National Aeronautics and Space Administration

the earth observer

The Earth Observer. September - October 2009. Volume 21, Issue 5.

Editor's Corner

Steve Platnick
EOS Senior Project Scientist – Acting

On September 1, NASA Headquarters released results for the 2009 Earth Science Senior Review. The review evaluated extended mission proposals submitted in late March for 13 satellite missions that are, or soon will be, beyond their Prime Mission lifetimes (ACRIMSAT, Aqua, Aura, CALIPSO, CloudSat, EO-1, GRACE, ICESat, Jason-1, QuikSCAT, SORCE, Terra, and TRMM); this was the first Senior Review for Aura and CALIPSO. Though the Senior Review is a biennial process, this year's review provided mission direction and funding guidelines for fiscal years (FY) 2010–2013; the FY2012-13 guidelines are considered preliminary and will be revisited at the next Senior Review in 2011.

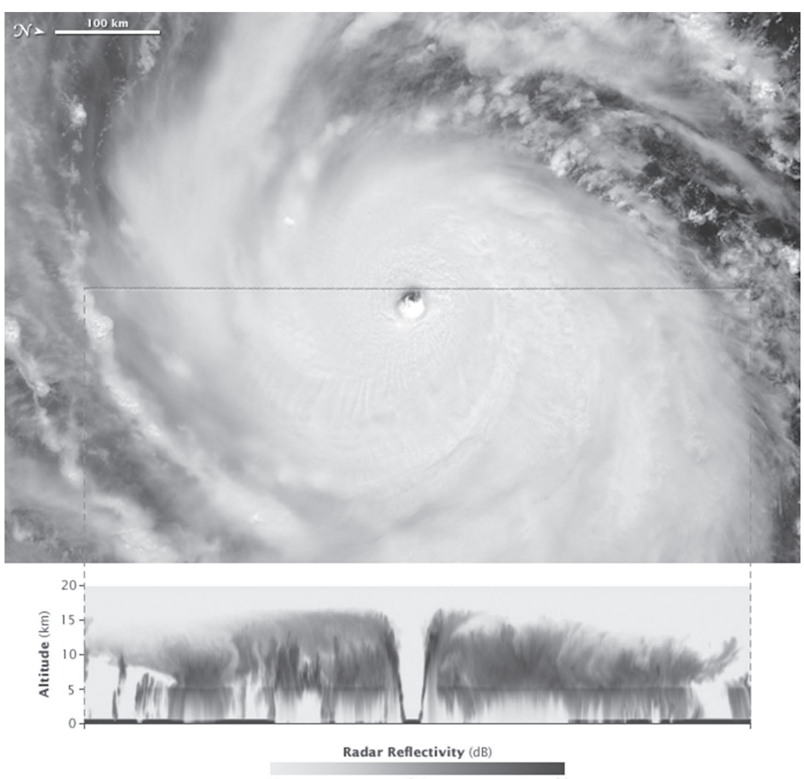
The process began with a call letter released on January 21. Two budgets were sought: an *in-guide budget* that covered continuation of the basic mission and its core products and a so-called *optimal budget* that would support additional activities. There were some notable differences compared to the 2007 Senior Review. First, there was no solicitation for new products or *enhanced* science. Second, while the total amount intended for mission Education and Public Outreach (E/PO) activities was requested, the details of the proposed effort and an itemized budget are being submitted separately in mission Implementation Plans that are due October 1 (as described in a separate call letter released on August 31).

continued on page 2

Super Typhoon Choi-wan had just become a Category 4 super typhoon on the morning of September 15, 2009, when the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured the top image. Approximately a minute later, the CloudSat satellite also flew over the storm system. Cloudsat's flight path (a section of which is shown as a grey line across the MODIS image) took it just north of the eye at the center of the storm.

In the lower image Cloudsat's radar recorded the cloud structure, capturing a vertical cross section view of the storm. The dense clouds at the center of the storm tower above fifteen kilometers. Most distinctive is the eye, which is completely clear to sea level. The clouds on either side of the eye are dense, sending a strong radar signal back to the satellite as indicated by the darkest shades.For more information and to view the images in color please visit: *earthobservatory.nasa.gov/NaturalHazards/view.php?id=40234*

Credit: NASA's Earth Observatory



eos.nasa.gov

In This Issue

Editor's Corner Front Cover

Feature Articles

A Shift in Direction: EOS in the Mid-1990s 4
EOS Data and Information System (EOSDIS): Where We Were and Where We Are, Part II 8
The Role of Visuals in Science Communication 15

Earth System Science at 20

A Symposium to Explore Accomplishments, Plans, and Challenges 18

Meeting/Workshop Summaries

Global Satellite Vegetation Monitoring: Summary of the 4th Global Vegetation Workshop 32
Landsat Science Team Meeting Summary 34
SMAP Algorithms & Calibration/Validation Workshop 40

In The News

NASA Satellites Unlock Secret to Northern India's Vanishing Water 44
Honey Bees Turned Data Collectors Help Scientists Understand Climate Change 46

Regular Features

EOS Scientists in the News 48
NASA Science Mission Directorate—Science Education Update 50
Science Calendars 51
The Earth Observer Information/Inquiries Back Cover

Two panels were convened to evaluate the proposals. The Science Panel had responsibility for reviewing the scientific merit of the mission, while the Core Mission Review Panel (CoMRP) consisted of two sub-panels: Technical & Cost and National Interests, the latter providing input primarily from research and operational data users from other federal agencies. The Science Panel evaluation included mid-May presentations from the mission Project Scientists (accompanied by key instrument and mission operations personnel) that responded directly to requests for further information from the panel.

Most mission funding guidelines were at or near the existing *in-guide budget* level (or at the *optimal* level in many cases) for the four years. Exceptions include EO-1, which was fully extended through FY2011 with funds in FY2012 for final dataset archiving/documentation and mission termination; mission extension into FY2012-13 may be reconsidered subject to improvement in the mission's utility as assessed by the National Interests Panel in the next Senior Review. EO-1, launched in late 2000 with a one-year baseline mission, was designed as a technology demonstration mission and successfully pioneered new techniques in high spatial/spectral resolution imagery. ACRIMSAT, launched at the end of 1999, was extended through FY2011 contingent on instrument characterization plans and implementation. Based primarily on laser life considerations for the last of the 3 GLAS lasers still operating, ICESat mission operations were directed to terminate following the second observation campaign in FY2010 (scheduled for spring 2010); FY 2011/12 activities will include the final processing and archiving of the ICESat dataset. ICESat was launched in January 2003. The ICE Bridge mission will use aircraft-based observations to gather similar data sets until the launch of the ICESat-II Decadal Survey Mission.

The Senior Review process involved a considerable amount of time for the mission teams and Project Scientists (in particular for multi-instrument/multi-center missions), as well as the panel members and chairs. On behalf of the broad domestic and international user communities, many thanks to all those who contributed to this process.

The full Senior Review report, including a description of the evaluation process and panel findings, is available at: *http://nasascience.nasa.gov/earth-science/mission_list.*

We continue our ongoing *Perspectives on EOS* series with two more articles in this issue. These personal remembrances help to preserve the EOS history and transform it into a dynamic story with relevance to future Earth Science missions. The first *Perspectives* article comes from **Mark Abbott**—see page 4 of this issue. The EOS Program was given a "new start" in 1990, but was the target of a series of political and budgetary assaults each year thereafter, and the system that emerged by the end of the decade—three mid-size "flagship" missions supplemented by numerous smaller satellites—was quite different than what was originally envisioned. Abbott served as chair of the EOS Payload Panel during this critical and volatile phase of the development of the EOS Program, and in his article, he shares some of his memories from that time.

The second *Perspectives* article concludes **Rama Ramapriyan's** two-part article on the evolution of the Earth Observing System Data and Information System

(EOSDIS)—see page 8 of this issue—Part I of which appeared in our July–August issue [**Volume 21, Issue 4**, pp. 4-10.]

We also have an interesting article from **Laura Rocchio** that summarizes "The Role of Visuals in Science Communication"—see page 15 of this issue. She highlights some of the history of the use of scientific visuals through the centuries and how technological advances like the printing press, and, more recently, computers and digital media greatly enhanced scientists' ability to create and share visual representations of their science results. In our November–December issue Rocchio will provide information on the "rules of thumb" of good scientific visuals and detail some of the resources available to assist with the development of scientific visualizations.

As mentioned in our last issue, the Earth System Science at 20 (ESS@20) Symposium took place June 22-24 at the National Academy of Sciences in Washington, DC. NASA's Earth Science Division worked with the National Academy of Sciences' Ocean Studies Board, Space Studies Board, and Board on Earth Sciences and Resources to organize this symposium. Over 300 people attended the three-day meeting, which bought together researchers, managers, and policy makers to examine the 20-year history of the NASA Earth system science program and offered glimpses into its future. Staff from *The Earth Observer* attended this meeting and we are pleased to present a summary report—see page 18 of this issue.

Finally, I would like to publicize an important new development on our EOS Project Science Website that adds a long sought-after capability. Our office has developed an on-line Search Tool for *The Earth Observer* newsletters. Currently one can search any issue dating back to January–February 1995[1] by one or more fields including: *Article Title*; *Article Type* (Editorial, Feature, Meeting Summary, News Story, etc.); *Issue*; *Author(s)*; and *Keywords* (scans the article text). I would like to recognize **Maura Tokay** for her hard work in setting up this database and some of the data entry, as well as **Nicole Miklus** and **Ryan Barker** who also helped with data entry. The tool can be accessed at: *http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/earth_observer.php*.

[1] Until now, all issues of *The Earth Observer* prior to 1995 (i.e., dating back to the very first issue in March 1989) have been preserved as hard copies in the EOS library; they were not available on line. The PSO is now in the process of scanning these older issues so that they can be viewed as *pdf* files, and possibly incorporated into the newsletter database at a later date.

NASA at World Climate Conference-3 (WCC-3)

Winnie Humberson and **Steve Graham** from the EOS Project Science Office worked with the U. S. State Department in planning NASA's exhibit for WCC-3 and attended the conference held from August 31-September 4 in Geneva, Switzerland. During the meeting, the State Department organized a ribbon-cutting ceremony at the exhibit booth (see picture). NASA was also represented at the conference by **Randy Friedl** (Chief Scientist, Earth Science and Technology Directorate, Jet Propulsion Laboratory) and **Shahid Habib** (Chief, Office of Applied Sciences at Goddard Space Flight Center).

WCC-3 was convened to establish an international framework to guide the development of climate services that can link science-based climate predictions to climate-risk management and adaptation strategies. The overarching theme of the conference was climate impacts and information for decision-making, focusing on scientific advances in seasonal to interannual timescales, and taking into account multi-decadal prediction.

Shere Abbott, Associate Director for Environment, White House Office of Science & Technology Policy, and **Douglas Griffiths**, Deputy Permanent Representative, United States Diplomatic Mission to the United Nations in Geneva, cut the ribbon at the NASA Exhibit. Photo courtesy of Steve Graham.

A Shift in Direction: EOS in the Mid-1990s

Mark R. Abbott, College of Oceanic and Atmospheric Sciences, Oregon State University, mark@coas.oregonstate.edu

During the height of Dan Goldin's tenure as NASA Administrator (1995–2000) I served as chair of the EOS Payload Panel, and we were tasked with advising NASA regarding a significant set of issues (driven both by ever-shrinking NASA budgets and a political climate that was increasingly hostile to climate observations).

This article continues our *Perspectives on EOS* series, in which we share perspectives on the history of EOS from people who were actually involved in "making" the history. It is our hope that the stories shared in these articles may be helpful to those tasked with planning future Earth observing missions.

The Earth Observing System (EOS) as it exists today has evolved a great deal from how it was originally conceived.[1] The original concept—known as *System Z*—came about in the early 1980s and called for several large platforms about the size of the Hubble Space Telescope, that would be launched from the Space Shuttle, and be maintained by astronauts in a manner similar to how Hubble is serviced today.[2] But the political priorities and budget realities of the Reagan administration—along with the 1986 *Challenger* disaster—soon resulted in a shift toward the idea of a series of "robotic" climate observing system missions. The result of this was that by the early 1990s the concept for EOS had evolved into a system of four large polar orbiting satellites that would launch on a *Titan IV* rocket, two contributed by NASA and one each by Europe (ESA) and Japan (NASDA).

The 1990s was a tumultuous time for EOS.[3] The program was given a "new start" in 1990, but political and budgetary pressures continued year after year, and the system that emerged by the end of the decade—three mid-size "flagship" missions supplemented by numerous smaller satellites—was quite different than what the original visionaries like **Dixon Butler** and **Shelby Tilford** conceived. During the mid-1990s **Mark Abbott** was chair of the EOS Payload Panel whose task was to advise NASA on a range of issues related to the development of the EOS missions. In this article, Abbott shares some of his memories of that time.

[1] Alan Ward's opening article in the *Perspectives on EOS* series entitled: "The Earth Observer: 20 Years Chronicling the History of the EOS Program" [**Volume 20, Issue 2**, pp. 4-8] includes a summary of the evolution of EOS.

[2] Dixon Butler discusses the original concept for EOS in his article in the *Perspectives on EOS* series entitled: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth" [**Volume 20, Issue 5**, pp. 4-7.]

[3] Greg Williams shares his recollections of EOS, including a discussion of the many "re"-views EOS was subjected to during the mid-1990s, in his article in the *Perspectives on EOS* series entitled: "A Washington Parable: EOS in the Context of Mission to Planet Earth" [**Volume 21, Issue 2**, pp. 4-12.]

In 1992, **Dan Goldin** became the NASA Administrator. Goldin believed in a philosophy of *Faster… better… cheaper*—i.e., he thought NASA could do more with less. Hence, Goldin did not support the idea of having large EOS platforms in space and in fact once referred to them as "Battlestar Galactica." He believed smaller, less expensive missions that could be built more quickly were the way to go and supported development of new programs that actually diverted funds from EOS. Goldin's "anti-EOS" philosophy, combined with the 1994 "Republican Revolution" and new Congressional leadership that diametrically opposed funding climate change research did not bode well for EOS funding during the mid-1990s.

During the height of Dan Goldin's tenure as NASA Administrator (1995–2000) I served as chair of the EOS Payload Panel, and we were tasked with advising NASA regarding a significant set of issues (driven both by ever-shrinking NASA budgets and a political climate that was increasingly hostile to climate observations). These ongoing issues would eventually culminate in the termination of the EOS AM and PM series (so named for morning and afternoon equator crossing times, respectively) after the

Mark R. Abbott

first set of missions—the original plan had called for three iterations of each series over 15 years, hence the names AM-1, PM-1, and CHEM-1.

When our group convened in November 1995, the Payload Panel did not foresee this outcome and instead was focusing on three main issues: (1) the need to develop an integrated strategy that included new technology and convergence with the operational satellite systems; (2) the development of a "federation of partners" for the EOS Data and Information System (EOSDIS) in light of a National Research Council report from the Board on Sustainable Development;[1] and (3) a refocusing of the EOS CHEM-1 to include measurements of tropospheric ozone. For this article, I will provide some perspective on the first issue of technology infusion and continuity, although the "federation" concept eventually encompassed both the observing system and EOSDIS.

Consistency and flexibility were always in tension from the earliest days of *System Z* and EOS—and reflected long-standing philosophical differences between NOAA and NASA. NOAA was a full partner in *System Z* from the beginning, but reconciling its operational requirements with NASA science requirements was always challenging. Discussions (and sometimes arguments) about orbit characteristics carried forward from meeting to meeting, with NOAA arguing for higher orbits to ensure continuity with its existing Polar-orbiting Operational Environmental Satellites (POES) series whereas NASA preferred lower orbits for better sensor performance and consistency with its earlier research missions. I recall one meeting in Silver Spring, MD, when **Stan Schneider** (one of the NOAA representatives) showed up in his full combat fatigues before heading off for weekend Army Reserve duties. His attire exemplified the ongoing interagency tensions between consistency and flexibility. Because of their differing requirements and resulting tensions, NASA and NOAA went their separate ways in the mid-1980s. Ten years later, in 1995, they started working together again, and the same tensions resurfaced between the operational and research missions of NOAA and NASA. The scientific needs for continuity and consistency for climate research conflicted with the equally important needs for innovation and flexibility.

Discussions (and sometimes arguments) about orbit characteristics carried forward from meeting to meeting, with NOAA arguing for higher orbits to ensure continuity with its existing Polar-orbiting Operational Environmental Satellites (POES) series whereas NASA preferred lower orbits for better sensor performance and consistency with its earlier research missions.

In June 1995, the Payload Panel produced a set of *white papers* that focused on new management approaches on the issues of EOSDIS, calibration and validation, technology infusion, and NASA/NOAA convergence. The opening paragraph of the overview stated:

> "One of the most significant challenges facing the Earth Observing System is the need to remain flexible so that it can respond to changes in budgets and future advances in scientific understanding yet maintain sufficient consistency to address long-term scientific questions related to Earth system

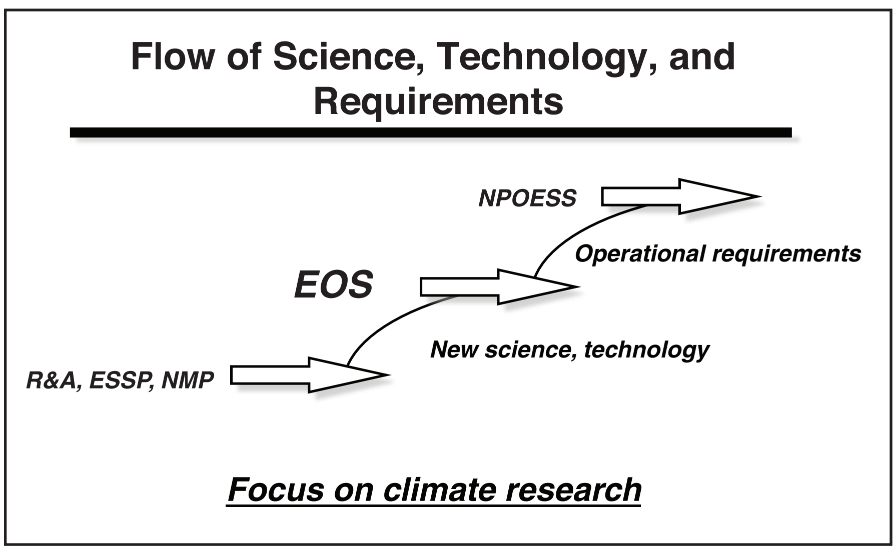
[1] To learn more about the ESIP Federation, please refer to Part II of Rama Ramapriyan's article "EOS Data and Information System (EOSDIS): Where We Were and Where We Are" on page 8 of this issue.

science and climate change. This objective has become more difficult in an environment where the available technology is evolving rapidly. Previous budget reductions in EOS have severely stressed the ability of the program to satisfy current requirements of the Global Change Research Program, and EOS cannot rely on previously defined solutions for Earth observation and data management in such an environment."

NPOESS represented a "federated" approach to the observing systems and was proposed as a means to reconcile the needs for innovation and stability in the context of Earth system science.

The Payload Panel report from November 1995 discussed this challenge and some possible approaches to maintaining an appropriate balance. The Panel described two models: (1) the *Nimbus model* that relied on technology development, the needs of individual scientific disciplines, and relatively flexible requirements; and (2) the *EOS model* that emphasized stable, integrated observing systems driven by coordinated planning of science and technical requirements. NASA used both the *Nimbus model* and the *EOS model* to balance innovation and stability (although generally not in an explicit manner). However, as budgets tightened and the NASA Administrator continued to rail against the large EOS platforms, it became difficult to maintain both approaches. New programs for innovation [e.g., the New Millennium Program (NMP) and the Earth System Science Pathfinder program (ESSP)] came into being to divert resources away from the centralized, stable EOS platforms. At the same time, NASA leadership saw its scientific needs for stability and continuity being fulfilled by the newly proposed National Polar-orbiting Operational Environmental Satellite System (NPOESS) and perceived an opportunity to shed its commitments to a long-term observing system.

The Payload Panel reports from the mid-1990s repeatedly stressed the needs for effective scientific involvement in the requirements process for NPOESS as well as the need for an effective management structure that could balance the requirements for



This slide is from Abbott's presentation to the May 1996 Payload Panel meeting and shows the planned flow of information from EOS to NPOESS, and from research and analysis (R&A) to operations. (As an interesting sidenote, this slide came from Abbott's very first *Power Point* presentation.)

long-term, science quality observations with the requirements to infuse new technology and new scientific understanding. The Panel's *white paper* on NASA–NOAA convergence recognized this tension as well as the cultural differences between the two agencies. However, the Panel did not explicitly point out a fundamental misconception: **a commitment to a permanent observing system in space is not the same as a commitment to long-term observations for Earth system science and climate research.** Clearly, the latter commitment depends on the first, but simply having a set of satellites in orbit does not necessarily fulfill the science requirements.

NPOESS represented a "federated" approach to the observing systems (to go along with the "federated" approach to data processing being proposed) and was proposed as a means to reconcile the needs for innovation and stability in the context of Earth system science. As envisioned, the new observing system would provide the long-term, consistent observables essential for climate research through a managed process of NASA–NOAA convergence. Technology development programs, such as New Millenium Program (NMP) and Earth System Science Pathfinder (ESSP), would provide the technological and scientific innovation that was the lifeblood of NASA. No longer would NASA be responsible for all aspects of the observing federation by being locked into repeated flights of the same platforms for two decades. After all, 20 years was not adequate for a climate observing system. We needed **permanence**, and that, we believed, would come from NOAA through NPOESS. A "bridge" mission (the NPOESS Preparatory Project) would serve as the primary tool for convergence.

In 2009, we are still missing a national commitment to a long-term (i.e., permanent) observing system capable of Earth system and climate research. We continue to confuse operational with climate.

The post-1995 period eventually saw the EOS series end with Terra, Aqua, and Aura, and was marked by increasing frustration in the science community with the NPOESS process. Many National Research Council (NRC) reports were commissioned, examining the capabilities (or lack thereof) of NPOESS to meet long-term observing requirements, the transition from research to operations, and other issues related to NASA/NOAA convergence. However, as noted in the 1995 Payload Panel report, there were fundamental obstacles related to agency interests, objectives, requirements, and culture that needed to be recognized and overcome. Without effective and continuing leadership, this *ad hoc*, federated approach soon came to the cusp of *"an observational collapse,"* as noted in the preliminary report of the NRC's Decadal Survey.

Fifteen years later, the Decadal Survey has helped structure the NASA portion of the Earth observing federation. With a portfolio of prioritized missions, a vigorous program of technology development, and small, innovative missions, NASA has moved away from the brink. **However, we are still missing a national commitment to a long-term (i.e., permanent) observing system capable of Earth system and climate research. We continue to confuse *operational* with *climate*.** Although many of the Earth system variables are useful for both *operational* (i.e., short-term prediction) and *climate* needs, there are fundamental differences in quality and consistency as well as the need for integration of multiple variables that lead to incompatibilities and gaps.

In 1995, the Payload Panel mentioned a NASA–NOAA merger but noted that it was a "long ways" off in the future. I can only speculate where we might be today if NASA and NOAA had merged, rather than pursue an ill-fated convergence of the nation's weather satellites with NPOESS. A merger would have been extraordinarily difficult, but perhaps we would have the long-term observing system that continues to elude us today. And as Dixon Butler would often say during *System Z* meetings, *"Sigh…"* ■

EOS Data and Information System (EOSDIS): Where We Were and Where We Are, Part II

H. K. Ramapriyan (Rama), NASA Goddard Space Flight Center, Rama.Ramapriyan@nasa.gov

Today EOSDIS processes over 150 million data products each year, but the journey to making EOSDIS the world-class data and information system it is today has been long and sometimes difficult—and the details of this journey make for a compelling story.

