National Aeronautics and Space Administration

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Editor's Corner

Steve Platnick
EOS Senior Project Scientist – Acting

I'm pleased to report another milestone for the Landsat program. We reported in our last issue that March marked the 25th anniversary of the launch of Landsat 5, and now, on April 15, Landsat 7 celebrated the 10th anniversary of its launch. The Landsat 7 mission operated flawlessly until May 2003 when a hardware component failure left wedge-shaped spaces of missing data on either side of the image. Despite the resulting loss of 22% of the image data from in each scene, Landsat 7 data continues to be highly useful. The excellent data quality, consistent global archiving scheme, and now free data of Landsat 7 are hallmarks of its impressive tenure. Both Landsat 5 and 7 have far exceeded their design life and continue to provide vital images of Earth's land surface. Congratulations to the Landsat Team on yet another remarkable milestone for the program! You can read a summary of the most recent Landsat Science Team meeting on page 27 of this issue. The summary contains updates on the current Landsat missions (Landsat 5 and 7) and plans for the Landsat Data Continuity Mission (LDCM), now targeted for launch at the end of 2012.

In other news, the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite has resumed normal operations after it had to switch from its primary to its backup laser earlier this year—nearly three years after launch and after the end of its prime mission. CALIPSO's Cloud–Aerosol Lidar with

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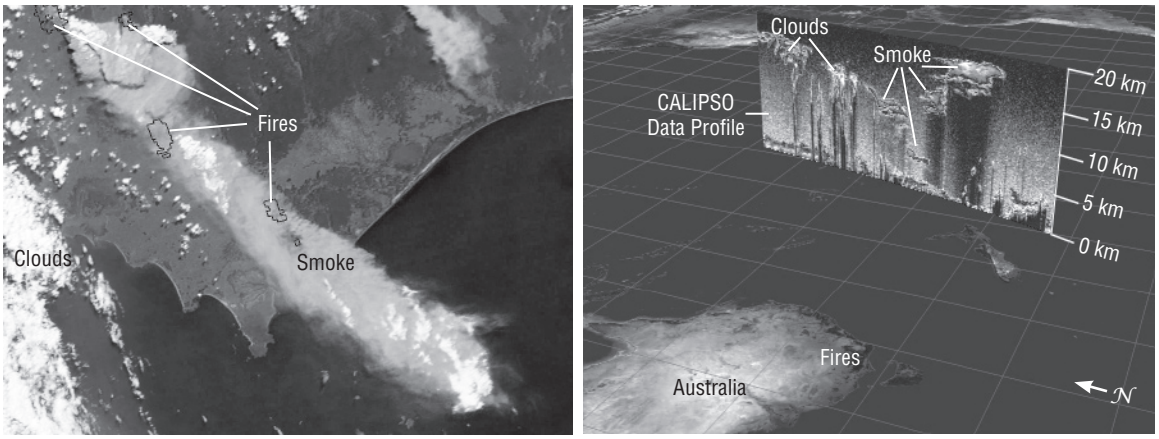


[*Left*] On February 7, 2009, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on Aqua collected this top-down view of smoke from powerful bushfires that were burning in Australia. To view image in color please visit: *rapidfire.sci.gsfc.nasa.gov/gallery/?2009038-0207* **Credit:** MODIS Rapid Response Team, NASA Goddard Space Flight Center.

[*Right*] Three days later, CALIPSO passed over the same smoke plumes that MODIS viewed. On February 10, the CALIOP lidar took a vertical "slice" of the atmosphere to see the distribution of clouds and aerosols. In this image, the CALIPSO data reveal that the smoke reached an unusually high altitude of 12 mi (20 km). The MODIS image by itself would not have revealed this detail, so this is a good example of the benefits of combined measurements made possible by the A-train formation. For more information and to view image in color please visit: *www.nasa.gov/centers/langley/news/researchernews/calipso-australia.html*. **Credit:** Chieko Kittaka, NASA's Langley Research Center.

the earth observer

editor's corner

eos.nasa.gov

In This Issue

Orthogonal Projection (CALIOP) lidar provides unique vertical profile measurement of clouds and aerosols, and is an important part of the Afternoon (or A-Train) Satellite Constellation.

