's Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP), an instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite launched in 2006, uses a laser to take measurements of polar plankton. **Image credit:** NASA/Timothy Marvel

NASA's Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP), an instrument aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO)[2] satellite launched in 2006, uses a laser to take measurements—see **Figure 1**. Scientists used the instrument to continuously monitor plankton in polar regions from 2006 to 2015.

[1] To read the paper, visit *http://www.nature.com/ngeo/journal/vaop/ncurrent/full/ngeo2861.html*.

[2] The CALIPSO satellite mission is a collaboration between NASA and France's space agency, the Centre National d'Etudes Spatiales. The University of Maine in Orono, the University of California, Santa Barbara, and Princeton University also participated in the study.

"CALIOP was a game-changer in our thinking about ocean remote sensing from space," said **Chris Hostetler** [LaRC—*Research Scientist*]. "We were able to study the workings of the high-latitude ocean ecosystem during times of year when we were previously completely blind."

Ocean ecosystems typically are monitored with satellite sensors that simply measure sunlight reflected back to space from the ocean. These instruments have a problem seeing the ocean plankton in polar regions because of limited sunlight and persistent clouds that obscure their view of the ocean surface. The lidar shines its own light—a later—and can illuminate and measure the plankton day or night, in between clouds, and even through some clouds.

The study also reveals that year-to-year variations in this constant push and pull between predator and prey have been the primary driver of change in Arctic plankton stocks over the past decade. In the Southern Ocean around Antarctica, though, changes in the ice cover were more important to phytoplankton population fluctuations than were differences in growth rates and predation.

"The take home message is that if we want to understand the biological food web and production of the polar systems as a whole, we have to focus both on changes in ice cover and changes in the ecosystems that regulate this delicate balance between predators and prey," said Behrenfeld.

The current CALIOP lidar was engineered to take atmospheric measurements, not optimized for ocean measurements. Nonetheless, the CALIOP ocean measurements are scientifically valuable, as demonstrated by the results of this study.

New lidar technology is being tested that would allow scientists to better measure how phytoplankton are distributed through the sunlit layer of the ocean. This new capability will improve knowledge of phytoplankton concentrations and photosynthesis and will reveal more about the causes of phytoplankton blooms. This knowledge is critical for understanding cycling of ocean carbon, and for determining and managing the health of global ocean ecosystems. ■

# CERES Science Team Meeting Summary

*continued from page 46*

**Nicolas Clerbaux** [RMIB] provided information on another instrument that will be providing ERB information in the future: The European Space Agency is developing EarthCARE,[8] a cloud, aerosol, and radiation mission that is scheduled to launch in the fourth quarter of 2018. Clerbaux explained that EarthCARE will have a Broad-Band Radiometer (BBR) that has two channels (SW and LW) and three fixed viewing directions (one nadir and two aft). He provided details on the radiance unfiltering[9] and radiance-to-flux conversion algorithms that have been developed

[8] To learn more about EarthCARE, visit *http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/EarthCARE/ESA_s_cloud_aerosol_and_radiation_mission*.

[9] Unfiltering is a process that accounts for missing energy received at the detector due to absorption by filters and optics used in the instrument.

**Summary**

The joint workshop was very productive with significant discussion of measurement accuracy and comparison of radiance and flux results across various ERB instruments. CERES, GERB, and ScaRaB showed small differences when observations are directly compared. There was very active participation from the modeling community in their use of and needs for ERB observations. Equilibrium Climate Sensitivity (ECS) radiative forcing and feedback equation used with observation provided the range of expected climate feedback under various scenarios. The ERB observations have identified processes within the climate model that still need to be improved especially in the formation of clouds.

The next CERES Science Team Meeting will be held May 16-18, 2017, at LaRC. ■

# NASA Announces First Geostationary Vegetation, Atmospheric Carbon Mission

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

NASA has selected a first-of-its-kind Earth science mission that will extend our nation's lead in measuring key greenhouse gases and vegetation health from space to advance our understanding of Earth's natural exchanges of carbon between the land, atmosphere, and ocean.