This article continues our ongoing *Perspectives on EOS* series. To date, the articles in this series have shared perspectives from a number of Earth Observing System (EOS) "pioneers"—scientists and managers who were personally involved in the early days of the program and actually involved in *making* what we now view as EOS history. Along the way, we've also learned something about the difficult political journey EOS faced as it progressed from inspiring idea to concrete reality.

But there are still more facets of the tale of EOS that need to be told. One of those is the story behind the development of the Earth Observing System Data and Information System (EOSDIS). Our EOS satellites beam back reams of data and information about the condition of Earth every single day, but this information would be all but useless without an effective system to efficiently process it all and make it readily available for use in science research and applications. Today EOSDIS processes over 150 million data products each year, but the journey to making EOSDIS the world-class data and information system it is today has been long and sometimes difficult—and the details of this journey make for a compelling story.

The Earth Observer asked H. K. "Rama" Ramapriyan of Goddard Space Flight Center to share some of the details of this story with us and he graciously agreed. Rama has been involved in the EOSDIS program since its inception and is thus well qualified to reflect on its history. (This article is the second of two articles from Rama—the first appeared in our July–August issue.)

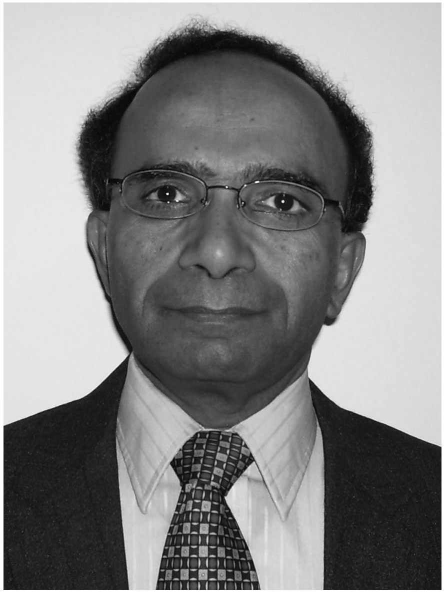
Introduction

In Part 1 of this two-part series, we discussed how the concepts for EOSDIS originated over 20 years ago and several of the initial steps leading up to the beginning of the EOSDIS Core System (ECS) contract. In this part, we will cover the numerous reviews of EOSDIS, some of the hurdles encountered and the remedies that led to a successful deployment of EOSDIS, the evolution of *Community* capabilities and the most recent evolution of the *Core* capabilities.

Reviews, Reviews and more Reviews

The period between 1992–1999 was a very intense period in the EOS Program as a whole and EOSDIS in particular. As **Greg Williams** discussed in a previous article in this series,[1] there were four "Re" exercises during 1991–1995—*Restructuring, Rescoping, Rebaselining and Reshaping*—resulting in substantial changes to the architecture, as well as reductions to the budget and scope of the EOS Program including EOSDIS. Given the size and impact of EOSDIS it had a lot of external visibility, resulting in several reviews. The reviews included: audits by the Government Accountability Office (GAO) and the Inspector General (IG), Independent Cost Assessment, cost presentations to the EOS Investigators' Working Group (IWG), National Research Council reviews, and multiple independent NASA reviews. In addition, for the ECS contract the Project organized reviews from a review panel

[1] Please see the article "A Washington Parable: EOS in the Context of Mission to Planet Earth", in the May–June 2009 issue of *The Earth Observer* [**Volume 20, Issue 3**, pp. 4-12.]



H. K. "Rama" Ramapriyan

consisting of members from the Data Panel and other experts within and outside NASA. The total number of reviews during 1992–1999 was 55 (see **Figure 1**). At one point, one of my colleagues reminded us of ***Cohn's Law***: *"The more time you spend in reporting on what you are doing, the less time you have to do anything. Stability is achieved when you spend all your time reporting on the* ***nothing*** *you are doing."* In fact, I was surprised that **Rick Obenschain**, our Project Manager from December 1996–October 1998, *actually* sent out a weekly report stating this in somewhat similar words.

The scientific community was involved in the development of ECS primarily through participation in the major reviews of the Science Data Processing Segment (SDPS) (e.g., System Design Review, Preliminary Design Review, Critical Design Review). Designed to meet over 800 requirements even at a moderate level of detail, the SDPS would operate at the Distributed Active Archive Centers (DAACs) to perform all the functions past Level 0 processing of data from all EOS instruments [starting with those on the Tropical Rainfall Measuring Mission (TRMM) scheduled for launch in 1997] and would also support all of NASA's *heritage* Earth science data extant in *Version 0* (*V0*). Most of the SDPS development followed the *waterfall* [2] method, but the part of SDPS deemed to be the most "user sensitive" was developed using an iterative approach with feedback from *tire-kickers* (as was done with *V0*). The review panel expressed a great deal of concern about the long delay between establishing requirements and delivery of demonstrable working capabilities due to the *waterfall* development model.

Most of the Science Data Processing Segment (SDPS) development followed the waterfall method, but the part of SDPS deemed to be the most "user sensitive" was developed using an iterative approach with feedback from ***tire-kickers*** *(as was done with V0).*

[2] See *en.wikipedia.org/wiki/Waterfall_model*

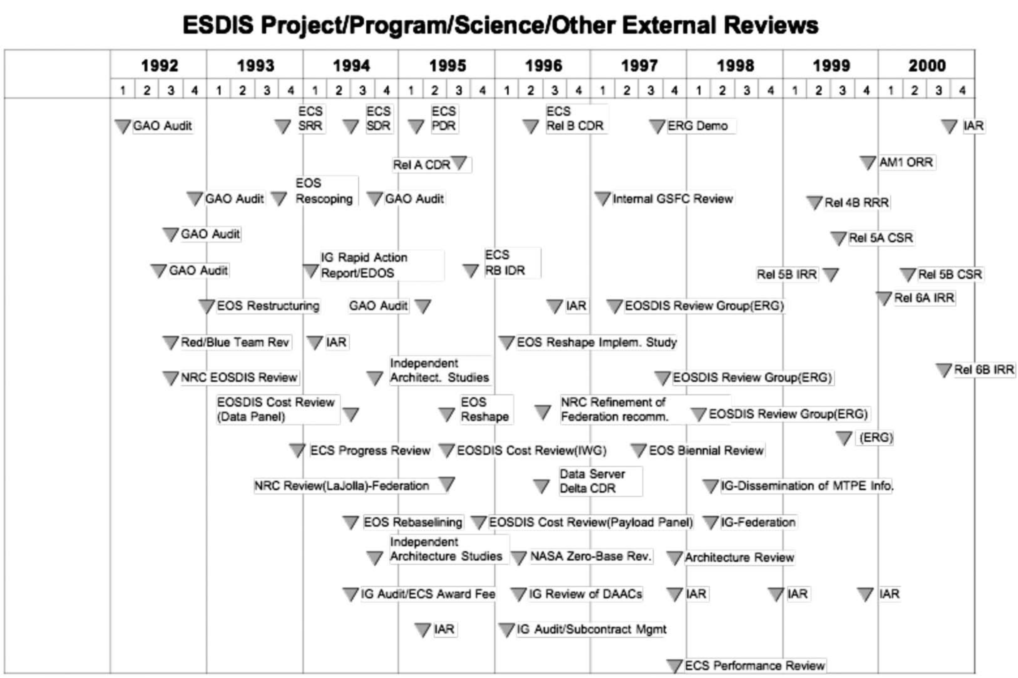


Figure 1. This chart shows that EOSDIS has been subjected to many and varied reviews over the years.

Hurdles and Remedies

The start up of the ECS development was quite rough. The award of the contract was delayed due to various reasons including more reviews to ensure that the language of the contract was just right including the addition of a Total System Performance Requirement (TSPR) clause to the contract.) The launch date assumed for the first EOS spacecraft (then a larger polar-orbiting platform called EOS-A) was December 1998, but after *restructuring*, the launch of the first EOS spacecraft—EOS-AM, later renamed Terra—was moved up to June 1998. (The idea behind this was that it was possible to build and launch the simpler spacecraft six months earlier.) However, this simplification had no bearing on the development of ECS. It just meant a six-month advance in the schedule, which had already been compressed due to the delay in awarding the contract. This prompted the contractor to build staff at a much faster rate than planned, with all the attendant difficulties in organization and communication.

The launch date assumed for the first EOS spacecraft (then called EOS-A) was December 1998, but after restructuring, the launch of the first EOS spacecraft—EOS-AM, later named Terra—was moved up to June 1998. ... However, this simplification had no bearing on the development of ECS. It just meant a six-month advance in the schedule, which had already been compressed due to the delay in awarding the contract.

This was also a time when the financial markets were booming and there was great demand for skilled programmers in the financial sector. Programmers would work on the ECS contract for less than two years and then take advantage of the experience to find much higher paying jobs in the financial sector. (Raises of 50% were quite common.) At times, the attrition rate from the ECS contract was about 30% (the peak was 38% in 1998). In March 1998, the reviews of the Flight Operations Segment revealed that it would not be ready for the launch of EOS-AM in June 1998. Consequently, a different approach was used to support the flight operations of EOS spacecraft and instruments. This approach took advantage of software that Raytheon had already developed in the commercial sector and resulted in what is now known as the EOS Mission Operations System (EMOS).

In addition, during the SDPS development it became clear that the system was too complex, due to the large number of requirements it had to meet. One year before the launch of TRMM, it was determined that the SDPS would not be ready to support TRMM. From 1996–2000, the Earth Science Data and Information System (ESDIS) Project, with considerable inputs from the science community (i.e., the Data Panel and the EOSDIS Review Group) through NASA Headquarters (HQ) program managers, took action to decentralize and simplify the development and meet the objectives of the overall data system. Existing systems based on *V0* at Goddard and Langley DAACs were enhanced to support TRMM. Generation of standard science data products was moved, in most cases, to Science Investigator-led Processing Systems (SIPSs) developed and operated by the respective instrument teams. The *V0* Information Management System (IMS) was modified to provide an *EOS Data Gateway (EDG)*—an access interface for data beyond the heritage data. The ESDIS Project also prioritized the remaining SDPS functions with inputs from the scientific user community, and scheduled more frequent releases of SDPS demonstrating increased functionality with each release. These steps led to the successful completion of all subsystems needed to support Landsat-7 (launched in April 1999) and Terra (launched in December 1999). Given the experience in getting ready for Landsat-7 and Terra, especially the multiple end-to-end tests [dubbed Mission Operations and Science System (MOSS) tests], the readiness for the Ice, Cloud, and land Elevation Satellite (ICESat), Aqua, and Aura missions went much more smoothly.

The ESIP Federation

As I mentioned in Part I, the scientific community had always emphasized the merits of a distributed and heterogeneous environment for managing Earth science data. In the mid-1990s, there was growing concern about the centralized nature of the development of EOSDIS and doubts about its ability to meet all of the broad community requirements. The National Research Council reviewed EOSDIS in 1995 and recommended that the science data processing, archiving, and distribution should be performed by a *"federation of competitively selected Earth Science Information Partners (ESIPs)"* In response to this recommendation, NASA initiated an experiment with a "self-governing" federation consisting initially of 24 competitively selected ESIPs, one half chosen to produce specialized research products and the other for products suitable for applications with commercial potential. The experimental federation initiated by NASA was called the Working Prototype ESIP (WP-ESIP) Federation. There were three types of ESIPs defined—*Type 1* whose role was to produce, archive, and distribute (mostly) satellite generated products in a robust and schedule-driven manner; *Type 2* whose role was to develop innovative products and technology for the benefit of Earth science research communities; and *Type 3* who were commercial and other organizations developing tools for Earth science. (A *Type 4* was later added to include the sponsoring organizations (e.g., NASA and NOAA) as members.) At the end of the initial funding period (1998–2002) the Federation was established, had governance procedures, and had a process for admitting new members. Today, the ESIP Federation continues to operate as an organization with NASA and NOAA as sponsoring partners, and includes 16 *Type 1*, 47 *Type 2*, and 45 *Type 3* ESIPs. The membership includes organizations and projects funded by NASA and other government agencies as well as commercial entities.

NASA initiated an experiment with a "self-governing" federation consisting initially of 24 competitively selected ESIPs, one half chosen to produce specialized research products and the other for products suitable for applications with commercial potential.

NewDISS and SEEDS

While the WP-ESIP Federation was being implemented, in 1998 NASA commissioned a New Data and Information Systems and Services (NewDISS) Strategy Team with the charter to *"define the future direction, framework, and strategy of NASA's Earth Science Enterprise (ESE) data and information processing, near-term archiving, and distribution"*. This team made a number of recommendations on how to proceed with ESE data and information systems and services over 6–10 years beyond the year 2000. **A NewDISS was not meant to be built as a replacement to EOSDIS.** It was to be a strategy to take advantage, in the near-term, of the investments that NASA had made in its Earth Science data systems (e.g., DAACs, ECS, mission data systems, pathfinder datasets, ESIPs) and to evolve the components in a science-driven manner to take advantage of innovations in technology. The recommendations from the NewDISS Strategy Team are documented in a report by Martha Maiden et al.[3]

Addressing the recommendations put forth by the NewDISS Strategy Team, NASA initiated a formulation study called Strategic Evolution of Earth Science Enterprise (ESE) Data Systems (SEEDS) for 2002–2003. The name of this study was changed intentionally from NewDISS to SEEDS to emphasize the fact that this was not intended to implement the "next version of EOSDIS", but to develop a strategy for the evolution of a more distributed and heterogeneous network of system and service providers. A GSFC team, led by **Steve Wharton**, conducted this study and solicited significant input from the scientific user community through a series of three workshops. The focus of this study was on how a system of highly distributed providers of data and services could be put in place with community-based processes and still be managed by NASA (in contrast to the self-governing experimental federation where there was no direct accountability to NASA as the funding organization). The areas considered in this study were: levels of service and costs; near-term mission standards; standards and interfaces processes; data life cycle and long-term archive; reference architectures and software reuse; technology infusion; and metrics planning and reporting. As a result of the recommendations from this study, NASA established a set of four Earth Science Data System Working Groups (ESDSWGs): (1) Standards Processes; (2) Software Reuse; (3) Technology Infusion; and (4) Metrics Planning and Reporting. The ESDSWGs continue to work vigorously and are a good conduit for providing recommendations on various aspects of data systems to NASA HQ from the community. The members of these working groups come from peer-reviewed data system activities funded by NASA through calls for proposals under Research Opportunities in Space and Earth Sciences (ROSES), as well as from the ESDIS Project and the DAACs.

[3] *Maiden et al*, NewDISS: A 6- to 10-year Approach to Data Systems and Services for NASA's Earth Science Enterprise, Draft Version 1.0, February 2002. See *esdswg.eosdis.nasa.gov/Info.html.*

Core and Community Systems

As the SEEDS study was being concluded, the performance period of the WP-ESIPs funded by NASA was nearing its end. The follow-up activity to get community involvement in data systems came in the form of a Cooperative Agreement Notice (CAN) calling for proposals for a Research, Education and Applications Solutions Network (REASoN). Forty-two REASoN projects were selected in 2003. Also, another program called Advancing Collaborative Connections for Earth System Science (ACCESS) began in 2005. The ACCESS Program aims to enhance and improve existing components of the distributed and heterogeneous data and information systems infrastructure that support NASA's Earth science research goals. There have been several calls for proposals in the ACCESS Program under the ROSES umbrella. There have been 27 ACCESS projects selected from 2005–2007. As the REASoN projects were coming to an end, a new program called Making Earth Science Data Records for Use in Research Environments (MEaSUREs) was devised to have a community of investigators generate long-term consistent records useful in Earth science research. There are currently 30 projects funded under the MEaSUREs Program.

As can be seen from the above discussion, EOSDIS has been continuously evolving over the last two decades. However, during 2004, NASA HQ sponsored a special focused study to consider the evolution of EOSDIS elements into the next decade.

Thus, currently NASA's Earth science data systems consist of *Core* and *Community* capabilities. The *Core* capabilities provide the basic infrastructure for robust and reliable data capture, processing, archiving, and distributing a set of data products to a large and diverse user community. Examples of core capabilities are: (1) the Earth Observing Data and Information System (EOSDIS); (2) the Precipitation Processing System; (3) the Ocean Data Processing System; and (4) the CloudSat Data Processing Center. The latter three examples are *loosely coupled* with EOSDIS, in that they exchange data with the EOSDIS Data Centers and are consistent with EOSDIS in the use of data format standards. In contrast to the *Core* capabilities, *Community* capabilities provide specialized and innovative services to data users and/or research products offering new scientific insight. The REASoN, ACCESS and MEaSUREs projects mentioned above are *Community* capabilities.

Both *Core* and *Community* capabilities are required for NASA to meet its overall mission objectives. The focus of the ESDSWGs so far has been on *Community* capabilities. While the membership of the four working groups is open to all, the primary participation is by members of the REASoN, ACCESS, and MEaSUREs projects. The working groups are a mechanism through which the community provides inputs for NASA to help with decisions relating to Earth science data systems. There is significant commonality in membership between the ESDSWG and ESIP Federation, thus bringing a broad community perspective into the NASA Earth science data systems.

Evolution of EOSDIS Elements

As can be seen from the above discussion, EOSDIS has been continuously evolving over the last two decades. However, during 2004, NASA HQ sponsored a special focused study to consider the evolution of EOSDIS elements into the next decade. A Study Team was commissioned with **Moshe Pniel** [Jet Propulsion Laboratory] as the chair and included members from the science community as well as information system experts not directly involved in the development and operation of EOSDIS. Also, a Technical Working Group was commissioned, chaired by **Mary Ann Esfandiari** who was the ESDIS Project Manager at the time, and consisting of civil servant members representing the ESDIS Project, DAACs and SIPSs. The goals of the evolution study are quoted below from the charter (initially signed by **Ghassem Asrar** and later amended and signed by **Mary Cleave**):

- *Increase end-to-end data system efficiency and interoperability*
- *Increase data usability by science research, application, and modeling communities*

- *Provide services and tools needed to enable ready use of NASA's Earth science data in the next-decadal models, research results, and decision support system benchmarking*
- *Improve support for end users*

The Study Team and the Technical Working Group defined a vision for 2015. The vision tenets and goals are shown in **Table 1** below. The Technical Working Group developed an implementation plan to address many of the goals in the near-term (*Step 1)*. This plan was approved in November 2005, and implemented during 2006–2008. Some of the responsibilities for science data processing, archiving, and distribution were moved between organizations, specifically for MODIS. The ECS was significantly simplified and deployed at three of the four DAACs where it was previously operating. The Goddard DAAC developed simpler *in-house* systems to replace ECS. The Langley DAAC replaced its *V0*-based system called Langley TRMM Information System (LaTIS) with a new system called Archive Next Generation (ANGe). Most of the robotic silo-based tape storage of data were moved to on-line disks facilitating easier access. It is expected that by the end of 2009, all data in EOSDIS will be archived on-line. The result of this step in evolution has been significant simplification in the systems, improved operability and a reduction of about 30% in annual costs.

It is expected that by the end of 2009, all data in EOSDIS will be archived on-line. Step 1 of evolution, implemented during 2006 -2008, has resulted in significant simplification in the systems, improved operability and a reduction of about 30% in annual costs.

Table 1. EOSDIS Element Evolution Vision Tenets and Goals

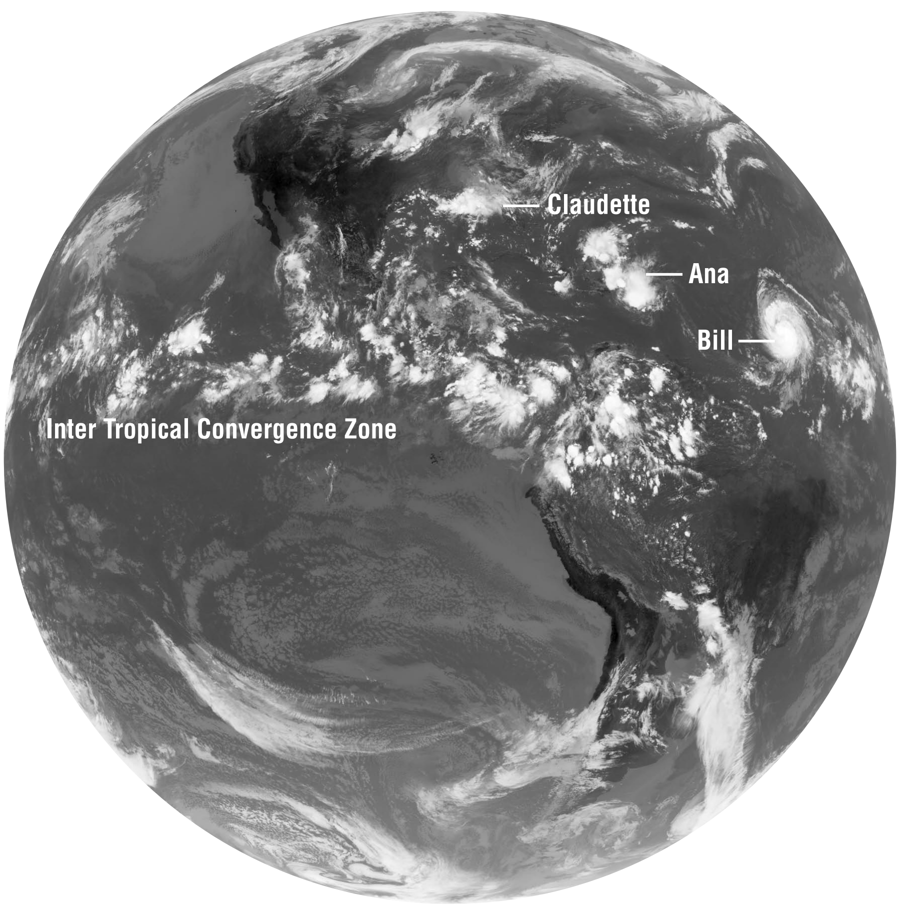
Vision Tenet	Vision 2015 Goals
Archive Management	• NASA will ensure safe stewardship of the data through its lifetime. • The EOS archive holdings are regularly peer reviewed for scientific merit.
EOS Data Interoperability	• Multiple data and metadata streams can be seamlessly combined. • Research and value added communities use EOS data interoperably with other relevant data and systems. • Processing and data are mobile.
Future Data Access and Processing	• Data access latency is no longer an impediment. • Physical location of data storage is irrelevant. • Finding data is based on common search engines. • Services are invoked by machine-machine interfaces. • Custom processing provides only the data needed, the way needed. • Open interfaces and best practice standard protocols are universally employed.
Data Pedigree	• Mechanisms to collect and preserve the pedigree of derived data products are readily available.
Cost Control	• Data systems evolve into components that allow a fine-grained control over cost drivers.
User Community Support	• Expert knowledge is readily accessible to enable researchers to understand and use the data. • Community feedback is directly to those responsible for a given system element.
IT Currency	• Access to all EOS data through services is at least as rich as any contemporary science information system.

Concluding Remarks

We have come a long way from the initial gleam in the eyes of a few people that conceived of EOSDIS in the 1980s to today's relatively mature operational state. The ride has, of course, not been smooth over the last two decades. This article described some of that journey, including the struggles between the engineers designing the system and the science community who would be using the system—especially in the earlier days of EOSDIS's history. In 1993 or 1994, I used the terms *box* and *cloud* cultures in a Senior Managers' meeting to describe the differences between the two cultures and consequent clashes. (I must admit they were not amused!)

Over the years, I believe a "Goldilocks" compromise—i.e., one that was "just right"—has been achieved with a variety of systems and a mix of box-like and cloud-like thinking in NASA's Earth Science Data systems as the Core and Community capabilities co-exist.