The backup laser was built into CALIPSO to make it robust, in the event the primary laser became unreliable, and the wisdom of redundancy was borne out early this year. The CALIPSO team, a joint effort between NASA and the French Centre National d'Etudes Spatiales (CNES), worked together to start up the backup laser, which hadn't been used in three years. It provided its "first light" aerosol and cloud vertical profiles on March 12, 2009. CALIOP then resumed normal operations and is undergoing a calibration review now. The release of standard data products should resume in mid May, and once data are re-processed the total gap due to the switch will be about 10 days. To learn more, please see the news story on page 46 of this issue.

Early in May, the Obama Administration submitted details of its Fiscal Year 2010 (FY10) budget request to Congress, where it was proposed that NASA receive $18.686 billion—an increase of $903.6 million (~5%) above the amount provided in the FY09 Omnibus Appropriations Act. Including the $1 billion in Recovery Act (stimulus) funds, NASA's FY09-11 budget has increased $2 billion over the FY09 plan, with the Earth Science budget increasing by $1.3 billion (~19%) from FY09-13.

The budget supports Earth Science missions currently in development—Glory, Aquarius, the National Polar-orbiting Operational Environmental Satellite Preparatory Project (NPP), the Landsat Data Continuity Mission (LDCM), including development of the Thermal Infrared Instrument (TIRS), and the Global Precipitation Measurement (GPM) mission. It also accelerates development of the first four missions identified by the Decadal Survey (called *Tier 1* missions)—i.e., SMAP, ICESat II, CLARREO, and DESDynI. Funds will also help initiate another of the Decadal Survey's recommendations, namely the creation of the Venture-class program for low cost science driven missions. For more complete details on the NASA budget please visit: *www.nasa.gov/news/budget/index.html*.

Just as we have done over the years with Earth Observing System missions, *The Earth Observer* will work to chronicle the progress of the Decadal Survey missions. To that end, **Mary DiJoseph** of the Earth Systematic Missions Program Office wrote an article that appeared in our January–February 2009 issue [**Volume 21, Issue 1**, pp. 21-22], giving an overview of the *Tier 1* and *Tier 2* missions. And now in this issue we are pleased to present our first summary of a Decadal Survey-related meeting as we report on the recent CLARREO community workshop (page 37).

We encourage other missions to submit reports on their meetings and progress. In addition, the EOS Project Science Office Website (*eospso.gsfc.nasa.gov/eos_homepage/mission_profiles/index.php*) has a section on the Decadal Survey that includes links to more detailed information about each of the 15 recommended missions. The site also has a section on Venture-class missions that will be expanded as more information becomes available.

On a related note, 13 Earth Science missions are presently taking part in the 2009 Earth Science Senior Review process to determine whether, and to what extent, continued funding for extended operations are warranted. Expect to read more details about the outcome of the Senior Review in a future issue of *The Earth Observer*.

The 40th Earth Day was celebrated on April 22. NASA joined in the Earth Day festivities on the National Mall on April 19th, with more than 3000 visitors stopping by to check out NASA's Earth Science activities. NASA scientists including **Max Bernstein, Jens Feeley, Ernie Hilsenrath, Compton Tucker, Diane Wickland**, and myself answered questions and explained how NASA missions are a critical part of Earth Science research. Activity booklets and other outreach products were distributed, arming participants with information about individual Earth Science missions. With their supplies exhausted by mid-afternoon, the volunteers, who represented NASA Headquarters, Goddard Space Flight Center, and Langley Research Center, completed another successful outreach event.

In keeping with the awareness of our environmental impact that Earth Day emphasizes, we'd like to again mention our *Go Green* campaign, first brought to your attention around this time last year. Out of our 5,600 subscribers, only 168 have currently opted to *Go Green* and receive each issue electronically, rather than as a hard copy. If you'd like to participate in this option, please send an email with the subject "Go Green" to *Steve.Graham@nasa.*gov or see the back of the newsletter for more information. You'll be notified via email when each new issue is available for download. We encourage you to consider trying our *green* approach, even if just for a few issues—if you find you prefer a hard copy, you can opt out of the electronic distribution list by following an option in the bimonthly email notification. ■

On April 19, 2009, more than 3000 visitors stopped by the NASA exhibit booth to participate in Earth Science activities as part of the Earth Day celebration on the National Mall.