The primary goals of the Geostationary Carbon Cycle Observatory (GeoCARB), led by **Berrien Moore** [University of Oklahoma in Norman],[1] are to monitor plant health and vegetation stress throughout the Americas, and to probe—in unprecedented detail—the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

The investigator-led mission will launch on a commercial communications satellite to make observations over the Americas from an orbit of approximately 22,000 mi (35,400 km) above the equator. The mission was competitively selected from 15 proposals submitted to the agency's second Earth Venture – Mission (EVM-2) announcement of opportunity for small orbital investigations of the Earth system.

"The GeoCARB mission breaks new ground for NASA's Earth science and applications programs," said **Michael Freilich** [NASA Headquarters—*Director of the Earth Science Division*]. "GeoCARB will provide important new measurements related to Earth's global natural carbon cycle, and will allow monitoring of vegetation health throughout North, Central, and South America."

GeoCARB will measure daily the total concentration of carbon dioxide, methane, and carbon monoxide in the atmosphere with a horizontal ground resolution of 3 to 6 mi (5 to 10 km). GeoCARB also will measure solar-induced fluorescence, a signal related directly to changes in vegetation photosynthesis and plant stress.

Total NASA funding for the mission over the next five years will be $166 million, which includes initial development, launch of the mission as a hosted payload on a commercial communications satellite, and data analysis.

The University of Oklahoma-led GeoCARB team will build an advanced payload that will be launched on a commercial communications satellite, employing otherwise unused launch and spacecraft capacity to advance science and provide societal benefit. By demonstrating GeoCARB can be flown as a hosted payload on a commercial satellite, the mission will strengthen NASA's partnerships with the commercial satellite industry and provide a model that can be adopted by NASA's international partners to expand these observations to other parts of the world.

From an orbit 22,000 mi (34,500 km) above the Americas, the Geostationary Carbon Cycle Observatory will monitor plant health and vegetation stress and probe the natural sources, sinks and exchange processes of key greenhouse gases. **Image credit:** NASA

GeoCARB is the second space-based investigation in the Earth Venture - Mission series of rapidly developed, cost-constrained projects for NASA's Earth Science Division. The Cyclone Global Navigation Satellite System (CYGNSS), selected in 2012, is the first mission in the series, launched on December 15, 2016. The Earth Venture missions[2] are part of NASA's Earth System Science Pathfinder (ESSP) program. The Venture Class small, targeted science investigations complement NASA's larger research missions.[3] ■

[1] Mission partners include the Lockheed Martin Advanced Technology Center; SES Government Solutions Company; the Colorado State University; and NASA's Ames Research Center, Goddard Space Flight Center, and NASA/Jet Propulsion Laboratory.

[2] The Earth Venture program selects new investigations, at regular intervals, to accommodate new scientific priorities using cutting-edge instrumentation carried on airborne platforms, small space missions, or as secondary instruments or hosted payloads on larger platforms. NASA's Langley Research Center manages the ESSP program for the agency's Science Mission Directorate.

[3] A National Academies 2007 report, *Earth Science and Applications from Space Decadal Survey*, recommended NASA undertake these regularly solicited, quick-turnaround projects.

# CYGNSS Hurricane Mission Measures "First Light" Science Data

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

NASA's Cyclone Global Navigation Satellite System (CYGNSS)[1] constellation of eight spacecraft made its "first light" measurements of the ocean surface on January 4, 2017. Measurements were made by one of the eight spacecraft, and mission scientists plan to activate the science instruments on the other seven in the near future.[2] Direct measurements are made of the global positioning system (GPS) power reflected by the ocean surface, from which near-surface wind speed can be derived over the tropical ocean and, in particular, inside hurricanes.

CYGNSS[3] was launched on December 15, 2016, at 8:37 AM EST into a low-inclination, low-Earth orbit over the tropics. The CYGNSS constellation will make frequent and accurate measurements of ocean surface winds in and near a hurricane's inner core, including regions beneath the eyewall and intense inner rainbands that previously could not be measured from space.

Direct science measurements are displayed as a Delay Doppler Map (DDM), which shows the GPS power reflected by the ocean in the vicinity of the targeted measurement location. One such DDM is shown the accompanying **Figure**, measured by constellation spacecraft FM03 on January 4, 2017, at 11:48:31 AM EST in the South Atlantic Ocean, east of Brazil.