The *box* culture, largely subscribed to by engineers, focused on requirements and precise specification so that we could develop a system. The *cloud* culture, largely subscribed to by scientists who were the customers of EOSDIS, focused on flexibility and impossibility of specifying requirements to the degree desired by the engineers. Over the years, I believe a *Goldilocks* compromise—i.e., one that was "just right"—has been achieved, with a variety of systems and a mix of *box*-like and *cloud*-like thinking in NASA's Earth Science Data systems, as the *Core* and *Community* capabilities co-exist. The *Core* capabilities continue to evolve with significant feedback from the user community through the DAAC User Working Groups and users' comments from the annual American Consumer Satisfaction Index (ACSI) surveys. NASA's free and open data policy and increased on-line accessibility of most of the data holdings have contributed greatly to their success. *Community* capabilities are funded through a peer-reviewed competitive process. They provide a mechanism for scientific and technological innovation, permit infusion of new products and services in the *Core* capabilities, and a means of making data system related recommendations to NASA through the community-based Earth Science Data System Working Groups. I hope that these capabilities will continue to evolve and adapt to new technologies as they develop—even though the pace of adaptation could be different in the two cases—and continue to serve the Earth science and applications communities for a long time to come. ■



On August 17, 2009, at 1:31 p.m. EST, the latest NASA/NOAA geostationary weather satellite, called GOES-14, returned its first full-disk thermal infrared (IR) image. Infrared images are useful because they provide information about temperatures. Scientists convert satellite data into an image by displaying cold temperatures as bright white and hot temperatures as black. The hottest (blackest) features in the scene are land surfaces; the coldest (whitest) features in the scene are clouds.

On this day a band of scattered storms across the equatorial Pacific shows the location of the Intertropical Convergence Zone, which is a belt of showers and thunderstorms that persists near the equator year round.

Visible in the upper right quadrant of the disk are the remnants of Tropical Storm Claudette over the eastern Gulf Coast, Tropical Depression Ana over Puerto Rico and the Dominican Republic, and Hurricane Bill approaching from the central Atlantic.

Credit: NASA image courtesy GOES science team.

The Role of Visuals in Science Communication

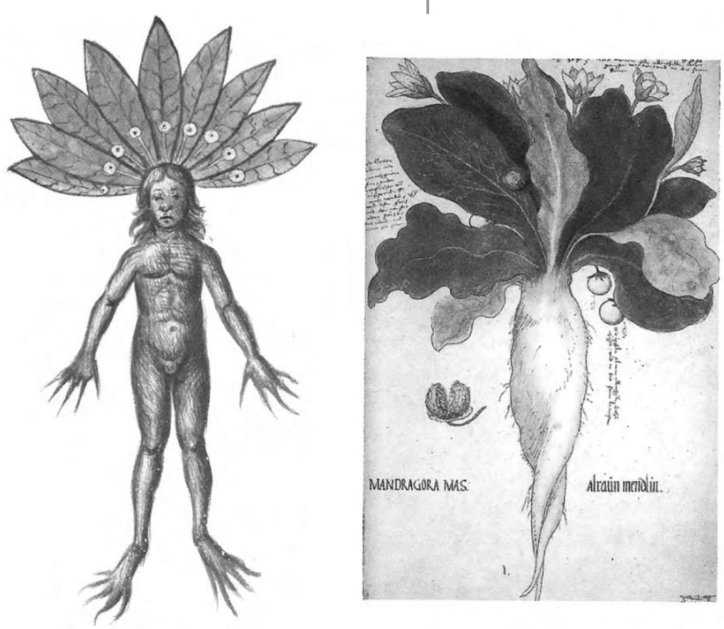
Laura Rocchio, Science Systems and Applications, Inc. (SSAI), NASA Goddard Space Flight Center, laura.rocchio@nasa.gov

As global population surges towards seven billion and anthropogenic impacts ricochet throughout Earth's environment, effective science communication has become essential. In today's digital world, where science communication must contend with stiff competition for audience attention, the role of good scientific visuals is paramount.

While urgency for good science communication has increased in recent years, its importance has long been acknowledged. Starting in the early part of the twentieth century, a cadre of American scientists began to advocate for better public understanding of science, arguing that better understanding of science meant a better quality of life, better public affairs deliberations, and the elevation of democracy and culture.

To improve science communication, many models of the communication process have been developed. In the 1940s science communication researchers adopted the *linear communication model* of electrical engineering. Over time, the one-way scientific communication of the linear model has come to be identified with the *deficit model* approach that assumes little prior scientific knowledge on the part of the receiver. The Mad Cow Disease outbreak in the United Kingdom highlighted a major failure of the deficit model. Beef safety was over-simplified in the communication process, and as a result people were given a false sense of security, many ended up sick, and public trust in government plummeted.

Of the many lessons learned from failures of the deficit model, arguably, the most significant lesson is that the public's prior knowledge and life experience are always brought to bear on the message, i.e., the message must be contextualized.



Left: A medieval drawing of a Mandrake plant that accompanied a copy of Dioscorides' *Da Materia Medica*. According to the book, the Mandrake screams when pulled from the ground. Right: Fuch's drawing of the Mandrake.

Of the many lessons learned from failures of the deficit model, arguably, the most significant lesson is that the public's prior knowledge and life experience are always brought to bear on the message, i.e., the message must be contextualized. Fortunately, scientific visuals can play a contextualizing role in science communication. Approximately 80% of sensory input comes from the visual system. And because humans are more cognitively efficient at recognizing patterns and making comparisons visually, research findings are often conveyed more effectively visually than by written or spoken words.

Historically, the evolution of scientific ideas and scientific visuals has been closely intertwined. As **Jean Trumbo** writes, "Effective visual representation is a tremendous tool in the communication of science to both expert and public audiences" [*Trumbo* 1999]. Science and scientific visual communication evolved in unison, largely because visual displays assist the thinking of both scientist and audience.

A Brief History of Scientific Visuals: *Saper Vedere*

When asked about the key to his monumental creativity, **Leonardo da Vinci** (1452–1519) would reply "*Saper Vedere*"—knowing how to see. In the 13,000 pages of da Vinci's notebooks, his written thoughts and sketches are inextricably combined and confirm his unceasing observation of the surrounding world [*Wikipedia* 2009].

In 1440, only a dozen years before da Vinci's birth, **Johannes Gutenberg** invented the printing press and shortly thereafter woodcuts were refined into tools of illustration capable of making exact reproductions of scientific drawings [*Ogilvie* 2007]. This was a watershed moment for visual science communication. In classic times, each scientific drawing was unique and subsequent handmade copies were often stylized and embellished [*Ogilvie* 2007].

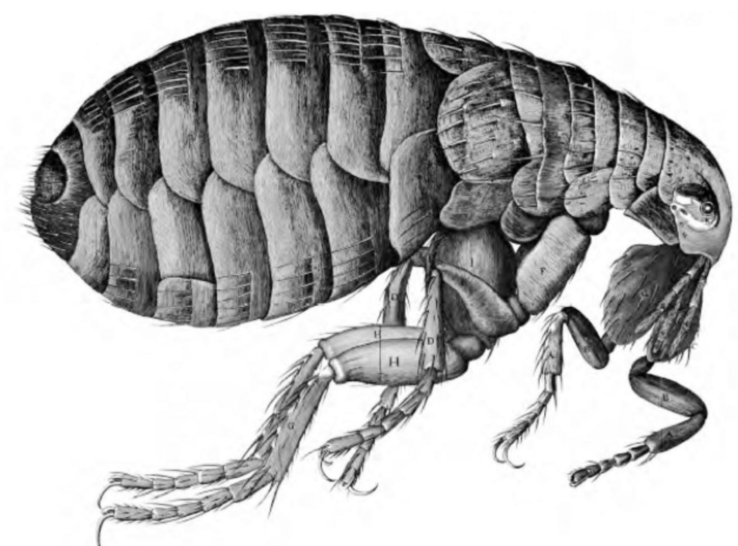
A century after the invention of the printing press, **Leonhart Fuchs**, a German physician and botanist published *De Historia Stirpium* (History of Plants), an encyclopedic work describing nearly 500 plants, all with accompanying woodcuts. Fuchs would stand over his illustrators to make sure their renderings were of utmost fidelity so that his readers could use them for the correct identification of plants [*Huxley* 2007]. In his book, Fuchs corrected many plant misconceptions that had been passed down through the ages.

Oculata Certitudine

The seventeenth century ushered in the *Age of Reason*. In addition to the frenzy of botanical and entomology books, such as those of **Maria Sibylla Merian**, new scientific instruments like the telescope and microscope elevated empirical science and debunked commonly held superstitions [*Lack* 2007].

Galileo Galilei was a champion of the cognitive shift in thought that came to hold experimental and observational science as the new standard of scientific rigor [*Gregory & Miller* 1998; *Tufte* 2006]. Galileo is famous for his extensive observational drawings of objects seen though this telescope. His renderings allowed him to publish his discoveries with *oculata certitudine,* i.e., visible certainty. His translation of observations into published images made readers, "virtual witnesses" [*Panese* 2006].

Galileo is famous for his extensive observational drawings of objects seen though this telescope. His renderings allowed him to publish his discoveries with oculata certitudine, i.e., visible certainty.



Your dog's best friend: a flea as shown in Robert Hooke's *Micrographica.*

Along the same lines as Galileo, **Robert Hooke** published his famous best-selling *Micrographica* in 1665, showing the world as seen though his microscope [*Ford* 2007].

The invention of the lithograph in 1798 made it possible to produce large colored prints at reasonably low prices; as the technology spread, the time-consuming hand painting of woodcuts grew unnecessary. This technology led to the abundant production and use of scientific wall charts for teaching [*Bucchi* 2006].

Political economist **William Playfair** was responsible for another major shift in science visualization during the 1800s. Before Playfair, scientific imagery consisted of rote analog depiction of natural reality. Playfair invented the graphical display of statistical information, thereby illustrating numbers and information that had no pictorial analog in reality for the first time.

Today's Digital World

The impact of modern computing and digital media has greatly increased the ability of scientist and science communicators to create and share visual representations of science [*Trumbo* 2000]. And today, visual communication is eclipsing written and verbal communication making good science visuals imperative [*Bertoline* 1998].

"The average person has not a very high tolerance of technical information, and they have less tolerance of technical information in a written form… we just have to do a lot better job in allowing people to see the imagery that we see," advises the Executive Director of *Climate Central*, **Berrien Moore**. The use of clear, compelling scientic visuals has historically been essential for effective science communication, and will only increasingly be so in the digital age.

In the next issue of *The Earth Observer*, the widely accepted tenets of successful visual scientific communication will be discussed.

"The average person has not a very high tolerance of technical information, and they have less tolerance of technical information in a written form… we just have to do a lot better job in allowing people to see the imagery that we see," —***Berrien Moore***.

Works Cited

Bertoline, G. R., 1998: Visual Science: An Emerging Discipline. *Journal for Geometry and Graphics*, **2,** 181–187.

Bucchi, M., 2006: Images of Science in the Classroom, Wall Charts and Science Education, 1850–1920. *Visual Cultures of Science*, L. Pauwels, Ed., Dartmouth College Press, 90–119.

Ford, B. J., 2007: Robert Hooke: Natural History Through The Microscope (1635–1703). *The Great Naturalists*, R. Huxley, Ed., Thames & Hudson, 99–103.

Gregory, J., and S. Miller, 1998: *Science in Public: Communication, Culture, and Credibility.* Basic Books, 294 pp.

Huxley, R., 2007: Unity in Diversity. *The Great Naturalists*, R. Huxley, Ed., Thames & Hudson, 7–19.

Lack, H. W., 2007: Maria Sibylla Merian. *The Great Naturalists*, R. Huxley, Ed., Thames & Hudson, 118–123.

Ogilvie, B. W., 2007: Leonhart Fuchs: The Value of Illustrations. *The Great Naturalists*, R. Huxley, Ed., Thames & Hudson, 48–58.

Panese, F., 2006: The Accursed Part of Scientific Iconography. *Visual Cultures of Science*, L. Pauwels, Ed., Dartmouth College Press, 63–89.

Trumbo, J., 1999: Visual Literacy and Science Communication. *Science Communication*, **20,** 409–425.

——, 2000: Seeing Science: Research Opportunities in the Visual Communication of Science. *Science Communication*, **21,** 379–391.

Tufte, E. R., 2006: *Beautiful Evidence.* Graphics Press.

Wikipedia, cited 2009: Leonardo da Vinci. [Available online at *en.wikipedia.org/wiki/Leonardo_da_Vinci.*]

NASA Earth System Science at 20: A Symposium to Explore Accomplishments, Plans, and Challenges

Alan Ward, NASA Goddard Space Flight Center, award@sesda2.com
Nicole Miklus, NASA Goddard Space Flight Center, nmiklus@sesda2.com
Paula Bontempi, NASA Headquarters, paula.bontempi@nasa.gov

NASA's capabilities and vision, together with the research community, have expanded to push the observational, modeling, and data management boundaries to usher in the next twenty years of Earth System Science.

Historical Context for the Symposium[1]

By the mid-1980s, NASA was leading the world in developing the notion that observations from space would further the understanding of how Earth's interacting systems function. In 1988, the Earth System Science Committee of the NASA Advisory Council, led by Francis Bretherton, published its landmark report *Earth System Science: A Closer View*—also called the *Bretherton Report*. The report called upon NASA and other agencies to embark on an ambitious program of integrated Earth system science. It became one of the seminal documents for this new field, which integrated studies of Earth's atmosphere, oceans, ice, land, geosphere, and biosphere and the interactions over different temporal and spatial scales. These documents provided the scientific framework for many national and international research programs, including the U.S. Global Change Research Program (which subsequently became known as the U.S. Climate Change Science Program.)

The Bretherton Report spelled out specific plans for observations and models to improve understanding of the Earth system. Many of these observations were new to science at the time, and required development of innovative technology. Realizing that satellite observations alone would not suffice for the desired improved understanding of the integrated Earth system, the authors called for process-oriented research with complementary *in-situ* observations and parallel developments of:

- information systems to link and make available to researchers observations from multiple sensors on multiple platforms; and
- new models to express our growing understanding of the complex processes at play in the dynamic Earth system. Inherent in this plan was inspiring the next generation of Earth scientists.

Twenty years later, the vision of Earth System Science has become reality. The Earth Observing System (EOS) is now fully implemented and additional Earth observing missions are being planned. The interconnected observational, data management, and modeling systems are achieving many of the goals established earlier, and new capabilities are under development. Meanwhile, society increasingly recognizes that the Earth has been changing at an unprecedented rate in recent decades, and that even more rapid change may occur in the future. Decision makers recognize the need to consider these changes as they develop public policy, and this has helped increase the visibility and public interest in Earth System Science. NASA's capabilities and vision, together with the research community, have expanded to push the observational, modeling, and data management boundaries to usher in the next twenty years of Earth System Science.

"Man must rise above the Earth—to the top of the atmosphere and beyond—for only thus will he fully understand the world in which he lives." —**Socrates**, ca 400 BC

A Symposium to Reflect on our Past… Present… and Future

Given this historical context, the Earth science community decided that it would be appropriate to take an opportunity to both look back and look ahead to the future of Earth System Science in this era of global change, taking into account two recent publications from the National Research

[1] An excellent resource for more historical perspective on EOS is a book called *Atmospheric Science at NASA: A History*, written by **Erik M. Conway**. In particular, Chapters 7–9 describe the "quest" to develop a climate observing system—which ultimately became known as EOS.

Council that provide a "roadmap" for the next decade of Earth System Science: the recently published *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (2007), and *Earth Observations from Space: The First 50 Years of Scientific Achievements* (2008). This was an opportunity for the community to reflect on questions like: What have we learned? Where do the foremost research challenges for the future lie? How well are we prepared to meet them?

NASA's Science Mission Directorate, Earth Science Division worked with the National Academy of Sciences' Ocean Studies Board, Space Studies Board, and Board on Earth Sciences and Resources to organize a scientific forum to discuss findings and new approaches that will continue the revolution in Earth System Science envisioned by Bretherton and his co-authors two decades ago. The National Academy of Science in Washington, DC hosted the meeting on June 22-24. Over 300 people attended the three-day meeting, which bought together researchers, managers, and policy makers to examine the 20-year history of the NASA Earth System Science program and offered glimpses into its future.[2]

What follows are summaries of each of the presentations given during the meeting. The full presentations for most of the talks can be viewed at: *eospso.gsfc.nasa.gov/ess20/agenda.php*.

Monday June 22

Ralph Cicerone [National Academy of Sciences—*President*] welcomed everyone and thanked the organizing committee for its hard work in organizing the meeting. Cicerone discussed the importance of taking time to look back and reflect. In Earth Science we learn a great deal that can inform our future by looking at what we've learned in the past—i.e., lessons learned.

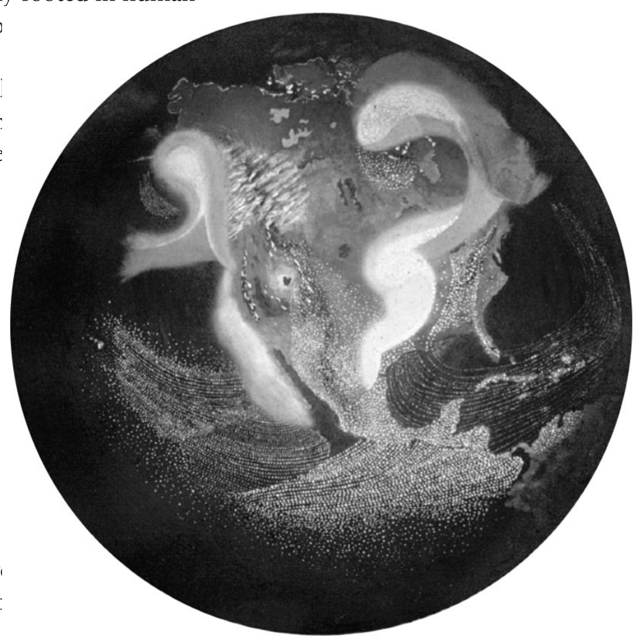
The Past and Present of NASA's Earth System Science

Session Chair: Mary Cleave [NASA Headquarters, *retired*]

Mary Cleave opened the session and commented that Earth Science has been part of NASA from the very start—and even prior to it. [The National Advisory Committee for Aeronautics (NACA) was NASA's precursor and there was an Atmospheric component located at Langley Research Center.] What makes NASA Earth Science unique is that we view the system as a whole versus looking at individual disciplines. The talks in this session focused on providing historical context for the evolution of Earth System Science— i.e., *how Earth System Science was launched.*

This was an opportunity for the community to reflect on questions like: What have we learned? Where do the foremost research challenges for the future lie? How well are we prepared to meet them?

Jim Fleming [Colby College] gave a talk discussing *Earth Observations from Space: Scientific Accomplishments at the Dawn of the Space Age* intended to give context into which Earth System Science fits. NASA history is "firmly rooted in human history," and bo rooted in Earth tions. In fact, F ing remarked th since there have been humans there have been Earth observations. He showed a *gnomon* (or sundial), which was an early tool used to track the movement of the sun, but actually can rev remarkable amc information.



In 1954, Henry Wexler was head of the U.S. Weather Bureau, and he commissioned an artist to develop this conceptual drawing of what satellite observations might look like. Note the conception is not unlike what satellite observations actually look like.

Fleming traced some of the important milestones in Earth observations prior to the satellite era. There was an ongoing quest for *altitude*—e.g., mountaintop observations, kites, towers, balloons, aircraft, and sounding rockets—and more *uniform coverage* around the globe that culminated with the satellite era. The continuous global observations that today's Earth observing satellites can provide have revolutionized our conceptions about and our knowledge of the Earth from what they were before the first satellites launched.

Fleming proceeded to summarize the early history of satellite launches, starting with the Russian *Sputnik I* in 1957, and progressing forward toward the present. Along the

[2] Text for the first two sections was modified from *eospso.gsfc.nasa.gov/ess20/index.php*.

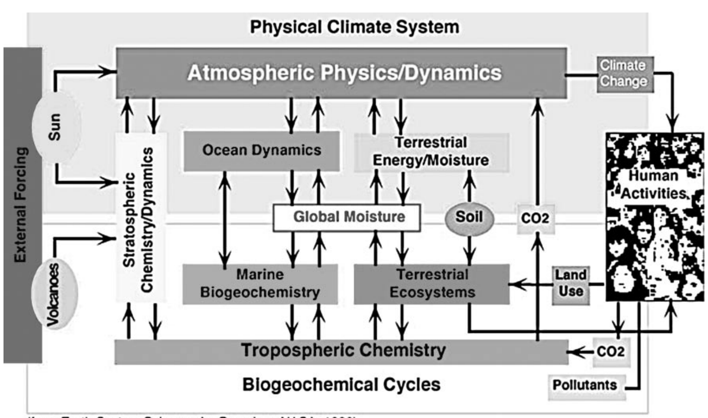
way, he showed numerous examples of early satellite imagery beginning with the famous Television and Infrared Observation Satellite (TIROS 1) image and progressing forward to show other images including now-famous ozone hole images from the Total Ozone Mapping Spectrometer (TOMS.)

Corell said that we've been living in "humanity's sweet spot"—i.e., a period of time where climate was pretty stable despite human activities—but now we are clearly entering a rapidly changing climate regime.

Fleming also mentioned two important surveys recently published by the National Academy. *Earth Science Applications from Space: National Imperatives for the Next Decade and Beyond* (a.k.a., The Decadal Survey) and *Earth Observations from Space: The First 50 Years of Scientific Achievement* (a.k.a., The Historical Survey.) As Ralph Cicerone said in his opening remarks, the past should inform our future, so both of these surveys complement one another.

Robert Corell [Heinz Foundation] described *The Scientific and Historical Foundations of Earth System Science*. (He began by pausing to remember Jack Eddy, a pioneer in Earth Science, who passed away this week.) Corell said that we've been living in "humanity's sweet spot"—i.e., a period of time when climate was pretty stable despite human activities—but now we are clearly entering a rapidly changing climate regime. He went on to trace the origins of humanity's desire to understand the large-scale behavior of our planet, mentioning Savante August Arrhenius who in 1896 first postulated that the activities of humans might lead to global warming.

One of the many versions of the "Bretherton Diagram."



(from Earth System Science: An Overview, NASA, 1988)

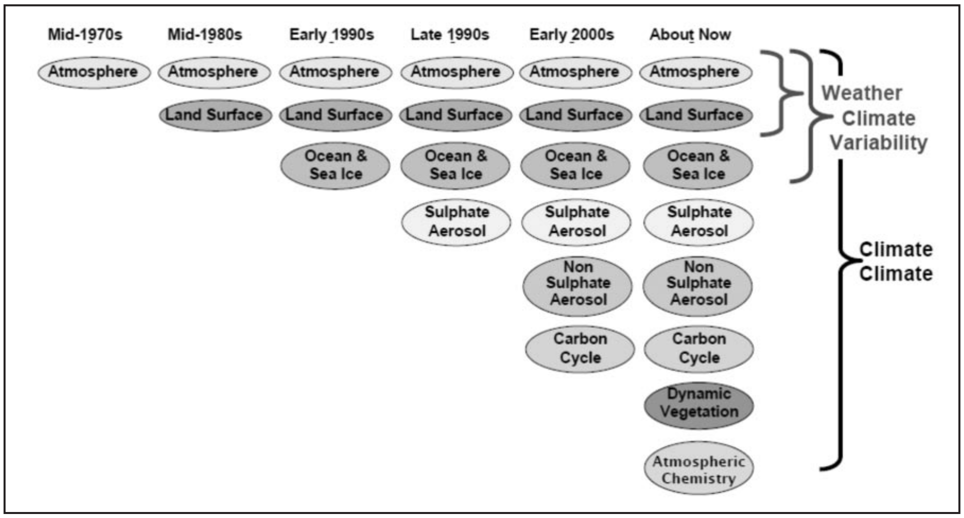
Corell discussed the pioneering work done by the NASA Advisory Council's Earth System Science Committee (chaired by Francis Bretherton) beginning in 1983—and leading to publication of a report called *Earth System Science: A Program for Global Change* (a.k.a., the Bretherton report) in 1988. Corell showed two incarnations of the *Bretherton Diagram* that were included in the report and depicted the complex task of studying the Earth as a system and the very many disciplines that are involved as one contemplates studying the Earth as a system. The Bretherton report laid the groundwork for the creation of U.S. Global Change Research Program in 1987, and a few years later Congress enacted the *Global Change Research Act of 1990* that formally endorsed the development of a climate change research program in the U.S.