Winter Camp: A Blog from the Greenland Summit, Part II

Lora Koenig, NASA Goddard Space Flight Center, lora.s.koenig@nasa.gov

*In the March-April 2009 [**Volume 21**, **Issue 2**, pp. 13-17] issue of **The Earth Observer**, we presented the first half of **Lora Koenig's** experience living and working at the National Science Foundation's (NSF) Greenland Summit Camp. Koenig—a remote-sensing glaciologist at NASA's Goddard Space Flight Center—took measurements that will be used to validate data collected by NASA's Aqua, Terra, and Ice, Clouds, and land Elevation Satellite (ICESat) satellites with ground-truth measurements of the Greenland Ice Sheet she made at Summit Camp from November 2008–February 2009. **The Earth Observer** is pleased to present excerpts from the second half of her stay here; the complete blog, along with color photos, is available at: **earthobservatory.nasa.gov/Features/GreenlandBlogKoenig/**.*

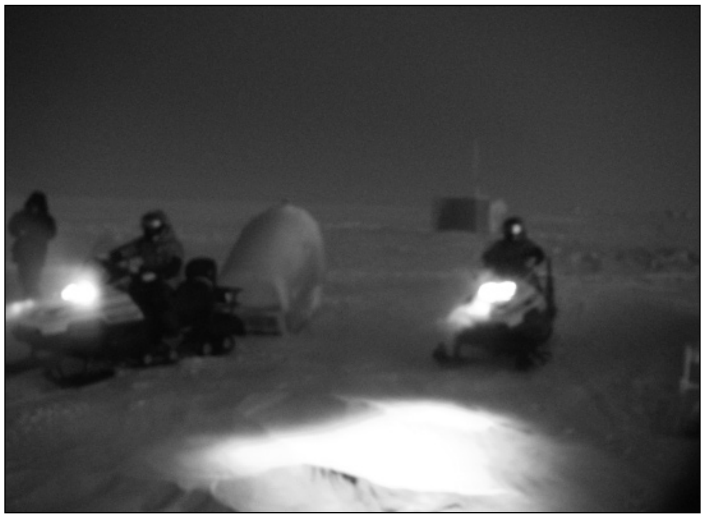
Week Eight
December 28, 2008

Temperature:
-45°C/-49°F

ICESat Transect

I hope everyone had a very Merry Christmas. Our Christmas morning started with a gift exchange and stockings. We figured we were one of Santa's first stops. Our dinner included lobster tails, mushroom fritters, German cabbage, and a chocolate cranberry tart. In the evening, the Northern Lights glowed green and swirled all the way across the sky.

Before Christmas, **Kat Huybers** and I completed one of our big monthly science tasks—a *Global Positioning Survey* (GPS) of the *ICESat transect*. The transect is a route just outside of Summit, marked by flag poles, that follows the "spots" measured by the Geoscience Laser Altimeter System (GLAS) instrument on board the ICESat satellite. In order to ground-truth the GLAS data, GPS and accumulation stake data are taken along the same transect, or ground track, of the satellite just to the north of Summit. The GPS data are corrected with the base station to give very accurate height measurements that are then compared to the satellite data. This is a very important project to make sure ICESat continues to give us good spatially-distributed science data.



Kat Huybers and Lora Koenig heading out of camp to take the GPS and accumulation measurements along the ICESat traverse line.

The transect is conducted on snowmobiles and takes us over three miles away where we often lose visual and radio contact with Summit Camp. We take two snowmobiles (in case one breaks down), hand-held radios, a satellite phone, two GPS units programmed with the camp's location, extra batteries, and a shelter sled—called the *polypod*—with two survival bags inside.

There is a flag line to follow on the ICESat transect but it is hard to see in the dark because the flags are spaced hundreds of feet apart. In the end we made it through the entire transect without losing the flag line. Had we gotten off the flag line we would have used the GPS units to lead us back to camp.