"Our first light DDMs are direct confirmation that the CYGNSS science instrument on FM03 is operating as expected," said **Christopher Ruf** [University of Michigan, Department of Climate and Space Sciences and Engineering—*CYGNSS Principal Investigator*]. "There are still many steps ahead of us leading to reliable improvements in hurricane forecasts, but this was a critical one and it feels great to have it behind us."

CYGNSS is the first of the missions competitively selected through NASA's Earth Venture Program to launch into orbit. The Earth Venture Program is managed by the Earth System Science Pathfinder (ESSP) Program Office at NASA's Langley Research Center.[4]

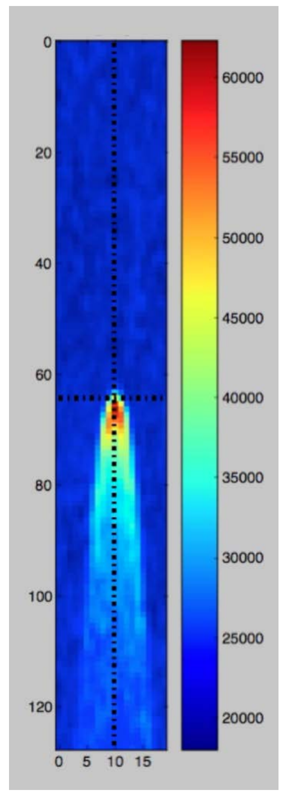


**Figure.** This image shows "first light" data from NASA's CYGNSS mission in the form of a Delay Doppler Map produced by one of the eight spacecraft (FM03) that make up the constellation at 11:48 AM EST on January 4, 2017. The peak in the center of the image represents scattered GPS signal from the ocean surface, from which near-surface wind speed can be derived. **Image credit:** NASA

[1] The CYGNSS mission is led by the University of Michigan, with the Southwest Research Institute in San Antonio, Texas leading the engineering development and operation of the constellation. The University of Michigan Climate and Space Sciences and Engineering department leads the science investigation, and the Earth Science Division of NASA's Science Mission Directorate oversees the mission.

[2] UPDATE: Check with the project for up to date status.

[3] To learn more about CYGNSS, read "Eight Microsatellites, One Mission: CYGNSS" in the November-December, 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 6**, pp. 4-13].

[4] This program focuses on low-cost, science-driven missions to enhance our understanding of the current state of the complex, dynamic Earth system and to enable continual improvement in the prediction of future changes.

# NASA Earth Science in the News

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**NASA: 2016 Was the Warmest Year on Record… Again!**, January 19, *universetoday.com*. According to independent analyses provided by NASA's Goddard Institute for Space Studies (GISS) and the National Oceanic and Atmospheric Agency (NOAA), 2016 was the warmest year since modern record keeping began in 1880. This represents a continuation of a most alarming trend, where 16 of the 17 warmest years on record have occurred since 2001. Together, the two organizations looked over global temperature data for the year of 2016 and came to the same conclusion. Based on their assessments, GISS determined that globally averaged surface temperatures in 2016 were 0.99 °C (1.78 °F) warmer than the mid-twentieth century mean. As **Gavin Schmidt** [GISS—*Director*] put it, these findings should silence any doubts about the ongoing nature of global warming, "2016 is remarkably the third record year in a row in this series. We don't expect record years every year, but the ongoing long-term warming trend is clear." NOAA's findings were similar, with an average temperature of 14.83 °C (58.69 °F) being reported for 2016. This surpassed last year's record by about 0.004 °C (0.07 °F), and represents a change of around 0.94 °C (1.69 °F) above the twentieth century average. The year began with a boost, thanks to El Niño; and for the eight consecutive months that followed (January to August) the world experienced record temperatures.