For the remainder of the presentation, Corell showed some of the results that document the progress we have made to date on answering the questions that the Bretherton report put forth. He emphasized the importance of interagency cooperation and, in particular, the support of the National Academy of Sciences.

Claire Parkinson [NASA Goddard Space Flight Center (GSFC)—*Aqua Project Scientist*] discussed *Satellite Contributions to Global Change Studies*. Parkinson began by showing some early TIROS images, which seemed amazing at the time although they appear quite primitive today. She then showed a sampling of the data collected on Hurricane Katrina in 2005, illustrating how far we have come in realizing the potential of satellite observations.

Parkinson discussed some of the "surprises" revealed as a result of satellite observations—e.g., desert dust traveling from western China to the east coast of the U.S., unexpected open water areas within the Antarctic sea ice cover, and lightning being primarily a land-based phenomenon. Most of her talk, however, centered on what the satellite data are revealing about human-induced changes.

Human activities such as industrialization, deforestation, and other land use change leave a "footprint" on our environment, and the global observations from satellites have helped us to see more clearly the impact of those activities. Parkinson took the audience on a "tour" that progressed roughly from the top of the atmosphere to the Earth's land, ocean, and ice surfaces and showcased data from a wide variety of Earth observing instruments. Satellite ob-



This diagram gives a sense of how far we have come in achieving the objectives put forth in the Bretherton Report—i.e., what areas we knew in the mid-1970s before EOS was conceived compared to what areas we know now.

servations have provided a vast array of data about environmental changes, and Parkinson showed samples related to stratospheric ozone, tropospheric trace gases and temperatures, ocean temperatures and chlorophyll concentrations, sea ice and ice sheets, sea and lake levels, terrestrial water storage, and deforestation. This information has helped to inform public opinion and, in some cases, even shape public policy—e.g., the ozone data were influential in leading to the enactment of the Montreal Protocol.

Parkinson concluded by showing a diagram illustrating the interconnectedness of the various Earth System components. She emphasized that whatever side one takes on the issue of climate change, it is essential that we get the facts right, and satellite observations help us to do that.

Chris Scolese [NASA Headquarters—*Acting Administrator*] discussed *Eyes on the Earth: Technology Capabilities of the Past, Present, and Future*. Scolese pointed out that the space age was really motivated by looking at the Earth—i.e., early pictures gave us *glimpses* of Earth from space and made us want to *see* more. In 1961, in the same speech where he called for us to *"go to the moon in this decade"*, President Kennedy also requested funds for a *"satellite system for worldwide weather observations."*

Scolese showed a timeline of Earth Monitoring: past (i.e., pre-EOS missions from 1960–2000); present (i.e., the current on-orbit EOS missions); and future (i.e., the missions recommended by the Decadal Survey). He also showed the 24 measurements called for in the Bretherton Report in 1988 and mentioned that significant progress has been made in most if not all of these areas.

Scolese reiterated what Parkinson said previously—sometimes we get unexpected benefits from satellites. He also mentioned that our technology also builds on successive generations of imagery—i.e., we learn from both human and robotic observations of Earth. Furthermore, there has always been a strong synergy between research and operations missions—flowing in both directions—and this synergy must continue into the future. It is almost always a science question that prompts development of new technologies, and then once the technology is established it becomes operational.

Scolese also reminded us that we also benefit from studies of the other planets and the universe. Not only do we study Earth as a system, but Earth itself is also part of a larger system. What we learn about the Universe helps to inform our view of the Earth and vice versa. Space exploration (e.g., the moon and Mars) opens up new vantage points to view the Earth and technologies (and science) developed for exploration may also be applied to study the Earth.

Rick Anthes [University Corporation for Atmospheric Research] presented a forward look—*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. Funding for Earth Science has been steadily declining. So much so that in a 2005 *interim report* of the Decadal Survey it was stated: *"Today, [our] system of environmental satellites is at risk of collapse."*

Funding for Earth Science has been steadily declining. So much so that in a 2005 ***interim report*** *of the Decadal Survey it was stated:* ***"Today, [our] system of environmental satellites is at risk of collapse."***

When reviewing proposed missions, the Decadal Survey placed potential societal benefits on equal footing with scientific discovery.

Traditionally funding has been divided among six science *disciplines*: solid earth, water, weather, climate, health, and ecosystems. However, this study emphasized the need to develop truly interdisciplinary missions. As a result, the six disciplines were mapped into six broadly defined *societal benefits*: water & food, energy security, early warning, ecosystem service, public health & environmental quality. When reviewing proposed missions, the Decadal Survey placed potential societal benefits on equal footing with scientific discovery. The result of the panel's deliberation was a recommendation for NASA and NOAA to undertake a set of 17 missions phased in over the next decade. NOAA is responsible for two of the proposed missions and will focus on transitioning their research to operational products; NASA will undertake the other 15 missions.

Some of the societal challenges identified above can be further subdivided to end up with a list that includes: climate prediction, improved weather prediction, extreme event warnings, human health, earthquake early warning, sea level rise, freshwater availability, ecosystem services, air quality, improved extreme storm warnings, and energy security. Anthes showed a series of slides that listed each of these societal benefits along with which of the proposed Decadal Survey missions would make significant contributions in that area.

Landmark Findings in Disciplines, Earth System Science or Climate
Session Chair: Martha Maiden [NASA Headquarters]

Rich Stolarski [GSFC] discussed *The Antarctic Ozone* and the four lines of history that converged on the discovery and understanding of it. They are: the discovery and measurement of stratospheric ozone, laboratory studies of the chemical properties of molecules that affect ozone, the early synthesis of chlorofluorocarbons (CFCs), and advances in our understanding of stratospheric meteorology.

Stolarski explained how chlorine and bromine from human-produced gases interact with the unique stratospheric conditions in the Antarctic and explained how satellite observations contributed to the understanding of the causes of the ozone hole. NASA's TOMS instrument on the Nimbus 7 satellite confirmed the existence of the

Panel Discussion: *The Journey from Disciplines of Earth Science to Earth System Science*

On Monday afternoon, there was a fascinating discussion that involved some of the "pioneers" in Earth System Science sharing stories and memories of their experiences. Panelists included:

- **Dixon Butler**[1] [Formerly NASA HQ, now House Subcommittee on Energy & Water Development] served as moderator for the panel and shared his memories of the "early years" of the program;
- **Shelby Tilford** [Formerly NASA HQ, now retired] shared some of his memories of his time at NASA and the movement from discipline-based studies to studying Earth as a system;
- **Tasaku Tanaka** [Formerly National Space Development Agency (NASDA)/Japan Aerospace Exploration Agency (JAXA), now Yamaguchi University] who discussed the Japanese contributions to EOS and future plans for Japanese missions;
- **Stan Wilson** [Formerly NASA HQ, now NOAA NESDIS] who was in charge of Earth Science in the mid-1970s and oversaw development of an Oceanography from Space Program, which was viewed at the time as the "missing piece" that would complete the overall program for studying Earth's climate from space; and
- **William Townsend** [Formerly NASA HQ, now Townsend Aerospace Consulting, LLC] served as Acting Associate Administrator for Earth Science for several years during the formative years of EOS and shared stories of his time at NASA including some of his interactions with former NASA Administrator Dan Goldin.

[1] *The Earth Observer's* ongoing "Perspectives on EOS" series contains reflections and memories of the early days of EOS from people personally involved in the program, and includes the perspective of **Dixon Butler** in our September–October 2008 issue [**Volume 19, Number 4**].

ozone hole discovered above the British Antarctic Survey station at Halley Bay, Antarctica in 1985.

With the Montreal Protocol in effect, the ozone hole is estimated to begin decreasing in the 2020s and be fully recovered by 2070. Future satellite measurements are necessary to track the expected recovery of the hole and how that recovery might be affected by climate change. The Aura mission's Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI) continue to provide measurement of ozone, chlorine, and nitrogen. These measurements are used to create maps of the hole's seasonal evolution. The NOAA series of Solar Backscatter Ultraviolet (SBUV) instruments on the polar orbiting satellites provide a continuity of ozone measurements to be followed by the Ozone Mapper and Profiler Suite (OMPS) instrument suite on National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) series of planned satellites.

Waleed Abdalati [University of Colorado] discussed *Ice Sheets, Sea Ice, and Satellites: Transforming Polar Paradigms*. Satellites have revealed remarkable changes in polar ice cover. Sea ice in the Arctic has been decreasing at a surprising rate, while Antarctic sea ice has been increasing slowly. Large parts of the Greenland and Antarctic ice sheets are shrinking more rapidly than was thought possible a decade ago.

Abdalati reviewed how remote sensing techniques pioneered by NASA and its partners have been used to examine the contribution of shrinking ice sheets to sea level rise by directly measuring changes in elevation, mass, and flow rates. He highlighted recent observations of the Greenland ice sheet, where satellites have revealed losses of substantial amounts of floating ice at the margins, and a subsequent acceleration of some of the fastest outlet glaciers to as much as double their speed. Satellites have also detected substantial increases in surface melt and associated summer acceleration of large sections of the ice sheet, as melt water penetrates through the ice and lubricates the ice-bedrock interface. Abdalati also discussed changes in Arctic sea ice, which the satellites have shown is getting smaller, thinner, and younger with time, becoming more vulnerable to the effects of climate change.

The talk concluded with Abdalati stressing the importance of satellite observations to anticipating future ice sheet and sea level change and how changes in polar ice cover will influence the rest of the Earth system. As fourteen of NASA's current fifteen science satellites are now past their design life, this powerful capability for understanding the world in which we live is at great risk. Rapid implementation of a robust set of Earth observing missions that include those identified in the Decadal Survey is necessary to meet the challenges society faces in the changing environment.

Jim Yoder [Woods Hole Oceanographic Institution] discussed *The Color of the Sea and What it Means*. Ocean color refers to light backscattered from the ocean that is measured with a radiometer in the visible and near-infrared wavelengths. The spectra of backscattered light depends on dissolved substances and particles in the water, such as chlorophyll *a* in phytoplankton.

Yoder explained how NASA's Coastal Zone Color Scanner, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and the Moderate Resolution Imaging Spectroradiometer (MODIS) have given biogeochemical oceanographers global views of phytoplankton biomass. From these, changes in primary production can be calculated and the *biological pump* component of Earth's carbon cycle can be studied. Satellite studies show large-scale variability in productivity—a strong seasonal cycle with higher production in the mid-latitudes in winter. The global impact interannual variability caused, for example, by El Niño events such as the large El Niño that started in 1997 is also evident in the imagery.

It's difficult to tell how climate change affects productivity in the ocean. A longer record is needed to determine if areas of low biological productivity are increasing. Despite this, Yoder stated that the future of advanced research ocean color satellite sensors remains unclear. Continued ocean color imagery is needed to show seasonal and interannual variability on longer time scales and to understand the impact of climate change on ocean productivity.

As fourteen of NASA's current fifteen science satellites are now past their design life, this powerful capability for understanding the world in which we live is at great risk.

Today, satellite use in numerical weather prediction is "mature". Satellite data have "closed the gap" in forecasting skill between the Northern and Southern Hemisphere, and even in the Northern Hemisphere, largely due to the new information provided from the Atmospheric Infrared Sounder on Aqua, satellites now provide more value than rawinsonde data.

Tuesday June 23

***Landmark Findings in Disciplines, Earth System Science or Climate** (cont)*
Session Chair: Dave Jones [Storm Center Communications Inc.]

Dave Jones opened the session, reflecting on how his past working simultaneously at Goddard and as a broadcast meteorologist developed his interest in linking research to applications. All of this morning's talks focus on those links between research and applications and discuss different aspects of *Space Observations for Improved Description and Dynamical Prediction of Weather and Climate*.

Eugenia Kalnay [University of Maryland, College Park] discussed *NASA's Impact on Numerical Weather Prediction: Past, Present, and Future*. In addition to all his other amazing achievements, Jule Charney was also a pioneer in using satellite data for numerical weather prediction; in 1969, he showed that inserting satellite temperatures could provide information on sea level pressure and winds. In 1980, a paper came out from a group at the National Meteorological Center (NMC) [*Tracton et. al.*, 1980] suggesting that the impact of satellite data on weather forecasting was negligible—but was later refuted (see **Robert Atlas'** presentation). In the early days, satellite measurements were especially helpful in improving the accuracy of forecasts in the Southern Hemisphere. Today, satellite use in numerical weather prediction is "mature". Satellite data have "closed the gap" in forecasting skill between the Northern and Southern Hemisphere, and even in the Northern Hemisphere, largely due to the new information provided from the Atmospheric Infrared Sounder (AIRS) and the Advanced Microwave Sounding Unit (AMSU) on Aqua, satellites now prove to be more value than rawinsonde data. Future efforts will focus on improving observations (e.g., adding lidar wind profiles), models, and data assimilation techniques. Kalnay mentioned that the use of Ensemble Kalman (EnKF) Filters is a promising new assimilation technique—it is already clearly better than three-dimensional variation (3D-Var) and shown to be competitive with four-dimensional variation (4D-Var) techniques.

Robert Atlas [NOAA Atlantic Oceanographic & Meteorological Laboratory—*Director*] spoke about *NASA's Satellite Observations for Weather and Climate Prediction.* Prior to the Global Weather Experiment (1979) it was widely believed that satellite observations would not have a significant impact on the accuracy of weather forecasting. However, during the U.S. Data System Test (1976) a group of researchers at Goddard were the first to demonstrate that satellite measurements could have a significant positive impact on forecast accuracy [*Ghil et.al.*, 1978.] In 1980 the paper from *Tracton et. al.* (that **Eugenia Kalnay** mentioned) was released claiming that satellite data had no significant impact on the NMC forecasts—and also suggested a higher resolution model would produce the same results. These early findings led to research efforts at Goddard (which included Atlas, Michael Ghil, and Milton Halem) that refuted the NMC findings and showed conclusively that a higher resolution model did in fact lead to more accurate forecasts [*Atlas et. al.*, 1982; *Atlas*, 1982.] Atlas went on to describe the impact of incorporating data from several instruments on satellites currently on orbit—e.g., SeaWinds, TRMM instruments, AIRS, MODIS, and the Multiangle Imaging Spectroradiometer (MISR). He also mentioned the potential added benefits of several proposed future missions—in particular space-based lidar wind measurements, dual frequency scatterometer measurements [e.g., from the Extended Ocean Vector Wind Mission (XOVWM)], and improved sounding data [e.g., from the Advanced Remote-sensing Imaging Emission Spectrometer (ARIES)[3] and Precipitation and All Weather Temperature and Humidity (PATH) missions].

Michele Rienecker [GSFC] presented on *NASA's Ocean Observations for Climate Analyses and Prediction*. The atmosphere and land conditions are important for shorter-term forecasting, but the oceans contain the real "memory" of the climate. Over the last 15 years, satellite remote sensing has been the only source of global ocean data on the spatio-temporal scales of interest for climate analysis and prediction. Rienecker reviewed the NASA ocean missions relevant for short-term climate forecasts. She then reviewed the Ocean Data Assimilation procedures in the

[3] ARIES is a proposed sounding mission that would combine aspects of MODIS and AIRS.

Global Modeling and Assimilation Office. Rienecker pointed out that most satellite measurements only give us a measurement at the surface of the ocean. Since the real "memory of the climate" lies beneath the surface in the *thermocline*, assimilation is essential to "project" information about climate variability at the surface to deeper layers. Rienecker went on to show some results that demonstrate the value of data assimilation for seasonal climate prediction: e.g., incorporating satellite altimetry data, sea surface temperature data, salinity data (future), etc. Results show that the altimetry does improve forecast skill, especially in the second season of the forecast. The results also indicate the importance of salinity information, so that Aquarius data may also help seasonal forecasts.

Christa Peters–Lidard [GSFC] discussed Opportunities and Challenges in Land Data Assimilation. Land Data Assimilation (LDA) is less mature than atmospheric and oceanic data assimilation, but this is an exciting time for terrestrial hydrology and ecology as so many new observations are becoming available. The "first generation" of land data assimilation came about as models began to incorporate moderate resolution satellite data (i.e., MODIS) into forecasts. The first efforts were to substitute observed data into models: as in the North American Land Data Assimilation System (NLDAS) and Global Land Data Assimilation System (GLDAS). These efforts in turn led to the "second generation" LDA supported by the implementation of direct insertion and EKF techniques in the Land Information System (LIS), which supports "true LDA". She went on to discuss some of the science achievements coming from LDA [e.g., Advanced Microwave Scanning Radiometer for EOS (AMSR-E) soil moisture, Gravity Recovery and Climate Experiment (GRACE) water storage, and MODIS snow covered area and irrigation.] She also discussed some of the opportunities for the future—e.g., surface water level estimation [Jason and Surface Water and Ocean Topography (SWOT)], the proposed "W" Train [which would include Global Precipitation Measurement (GPM), Soil Moisture Active–Passive (SMAP), SWOT, and GRACE-II]. She also discussed some of the challenges that need to be overcome to achieve the full potential of LDA.

All four of the morning's speakers formed an impromptu panel and fielded some questions from the audience. Each was asked to address the biggest concerns facing each of their respective discipline—and its needs in terms of science and technology. There was agreement that science is evolving faster than computational capabilities, which was an excellent lead-in to the next presentation.

Jagadish Shukla [George Mason University] focused on *Advances in Climate Model Validation from Space Observations*. Shukla shared two important stories about how NASA space observations have advanced Earth System Science—namely weather prediction, and climate prediction. Improvements in weather prediction have come about because of improved initial conditions of the atmosphere, while improvements in climate prediction have resulted from space measurements and model predictions of global boundary conditions. He showed the *Charney diagram* showing the three-legged stool of models, observations, and theory. He spent some time reviewing the history of satellite observations, touching on some of the same milestones that some of the other talks this morning highlighted. He showed examples from weather prediction, climate prediction, and climate model validation. He also discussed some of the challenges that still remain. The biggest challenge is that we simply aren't using all of the data that we have available—not by a long shot! Currently we use about 1–10% of the available information and the main reason is because we lack both computing capability and scientific staff to assimilate them. We also need to move from *synoptic* scale cyclone resolving global models to *cloud-system* resolving global models. Shukla showed an example of results from an existing 200-km global model versus the possibility of a 4-km resolution global model.

Ramakrishna Nemani [NASA Ames Research Center] spoke on behalf of **Jim Tucker** [GSFC] and discussed *Composition, Condition, and Function of Global Land Vegetation*. Nemani summarized where we were 25 years ago, where we are now, and the uncertain road ahead. He showed a diagram reviewing the carbon cycle and mentioned some of the "outstanding" questions that remain. He

Land Data Assimilation (LDA) is less mature than atmospheric and oceanic data assimilation, but this is an exciting time for terrestrial hydrology and ecology as so many new observations are becoming available.

discussed how humans are impacting the cycle with fossil fuel burning and land use changes. He next discussed some outstanding questions that remain unanswered in the realm of land vegetation. Satellite data play important roles in helping to answer these questions—e.g., monitoring changes in landcover, growing season, and primary production. Ground-based observations (e.g., flux towers) complement satellite observations. Nemani also discussed work to monitor tropical deforestation and biomass burning using satellite data. He identified challenges that lie ahead in the next 20 years—one of the biggest being "looming interruptions" in flow of satellite data. Nemani also suggested the need to strike the phrase "research to operations" from our vocabulary and use instead "research **and** operations." Climate research, mitigation, and adaptation all require long-term, well-calibrated data to make informed decisions, and these infrequently come from "operational" sources.

Fung reminded the audience that "Planet Earth has more than a fever… the outlook is not very rosy." Our home planet needs an annual checkup and only Earth System Science can accomplish this.

Inez Fung [University of California–Berkeley] offered a commentary on Nemani's talk. Fung recognized Jim Tucker's contribution to Earth System Science, which has been transformative—the term NDVI is so widely known that it hardly needs to be spelled out. Also, Tucker's vegetation classification using the NDVI—based for the first time on function, rather than on appearance or habitat—is an early example of affirmative action. She spoke about how she personally relied on NASA MODIS Rapid Response during the 2008 California fires. EOS Interdisciplinary Science Teams, such as the one led by Piers Sellers (a.k.a., the human satellite) have been critical in producing "the *now* generation of Earth System Scientists." Fung reminded the audience that *"Planet Earth has more than a fever… the outlook is not very rosy."* Our home planet needs an *annual checkup* and only Earth System Science can accomplish this. It is disturbing to think of how few missions might be in orbit in the next few years. We need to try and recapture the *wonder* of looking at our planet so that future generations can get excited about studying Earth again.

***Landmark Findings in Disciplines, Earth System Science or Climate** (cont)*
***Session Chair**: Mark Abbott [Oregon State University]*

Lee-Lueng Fu [Jet Propulsion Laboratory] discussed *Ocean Circulation, Sea Level, and Climate*. Planet Earth is mostly ocean, and the ocean has absorbed more than 80% of the heat from global warming in the past 50 years. Measuring o*cean surface topography*—the height of the sea surface above a surface of uniform gravity called the *geoid*—with satellite altimetry is the best way to understand how ocean currents and circulation distribute this heat.

Fu gave a history of ocean surface topography missions, describing the contributions of TOPEX/Poseidon, Jason-1, and the Ocean Surface Topography Mission (OSTM)/Jason-2. He explained how a hundred fold improvement in satellite accuracy has occurred since the launch of Geodetic and Earth Imaging Satellite (GEOS)-3 in 1975. The measurement of ocean surface topography from space has revolutionized the study of global ocean circulation patterns, sea level change, and phenomena like El Niño and La Niña and the Pacific Decadal Oscillation. Fu emphasized that the continuation of precision altimetry missions is essential for monitoring and predicting future sea level change. Although NOAA has taken over the operation of altimetry missions, the complex interdisciplinary problem of sea level rise requires a wide range of other space measurements and NASA is uniquely positioned to tackle the long-term, sea level rise problem.

Challenges for ocean surface topography missions still remain. For example, about 50% of the vertical motion and mixing that takes place in the upper ocean at scales shorter than 100 km hasn't been observed yet. Understanding small-scale ocean currents is necessary to fully determine the ocean's capacity for regulating climate change.

"We shall not cease from exploration, and the end of all our exploring will be to arrive where we started and know the place for the first time." —**T. S. Eliot**

Jeff Halverson [University of Maryland, Baltimore County] discussed *Exploring Hurricanes: NASA's Investigations Using Satellites, Supercomputers and High Altitude Aircraft.* The three-prong approach to studying hurricanes uses models, aircraft (e.g., ER-2, DC-8), and satellites.

As Claire Parkinson showed in an earlier presentation, satellites were important for studying Hurricane Katrina. The Tropical Rainfall Measuring Mission (TRMM) provided rain intensity information; the Aqua mission measured the fuel of hurricanes, sea surface temperatures (SSTs); and the Quick Scatterometer (QuikSCAT) gave wind speeds. The TRMM precipitation radar gives scientists a look at the unusually deep convective clouds thought to be responsible for hurricane intensification.

Meanwhile, aircraft field campaigns provide *in situ* and satellite data sets, serve as a technology testbed, and improve models through data assimilation. NASA's Genesis and Rapid Intensification Processes campaign (GRIP) of 2010 will use an unmanned *Global Hawk* aircraft to conduct hurricane surveillance.

Halverson presented stunning 3-D images of hurricane anatomy derived from near-real-time satellite data and explained how tropical cyclogenesis and the role of African dust in it are still largely a mystery.