We were very happy to have completed our darkest ICESat transect. Next month finding the poles will be much easier with the additional sunlight and, hopefully, our hands will be a bit warmer.

Week Nine
January 4, 2009

Temperature:
-29°C/-22°F

The New Year and Passive Microwave Measurements

Happy New Year. The New Year brought the best weather we have seen yet at Summit Camp as well as some incredible Northern Lights. On Saturday, we saw shooting stars—the *Quadrantid* meteor shower—going through the aurora.

Kat and Lora taking *radiometer* measurements in a two meter snow pit. The radiometer measures the natural emission of the firn/snow column above. **Photo credit:** Brad Whelchel.

I took advantage of the nice weather to do a science project that had been postponed because of weather conditions. I am very interested in *passive microwave remote sensing* on the ice sheets. *Passive microwave sensors* record the natural long-wavelength energy that is emitted by the Earth. The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) is the *passive microwave sensor* on NASA's Aqua satellite (*aqua.nasa.gov/about/instrument_amsr.php*). You may have seen images from AMSR-E showing the sea-ice extent in the Arctic Ocean; this is one of the most newsworthy applications of *passive microwave remote sensing*.

Passive microwave data can also be used on the ice sheets to measure melt extent, the temperature of *firn*—snow on ice sheets that has persisted through one melt season or year old snow—and *firn* properties like grain size, grain type, and density. My project takes field measurements of how deep the passive microwave satellites measure into the *firn*. I use a *radiometer*—a sensor that records passive emission similar to sensors on-board satellites—to measure the *natural emission* of *firn*.

This weekend was the first time the temperatures were warm enough to be able to move the *radiometer* without breaking wires. The winds were low enough to ensure no blowing snow would get into the electronics of the instrument. I dug a two meter (6.6 ft) snow pit, placed the *radiometer* in the pit below a column of *firn*/snow, and measured the *radiance*. I then shortened the column of snow and measured again.

Week Ten
January 11, 2009

Temperature:
-56°C/-69°F

Our Cold Week/Answers to Some Questions

This week was downright cold—even for the Arctic! The extremely cold temperatures bring clear skies which make the few hours of light we get brighter. Our science week this week was fairly standard so I thought I would answer some questions from blog readers.

What do you do in an emergency?

If we were to have a medical emergency, we would call for a *Twin Otter* aircraft. Weather dependent, we can get a flight into Summit and to medical attention within

12–24 hours. If the generator and back up generator both died, we can use small generators to heat specific areas in camp while we wait for a plane. If all the buildings in camp were to burn down, there are emergency shelters and bags with tents, food, fuel, and stoves. If we lost all forms of communication (the Internet, phones, satellite phones, and high frequency radios), we would miss our check-in call with personnel at Kangerlussaq and would be rescued within 24 hours.

What kind of medical supplies do you have?

We always have a designated medic at Summit as well as a fully stocked medical room. **Bill McCormick** is the medic this winter. Additionally, all of us are certified Wilderness First Responders (WFRs). We have a 24-hour phone number that links us directly to a doctor. Each week we have a safety meeting where we practice our medical skills with real scenarios. These training scenarios familiarize us with our medical gear and prepare us for a real emergency.

How are the buildings heated?

The buildings are heated with electrical heaters powered by the generator, diesel furnaces, or waste heat from the generator. We have a diesel generator that we run off *AN8*—a type of propellant modified with a deicing agent for use in cold climates—to power all of camp.

Week Eleven
January 18, 2009

Temperature:
-30°C/-23°F

The NOAA Observations

Happy Birthday, Brad! On Wednesday we celebrated **Brad Whelchel's** 28th birthday with corned beef and cabbage, pasta, and a chocolate triple layer cake. Brad admits it was his coldest and darkest birthday.

Lora launching an *ozonesonde* weather balloon. The balloons this winter at Summit have been reaching heights of over 20 km before they burst and the *ozonesonde* then parachutes back to the ground. A parachute attached to the balloon helps to guide the *ozondesonde*—in the box below it—on the way down.