**NASA Plans Another Busy Year for Earth Science Fieldwork**, January 13, *spacedaily.com*. NASA scientists are crisscrossing the globe in 2017—from a Hawaiian volcano to Colorado mountaintops and west Pacific islands—to investigate critical scientific questions about how our planet is changing and what impacts humans are having on it. Such field experiments are an important part of NASA's Earth science research as scientists worldwide use the agency's field data, together with satellite observations and computer models, to tackle environmental challenges and advance our knowledge of how the Earth works as a complex, integrated system. "At NASA we are always pushing the boundaries of what can be done from space to advance science and improve lives around the world," said **Thomas Zurbuchen** [NASA Headquarters (HQ)—*Associate Administrator for the Science Mission Directorate*]. "These field campaigns help us build better tools to address such issues as managing scarce water resources and alerting the public to natural disasters."

**NASA Made an Animated Map of the Rains Flooding California**, January 13, *cnbc.com*. A map from NASA's Earth Observatory[1]—see **Figure**—provides a striking visual portrayal of the heavy rains that hit California and the southwestern U.S. from January 7-10, 2017. The heavy rains are the result of a flow of moist air known as the *pineapple express*—so named because the source region is typically near Hawaii—that travels eastward over the Pacific into the Western U.S. The pineapple express is an example of an *atmospheric river*, which are much like what the term suggests: streams of moist air that flow through the atmosphere. What makes them noteworthy is that they can be loaded with up to 15 times the amount of water that flows through the mouth of the Mississippi River, according to the National Oceanic and Atmospheric Administration. The map was created using data from the Integrated Multi-Satellite Retrievals for GPM (IMERG), a product of the Global Precipitation Measurement (GPM) mission.

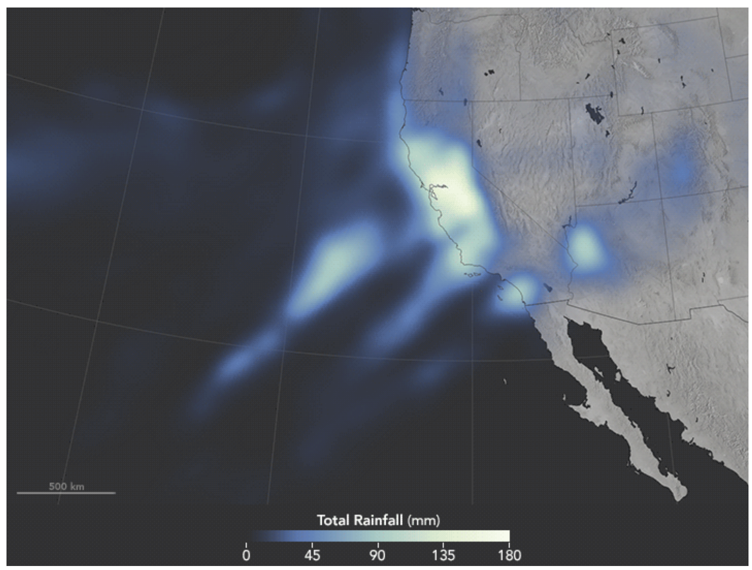


**Figure.** This map shows satellite-based measurements of accumulated rainfall over California and the western U.S. from 4:30 PM PST on January 7 to 4:30 PM on January 10. These rainfall totals are remotely-sensed estimates; local amounts can be significantly higher when measured from the ground. **Image credit:** NASA's Earth Observatory.

[1] To view the animated map, visit *http://earthobservatory.nasa.gov/IOTD/view.php?id=89442&eocn=home&eoci=iotd_previous*.

**NASA Scientists Find Link between Fire and Drought in Africa**, January 10, *upi.com*. Researchers have identified a unique link between fire and drought in Africa. Previous studies have shown the role drought plays in bolstering the risk of wildfire—but the latest research shows the converse. NASA scientists found a link between wildfire and controlled burning in northern sub-Saharan Africa and their effects on the region's water cycle. "We wanted to look at the general impacts of burning on the whole spectrum of the water cycle," said **Charles Ichoku** [NASA's Goddard Space Flight Center—*Senior Research Scientist*]. Researchers examined satellite data collected by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and the Tropical Rainfall Measurement Mission (TRMM) between 2001 and 2014. Their data analysis teased out a relationship between fire activity and hydrological indicators, including soil moisture, precipitation, evapotranspiration, and vegetation greenness—all factors that help trigger rain. "There is a tendency for the net influence of fire to suppress precipitation in northern sub-Saharan Africa," Ichoku concluded.