Dave Atlas [NASA GSFC, *retired*] gave a brief commentary entitled *Reflections of a Weather Worn* Meteorologist. He reflected on Halverson's presentation, noting how TRMM and the ER-2 have given exciting insights he never dreamed of 50 years ago when working on an airborne Doppler radar program. The measurement of rainfall from space is truly a great achievement, especially since in earlier days rain drop size was measured by counting tens of thousands of drops one-by-one on exposed dyed filter paper. Atlas concluded by expressing his excitement at witnessing the last 20 years of Earth System Science discoveries, and his hopes to witness more breakthroughs in the years ahead.

Bernard Minster [University of California, San Diego] discussed *Monitoring the Planet's Heartbeat: Keeping Track of the 'Solid' Earth.* Space geodesy is a NASA science that cuts a wide and important swath through the scientific landscape. Space-geodetic technologies have enabled the many ways we look at the planet and how it changes over time.

The 1970 *Williamstown Report* recommended the development of space geodesy and related Earth observing missions including altimetry and gravity satellites. During the past 20 years Space Geodesy has contributed enormously to understanding the physical changes resulting from climatic and tectonic forces. Space Geodesy provides the ability to measure and track minute changes in mass and displacement on global, regional and local scales. It is a critical component of the new advances in our ability to measure and understand sea level change, water resources, ocean circulation, natural hazards including earthquakes, landslides, volcanic eruptions, and even weather prediction using GPS occultation measurements. For example, these advances require that we determine the shifting locations of the center of Earth and its pole of rotation to better than half an inch, and the variable length of day to better than a thousandth of a second, every day and sometimes more often than that! This could not have been achieved without the development of advanced orbital dynamics, that includes relativistic corrections.

Because of our reliance upon geodetic networks and reference frames, a strong global network is necessary to ensure space geodesy is ready for the future missions of the Decadal Survey. The global geodetic observing network Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) instruments developed in response to the Williamstown Report are still in service nearly forty years later. The demands on performance of the global network now far exceed its capability. New instrument and network designs are in the later stages of development but they will require significant investment similar to the Crustal Dynamics Project to meet the challenges raised by global environmental change, and the missions that aim to keep track of it.

A public showcase called, Observations of Our Changing Earth from Space, followed the presentations and featured discussions by **Jim Yoder, Waleed Abdalati, Chris Justice,** and **Marshall Shepard.** Former astronaut **Kathy Sullivan** [Ohio State University]

Land Data Assimilation (LDA) is a bit newer than atmospheres and oceans, but this is an exciting time for terrestrial hydrology and ecology as so many new observations are becoming available.

moderated the event. Violinist **Kenji Williams** concluded the evening playing ***Bella Gaia: A Poetic Vision of Earth from Space*****, an audiovisual performance showing the Earth through the eyes of astronauts.**

June 24

Landmark Findings in Disciplines, Earth System Science or Climate *(cont)*
Session Chair: Randy Friedl [NASA/Jet Propulsion Laboratory]

Near real-time satellite data have revolutionized how we view the ocean and thus revolutionized interdisciplinary oceanography; we now have the ability to go to the right place at the right time thanks to satellite data.

David Siegel [University of California, Santa Barbara] presented on *The Ocean Mesoscale, its Impact on Pelagic Ecosystems and How Satellite Views Changed (Created?) Interdisciplinary Oceanography*. Siegel started with some "classic" views of the Gulf Stream: he showed Ben Franklin's view of the Gulf Stream, and then showed various views of Stommel's Gulf Stream. Then he showed the Gulf Stream as viewed from space on an ocean color map and how we now can use satellite altimetry to follow *mesoscale eddies*. His point is that near real-time satellite data have revolutionized how we view the ocean and thus revolutionized interdisciplinary oceanography; we now have the ability to go to the right place at the right time thanks to satellite data.

Satellite data show *mesoscale eddies* throughout the oceans. Siegel discussed the characteristics of these eddies, and techniques to sample them from ship and from space. He also discussed the biological role of mesoscale eddies; they are important for understanding the biogeochemistry and ecology of the open ocean. In the open ocean, nutrients are normally almost undetectable at the surface but the presence of eddies should bring nutrient rich water to the lit region of the ocean through a process called *vertical nutrient pumping*. However, satellite ocean color observations show consistent signals with the presence of eddies—but differently from what one would expect to be attributed to vertical nutrient pumping. This hints at a subsurface nature of the biological influences of eddy motions. Siegel talked about how satellite data can be used for eddy hunting and showed field observations from the Sargasso Sea demonstrating that much of this biological activity is found at depth. He ended by talking about some of the tools that are available (or may be available) to continue studies. He suggested what contributions NASA data may be able to make in the future.

Michael King [University of Colorado] discussed *Aerosols, Clouds, and Climate*. He mentioned the techniques that were available to measure aerosols from space prior to Terra. He showed some airborne data from the Smoke/Sulfates, Clouds and Radiation–Brazil (SCAR-B) field experiment conducted in 1995 and illustrated how smoke obscures vision in the visible spectrum but is "transparent" in the near-infrared. He described the late Yoram Kaufman's pioneering work to come up with a way to retrieve aerosol optical thickness over land taking advantage of the transparent view of the surface in the near-infrared, which was implemented globally—it worked well for areas of dense dark vegetation around the globe.

King then went on to describe how MISR provided *"a new angle on haze."* Using the multi-angle data, it became possible to derive aerosol properties. King showed some examples of MISR's capabilities. MISR has a narrow swath so it is best to use it over longer time intervals.

King then touched on a theme that several other speakers mentioned previously as he discussed what he called *serendipitous discoveries*—things they are able to do that they never intended to do. One example is the *deep blue* algorithm used to get aerosol optical thickness (AOT) over very bright land areas (e.g., deserts) and also single scattering albedo (absorption) of dust. He also described efforts to monitor air quality using MODIS and ground-based instruments.

King also discussed cloud monitoring techniques for MODIS. He showed a diagram that explained the physical complexity of monitoring clouds from space. He described how various upper atmosphere field campaigns have helped improve understanding of the shapes and size distributions of ice crystals in cold clouds. He then showed the global cloud fraction as a function of time from MODIS on Terra and Aqua, and showed that there are more clouds over land in the afternoon, but more clouds over ocean in the morning. The overall cloud fraction is virtually identical in the afternoon and morning hours. He showed cloud optical properties of the entire globe, derived from MODIS, and that the mode effective radius of liquid water clouds is around 10-11 μm over land and 12-13 μm over ocean, with a long tail with fewer clouds having larger particle sizes.

Well-calibrated sensors made possible aerosol and cloud optical observation. King closed by commenting that it will be a sad day when we lose MODIS since it has been such a workhorse!

Judith Lean [Naval Research Laboratory] presented a talk called *How Bright is the Sun; how does it vary; why do we care?* She discussed measurements, variability, and what impact that variability may have on climate change.

Lean discussed a century of inquiry into the question: *How bright is the sun?* We now have lots of measurements, but the question is still not answered with certainty—there has been heated debate between Active Cavity Radiometer Irradiance Monitor (ACRIM) and Solar Radiation and Climate Experiment (SORCE) Total Irradiance Monitor (TIM). Lean reviewed spectral irradiance variability across the electromagnetic spectrum and summarized the measurements that have been made to date.

Lean then addressed the question: *How does the solar irradiance vary?* We know that there is an 11-year solar cycle, and 27-day solar rotation, and 5-minute oscillation. We don't have enough data yet to know if there are even longer-term variations. Both sunspots and *faculae* contribute to variation in solar irradiance—and each are wavelength dependent; sunspots darken and faculae brighten. Both sources of irradiance variability change with solar activity.

Lean then went on to discuss: *Why do we care—i.e., what impact does solar variability have on climate?* She discussed some of the work that has produced estimates of solar variability, including on centennial time scales. She talked about the natural and anthropogenic influences on global surface temperature. Lack of warming over the past decade can be attributed in part to declining solar irradiance from 2002 to the current solar minimum. But natural components can account for <15% of the observed warming since 1890. Significant local changes do not imply global change of equal magnitude.

Lean ended by considering: *How and Why Will Climate Change in the Next Decades?* She presented some "predictions" using the past as prologue, suggesting that global surface temperatures will increase in the next five years more rapidly than IPCC estimates, due to the anticipated increase in solar irradiance during Cycle 24.

Earth Science in the Next 20 Years: Challenges/Vision for Earth System Science or Climate

Session Chair: Jack Kaye [NASA Headquarters]

Sara Graves [University of Alabama] discussed *Data Access, Integration and Stewardship Challenges for the Future*. Effective leveraging of data is essential to making better decisions. The challenge is to increase usability of data and technologies to address the diverse needs of the flood of users. Heterogeneity leads to data usability problems since data have many different formats and states of processing and are in enormous volumes.

Success in increasing data usability builds on: (1) the integration of science domains and disciplines; and (2) collaborations between physical scientists and data and information scientists. Graves discussed how applications have increasingly demanding requirements and then reviewed the characteristics of adaptable data systems and services.

Integrated use of NASA data has numerous applications, such as aiding in disaster response. Ease of use is especially important with interfaces since the ultimate goal is to bring global data to local users.

Tony Janetos [Joint Global Change Research Institute/Pacific Northwest National Laboratory/University of Maryland] discussed *Reaching the Operational Realm: Success in Enabling Capabilities*. Because human decisions and actions interact with Earth science processes more closely than previously thought, there are new challenges in moving from research to operational domains. Janetos reviewed findings from the Millenium Ecosystem Assessment, explaining the unprecedented change in structure

Because human decisions and actions interact with Earth science processes more closely than previously thought, there are new challenges in moving from research to operational domains.

Field gave a brief history of the Intergovernmental Panel on Climate Change (IPCC) and explained that the fifth assessment will have a shift in focus from a "Is climate change real?" perspective to a "Yes ... and here is how to adapt to change and make good decisions for your stakeholders" one.

and function of land that has occurred since 1950. Although ecosystem recovery efforts are underway, conversion rates are still high in certain regions of the globe.

Changes to ecosystems have had positive impacts for humans, such as increases in food production and decreases in food prices. The challenge in ecosystem degradation is to mitigate the harmful effects while at the same time meeting increasing demands of society and a growing population. Janetos stressed that terrestrial carbon storage is a valuable method to counter emissions from land use change. By examining the contribution of each Decadal Survey mission, NASA will be prepared to address continuing challenges with ecosystem change.

Chris Field [Carnegie Institution for Science] discussed *Remote Sensing and the Success of the next IPCC Assessment*. Field gave a brief history of the Intergovernmental Panel on Climate Change (IPCC) and explained that the fifth assessment will have a shift in focus from a "Is climate change real?" perspective to a "Yes climate change is real... and here is how to adapt to change and make good decisions for your stakeholders" one. The fifth assessment will have a risk management framework and focus on adaptation to climate change.

He described the three keys to a successful assessment: salience, credibility, and legitimacy; he discussed key areas that have not been mentioned in previous assessments. These include: ocean impacts, deforestation, global wildfire and carbon emissions, energy and infrastructure at risk, coastal hazards, and animal populations. He also explained why the occurrences of *satellite* and *remote sensing* topics in previous assessments were low.

Michael Kurylo [Goddard Earth Sciences and Technology Center/University of Maryland Baltimore County] discussed the successful interface between scientific research and international environmental policy in *The Role of Suborbital Research in Addressing NASA's Mandate in Atmospheric Composition*.

Kurylo reviewed discoveries in stratospheric chemistry following the 1975 U.S. Congressional directive that authorized NASA to conduct a comprehensive program of research, technology, and monitoring of the upper atmosphere. He highlighted several airborne campaigns focused on polar stratospheric ozone chemistry beginning with the Airborne Antarctic Ozone Experiment (AAOE) that confirmed the connection between anthropogenic halocarbons and the Antarctic Ozone Hole. Kurylo then discussed the progression of subsequent airborne science campaigns to addressing issues of atmospheric chemistry and climate and illustrated the importance of ground-based and balloon-borne measurements as integral components of NASA's observational strategy.

Kurylo concluded by stating that NASA's integrated observations from the ground through space, together with a robust research and analysis program, have provided key input to international assessments for ozone and climate.

Brent Holben [GSFC] discussed *Aerosol Properties and Distributions for Earth System Science from Ground-based Networks: What We've Accomplished and What We Need to Accomplish*. Two of NASA's ground-based satellite networks, AERosol Robotic NETwork (AERONET) and Micro Pulse Lidar Network (MPLNET) have been critical to the development of Earth System Science. AERONET, with over 400 sites, measures spectral total column optical depth and MPLNET, with eighteen sites, measures aerosol vertical distributions and cloud base heights. These measurements have validated satellite and model aerosol retrievals as well as providing dynamic measurements of aerosol optical and microphysical properties through the time domain. Holben explained that there is room for growth of the network in Africa and Asia and that potential areas of improvement for AERONET are the ocean, cloud properties, aerosol forcing at the surface, and lunar photometry for night observations.

Ralph Cicerone [National Academy of Sciences—*President*] concluded the symposium with some final thoughts on *The Next 20 Years of NASA Earth System Science*.

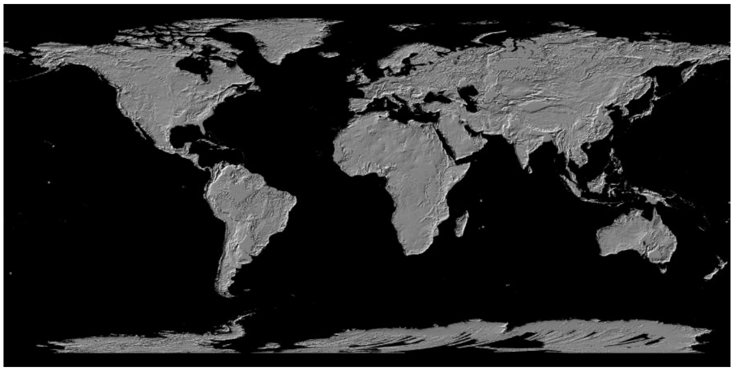
REFERENCES

Atlas R., 1982: The Growth of Prognostic Differences Between GLAS Model Fore-

continued on page 39

METI and NASA Release ASTER Global DEM

The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA) jointly released *Version 1* of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) on June 29, 2009. Previously, METI and NASA announced their intent to contribute the ASTER GDEM to the Global Earth Observation System of Systems (GEOSS). Consequently, the ASTER GDEM is available at **no charge** to users worldwide via electronic download from the Earth Remote Sensing Data Analysis Center (ERSDAC) of Japan and from NASA's Land Processes Distributed Active Archive Center (LP DAAC).



ASTER Global Digital Elevation Model (DEM)

The ASTER instrument was built by METI and launched onboard NASA's Terra spacecraft in December 1999. It has an along-track stereoscopic capability using its near infrared spectral band and its nadir-viewing and backward-viewing telescopes to acquire stereo image data with a base-to-height ratio of 0.6. The spatial resolution is 15 m in the horizontal plane. One nadir-looking ASTER Visible and Near Infrared (VNIR) scene consists of 4,100 samples by 4,200 lines, corresponding to about 60 km-by-60 km ground area.

The methodology used to produce the ASTER GDEM involved automated processing of the entire 1.5-million-scene ASTER archive, including stereo-correlation to produce 1,264,118 individual scene-based ASTER DEMs, cloud masking to remove cloudy pixels, stacking all cloud-screened DEMs, removing residual bad values and outliers, averaging selected data to create final pixel values, and then correcting residual anomalies before partitioning the data into 1°-by-1° tiles. It took approximately one year to complete production of the beta version of the ASTER GDEM using a fully automated approach.

The ASTER GDEM covers land surfaces between 83°N and 83°S and is composed of 22,600 1°-by-1° tiles. Tiles that contain at least 0.01% land area are included. The ASTER GDEM is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. It is referenced to the WGS84/EGM96 geoid. Pre-production estimated accuracies for this global product were 20 meters at 95 % confidence for vertical data and 30 meters at 95 % confidence for horizontal data.

Initial studies to validate and characterize the ASTER GDEM confirm that pre-production accuracy estimates are generally achieved for most of the global land surface, although results do vary and true accuracies do not meet pre-production estimates for some areas. In addition, *Version 1* of the ASTER GDEM does contain certain residual anomalies and artifacts that affect the accuracy of the product and may be impediments to effective utilization for certain applications. Consequently, METI and NASA acknowledge that *Version 1* of the ASTER GDEM should be viewed as "experimental" or "research grade." Nevertheless, they are confident that the ASTER GDEM represents an important contribution to the global earth observation community.

ASTER GDEM tiles are available for electronic download from the following two sources:
LP DAAC: *wist.echo.nasa.gov/wist-bin/api/ims.cgi?mode=MAINSRCH&JS=1*
ERSDAC: *www.gdem.aster.ersdac.or.jp/*

For more information, please contact LP DAAC User Services:
Voice: 605-594-6116
Toll Free: 866-573-3222 (866-LPE-DAAC)
Fax: 605-594-6963
E-mail: *LPDAAC@eos.nasa.gov*

Global Satellite Vegetation Monitoring: Summary of the 4th Global Vegetation Workshop

Joanne Nightingale, Innovim LLC/Goddard Space Flight Center, joanne.m.nightingale@nasa.gov
Steven Running, University of Montana, swr@ntsg.umt.edu

The 4th Global Vegetation Workshop, held from June 16-19, 2009, in Missoula, MT illuminated critical issues related to the current status and future of satellite vegetation monitoring in the climate change and carbon-trading era. The three-day workshop attracted 120 scientists representing 12 countries. The meeting focused on issues related to: satellite-derived land product validation; sensor and dataset continuity; data policy and international frameworks for collaboration.

Each morning, the meeting opened with a plenary talk given by distinguished remote sensing/vegetation–ecosystem monitoring scientists. **John Townshend** [University of Maryland, College Park] presented an overview of the *Grand Challenges in Global Remote Sensing*. He focused not only on the current roles and capabilities of remote sensing in global vegetation monitoring, but presented a candid impression of requirements critical for advancement in the field. **Richard Waring** [Oregon State University] presented new ecological insights to improve predictions of terrestrial carbon balances from satellite datasets. **Compton Tucker** [Goddard Space Flight Center (GSFC)] presented a synopsis of land observations, climate data gaps and essential climate variables for global vegetation monitoring.

The workshop agenda followed a logical progression from overviews of existing global satellite-derived land products and science data networks to international program coordination activities and future plans for global vegetation monitoring. The following presenters gave overviews of the currently available global land products: **Crystal Schaaf** [Boston University] for surface radiation/albedo products, **Pierre Defourny** [Universite Catholique de Louvain, Belgium] for land cover/change products, **Alfredo Huete** [University of Arizona] for vegetation indices and **Steve Running** [University of Montana] for biophysical variables.

Rama Nemani [Ames Research Center (Ames)] discussed the importance and progress of *Integrating Satellite Data with Ecosystem Models*, and the development of a prototype exercise for a community-focused data-modeling center to be hosted at NASA Ames. **Beverly Law** [Oregon State University] and **Michael Keller** [National Ecological Observatory Network (NEON)] presented science network updates for FLUXNET and the planned NEON project, respectively. Scheduled to commence in 2010, NEON will create a new national observatory network to collect ecological and climatic observations across the continental U.S., including Alaska, Hawaii and Puerto Rico.

The workshop largely focused on international program coordination activities related to global vegetation monitoring. In 2008, the Global Climate Observation Strategy (GCOS) defined 28 *Essential Climate Variables* (ECVs) in support of the United Nations Framework Convention on Climate Change. These ECVs play an important role in understanding land-surface-climate interactions. Among the 28 ECVs listed, eight are directly relevant to the global satellite vegetation monitoring community, including: snow cover, land cover, fire disturbance, albedo, leaf area index (LAI), the fraction of absorbed photosynthetically active radiation (*f*APAR), biomass, and soil moisture. With the recent emphasis on the independent and systematic evaluation and validation of terrestrial ECVs, the Land Product Validation (LPV) group—a sub-group of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV)—established corresponding ECV focus groups with international co-chairs who have been actively involved in validation activities. **Frederic Baret** [Institut National de Recherche Agronomique, France] presented a status update on the Land Product Validation sub-group.

The Global Observation of Forest Cover/Land Dynamics (GOFC/GOLD) program is working to encourage continuous space-based and field observations for global monitoring of terrestrial resources with emphasis on land cover, fire and biomass products. **Martin Herold** [Friedrich-Schiller-University, Germany] and **Christopher Justice** [University of Maryland, College Park] provided updates on the land cover and fire groups, respectively. GOFC/GOLD in cooperation with the CEOS working groups are required to help provide standard product definitions and quality control procedures for ground-based measurements and reporting, to ensure the availability of the highest quality and most accurate data sets. **Martin Herold** also provided an overview of the European Space Agency's (ESA) GLOBCARBON project, which aims to generate fully calibrated estimates of land products (e.g., burned area, Leaf Area Index (LAI), *f*APAR and vegetation growth cycle products) for use in dynamic global vegetation and atmospheric transport models. Products are produced for ten complete years, from 1998–2007, when overlap exists between ESA Earth Observation sensors [e.g., Along Track Scanning Radiometer (ATSR-2), Advanced Along-Track Scanning Radiometer (AATSR) and Medium Resolution Imaging Spectrometer (MERIS)] and VEGETATION. **Roselyn Lacaze** [Centre National d'Etudes Spatiales (CNES)] presented an overview of the GEOLAND-2, Global Monitoring for Environment and Security (GMES) project that aims to provide reliable and timely geo-information services for environmental and security issues. GMES supports public policy makers' needs and is a European Union-led initiative, currently implemented by ESA.

The Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat Enhanced Thematic Mapper (ETM) are essential climate sensors that continue to play a vital role in regional–global scale vegetation monitoring. The Long-Term Data Record (LTDR) from the AVHRR [**Eric Vermote** (University of Maryland, College Park)], and Landsat [**Mike Wulder** (Pacific Forestry Centre, Canada)], are extremely important for documenting historical trends in land surface properties. The land science community is counting on the continuity of data from AVHRR to MODIS to be extended by the Visible Infrared Imager Radiometer Suite (VIIRS) [**Bob Murphy** (National Oceanic and Atmospheric Administration [NOAA])], which will be launched as part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project [NPP] Mission in 2011. The terrestrial observing satellites specified in the U.S. NASA Decadal Survey promise a rich array of sensors including Soil Moisture Active Passive (SMAP)—**John Kimball** [University of Montana], Hyperspectral Infrared Imager (HyspIRI)—**Simon Hook** [Jet Propulsion Laboratory (JPL)] and Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI)—**Ralph Dubayah** [University of Maryland, College Park]. **Bob Yu** [NOAA] presented a status report on NOAA's Geostationary Operational Environmental Satellites (GOES) for land studies.

M.D. Behera [Indian Space Agency] and **Yuan Zeng** [Chinese Space Agency] each presented overviews of current satellite programs for their respective agencies. The China–Brazil Earth Resources Satellite (CBERS) program is a technological cooperation program between the two countries to develop and operate Earth observation satellites. **Sebastien Garrigues** [CNES] gave an overview of the Venμs Mission, a new superspectral, high spatial and temporal revisit resolution sensor developed by the French space agency.

It is truly an exciting period to be involved in global vegetation monitoring. There are multiple sensors with long-time series, 36+ years of Landsat, 28+ years of AVHRR, and 10+ years of MODIS data that can be utilized to assess trends in global land surface properties. There are a host of land products available at multiple spatial resolutions, e.g., global land cover products at 300 m, 500 m, and 1 km. With free access to the Landsat archive it is not unreasonable to presume the development of 30-m global land products.