On Monday Kat and I launched a weather balloon to measure atmospheric ozone levels; balloons were launched from around the world at the same time. After the launch we went to the Temporary Atmospheric Watch Observatory (TAWO) tower to complete the daily checks of the National Oceanic and Atmospheric Administration (NOAA) instruments.

NOAA maintains many instruments at Summit that are taking *baseline* observations of atmospheric conditions. These observations are used to monitor gases in the atmosphere including ozone, greenhouse gases, and carbon levels. These measurements are duplicated at other sites around the world.

On a daily basis instruments record wind speeds, wind directions, and temperature at 2 and 10 meters above the surface. These data are recorded every minute. We also check three NOAA instruments that are constantly sampling the atmosphere—an *aethalometer*, a *surface ozone machine*, and a *gas chromatograph*. The *aethalometer* measures "black" carbon in the atmosphere by pumping in outside air and collecting the carbon on a quartz tape inside the machine. The *surface ozone machine* measure surface ozone levels and the gas *chromatograph* measures trace gases, including nitrous oxide, chlorofluorocarbons, and chlorinated solvents.

For additional information and data on these NOAA observations check out: *esrl.noaa.gov/gmd/index.html.* At this site you can also look at the data gathered here at Summit and from other sites around the world.

Week Twelve
January 25, 2009

Temperature:
-44°C/-46°F

Wow, Time Flies!

Our time at Summit is flying by. We are less than two weeks from the new crew arriving for *turnover* on February 6, 2009—weather permitting. With *turnover* rapidly approaching, our focus this week was on *End of Season* projects.

One task is to write an *End of Season* report that details what we accomplished and lists problems we encountered and the solutions we found. This report passes knowledge on to the next crew. In the *End of Season* report we discussed how to keep inlet and outlet tubes clear of blowing snow on the buried Green House roof.

Lora using the backpack GPS to survey large drifts around camp.

A second *End of Season* task we completed this week was a GPS survey of camp. This survey is used to monitor drifting caused by the camp buildings. In March, operators come into camp and clear the drifts to flatten out camp for the summer swelling of scientists and staff. To complete the camp survey, we mounted the GPS system onto a sled and drove a snowmobile at 10 km per hour in a grid pattern over the camp. Because we had such large drifts this winter, we did an additional GPS survey of camp with the GPS system loaded into a backpack. This week we also measured the *ICESat transect* for the final time this season.

The inauguration of President Obama was not missed at Summit Camp. A nice benefit of Summit Camp is the availability of the Internet. On Tuesday we gathered around Bill's computer to listen to the inaugural speech. We enjoyed being able to take part in the historic event even though we were far from home.

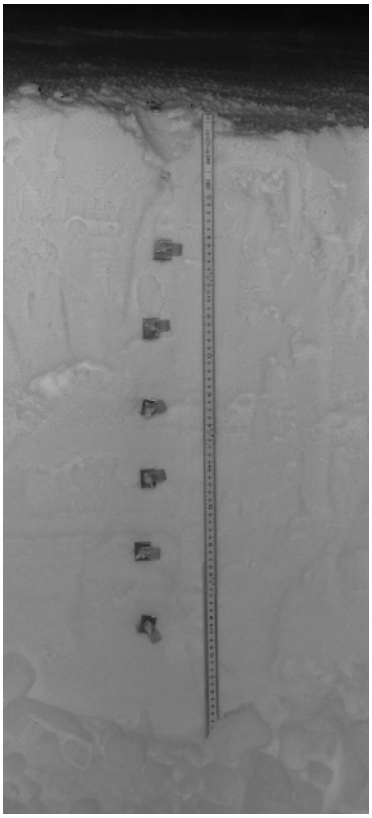
Week Thirteen
February 1, 2009

Temperature:
-47°C/-52°F

The Sun Appears

On January 29, 2009, we saw the sun for the first time since November 13, 2008. We watched the sun come up over the horizon and then set 1 hour and 59 minutes later. When the sun came up Bill made a jubilant radio call to make sure we all saw it. Kat and I were already outside cleaning the TAWO tower. We stopped working to take a nice walk in the sun. Today we had 3 hours and 9 minutes of sunlight. We discussed pulling our sunglasses out from the back of our closets and then decided we still need to take our Vitamin D tablets until we reach more southerly latitudes.