**A Massive Chunk of Antarctic Ice is About to Break Off**, January 9, *theweathernetwork.com*. A chunk of ice the size of Delaware is about break off from a major ice shelf in Antarctica. Following the collapse of the Larsen A ice shelf in 1995 and the break-up of Larsen B in 2002, scientists have been monitoring a wide rift in Larsen C with some apprehension. That apprehension was soon validated. Researchers at the U.K.-based Project Midas found that the Larsen C rift had grown significantly during the Antarctic polar night. In August 2016 the rift was roughly 14 mi (~22 km) longer than the measurements from March of the same year, and in December, the rift expanded an additional 11 mi (~18 km) within a few weeks time. Due to this acceleration in the rift's expansion, researchers are now saying it may only be a few months time until the slab of ice breaks off completely. In November 2016 scientists on NASA's IceBridge mission measured the Larsen C fracture to be roughly 70 mi (~113 km) in length and more than 1600 ft (~488 m) in depth. "The crack completely cuts through the ice shelf but it does not go all the way across it," NASA said in a statement. "[O]nce it does, it will produce an iceberg roughly the size of the state of Delaware." This iceberg is expected to be one of the 10 largest in recorded history. Ice shelves are a floating sheet of ice that are connected to a landmass, and many of the world's ice shelves are along Antarctica's coastline. According to NASA, when ice shelves collapse, ice behind the shelves accelerate toward the ocean, consequently adding to rising sea levels.

***NASA Uses Space Laser to Study Polar Ocean Plants**, December 25, *engadget.com*. The boom and bust of plankton is a good indicator of ocean health. Until recently, NASA could only measure plankton levels from satellites when it could see the reflection of the sun on the ocean, but the Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP) aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite can measure plankton levels through clouds. The lidar-based system doesn't rely on outside light sources to measure the amount of sea plants. Instead it can observe vegetation day or night and even through some light clouds. "CALIOP was a game-changer in our thinking about ocean remote sensing from space. We were able to study the workings of the high-latitude ocean ecosystem during times of year when we were previously completely blind." said **Chris Hostetler** [NASA's Langley Research Center—*Research Scientist*]. The researchers have been able to study the variations in plankton with CALIOP since 2006. "The take-home message is that if we want to understand the biological food web and production of the polar systems as a whole, we have to focus both on changes in ice cover and changes in the ecosystems that regulate this delicate balance between predators and prey," said **Michael Behrenfeld** [Oregon State University in Corvallis].

***NASA's Experimental Hurricane Monitoring Fleet Launched by Pegasus Rocket**, December 16, *universetoday.com*. NASA's constellation of experimental hurricane monitoring microsatellites was successfully air launched by the unique Orbital ATK Pegasus rocket on December 15, 2016. This opens a new era in weather forecasters' ability to measure the buildup of hurricane intensity in the tropics from orbit, and will eventually help save lives and property from impending destructive storms here at Earth's surface. The agency's innovative Cyclone Global Navigation Satellite System (CYGNSS) mission was launched from a designated point over the Atlantic Ocean off the east coast of Florida. "The launch of CYGNSS is a first for NASA and for the scientific community," said **Thomas Zurbuchen** [NASA HQ—*Associate Administrator for the Science Mission Directorate*]. "As the first orbital mission in our Earth Venture program, CYGNSS will make unprecedented measurements in the most violent, dynamic, and important portions of tropical storms and hurricanes."

*See news story in this issue.

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

# NASA Science Mission Directorate – Science Education and Public Outreach Update

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

**NASA Postdoctoral Fellowships**

**Audience:** Postdoctoral students (doctoral degree attained by the time the appointment begins).

**Application Deadline:** March 1, 2017

The NASA Postdoctoral Program (NPP) offers scientists and engineers unique opportunities to engage in NASA research in Earth science, heliophysics, astrophysics, planetary science, astrobiology, space bioscience, aeronautics and engineering, human exploration and operations, and space technology.