Discussions among participants in the workshop formulated several key requirements for global satellite vegetation monitoring:

- Land product accuracy assessment and evaluation must be considered a global activity that necessitates collaborative effort with transparent data and resource sharing mechanisms.
- Dataset and sensor continuity are critical for assessing long-term trends in climate-vegetation interactions.
- Atmospherically and geometrically corrected data should be available via user-friendly interfaces and efficient retrieval mechanisms free of charge.
- International space agencies should be encouraged to work in concert with structures such as the Group on Earth Observation (GEO), Committee on Earth Observation Satellites (CEOS) and the GOFC/GOLD program to ensure internationally coordinated definitions and evaluations of ECVs.

The three-day meeting featured over 80 scientific posters on display. Poster topics extended six key themes: surface radiation, land cover/change, vegetation indices, biophysical variables, application of global vegetation monitoring to societal benefit areas, and integration of modeling and satellite data sets. In addition, four parallel sets of meetings were held during the week of the Global Vegetation Workshop for: (1) the CEOS WGCV Land Product Validation sub-group; (2) a newly formed GOFC/GOLD working group for biomass; (3) VIIRS land validation science team; and (4) the satellite-derived land surface phenology community. The diversity of the parallel meetings proved the convenience and suitability of this workshop to bring together the national and international scientific community.

The Global Vegetation Workshop is renowned for the outings that bring scientists together in a social setting, and this year was no exception. On behalf of all meeting attendees, I would like to thank **Steve Running** and **Youngee Cho** [University of Montana] and the team of organizers at the University of Montana who made this meeting a fourth generation success. Oral presentations and posters presented at the meeting are available at *www.ntsg.umt.edu/VEGMTG/*.

Landsat Science Team Meeting Summary

Thomas R. Loveland, U.S. Geological Survey Earth Resources Observation and Science Center, loveland@usgs.gov
Michelle A. Bouchard, SGT, Inc Earth Resources Observation and Science Center, Mbouchard@usgs.gov
James R. Irons, NASA Goddard Space Flight Center, James.R.Irons@nasa.gov
Curtis E. Woodcock, Department of Geography and Environment, Boston University, curtis@bu.edu

Meeting Overview

The Landsat Science Team—sponsored by the U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA)—met at the Rochester Institute of Technology (RIT) in Rochester, NY from June 22-24, 2009. **John Schott** [RIT Center for Imaging Science—*Landsat Science Team Member*] hosted the meeting. All presentations from the meeting are available at *landsat.usgs.gov/science_june2009MeetingAgenda.php*.

The meeting marked the halfway point in the Landsat Science Team's term. The two Landsat Science Team Chairs, **Tom Loveland** [USGS] and **Jim Irons** [NASA Goddard Space Flight Center] acknowledged the Team's exceptional input on a number of Landsat and Landsat Data Continuity Mission (LDCM) topics. Since the Team was assembled, they have witnessed the opening of the entire Landsat archive to free Internet access, the formulation of a Thermal Infrared Sensor (TIRS) for LDCM, and congressional interest in a Landsat 9 mission. Over the past six months, the Team has provided strong technical input and advice on TIRS, the Landsat Multispectral Scanner (MSS) backlog, Landsat data gap, and Landsat product topics.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] commented on how free web-enabled Landsat data has had a real impact on science and education. He stressed the need to learn more about how to mine the archive, and in particular, how to make it easier for the larger user community to use the archive. Woodcock also stressed the opportunity researchers now have to document the changes on the global land surface and report what these changes mean.

The RIT meeting primarily focused on three topics: (1) working group deliberations; (2) Landsat and LDCM status; and (3) science reports by the Landsat Science Team Principal Investigators.

Working Group Reports

At the conclusion of the January 2009 meeting, the Landsat Science Team organized four working groups to address: (1) future Landsat missions; (2) Landsat data gap readiness; (3) Landsat product issues; and (4) consolidation of the global Landsat archive. The first day of the RIT meeting focused on reports from the first three of these working groups.

Future Missions Working Group Report

The purpose of this working group is to develop and recommend to the USGS and NASA operational mission standards, requirements, and characteristics for future Landsat missions. The future missions group held several telephone meetings over the previous four months to discuss operational Landsat needs and issues.

The future missions group drew three conclusions. First, they concluded that the long-standing Landsat mission statement and fundamental mission capabilities are still appropriate. Monitoring land use and land cover change at the scale of human activity has been fundamental to the Landsat mission to date, but monitoring land-related carbon will become one of the key drivers for future Landsats. Schott reminded the group that while many Earth observation missions contribute to global science, only Landsat is at a resolution appropriate for managing global resources. The Landsat Science Team offered to work with NASA's Education and Public Outreach Program to document societal benefits for fact sheets that will highlight the value of Landsat.

Second, the group endorsed **Sam Goward's** [University of Maryland, College Park (UMCP)] conclusion that Landsat utilization can be greatly increased through the development of advanced land monitoring data sets (e.g., land cover change, vegetation canopy properties, etc.). A suite of operational GIS-ready geophysical products will expand the Landsat user base and increase the value of the Landsat Program.

Finally, the future missions group discussed a congressional appropriations committee request for a Landsat 9 strategy. The team strongly endorsed the efforts of NASA and the USGS to provide a strategy that can lead to the authorization and earliest possible launch of Landsat 9.

The conclusion from the future missions working group, consistent with the recommendations of the Future of Land Imaging working groups, is that future Landsat missions should be led by the Department of the Interior (DOI), and that NASA must build the satellites and be responsible for technology development missions. On behalf of the Landsat Science Team, Woodcock sent a letter to the new Secretary of the Interior, Kenneth Salazar, urging DOI to assume leadership of the Landsat Program and pursue funding from Congress at the earliest opportunity to build and launch another Landsat satellite—in partnership with NASA. Woodcock also stressed the need to minimize time between launches by reusing LDCM capabilities. Finally, he stressed the need to work with Congress and the Office of Science and Technology Policy to formally implement a National Land Imaging Program.

Data Gap Working Group

Tom Holm [USGS—*Data and Information Project Manager*] summarized discussions with the working group dealing with alternative sources of moderate resolution imagery should Landsats 5 and 7 fail prior to the planned December 2012 LDCM launch. Previous evaluations identified the India ResourceSat and China–Brazil Earth Resources Satellite (CBERS) missions as the preferred solution to provide the spectral and twice-annual global coverage requirements. The working group, however, recommended looking at other missions, even those that may not meet the original data gap minimum specifications. The group concludes that the most basic requirement should be the acquisition of at least one clear pixel per year for the entire global land surface. After that, options should be prioritized according to how to best meet the original data gap specifications (e.g., shortwave infrared (SWIR) bands, twice annual global coverage, etc.) for as many areas of the Earth as possible.

Using input from the working group, the USGS will evaluate opportunities with other potential providers including the French Satellite Pour l'Observation de la Terre (SPOT) and the German *RapidEye* satellite constellation. The USGS will also develop a readiness plan that includes an architectural concept for using Earth Resources Observation and Science (EROS) reception, archive, and data discovery/delivery capabilities and proprietary data processing capabilities for product generations.

Products Working Group

This group was established to address a number of Landsat processing issues including data grids, cloud and shadow masking, and generation of surface reflectance datasets. The gridding issues are associated with the necessity for geospatial consistency of multi-date Landsat images. Schott concluded that the processing used by the USGS to generate Level One-T Data Products (L1Ts) are producing data sets gridded to the same post, but that issues arise because of differences in pixel origins used by different software vendors. The group concluded that there is a need to provide clear product specifications to software developers.

John Dwyer [USGS—*Landsat Project Scientist*] reviewed several topics associated with LDCM product specifications, including recent decisions to use scene center solar zenith to calculate top-of-atmosphere (TOA) reflectance, quality assurance band properties, and off-nadir acquisition naming conventions. Dwyer also mentioned that there are no plans at this time to add cloud shadow mask information to the quality assurance band, but that there is an option to add it if a shadow masking capability can be developed. Finally, Dwyer reaffirmed the necessity to co-register TIRS and Operational Land Imager (OLI) data.

The working group also addressed Goward's comments regarding the need for higher-level Landsat products. In order to produce the data sets discussed earlier, the Team concluded that there was an immediate need to go beyond the current L1T specification and establish surface reflectance products for all Landsat data. The Team suggested that the basic foundation for higher-level products includes cross-instrument calibration, accurate geo-location and orthorectification, cloud and shadow masking, TOA reflectance calculation, and surface reflectance–surface temperature (or surface brightness temperature) processing. Once this foundation is established, higher-level geophysical products suited for detecting long-term trends should be produced. Calibration across the full Landsat record and implementation of orthorectification capabilities has been completed, and the Team has defined the TOA processing strategy. The Landsat Science Team concluded that it is now time to address the remaining issues (e.g., cloud and shadow masking, surface reflectance processing) and to begin identification of future higher-level products that enable monitoring the state and dynamics of the Earth's terrestrial land surface.

Landsat Status

The Landsat session included an update on Landsat 5 and 7 status, global Landsat archive consolidation, planning for Global Land Survey (GLS) 2010, and a USGS discussion on potentially watermarking Landsat data.

Kristi Kline [USGS—*Landsat Project Manager*] reported that Landsats 5 and 7 continue to add to the global archive. Landsat 5 reached an incredible milestone this year by celebrating the 25th anniversary of its launch—March 1. Even though it is 22 years past its design life, Landsat 5 continues to acquire Thematic Mapper (TM) imagery over the U.S. and other selected areas around the world. Because there are no data recorders on Landsat 5, data are only being acquired through direct broadcast to an international ground station and to the USGS EROS data center. Global Landsat 5 coverage was expanded this year due to the establishment of temporary Global Land Survey (GLS) 2010 campaign stations covering portions of East Africa, northern Russia, and Central America. Landsat 7 continues to aggressively collect global coverage according to the Long-term Acquisition Plan. Assuming no technical failures, both satellites have sufficient fuel to operate until 2014 (Landsat 5) and 2015 (Landsat 7).

With all Landsat data now available via the Internet at no cost, many data users are able to undertake studies over large areas and long time periods that were previously unaffordable. Less than a year after the USGS made all Landsat data free, over 800,000 scenes have been downloaded and the estimate for the first 12 months of web-enabled access is 1.1 million scenes. In the best year of data sales (2001) prior to this, 19,100 scenes were distributed.

While the opening of the Landsat archive has been successful, efforts to improve access are still ongoing. Perhaps the biggest challenge that still exists involves access to Landsat 1-5 Multispectral Scanner (MSS) data. USGS MSS processing capabilities are being modernized, but until the modernization is complete, orthorectification throughput is limited. As a result, the backlog for processing Landsat MSS to the L1T specification became unacceptably long and users needed to wait for a month or more for on-demand processing orders to be completed. To remedy the backlog, the USGS has increased daily throughput by temporarily reducing geolocation specifications. At the same time, an improved automated orthorectification process is being developed, and when completed (planned for Fall 2009), the geometric quality of MSS data will be significantly improved.

Kline briefly touched on the status of planning for a Landsat global archive consolidation initiative. An estimated 1.3 petabytes of Landsat data exist in past and current international ground station archives. While some of the data may already be duplicated in the USGS archive, there is a significant amount of data going back to 1972 that represents an invaluable resource for studies of global environmental change. The USGS has completed preparing an initial cost estimate and implementation plan that would result in bringing as much of the international holdings as possible into the USGS Landsat archive. The Landsat Science Team members strongly endorsed pursuit of funding for this initiative and offered to assist in the identification of priorities for acquiring data.

Jeff Masek [NASA GSFC—*LDCM Deputy Project Scientist*] and **Garik Gutman** [NASA Headquarters—*Land Cover and Land Use Change Program Manager*] provided an update on the overall GLS activity. Regarding GLS 2005, 8,860 scenes of the nearly 9,000 Landsat scenes have been added to the collection. EROS is awaiting delivery of additional scenes by Brazil and Thailand—international cooperators. Scenes from the advanced Land Imager on Earth Observing-1 covering islands will be added by late-July 2009. For GLS 2010, Landsat 5 Thematic Mapper (TM) data are being collected from eight campaign stations. In addition, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data are being collected over the rest of the global land mass. Efforts are continuing to establish cooperation through the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging Constellation initiative to add data from additional sources. So far, the response has been minimal.

Gutman provided an overview of NASA-sponsored land cover research based on GLS data. NASA is currently funding seven research projects ranging from humid tropical forest mapping and monitoring to Synthetic Aperture Radar (SAR) optical data fusion. He challenged the Team to work toward a goal of establishing international collaboration between operators of all Landsat-scale missions to work together to provide daily 30-m global coverage by the year 2020.

Bruce Quirk [USGS—*Land Remote Sensing Program Coordinator*] briefed the Team on the possibility for adding a USGS watermark to Landsat L1T data. *Watermarking* has been suggested as an approach to increase the visibility of the role of the USGS in providing Landsat data. The Landsat Science Team supported the concept of increasing USGS visibility but concluded that the scientific value and integrity of the data would be reduced through watermarking. The team elected to provide input to the USGS Director regarding their opposition to Landsat watermarking. (**Update**: Based on the Team's input, the USGS is no longer pursuing watermarking L1T data.)

Anita Davis [NASA GSFC—*Education and Public Outreach*] was the last speaker in the Landsat Status session, and led a discussion on Landsat-specific outreach activities. NASA supports a number of educational activities through the development of brochures, training kits, and other materials addressing Landsat and other aspects of environmental remote sensing. Davis summarized efforts to support tribal educators through faculty development and student internships at Salish Kootenai College and a Bureau of Indian Education high school teacher's workshop. NASA is also contributing to public outreach through the *Earth and Sky* initiative and as part of that effort they are actively fostering collaboration between the science and interpretation/education communities of the National Park Service and U.S. Fish and Wildlife Service in ways that enrich the visitation experiences of park and refuge visitors. Finally, Davis described the Integrated Geospatial Education and Technology Training (iGETT) project, which is focused on training two-year college faculty in the integration of remote sensing into existing GIS programs.

LDCM Status

Bill Ochs [NASA GSFC—*LDCM Project Manager*] initiated an in-depth update of the status of LDCM development. He provided an overview of all major mission components. Ochs briefly discussed the July LDCM Preliminary Design Review (PDR) in which the LDCM team must demonstrate that the overall preliminary design meets all requirements with acceptable risk and within cost and schedule constraints. This review establishes the basis for proceeding with detailed design[1]. The Mission Confirmation Hearing, in which NASA commits to Congress the cost and schedule for LDCM launch, begins with the July PDR and includes a non-advocate review in which an independent assessment of the readiness of the project to proceed to implementation is made. These events lead to the NASA Key Decision Point-C meeting in which the NASA Program Management Council will determine whether LDCM is confirmed to build to launch—this decision is expected in November 2009.

Ed Knight [Ball Aerospace and Technology Corporation—*Systems Engineer*] reviewed Ball's progress in building the LDCM Operational Land Imager (OLI). OLI represents the next generation Landsat imager and replaces the ETM+. OLI is a pushbroom Visible–Near Infrared (VNIR)/SWIR sensor with a four-mirror telescope, a focal plane array (FPA) consisting of 14 passively cooled sensor chip assemblies, and on-board calibration with both diffusers and lamps. Knight reported that the telescope mirrors and main optical bench assemblies are completed and the telescope build is underway. The engineering development unit focal plane array (FPA) is completed and the FPA flight parts are proceeding on schedule. Early measurements showed degradation in some of the silicon detectors but NASA, Ball Aerospace, and Raytheon engineers conducted an investigation and found the root cause and now, new flight detectors are being manufactured. Knight summarized his presentation with the conclusion that the major hardware is being delivered, artifacts are being identified and corrected, and performance predictions are all positive.

Dennis Reuter [NASA GSFC—*TIRS Instrument Scientist*] provided a thorough review of TIRS development. TIRS is a stand-alone two channel (10.8 and 12 um) pushbroom thermal imager that provides thermal data continuity for LDCM. It will operate in concert with, but independently of, the OLI. TIRS uses Quantum Well Infrared Photometer (QWIP) detectors and FPA that are being built in-house at GSFC. TIRS will provide 12-bit data with <120 m Ground Sample Distance (100 m nominally) resolution for a 185-km ground swath (15° field of view). It is a *Class C* instrument with a three-year design life. TIRS will produce radiometrically calibrated, geo-located thermal image data. The scene data will be merged with OLI into a single data product by the USGS. TIRS instrument delivery is scheduled for December 2011, a year prior to the December 2012 LDCM launch readiness date.

Jim Irons added to the TIRS discussion by retracing the history that is leading to the development of TIRS. The Fiscal Year 2009 omnibus budget legislation authorized the development of a thermal instrument based on the most affordable and efficient approach. A key consideration was to develop an instrument that could be ready for an LDCM launch in December 2012. Recently, NASA considered moving the instrument from LDCM to a replacement mission for the failed Orbital Carbon Observatory. However, based on a thorough evaluation of the impacts of that option, NASA is staying on course to include TIRS on LDCM.

Bill Anselm [NASA GSFC—*LDCM Observatory Manager*] summarized spacecraft development progress. NASA contracted with General Dynamics Advanced Information Systems to develop the spacecraft/observatory and simulators, and provide mission operations support. Anselm described the spacecraft as a kit in which the LDCM-specific components are being knitted to the spacecraft's major modules—the primary structure (main body), propulsion, and instrument deck. He concluded that the spacecraft relies on sound heritage designs, is sound, buildable, testable, and meets the mission's needs.

John Dwyer [USGS—*LDCM Project Scientist*] concluded the LDCM session with an update on the status of the LDCM ground system development. Due to budget challenges, the USGS has adjusted the overall ground system approach and architecture to take advantage of existing Landsat processing capabilities to the extent possible. As a result, the budget shortfall has been mitigated to the extent possible and additional funding has been requested to fully resolve the problem. Dwyer also reported that the ground system preliminary design now includes accommodations for processing TIRS data and integrating it with OLI into integrated data sets. The Preliminary Design Review of the ground system is set for September 2009, and the Critical Design Review is tentatively scheduled for March 2010.

Update on European Space Agency (ESA) Sentinel 2 Mission

The meeting included a special session on Earth observation cooperation with the European Space Agency. **John Cullen** [USGS—*Senior Advisor for Geography*] explained that the U.S. has been engaged in a space policy dialog with the European Union (EU) since 2006. As part of this, the USGS and ESA, along with NASA, are discussing LDCM and Sentinel 2 mission cooperation for the purpose of advancing the use of Earth observations for sustainable development and increasing scientific exploration and knowledge.

[1] The Preliminary Design Review took place July 14-17 and went very well.

Tim Stryker [USGS—*Land Remote Sensing International Cooperation Coordinator*] elaborated on the LDCM–Sentinel 2 relationship by outlining areas of cooperation including Landsat and Sentinel 2 acquisitions coordination, science and applications development, operational decision support tools, and contributions to international treaties.

Philippe Martimort [ESA—*Sentinel-2 Mission and Payload Manager*] provided a detailed introduction to the key features of the Sentinel 2 mission. Sentinel 2 is part of the EU Global Monitoring for Environmental Security (GMES) Program, and includes a series of dedicated satellites—i.e., "the Sentinels." GMES is to provide data and integrated services that contribute to the European goals for environmental monitoring and security. There are five Sentinel series; the Sentinel 2 series is similar to Landsat and provides high-resolution optical imaging. There are two Sentinel 2 satellites planned and they are to provide both general and thematic services that include:

- **General services:** Global carbon, crop monitoring, spatial planning (vegetation, urban), forest monitoring, water services, soil erosion, large-scale natural or man-made disasters, and surveillance of infrastructures.
- **Thematic services:** Sustainable management of developing countries, nature protection services, support to humanitarian aid, and food security.

Sentinel 2 will carry a pushbroom multispectral instrument that provides 13 channels of 12-bit data VNIR and SWIR imagery. The spectral bands will have 10-20-60-m ground resolution. The imaging swath is 290 km with a 10:30 a.m. viewing and the imaging range will be 84°N–56°S. When both Sentinel 2 satellites are in orbit, this will provide 5-day repeat coverage at the equator. Sentinel 2 will also have a pointing mode that can be used in emergencies to provide 1–2 day repeat imaging. The planned lifetime of each satellite is 7.25 years with 12 years of consumables.

Sentinel 2 will use four core ground stations. There will be a direct download capability but the primary approach is to downlink to the network of four stations. Three product levels are planned. Level 1 products include radiometric and geometric corrections, level 2 will have cloud screening, atmospheric corrections, and geophysical variables, and level 3 products will represent spatial and temporal synthesis. The first Sentinel 2 satellite is scheduled for launch in late 2012.

Principal Investigator Science Presentations

The final day of the meeting was devoted to research presentations by the members of the Landsat Science Team. The following is a brief summary of each presentation (full presentations are available at: *landsat.usgs.gov/science_june2009MeetingAgenda.php*.

John Schott [RIT] presented an overview of the RIT Digital Imaging and Remote Sensing Laboratory (DIRS). DIRS research focuses on spectral measurements and phenomenology, sensor system development, physics-based algorithms and phenomenology, and modeling and simulation of land surfaces through a wide variety of sensors. Schott presented a method for calibrating Landsat 5 thermal data using a physics-based approach. By modeling water temperatures from the long standing National Data Buoy Center, they were able to determine the calibration curve over the life of the instrument.

Martha Anderson [USDA Agricultural Research Service] summarized work on sharpening thermal images with NDVI for use in mapping evapotranspiration (ET) over irrigated landscapes. Even with sharpening, resolutions of greater than 100 m are too coarse for mapping ET over U.S. irrigated lands.

Eric Vermote [University of Maryland, College Park] provided an update of his work on a surface reflectance standard product for LDCM. Error budget and performances were developed for each Landsat band. The product also produces a pixel-based cloud and shadow mask.

Jennifer Dungan [NASA Ames Research Center] discussed progress toward developing an operational capability to produce vegetation green leaf area index from Landsat surface reflectance data and ancillary parameters.

Feng Gao [Earth Resources Technology, Inc.] reported on his research using multi-temporal Landsat data to look at the rate of change of impervious surfaces. This technique will provide a consistent map to the user because it only allows uni-directional change. Gao also updated the team on the use of StarFM for burn severity mapping and forest monitoring.

Rick Allen [University of Idaho] found that systematic geo-registration error between OLI and TIRS could effect evapotranspiration retrievals. Allen also presented research that showed how thermal images and retrieved evapotranspiration increased vegetation classification accuracy in northeastern Portugal.

Randy Wynne [Virginia Tech] used a multi-temporal approach to delineate reclaimed mines and changes in vegetation development pattern. They are also working on web-based ecosystem service models to determine real-time carbon estimates and water quality.

Sam Goward [UMCP] made the case for acquiring all Landsat scenes due to the prevalence of persistent cloud cover in some areas. The use of Long Term Acquisition Plan (LTAP)-8 may reduce the possibility of retrieving cloud-free pixels.

Aaron Gerace [RIT], with **John Schott**, modeled the retrieval process of constituents in optically complex waters. LDCM shows promise for retrieving chlorophyll, suspended materials, and color dissolved organic matter.

Eileen Helmer [USDA Forest Service] discussed the creation of cloud-free Landsat image mosaics for vegetation and land-cover mapping over tropical landscapes using regression tree normalization.

Jim Vogelmann [USGS EROS] updated his research on the use of a Landsat time series for landscape change assessments in the western U.S. He used ancillary data about forest health to strengthen his assessment.

Mike Wulder [Canadian Forest Service] presented approaches for disturbance and ecosystem characterization in forested landscape using Landsat and ancillary data.

Warren Cohen [USDA Forest Service] described research focused on automated time-series change maps to look at disturbance intensity and recovery rates. He used human interpretation and ancillary data sets to validate the series.

Curtis Woodcock [Boston University] discussed the need to work toward a global land surface history in the Landsat era.

Lazaros Oreopoulos [NASA GSFC] updated his research on LDCM cloud detection, including cirrus and marine clouds.