This week I finished my science projects. On Monday, I did a final *radiometer* pit. On Saturday, I dug up some *ibuttons* that I had buried in the snow. I wanted to monitor how surface temperatures diffuse into the *firn*. Snow is an insulative material so as the surface temperature varies that variation is damped as it travels deeper into the snow. The temperature profiles in the *firn* that the *ibuttons* were recording tell about the *thermal diffusivity* of the *firn*, and can be used to validate modeled temperature profiles when modeling *passive microwave brightness temperatures*. Another reason for burying the *ibuttons* was to see if they could survive the cold, harsh conditions. They did! I was able to recover all the *ibuttons* and get good, quality data.



A row of buried *ibuttons* that measure the vertical temperature profile in the snow. These data can be used to determine snow *thermal diffusivity*, as well as to validate models of *passive microwave brightness temperatures.*

This week was also marked with preparing for the arrival of the *Twin Otter* on February 6. Seven more people will be joining us for our final week at Summit Camp. Included in the seven are three new crew members for *Phase III* (February–May 2009). There will be two supervisors coming up to help with training, one scientist from the University of Colorado, and one NOAA scientist. Only three of the seven arriving will stay past February 13. Kat will be staying for *Phase III* and will complete the next team of four at Summit. Brad, Bill, and I will be replaced with a new mechanic, manager, and science tech, respectively.

Week Fourteen
February 8, 2009

Temperature:
-39°C/-38°F

Still Waiting

The Summit Camp population is still four. We had expected the population to be 11 by now but we are still waiting for the arrival of the *Twin Otter*. The weather in Kangerlussaq has canceled the inbound flight for the past three days. Delays are not uncommon on an ice sheet, but they are always a bit hard on morale. It is especially difficult to understand the delays when we have great weather on our end. We are making the best of the situation; today we replaced the incoming flight with a leisurely brunch of homemade sourdough pancakes by Bill.

It is not only our flight to Summit that has been canceled. On Saturday, no commercial planes came or went from Kangerlussaq. The winds were too high. This is not uncommon for travel in Greenland. *Air Greenland*, the only commercial carrier in Greenland is used to delayed and cancelled flights.

Since the first anticipated flight day, we've been getting up earlier. Bill starts calling in the Summit weather observations to Kangerlussaq at 6:00 A.M. He reports every half hour the temperature, humidity, cloud heights, obscurtions—which include freezing fog or ice crystals, wind speed and direction, horizon definition, and the visibility distance. To report the visibility distance we have markers at a half, one, two and three miles. The three mile marker is fun—it's shaped like a polar bear.

While Bill is busy with the weather observations, Kat and I are rushing to finish the daily science tasks before 10:00 A.M. We finish our daily tasks early on anticipated flight days because when the flight arrives it is all hands on deck. Kat and I will be responsible for driving the snowmobiles with sleds to the plane to pick up the passengers and gear. Brad and Bill will refuel the plane by hauling out a refueling sled and

Bill at the three mile "polar bear" marker preparing to clean the *rime* off for weather observations. **Photo credit:** Brad Whelchel.

hooking up the fuel hose, which is always frozen, stiff, and very difficult to move. The planes do not like to be on the ground any longer than they have to be, so this process is completed as quickly as possible.

Week Fifteen
February 17, 2009

On Our Way!

Our final week turned out to be our busiest. On February 9, the *Twin Otter* finally arrived on a beautiful sunny, but rather cold day. With it came Amy, the new science tech; Ken, the new camp manager; Dan, the new mechanic; Sandy and Russ, Summit Camp supervisors from Polar Field Services; and Jacques and Andy, scientists from the University of Colorado and NOAA, respectively. The plane also brought fresh milk, lettuce, bell peppers, mushrooms, and care packages, which were greatly appreciated.

Lora standing on solid ground in Kangerlussaq with her husband who came to greet the crew.