*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*: U.S. citizens, lawful permanent residents, or foreign nationals eligible for J-1 status as a research scholar may apply. Applicants must have completed a PhD or equivalent degree before beginning the fellowship, but may apply while completing the degree requirements. Fellowships are available to recent or senior-level PhD recipients.

To obtain more information and to apply for this exciting opportunity, visit *https://npp.usra.edu*.

**New Storybook From Elementary GLOBE: "What in the World Is Happening to Our Climate?"**

The latest storybook in the Elementary GLOBE series is available online. "What in the World Is Happening to Our Climate?" is a science instructional reader. In this story, the GLOBE kids learn the factors that regulate Earth's climate. Three new Elementary GLOBE learning activities accompany the story. These materials were developed by the University Corporation for Atmospheric Research and are supported by NASA and the National Oceanic and Atmospheric Administration. The Elementary GLOBE resources introduce students in grades K through 4 to the study of Earth system science. All of these resources are free online at *http://www.globe.gov/web/elementary-globe*.

**Bring the Story of *Hidden Figures* to the Classroom with the "Who Is Katherine Johnson?" Profiles and Modern Figures Toolkit**

In the 1960s the U.S. was on an ambitious journey to the moon, and Katherine Johnson and her fellow human computers helped get NASA's astronauts there. Bring the excitement of their story to your classroom with new resources from NASA Education. Learn more about Katherine Johnson with the "Who Is Katherine Johnson?" profiles written just for students. Versions written for K-4 and 5-8 students are available.

***"Who Is Katherine Johnson?"—Version for Grades K through 4***
*https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/who-is-katherine-johnson-k4*

***"Who Is Katherine Johnson?"—Version for Grades 5 through 8***
*https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/who-is-katherine-johnson-5-8*

**Prepare for the August 2017 Total Solar Eclipse**

On August 21, 2017, a total eclipse of the sun will be visible from the contiguous U.S. for the first time since 1979. The track of the moon's shadow cuts diagonally across the nation from Oregon to South Carolina. Inside the 70-mile-wide path of totality the moon will completely cover the sun's disk as the landscape is plunged into an eerie twilight, and the solar corona is revealed to naked eye observers for over two minutes. Please visit *https://eclipse2017.nasa.gov* to plan your viewing experience.

**Don't Miss Out on Upcoming NASA Education Opportunities.**

For a full list of events, opportunities, and more, visit the Educator and Student Current Opportunity pages on NASA's website:

***Educators:*** *http://www.nasa.gov/audience/foreducators/current-opps-index.html*
***Students:*** *http://www.nasa.gov/audience/forstudents/current-opps-index.html*

Are you looking for NASA educational materials to support your STEM curriculum? Search hundreds of resources by subject, grade level, type, and keyword at *http://www.nasa.gov/education/resources*. Find NASA science resources for your classroom. NASA Wavelength is a digital collection of Earth and space science resources for educators of all levels—from elementary to college, to out-of-school programs: *http://nasawavelength.org*.

**Check Out the New "Explore NASA Science" Website, and More**

Science starts with questions, leading to discoveries. Explore the redesigned NASA Science site and send us feedback. Visit *https://science.nasa.gov*. To view the site in Spanish, visit *http://ciencia.nasa.gov*. ■

## EOS Science Calendar

**April 12–13, 2017**
LCLUC Spring Science Team Meeting,
Rockville, MD.
*http://lcluc.umd.edu/meetings/2017-lcluc-spring-science-team-meeting-apr-12th-13th-and-musli-meeting-april-14th*

**April 17-18, 2017**
AIRS Science Team Meeting,
Pasadena, CA.
*http://airs.jpl.nasa.gov/events*

**May 16-18, 2017**
CERES Science Team Meeting,
NASA's Langley Reseach Center, VA.
*https://ceres.larc.nasa.gov/science-team-meetings2.php*

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

## Global Change Calendar

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

**April 23–28, 2017**
European Geosciences Union, Vienna, Austria.
*http://www.egu2017.eu*

**May 20–25, 2016**
JpGU-AGU Joint Meeting, Chiba, Japan.
*http://www.jpgu.org/meeting_e2017*

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

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

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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