At the end of the presentations, the Team concluded that the availability of free Landsat data allows them to be more creative about how they approach studies. Time series data are important for consistent change detection, but improvements in cloud and shadow screening are needed if the uses of longer Landsat time series, and studies of larger geographic areas are to become operational. The team also concluded that now is the time to work toward operational provision of higher-level geophysical products.

Future Meetings

As a result of the technical discussions on Landsat products, the Team agreed to hold a "specialists" meeting from October 27-29, 2010 in Boston, MA to address data products and processing strategies. Topics that will be addressed include cloud- and shadow-masking approaches, top-of-atmosphere parameters, surface reflectance processing, and priorities for generating essential climate variables.

The next full meeting of the Landsat Science Team is scheduled for January 19-21, 2010 and will be held at the NASA Ames Research Center in California. ■

NASA Earth System Science at 20: A Symposium to Explore Accomplishments, Plans, and Challenges

continued from page 30

casts from SAT and NOSAT Initial Conditions, *NASA Technical Reports*.

Atlas. R, M. Ghil, and M. Halem, 1982: The Effect of Model Resolution and Satellite Sounding Data on GLAS Model Forecasts. *Monthly Weather Review*, **110:7**, 662-682.

Ghil, M. K., M. Halem, and R. Atlas, 1979: Time Continuous Assimilation of Remote-Sounding Data and Its Effect on Weather Forecasting. *Monthly Weather Review*, **107:2**, 140-171.

Tracton, M. S., A. J. Desmarais, R. J. van Haaren, and R. D. McPherson, 1980: The Impact of Satellite Soundings on the National Meteorological Center's Analysis and Forecast System—The Data Systems Test Result, *Monthly Weather Review*, **108:5**, 543-586. ■

SMAP Algorithms & Calibration/Validation Workshop

Peggy O'Neill, NASA Goddard Space Flight Center, Peggy.E.ONeill@nasa.gov
Mahta Moghaddam, University of Michigan, mmoghadd@eecs.umich.edu
Thomas Jackson, USDA ARS, Tom.Jackson@ars.usda.gov

Background on Meeting

The Soil Moisture Active and Passive (SMAP) mission is one of four "Decadal Survey" missions recommended by the U.S. National Research Council for launch in the early part of the next decade (in its 2007 report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond)*. The SMAP launch is currently targeted for March 2014. The SMAP mission design consists of an L-band (microwave) radar at 1.26 GHz and an L-band radiometer at 1.41 GHz sharing a single rotating 6-m mesh reflector antenna. Once on orbit, these instruments will provide high-resolution and high-accuracy global maps of soil moisture and freeze–thaw state every two to three days. The soil moisture and freeze–thaw information provided by SMAP at high resolution will enable improvements to a wide variety of applications, including weather and climate forecasts, flood prediction and drought monitoring, and estimation of net CO_2 uptake in forested regions.

The SMAP mission is currently in its formulation phase, and SMAP project science activities are focusing on the refinement of sensor and geophysical product algorithms and creation of a calibration/validation (Cal/Val) plan. These activities, including the selection of baseline algorithms and the development of ground-based infrastructure for core validation sites, are greatly strengthened by the involvement and review of the broader science community.

In order to engage the science community on issues relevant to SMAP science activities, the first SMAP Algorithms & Cal/Val Workshop took place on June 9-11, 2009, in Oxnard, California. This workshop was open to the science community and attracted approximately 80 attendees, including international participants from Europe, Asia, and Australia [see group photo]. The workshop dedicated 1.5 days each to discussions of algorithms and the Cal/Val plan. The Algorithms portion of the workshop provided a forum for the science community to review the status of algorithm development for SMAP data products and make the project aware of alternate algorithms to consider. Similarly, the Cal/Val portion of the workshop created an opportunity for the community to provide inputs to the development of the science data calibration and validation plan. The workshop started with overview presentations by SMAP team members on the SMAP mission concept and expected science outcomes, current mission status, details of the radar and radiometer instruments, data systems, and the computing testbed being developed for testing and validating the science algorithms, followed by more detailed discussions on specific algorithms and Cal/Val issues.

Algorithms Workshop

Mahta Moghaddam [University of Michigan, Department of Electrical Engineering and Computer Science —*Workshop Co-chair*] began the Algorithms portion of the workshop with a brief introduction and discussion of expected outcomes. The main goals of the workshop were stated to be:

- to review the algorithms currently being implemented by the mission;
- to assess current vs. alternate algorithms; and
- to identify areas requiring further research and development.

These topics were addressed separately for each of the standard SMAP mission products. SMAP has de-

SMAP Algorithm & Cal/Val Workshop participants assemble on the beach, Oxnard, CA, June, 2009.

Table 1. Proposed SMAP data products

Data Product	Description	Nominal Spatial Resolution (km)
L1B_S0_LoRes	Low resolution normalized radar backscattering coefficient in time order	30
L1C_S0_HiRes	High resolution normalized radar backscattering coefficient on Earth grid	1-3
L1B_TB	Radiometer brightness temperature in time order	40
L1C_TB	Radiometer brightness temperature on Earth grid	40
L3_F/T_HiRes	Freeze/Thaw state on Earth grid	3
L3_SM_HiRes	Radar-derived soil moisture on Earth grid	3
L3_SM_40km	Radiometer-derived soil moisture on Earth grid	40
L3_SM_A/P	Radar-Radiometer soil moisture on Earth grid	10
L4_SM	Surface and root-zone soil moisture on Earth grid	10
L4_C	Carbon net ecosystem exchange on Earth grid	10

fined a number of data products, each with associated algorithms for its production. These data products and their high-level attributes are shown in **Table 1**.

The Algorithms workshop consisted of a sequential discussion of each of these data products. For each product, the Lead of the respective algorithm development team within the project gave an overview presentation on the current candidate algorithms. The floor was then opened for general discussion and critique of the algorithm, followed by an opportunity for any member of the community to briefly present any alternate algorithms. The latter portion was formatted such that proposers of alternate algorithms could describe their algorithms with a summary slide, highlighting its performance features and benefits. The attendees were notified of the opportunity well in advance of the workshop and were requested to send their inputs to be included in the program. The inclusion of the one-page presentations for getting community input on alternate algorithms was a successful model, whereby several viable algorithm options could be proposed. These alternate and/or complementary algorithms will be important in finalizing the selection of mission baseline algorithms.

Level 1 Data Products

Consistent with definitions established for previous missions for defining data products, Level 1 products (all products preceded by "L1" in **Table 1**) are those that have been processed from raw instrument data into physical quantities that can be ingested by geophysical algorithms. In the case of the radiometer, these are calibrated brightness temperature values, and for the radar, they are calibrated backscattering coefficient values. No alternate algorithms to those presented by the mission team were proposed. Issues brought up for each of the Level 1 products focused on calibrating the data for both the radiometer and the radar to ensure that the nominal mission science requirements are met.

Level 3 Data Products

Level 3 data products (all products preceded by "L3" in **Table 1**) are the surface geophysical products directly generated from Level 1 data through physical (including empirical) models of emission and scattering. The first Level 3 product to be discussed was the 40-km soil moisture product from the radiometer. The main focus of discussions for this product was on the error caused in soil moisture estimation by vegetation effects, and methods of correcting for this unwanted contribution to the surface soil moisture signal. Several one-page presentations were made to suggest approaches for incorporating such vegetation effects. The discussions emphasized the need for a reliable and accurate measure of the presence and extent of bodies of water in each 40-km pixel, and some techniques by which this information could be provided were suggested for further consideration.

The discussion then turned to the high-resolution (3 km) soil moisture product from the SMAP radar. This area attracted the most discussion related to the specific soil moisture estimation algorithm that would be suitable for SMAP, especially in the way that vegetation effects can be included. This conversation highlighted the need for ancillary data (which was also true for the 40-km radiometer-derived soil moisture product) to complement the small number of data channels of SMAP radar with other information about known characteristics of the scenes under study. Several one-page presentations were given in this segment as well. The group discussed the need for extensive validation of all candidate algorithms, as well as the necessity for extensive sensitivity analyses and error assessments leading to clear requirements on instrument and Level 1 data calibration.

The most unique product from SMAP will be the combined active–passive 10-km global soil moisture product. The project team presented the algorithm currently under consideration, and highlighted some of the areas in need of further investigation. There were no alternate algorithm proposals for the combined use of radar and radiometer data, but there was a healthy amount of discussion on the algorithm features, biases, and plans for validation.

The next presentation focused on the algorithm for the Level 3 freeze–thaw product that will be generated at the 3-km resolution from the radar. This algorithm is relatively well established, though it hinges on the determination of an accurate threshold value for the freeze–thaw transition backscattering coefficient. The approach for pre- and post-launch studies to determine these threshold values was discussed. No alternate algorithms were presented, but discussion included the possibility of also retrieving thaw depth from the radar data.

Level 4 Data Products

Level 4 data products (all products preceded by "L4" in **Table 1**) are value-added geophysical products generated from the Level 3 surface products through data assimilation or other physics-based ecosystem models. The team presented the Level 4 root zone soil moisture algorithm currently under consideration and opened the floor for discussion. No alternate algorithms were proposed. (The mission team responsible for this product had already sent a detailed description of their algorithms to several members of the science community for review and feedback, which were incorporated into the presentation.) The major areas in need of further investigation were the validation approach as well as which Level 3 products (active only, passive only, or combined active–passive) would be most suitable as inputs to the Level 4 model.

The next presentation described the proposed Level 4 carbon product (net ecosystem exchange of CO_2). (The model for this product had also gone through a community review prior to the workshop, and comments from reviewers were incorporated into the presentation.) Discussions on this product centered on the need for well-planned validation campaigns, initializing model parameters through pre- or post-launch activities, and whether it is more suitable to use Level 3 or Level 4 soil moisture products as inputs to the Level 4 carbon product. No alternate algorithms were presented.

Finally, there was a proposal for another data product from the high-resolution radar data—namely, a map of the *Faraday rotation angle* caused by the ionosphere. Such a map can be used directly to obtain the total electron content in the ionosphere, which has applications in many areas of science including space weather. The mission team is currently evaluating whether or not this product will be included in the final suite of standard mission products.

Moghaddam concluded the Algorithms portion of the workshop with a summary of all of the discussions, alternate algorithms, and requests for further investigation brought forward by the attendees. A follow-on workshop has been tentatively suggested to be held in the Washington, DC area on March 5, 2010 (following the MicroRad 2010 conference).

All members of the science community interested in joining the SMAP algorithm discussion are encouraged to join the SMAP Algorithms Working Group by sending an email to Mahta Moghaddam at *mmoghadd@umich.edu*.

Calibration & Validation Workshop

After the conclusion of the Algorithms portion of the meeting at noon on Day 2, **Tom Jackson** [U.S. Department of Agriculture (USDA) Agriculture Research Service (ARS)—*Workshop Co-chair*] led the remainder of the workshop that focused on SMAP calibration/validation (Cal/Val) needs. Expectations for the Cal/Val Workshop were to:

- solicit comments on the approach and scope of the Cal/Val plan;
- identify ATBD requirements for Cal/Val and assign priorities;
- start the process of developing specific plans for mission product validation with a focus on establishing infrastructure;
- discuss opportunities for international cooperation/participation ;
- identify key elements of near-term field experiments; and
- develop a strategy for longer range experiment plans

Workshop presentations consisted of invited talks by experts and SMAP Science Definition Team (SDT) members as well as a number of valuable short contributions from SMAP Cal/Val working group members from the broader science community.

The Cal/Val workshop began with an overview of the preliminary Cal/Val Plan and activities that will contribute to mission objectives during both the SMAP pre- and post-launch periods. Concepts and definitions developed by the Committee on Earth Observation Satellite's (CEOS) Working Group on Calibration and Validation and the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission were integrated into the SMAP Plan.

The drivers for Cal/Val during pre-launch are: (1) the activities necessary for the development and implementation of the highest quality algorithms; and (2) establishing the infrastructure for post-launch validation. A key issue that was identified in this portion of the workshop was the recognition of the timeliness of Cal/Val activities if they are to meet the objectives and timelines of the project and Cal/Val Plan. Pre-launch data collection will have the greatest value early in the algorithm development and selection process. Post-launch Cal/Val focuses on the period 2–14 months after launch.

One of the reasons for combining the Algorithms and Cal/Val Workshops into a single meeting was to facilitate the transmission of the needs and priorities, especially pre-launch, identified by the algorithm teams to Cal/Val planning. Therefore, one of the first issues on the Cal/Val workshop agenda was a review and compilation of the research activities identified by the mission product Algorithm Theoretical Basis Documents (ATBDs) that will require additional data collection.

Post-launch ground-based *in situ* validation was the dominant topic of conversation for this portion of the workshop. Initial discussion focused on exploiting existing resources in the U.S. (or available from international organizations) that have soil moisture as a primary observation. Attendees heard presentations on the existing USDA Soil Climate Analysis Network (SCAN) [**Garry Schaeffer,** USDA Natural Resources Service]; the NOAA Climate Reference Network [**Tim Wilson**, NOAA Air Resources Laboratory]; the Oklahoma Mesonet [**Jeff Basara**, Oklahoma Climatological Survey]; and USDA Agricultural Research Service watershed networks [**Mike Cosh**, USDA ARS]. Two other potential networks were also described, the COSmic-ray Soil Moisture Observing System (COSMOS) [**Marek Zreda**, University of Arizona] and the GPS Reflectometer (GPSR) [**Eric Small**, University of Colorado]. **John Kimball** [University of Montana] described the existing meteorological networks that are the primary source of *in situ* data for freeze–thaw detection. Subsequent discussions identified additional resources and watershed sites and these will be evaluated in the near future.

A distinguishing feature of all of these existing data networks is their generally low density of observations. With the exception of the ARS watersheds, the current networks are data sparse with no more than a single measurement location within a SMAP product grid cell or footprint. Because of soil moisture's inherent spatial variability, this is a major issue for soil moisture validation for a space mission like SMAP. The low measurement density is less critical for SMAP's freeze–thaw product. Several presentations discussed methodologies for scaling point observations to grid cells/footprints. These included Replication and Variability [**Jay Famiglietti**, University of California, Irvine], Temporal Stability [**Mike Cosh**], Enhanced Temporal Stability [**Binayak Mohanty**, Texas A&M University], and Model Enhanced Approaches [**Wade Crow**, USDA ARS]. From these presentations and discussions, a working group (to be led by **Wade Crow**) was established to develop a general strategy for scaling points and to conduct intercomparisons and exploratory field studies.

Another issue regarding the various *in situ* resources, particularly for soil moisture, is the diversity of protocols that are used to make the measurements. Different sensor technologies, installations, depths, integrating depths, and soil volumes are involved. It would be advantageous to integrate the various resources through standardization and cross-comparison. As a first step in this process, a working group (to be led by **Mike Cosh**) was established to initiate the development of *in situ* instrument test beds. At these sites the various instruments utilized by networks would be installed and compared to reference soil moisture. These analyses would facilitate our understanding of the utility of each data source in subsequent calibration/validation activities.

Although valuable, these sparse networks cannot meet all of the needs of SMAP mission Cal/Val. Therefore, SMAP will also need to establish a number of core validation sites. As successfully employed in other satellite programs, these sites would be well-characterized and represent locations with local infrastructure and support. In the case of soil moisture, an important feature is the availability of a statistically significant number of measurement sites within a SMAP product grid cell/footprint. **Tom Jackson** discussed the design of an optimal validation site for soil moisture, and **John Kimball** covered this aspect for freeze–thaw. A baseline set of requirements and candidate sites were discussed with the understanding that these would be refined following the workshop.

SMAP Cal/Val can also benefit from international participation and contributions. Since SMAP will produce global products, the Cal/Val Plan should attempt to include diverse surface conditions and climates throughout the world. **Tom Jackson** led a discussion of this topic. It was noted that there are several ongoing soil moisture validation programs, specifically

continued on page 49

NASA Satellites Unlock Secret to Northern India's Vanishing Water

Gretchen Cook-Anderson, NASA Earth Science News Team, gretchen.cook-anderson@nasa.gov

Beneath northern India's irrigated fields of wheat, rice, and barley ... beneath its densely populated cities of Jaiphur and New Delhi, the groundwater has been disappearing. Halfway around the world, hydrologists, including **Matt Rodell** of NASA, have been hunting for it.

Where is northern India's underground water supply going? According to Rodell and colleagues, it is being pumped and consumed by human activities—principally to irrigate cropland—faster than the aquifers can be replenished by natural processes. They based their conclusions—published in the August 20 issue of *Nature*—on observations from NASA's Gravity Recovery and Climate Experiment (GRACE).

"If measures are not taken to ensure sustainable groundwater usage, consequences for the 114 million residents of the region may include a collapse of agricultural output and severe shortages of potable water," said Rodell, who is based at NASA's Goddard Space Flight Center.

Groundwater comes from the natural percolation of precipitation and other surface waters down through Earth's soil and rock, accumulating in *aquifers*—cavities and layers of porous rock, gravel, sand, or clay. In some of these subterranean reservoirs, the water may be thousands to millions of years old; in others, water levels decline and rise again naturally each year.

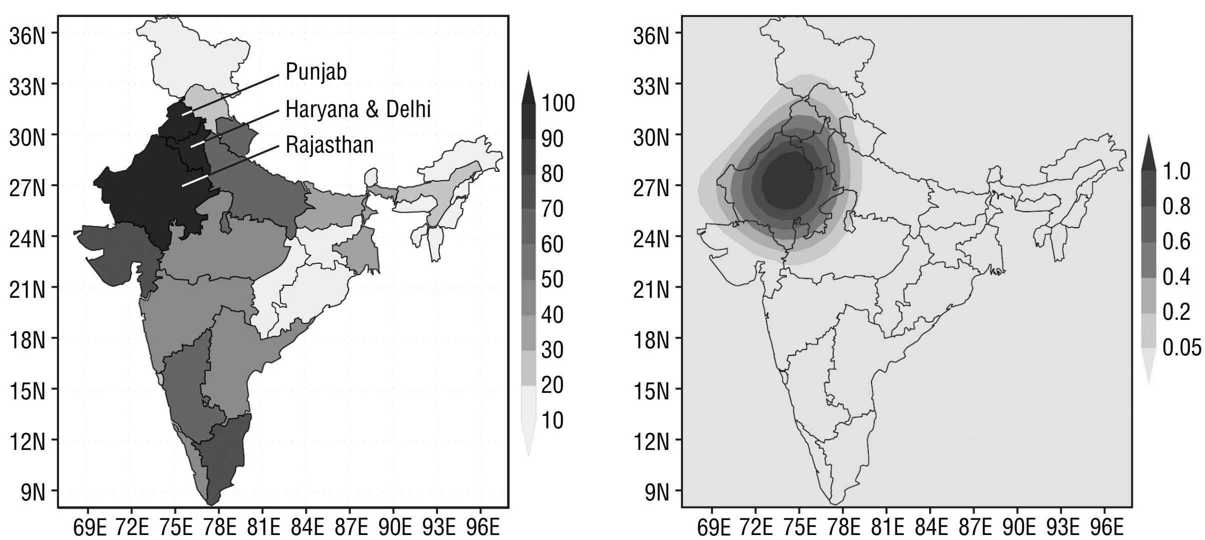
Groundwater levels do not respond to changes in weather as rapidly as lakes, streams, and rivers do. So when groundwater is pumped for irrigation or other uses, recharge to the original levels can take months or years.

Changes in underground water masses affect gravity enough to provide a signal, such that changes in gravity can be translated into a measurement of an equivalent change in water.

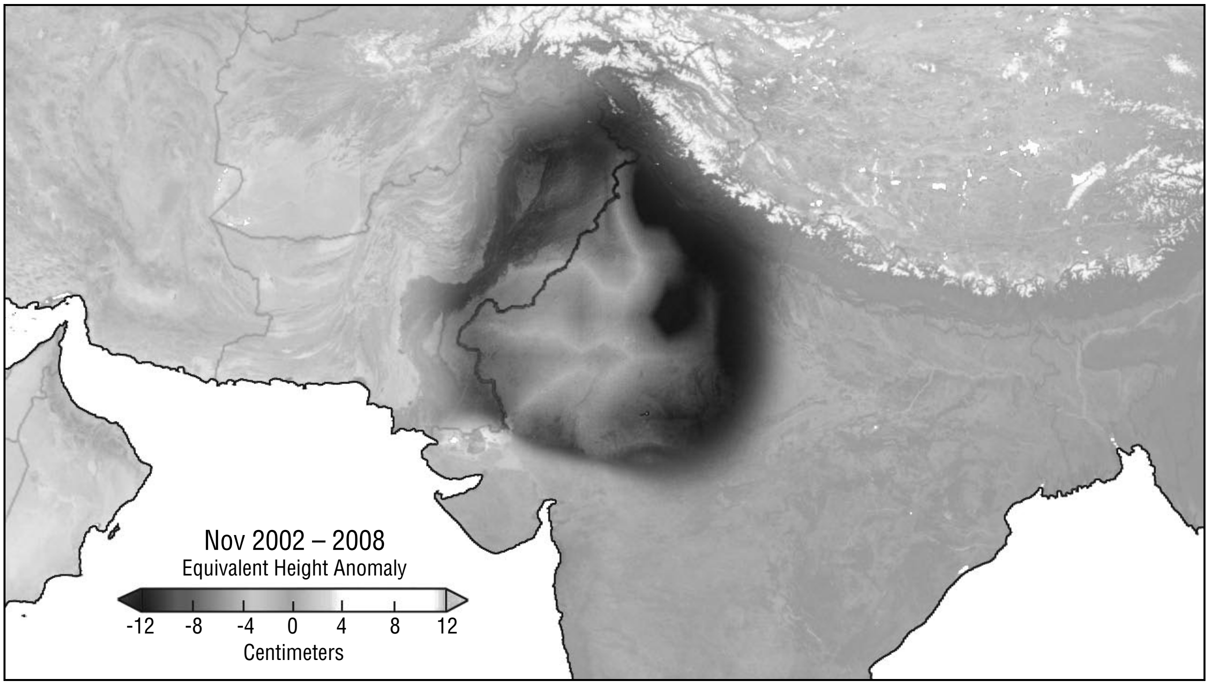
"Water below the surface can hide from the naked eye, but not from GRACE," said Rodell. The twin satellites of GRACE can sense tiny changes in Earth's gravity field and associated mass distribution, including water masses stored above or below Earth's surface. As the satellites orbit 300 mi (482 km) above Earth's surface, their positions change—relative to each other—in response to variations in the pull of gravity. The satellites fly roughly 137 mi (220 km) apart, and microwave ranging systems measure every microscopic change in the distance between the two.

With previous research in the United States having proven the accuracy of GRACE in detecting groundwater, Rodell and colleagues **Isabella Velicogna**, of NASA's Jet Propulsion Laboratory and the University of California-Irvine, and **James Famiglietti**, of UC-Irvine, were looking for a region where they could apply the new technique.

"Using GRACE satellite observations, we can observe and monitor water changes in critical areas of the



The map on the left, shows groundwater withdrawals as a percentage of groundwater recharge, based on state-level estimates of annual withdrawals and recharge reported by India's Ministry of Water Resources. The three states included in this study are labeled. The map on the right shows the averaging function (spatial weighting) used to estimate terrestrial water storage changes from GRACE data. Darker shades indicate greater sensitivity to terrestrial water storage changes. To view these images as a color please visit: *www.nasa.gov/topics/earth/features/india_water.html* **Credit:** NASA/Matt Rodell.



Groundwater storage varied in northwestern India between 2002 and 2008, relative to the mean for the period. These deviations from the mean are expressed as the height of an equivalent layer of water, ranging from -12 cm (darkest shades) to 12 cm (lightest shades). To view this information as a color animation please visit: *www.nasa.gov/topics/earth/features/india_water.html* **Credit:** NASA/Trent Schindler and Matt Rodell.

world, from one month to the next, without leaving our desks," said Velicogna. "These satellites provide a window to underground water storage changes."