Once the plane landed, we unloaded the passengers and cargo. Brad and Bill refueled the plane as we loaded the retro cargo and the plane left about 40 minutes after it had arrived.

Kat and I started training Amy just a few hours after she got off the plane. (We did let her eat lunch first.) We started with a safety briefing on working at Summit, including tower climbing and working in the cold conditions. As the week progressed we worked our way through snow sampling, snow pits, accumulation measurements, *ozonesondes* and balloon launches, atmospheric sampling equipment, and more. By the end of the week, Amy assumed her role as science tech armed with a new paint brush to fight off the *rime* on the instruments.

On February 15, the *Twin Otter* arrived again, bringing in more fresh food for the new crew and taking Bill, Brad, and I back to Kangerlussaq and off "the ice" for the first time since November 3, 2008. We said our goodbyes to Kat; she will stay at Summit as a science tech until mid-May. (Sandy, Russ, Andy, and Jacques also left on the flight.) About three hours after boarding the plane, we were standing on the ground in Kangerlussaq being greeted by friends and family. On February 16, our winter team split again. Bill stayed in Kangerlussaq for a few more days before leaving for Iceland and the Farrow Islands. Brad and I boarded a plane to Copenhagen. From Copenhagen, Brad caught a flight to New Zealand where he will work on a boat. I will spend one more day in Copenhagen (where I'm at as I write this) before heading back to Goddard.

I want to thank everyone for checking in and reading this blog. I hope you have enjoyed hearing about life and science at Summit, Greenland this winter. Please check the NASA Cryospheric Sciences Branch website (*neptune.gsfc.nasa.gov/csb/*) often for updates on news and science from the Polar Regions. Until next time. ■

MOPITT Science Team at NCAR Releases New Product

The Measurements of Pollution in the Troposphere (MOPITT) Science Team at the National Center of Atmospheric Research (NCAR) announces the availability of the *Version 4 (V4)* product for tropospheric carbon monoxide (CO). This product is currently "provisional" and is available both from the NASA Langley Data Pool (*eosweb.larc.nasa.gov/HPDOCS/datapool/*) and the Warehouse Inventory Search Tool (WIST)/EOS Clearing House (ECHO) system (*wist.echo.nasa.gov*). New *Level 2* and *Level 3* (gridded) products are available.

Users of the new *V4* product should obtain the new *V4 User's Guide* available at the MOPITT website (*www.acd.ucar.edu/mopitt/publications.shtml*) or through the Langley Data Pool. Processing of the current *Version 3 (V3)* product will cease this summer. Further updates on the *V4* product will be posted to the "MOPITT News" webpage at *www.acd.ucar.edu/mopitt/news.shtml*.

The retrieval algorithm used to generate the *V4* product benefits from significant advances in radiative transfer modeling, state vector representation, and *a priori* statistics. Differences between the *V3* and *V4* products are generally significant and are detailed in the *V4 User's Guide*. Retrieval performance has been improved in many respects, particularly in regions of very low and very high CO concentrations. Problems with long-term bias drift are also evidently weaker in *V4* than in *V3*. The new *V4* product also includes new diagnostics, including the retrieval averaging kernels.

Questions regarding the MOPITT *V4* retrieval algorithm should be directed to **Merritt Deeter** (*mnd@ucar.edu*). Questions regarding MOPITT product availability should be directed to **Dallas Masters** (*mastersd@ucar.edu*).

Watching the Corn Grow: Field Studies of Remote Sensing of Photosynthesis

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Elizabeth Middleton, NASA Goddard Space Flight Center, elizabeth.m.middleton@nasa.gov

It's dawn when the *Spectral Bio-Indicators* team arrives in the cornfield in Beltsville, MD. The air is cool and grass is covered with dew. On this August morning the team knows just what needs to be done and, with practiced efficiency, sets up the instruments, starts the computers, and lays out power cords through the cornfield. Along with getting the equipment ready, the team members prepare themselves for the long day, smearing on sunscreen and insect repellent. They know that the heat of the day will stress both them and the corn, and that's why they are there. The purpose of their fieldwork is to develop methods that use the *spectral reflectance* of corn to determine its rate of *photosynthesis*, so the team wants to see what happens to the corn when it is stressed.