The northern Indian states of Rajasthan, Punjab, and Haryana have all of the ingredients for groundwater depletion: staggering population growth, rapid economic development and water-hungry farms, which account for about 95% of groundwater use in the region.

Data provided by India's Ministry of Water Resources suggested groundwater use was exceeding natural replenishment, but the regional rate of depletion was unknown. Rodell and colleagues had their case study. The team analyzed six years of monthly GRACE gravity data for northern India to produce a time series of water storage changes beneath the region's land surface.

They found that groundwater levels have been declining by an average of one foot per year (one meter every three years). More than 26 mi^3 (109 km^3) of groundwater disappeared between 2002 and 2008—double the capacity of India's largest surface water reservoir, the Upper Wainganga, and triple that of Lake Mead, the largest man-made reservoir in the United States.

"We don't know the absolute volume of water in the Northern Indian aquifers, but GRACE provides strong evidence that current rates of water extraction are not sustainable," said Rodell. "The region has become dependent on irrigation to maximize agricultural productivity, so we could be looking at more than a water crisis."

The loss is particularly alarming because it occurred when there were no unusual trends in rainfall. In fact, rainfall was slightly above normal for the period.

The researchers examined data and models of soil moisture, lake and reservoir storage, vegetation and glaciers in the nearby Himalayas, in order to confirm that the apparent groundwater trend was real. Nothing unusual showed up in the natural environment.

The only influence they couldn't rule out was human.

"At its core, this dilemma is an age-old cycle of human need and activity—particularly the need for irrigation to produce food," said **Bridget Scanlon**, a hydrologist at the Jackson School of Geosciences at the University of Texas in Austin. "That cycle is now overwhelming fresh water reserves all over the world. Even one region's water problem has implications beyond its borders."

"For the first time, we can observe water use on land with no additional ground-based data collection," Famiglietti said. "This is critical because in many developing countries, where hydrological data are both sparse and hard to access, space-based methods provide perhaps the only opportunity to assess changes in fresh water availability across large regions."

Honey Bees Turned Data Collectors Help Scientists Understand Climate Change

Adam Voiland, NASA Earth Science News Team, avoiland@sesda2.com

Estimates are that there are somewhere between six and ten million species of insects on the planet, yet few are as charismatic as the honey bee.

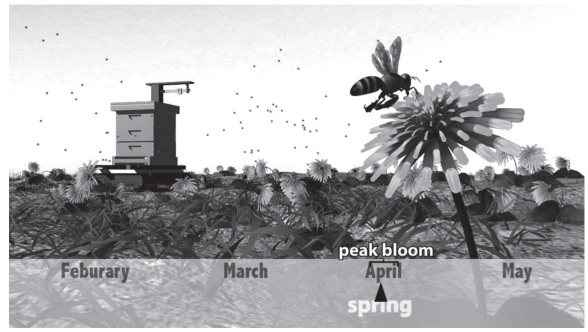
Part of an order of winged insects called *Hymenoptera*, honey bees are best known for being prodigious producers of honey, the sweet amber substance they produce by partially digesting and repeatedly regurgitating the sugar-rich nectar found within the petals of flowering plants. They're also the workhorses of the modern industrial agricultural system, relied upon to pollinate crops ranging from almonds to watermelons to peaches. And they're even noted dancers capable of performing an array of complex "waggle" dances to communicate.

And now—thanks to an innovative project conceived by **Wayne Esaias**, a veteran oceanographer at NASA's Goddard Space Flight Center—bees have yet another role: that of climate data collectors.

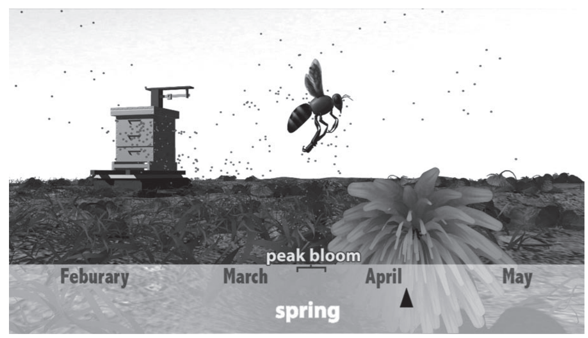
When honey bees search for honey, colony scouts tend to scour far and wide and sample the area around a hive remarkably evenly, regardless of the size of the hive. And that, Esaias explained, means they excel in keeping tabs on the dynamics of flowering ecosystems in ways that even a small army of graduate students can not.

The key piece of data bees collect relates to the nectar flow, which in the mid-Atlantic region tends to come in a burst in the spring. Major nectar flows, typically caused by blooms of tulip-poplar and black locust trees, leave an unmistakable fingerprint on beehives—a rapid increase in hive weight sometimes exceeding 20 lbs/day. When a nectar flow finishes, the opposite is true: hives start to lose weight, sometimes by as much as a pound a day.

Wayne Esaias, a NASA scientist, records the weight data of one of his beehives. Esaias is investigating beehives' seasonal cycle of weight gain and loss and relating that to satellite data showing vegetation change to better understand the impact of climate change on pollinators and the flowering plants they frequent. **Credit:** Elaine Esaias.



Nector flows are changing in all parts of the country. If pollination dates keep creeping forward plants and pollinators could get out of sync. Currently young bees are able to grow and get out on the hunt by the time plants are in bloom.



If plants bloom before bees are ready, plants won't get pollinated and bees go hungry. To view these images as a color video please visit: *www.nasa.gov/topics/earth/features/beekeepers.html* **Credit:** NASA.

By creating a burgeoning network of "citizen scientists" who use industrial-sized scales to weigh their hives each day—*HoneyBeeNet*—Esaias aims to quantify the dynamics of nectar flow over time. Participating beekeepers send their data to Esaias who analyzes it, and posts nectar flow trend graphs and other environmental data for each collection site on HoneyBeeNet's webpage.

The size of *HoneyBeeNet*, which relies almost entirely on small-scale backyard beekeepers, has doubled over the last year and now includes more than 87 data collection sites. While the majority of sites are in Maryland, *HoneyBeeNet* now has sites in more than 20 states.

Data from the network, when combined with additional data that reach back to the 1920's, indicate that the timing of spring nectar flows have undergone extraordinary changes. "Each year, the nectar flow comes about a half-day earlier on average," said Esaias. "In total, since the 1970s, it has moved forward by about month in Maryland."

Esaias and Goddard colleague Robert Wolfe recently compared nectar flow data from *HoneyBeeNet* to satellite data that measures the annual "green up" of vegetation in the spring, one of the first times that scientists have attempted such a comparison. They corresponded nearly perfectly, confirming the usefulness of the citizen-science derived data from HoneyBeeNet to address changes in nectar flows.

What's to blame for the remarkable warming trend in Maryland? Washington's growth has certainly played a role. Urban areas, explained Esaias, produce a "heat island" effect that causes temperatures in surrounding areas to creep upward. But, in addition to that, Esaias suspects that climate change is also contributing.

And that has him nervous. "A month is a long time. If this keeps up, and the nectar flows continue to come earlier and earlier, there's a risk that pollinators could end up out of sync with the plant species that they've pollinated historically," Esaias said.

He's not the only researcher who's looking at this issue. The National Academies of Science published a landmark report in 2007 that highlighted the precarious status of pollinators in North America.

Many pollinators—ranging from honey bees, to bumble bees, to lesser known species seem to be in the midst of protracted population declines. Managed honey bee colonies, for example, have seen their numbers fall from about 5.9 million in 1947 to just 2.4 million in 2005.

In most cases, it isn't clear what's causing the population declines or whether climate change is exacerbating the problem, though many researchers suspect that new types of viruses, mites, and other parasites and pesticides are important factors.

"But it's not just the honey bees that we need to be looking at," said **May Berenbaum**, an ecologist at the University of Illinois at Urbana–Champaign and the lead author on the National Academies report. "For honey bees, at least we can truck them around or feed them when there's a problem. It's the wild species of pollinators that are the greatest cause for concern."

Bumblebees, wasps, butterflies, and countless other insects—as well as some bats and birds—are the glue that keeps many wild ecosystems intact through pollination. And scientists are only beginning to comprehend the potential consequences that could unfold if the pollinators and the plants that rely on them get so far out of sync that extinctions begin to occur.

"To borrow an old analogy that **Paul Ehrlich** often used, with the wild pollinators, losing a species is a bit like losing screws in a plane" said Berenbaum. "If you lose a few here or there, it's not the end of the world, and your plane can still fly. But if you lose too many, at some point, the whole plane can suddenly come apart in mid-flight."

Indeed, entomologists have hardly begun the task of identifying wild pollinators, not to mention determining definitely which species are threatened or how they might respond as the climate shifts. Esaias' research offers hints about how bees might respond to climate change. Still, scientists estimate that there are more than 30,000 different bee species alone, and only about half of them have been formally described.

Though just a proverbial drop in the honey bucket, *HoneyBeeNet* is one way that citizens can help scientists better understand how climate change is affecting one species of pollinator. **Alice Parks**, a backyard beekeeper from West Friendship, MD, has participated for two years. She bought a used scale for just $26 at an auction, and weighs her hive every night.

"Weighing can be a chore sometimes," she said. "But it's such an incredibly rewarding project that it's worth it. I'm learning so much about my bees that's making me a better beekeeper, but I'm also contributing to a larger project that's helping scientists address environmental problems on a global scale."

A beehive in West Friendship, MD, sits atop a scale. Once a day, the hive's owner, a backyard beekeeper, measures the hive's weight, which increases significantly during nectar flows in the spring.
Credit: Brent Parks.

EOS Scientists in the News

Kathryn Hansen, NASA Earth Science News Team, khansen@sesda2.com

The 800-Pound Gorilla, June 25; *Discovery News, Earth Pub*. In the face of rising temperatures in the atmosphere and the oceans at high latitudes, there are signs that the Greenland gorilla is waking, and **Waleed Abdalati** (NASA GSFC) describes the impact of melting Arctic ice and, more specifically, changes to the Jakobshavn Glacier.

Wayne Esaias on Honeybee Behavior, June 29; EarthSky. **Wayne Esaias** (NASA GSFC) spoke to EarthSky about using skills honed as a NASA scientist on his current project, collecting and analyzing climate change data as indicated in the behavior of bees—See page 46 in this issue of *The Earth Observer* for the story.

L.A. is Set to Record a Fourth Straight Year with Below-Average Rainfall, June 30; *Los Angeles Times*. Despite a gloomy June, Los Angeles was poised at the end of the month to record its fourth year in a row with below-normal rainfall—from July 1, 2008 to June 20, 2009, a period designated as a "rain year," only about 9 in of rain fell in Los Angeles compared to an average of slightly more than 15 inches, according to **Bill Patzert** (NASA JPL).

L.A. From Space: New View From JPL and NASA, June 30; *Los Angeles Times*. NASA scientists led by **Michael Abrams** (NASA JPL), in collaboration with agencies in Japan, have put together a topographical map that covers 99% of Earth's land mass, a more complete map than was previously available.

Hand-Held Devices That Can Detect Presence of Aerosols in Air Above Oceans, June 30; *Asian News International*. A team of scientists including **Alexander Smirnov** (NASA GSFC) is developing hand-held devices that can detect the presence of aerosols in air above oceans by measuring how light scatters as it strikes the particles.

New Map Shows 99% of Earth's Terrain, July 1; *CNN, Going Green*. NASA and Japan's Ministry of Economy, Trade and Industry have released a new digital topographic map of Earth that accurately portrays more of our planet than ever before, and **Woody Turner** (NASA HQ) and **Michael Kobrick** (NASA JPL) explain how the new map improves upon similar previous maps.

NASA Satellites Reveal Extent of Arctic Sea Ice Loss, July 8; *Guardian*. Scientists including **Ron Kwok** (NASA JPL) show in a new study that the Arctic Ocean's permanent blanket of ice around the North Pole has thinned by more than 40% since 2004, and the results could force experts to reassess how quickly the Arctic ice in the summer may disappear completely.

El Niño's Coming, and it May Mean More California Rain, July 17; *The Sacramento Bee*. **Bill Patzert** (NASA JPL) believes the Pacific Decadal Oscillation, a different ocean temperature pattern, is interacting with, and weakening, the developing El Niño—a relaxation of trade winds that can alter global weather patterns, which is of interest to Californians because it can bring higher-than-normal winter precipitation to that region.

A Less Shady Future: Could Climate Change Mean Fewer Clouds? July 23; *Scientific American*. **Anthony Del Genio** (NASA GISS) notes that the relationship between clouds and climate is currently not well understood, as a new study led by the University of Miami is trying to piece together the complicated dynamic.

Seawater Gets a New Definition, July 27; *Scientific American*. A new definition of seawater, which accounts for more accurate assessments of salinity and other crucial properties, will be "important in the long run," according to **Gary Lagerloef** (Earth & Space Research), who is leading NASA's Aquarius satellite mission to measure ocean salinity from space.

World Will Warm Faster Than Predicted in Next Five Years, Study Warns, July 27; *Guardian*. New research carried out by **Judith Lean** (U.S. Naval Research Laboratory) and **David Rind** (NASA GISS) assesses the combined impact on global temperature of four factors—human influences such as CO_2 and aerosol emissions; heating from the sun; volcanic activity and the El Niño Southern Oscillation—and finds that the world could face record-breaking temperatures in coming years.

In Quest for Efficiency and Conservation, NASA Turns Technology Earthward, August 7; *The New York Times, Green Inc*. As part of a partnership with the city of Los Angeles and the Los Angeles Department of Water and Power, NASA's Jet Propulsion Laboratory will repurpose technology developed to explore the cosmos and monitor Earth's environment, and **Charles Elachi** (NASA JPL) explains how that technology can be used to inform decision makers about energy, water and natural hazards.

Ozone is a Long-Range Killer, August 13; *New Scientist*. More than 20,000 lives a year could be saved if major industrial regions cut their emissions of ozone-triggering gases by a fifth, a new study found, and study co-author **Drew Shindell** (NASA GISS) notes that many of those impacted live in Europe—the destination of ozone pollution carried by prevailing winds from the U.S.

India's Water use 'Unsustainable,**'** August 13; *BBC News.* Parts of India are on track for severe water shortages, according to scientists including **Matt Rodell** (NASA GSFC) who used a NASA gravity satellite to discover that in the country's north-west—including Delhi—the water table is falling by about 4 cm/yr—See page 44 in this issue of *The Earth Observer* for the story.

NASA Drops "Spiders" Into Volcano, August 13; *National Geographic News.* **Steve Chien** (NASA JPL) and **Sharon Kedar** (NASA JPL) are among the scientists using high-tech devices placed inside and around the mouth of Mount St. Helens in the hopes they can detect an impending eruption.

Of Farming, Methane Bubbles, and Antarctic Glaciers, August 21; *The Christian Science Monitor, Bright Green Blog.* In a new study, scientists warned that the Pine Island Glacier in West Antarctica is shedding ice four times faster than a decade ago, and earlier this year, **Robert Bindschadler** (NASA GSFC) told Yale's environment360 magazine that the Pine Island Glacier now flows into the sea at a rate of 1 ft/hr, 50% faster than five years ago.

SMAP Algorithms & Calibration/Validation Workshop

continued from page 43

those associated with SMOS and the Japanese Global Change Observation Mission—Water (GCOM-W), which could evolve into SMAP core sites or network resources. It was recommended that a mechanism for engaging these groups through a formal unfunded agreement, similar to that employed by SMOS Cal/Val, be pursued in cooperation with NASA HQ.

Current and future satellite data will play a significant role in both pre-launch and post-launch Cal/Val. During the ATBD presentations, the leads described what data would be of value for each product. **Yann Kerr** [Center Nationale d'Etudes Spatiales] discussed SMOS data availability and Cal/Val interaction with SMAP. **David LeVine** [NASA GSFC] provided presentation material on Aquarius and **Toshio Koike** [University of Tokyo] on GCOM-W. **Craig Dobson** [NASA HQ] described opportunities that could be pursued with the Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) mission—another proposed Decadal Survey mission.

The final topic of presentations/discussions was planning for upcoming field experiments. As noted earlier, timeliness is critical if the data are to be fully exploited by the SMAP project. Of immediate concern was striking a balance between this issue and the logistics and careful planning of a costly field campaign. At the time of the workshop, the launch date of SMAP was under revision from first-quarter 2013 to first-quarter 2014. A basic question was whether to plan the next experiment for 2010 or 2011. Factors considered were the lead-time for conducting a fully comprehensive science experiment, the readiness of aircraft simulators, and the launch dates of valuable satellite resources (e.g., SMOS and Aquarius). The general consensus was to move forward with tower-based and limited aircraft experiments (pending opportunities and priorities) for 2010 and to plan the major campaign for 2011. Opportunities supported by collaborators should also be fully exploited in 2010, such as a series of aircraft experiments planned for Australia [Jeff Walker, University of Melbourne].

Longer range and post-launch planning will be addressed at future meetings. Follow-on meetings will be scheduled to move forward on both the core site issue and the 2010/2011 field campaigns.

All members of the science community interested in joining the SMAP Cal/Val discussion are encouraged to join the SMAP Calibration/Validation Working Group by sending an email to Tom Jackson at *tom.jackson@ars.usda.gov.*

NOTE: The SMAP mission has established four working groups to facilitate community engagement with the mission science. These include: 1) Algorithms Working Group; 2) Cal/Val Working Group; 3) Applications Working Group; and 4) Radio-Frequency Interference Working Group. The calendar of future working group workshops as well as the contact information for each Working Group Lead are posted on the SMAP web site at: *smap.jpl.nasa.gov/science/.*

NASA Science Mission Directorate – Science Education Update

Ming-Ying Wei, mwei@hq.nasa.gov, NASA Headquarters
Liz Burck, Liz.B.Burck@nasa.gov, NASA Headquarters
Theresa Schwerin, theresa_schwerin@strategies.org, Institute of Global Environment and Society (IGES)

A Day at Goddard: Opportunity for DC Metro Teachers (Grades 8-12)

Teachers in the DC Metro area are invited to bring their students to NASA Goddard Space Flight Center for a day spent learning what it is like to work for NASA. Field trips begin with a meet-and-greet at the visitor's center featuring a scientist and engineer. Students will also see the *Science on a Sphere* program. After lunch the group is invited into the Center to tour the satellite testing facility and conduct an inquiry based science lab activity. Programs are highly customizable, teacher-friendly and designed for grades 8-12. Contact Aleya Van Doren with your desired date and class information to reserve your spot at *aleya.vandoren@nasa.gov.* Slots fill up quickly so register today!

GLOBE Africa Student Research Expedition

The GLOBE Africa Regional Consortium will host a student scientific research expedition to the summit of Mount Kilimanjaro in Tanzania, Africa September 24 though October 2. Students will create a "classroom on the mountain," installing permanent soil monitoring equipment at various elevations on the mountain to provide valuable ground temperature data. This will allow scientists and students from around the world to conduct research on environmental change taking place on Mt. Kilimanjaro. The growth of GLOBE activities in Africa has been made possible largely through NASA's support of the program. In appreciation, the GLOBE Africa Regional Consortium has invited NASA GLOBE Program Officer, **Ming Ying Wei**, to plant the NASA and GLOBE flags on the summit of Mt. Kilimanjaro. To learn more about GLOBE Africa visit: *www.globe-africa.org/*.

Laboratory Earth: Online Science Courses for K-12 Educators

Laboratory Earth is a series of three credit graduate level courses designed for K-12 educators. The courses are offered online through the University of Nebraska, Lincoln. They are application and inquiry-based, module-based, and aim to improve Earth science content knowledge. Upcoming courses include:

- NRES 809 Laboratory Earth: Earth and Its Systems (Offered Fall Semesters)
- NRES 822 Laboratory Earth: Earths Changing Systems (Offered Summer 2009)
- NRES 898 Laboratory Earth: Earth & Geospatial Technology (Offered Summer 2009)

Apply online at *www.unl.edu/gradstudies/*. For more information contact Cindy Larson–Miller at *clarsonmiller2@unl.edu*.

Solar Dynamics Observatory (SDO) Ambassador in the Classroom

Let NASA take over your classroom for the day! Teachers in the DC Metro area and southern Pennsylvania are eligible for a visit from an SDO educator or scientist. Your students will learn about solar clocks, Earth's place in the solar system, electricity, and magnetism, the electromagnetic spectrum, and the Doppler effect. Visits are free, include all supplies for the activity, and can be customized for each teacher. Register at: *sdo.gsfc.nasa.gov/epo/educators/ambassador.php*.

International Year of Planet Earth & Earth Science Week 2009 Photography Contest

Entries due October 16

To celebrate the International Year of Planet Earth and Earth Science Week 2009, the American Geological Institute is sponsoring a major international photography contest. Photographs should focus on the topic *Exploring Earth Science Around the World*. The contest is open to anyone of any age from anywhere around the world. Entries must be submitted electronically. Go to: *www.earthsciweek.org/contests/iypephotocontest/index.html.* ■

EOS Science Calendar

November 3–5
CERES Science Team Meeting, Fort Collins, CO.
URL: *science.larc.nasa.gov/ceres/meetings.html*

November 3–5
HDF-EOS Workshop XIII: Closing the Gap—Harnessing the Power of HDF Through Established Technologies. URL: *hdfeos.net/workshops/ws13/workshop_thirteen.php*

November 5–6
GRACE Science Team Meeting, Austin, TX.
URL: *www.csr.utexas.edu/grace/GSTM/*

January 19–21, 2010
Landsat Science Team Meeting, NASA Ames Research Center, Moffett Field, CA.

October 27–29, 2010
Landsat "Specialists" Meeting, Boston, MA.

Global Change Calendar

October 18–21
Geological Society of America Annual Meeting, Portland, OR. URL: *www.geosociety.org/meetings/2009/*

November 3–5
6th GOES Users' Conference, Monona Terrace Convention Center, Madison, Wisconsin. Contact: *Dick.Reynolds@noaa.gov* or *james.gurka@noaa.gov*
URL: *cimss.ssec.wisc.edu/goes_r/meetings/guc2009*

November 13–14
GEOSS Workshop XXXI, Washington, DC.
URL: *www.ieee-earth.org/Conferences/GEOSSWorkshops*

December 14–18
American Geophysical Union Fall Meeting, San Francisco, CA. URL: *www.agu.org/meetings/fm09/*

December 7-18
United Nations Climate Change Conference (COP-15) Copenhagen, Denmark. URL: *en.cop15.dk/*

January 17-21, 2010
American Meteorological Society Meeting Atlanta, GA
URL: *www.ametsoc.org/MEET/annual/*

Code 610
National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

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

(affix mailing label here)

eos.nasa.gov

The Earth Observer

The Earth Observer is published by the EOS Project Science Office, Code 610, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, telephone (301) 614-5561, FAX (301) 614-6530, and is available on the World Wide Web at *eospso.gsfc.nasa.gov/eos_homepage/for_scientists/earth_observer.php* or by writing to the above address. Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address.

To subscribe to *The Earth Observer*, or to change your mailing address, please call Steve Graham at (301) 614-5561, or send a message to *Steve.Graham@nasa.gov*, or write to the address above. If you would like to stop receiving a hard copy and be notified via email when future issues of *The Earth Observer* are available for download as a PDF, please send an email with the subject **"Go Green"** to *Steve.Graham@nasa.gov*. Your name and email address will then be added to an electronic distribution list and you will receive a bi-monthly email indicating that the next issue is available for download. If you change your mind, the email notification will provide an option for returning to the printed version.

The Earth Observer Staff

Executive Editor: Alan Ward (*award@sesda2.com*)

Assistant Editor: Nicole Miklus (*nmiklus@sesda2.com*)

Technical Editors: Tim Suttles (*4suttles@bellsouth.net*)
Chris Chrissotimos (*cchrissotimos@sesda2.com*)

Design, Production: Deborah McLean (*Deborah.F.McLean@nasa.gov*)