Photosynthesis is driven by the energy from sunlight absorbed by the plant. If the plant becomes stressed by not having enough water or nutrients, for example, the rate it can photosynthesize drops. The *photosynthetic rate* is described as the amount of carbon taken per unit of light absorbed by the vegetation; this ratio is called the *light use efficiency*.

Plants experiencing stress have a problem—their leaves continue to absorb light but they cannot use all of that energy for *photosynthesis*. Plants must dump this excess energy to protect the photosynthetic structures in their leaves. Plants have multiple ways to "dump" energy. One way is through chemical reactions in some leaf pigments, called *xanthophylls*. These reactions release heat and change the concentrations of pigments in the leaf. Changes in *xanthophyll* pigment concentrations cause subtle changes in *leaf reflectance*. If we measure the radiation the leaf reflects in certain carefully chosen electromagnetic wavelengths—or *narrow spectral bands*—the differences between the stressed and unstressed vegetation become quite evident. Thus we can use this information as a means to help us quantify what happens to the corn when it is stressed.

The Spectral Bio-Indicators Project is working to find the best ways to detect these stress-related spectral changes in vegetation; to determine how these spectral indices relate to the rate of ecosystem carbon uptake; and to understand how these relationships vary spatially, temporally, and are affected by vegetation structure.

Qingyuan Zhang and Larry Corp measure the *spectral reflectance* of corn leaves in the field.

Another way for plants to shed excess energy is through *fluorescence*, where leaves actually emit photons of light. Although the amount of fluoresced light is not as great as the amount reflected by a leaf, there is once again a specific spectral pattern to the fluoresced light that can also be detected using a number of *narrow spectral bands*.

The *Spectral Bio-Indicators Project* is working to find the best ways to detect these stress-related spectral changes in vegetation using remote sensing; to determine how these spectral indices relate to the rate of ecosystem carbon uptake; and to understand how these relationships vary spatially, temporally, and are affected by vegetation structure.

The *Spectral Bio-Indicators* team is led by **Elizabeth Middleton** of NASA Goddard Space Flight Center (GSFC) and includes **Petya Campbell**, **Fred Huemmrich**, and **Qingyuan Zhang** [University of Maryland, Baltimore County (UMBC)], **Larry Corp** and **Dave Landis** [Science Systems and Applications, Inc. (SSAI)], and **Yen-Ben Cheng** (GSFC). The strategy of the fieldwork is to link vegetation optical proper-

The strategy of the fieldwork is to link vegetation optical properties and carbon fluxes at different temporal and spatial scales by measuring them at the same time.

ties and carbon fluxes at different temporal and spatial scales by measuring them at the same time. The cornfield study focuses on making *hyperspectral reflectance* measurements—which refers to measuring multiple contiguous spectral bands over a range of wavelengths—along with *carbon flux* measurements of individual leaves and the entire canopy. At the study site in the Beltsville Agricultural Research Center, we collected the first measurements on June 25 from corn planted in mid-June. We repeated measurements about once a week through the growing season, ending on October 7—data were collected on 12 different days. On each of the measurement days, we collected data from dawn to dusk.

Throughout the measurement days we used portable photosynthesis systems to measure carbon exchange at leaf level. We attached a small chamber to selected leaves and measured the change in carbon dioxide (CO_2) concentration in the chamber using an infrared gas analyzer. Meanwhile, we also collected continuous measurements of *carbon fluxes* using *eddy covariance techniques* from a flux tower located in the cornfield. The flux tower, operated by **Bill Kustas**, **John Prueger**, and **Andy Russ** of the United States Department of Agriculture (USDA) Agriculture Research Service (ARS), measures the water, energy, and *carbon fluxes* from a large *footprint* within the cornfield.

Throughout each measurement day, we measured reflectances of leaves near the photosynthesis system chambers. We also measured reflectance hourly at meter intervals along a 328 ft (100 m) transect through the cornfield to match up the captured field-level reflectance with fluxes from the flux tower. We collected reflectances at multiple view angles at selected locations in the field.

The portable photosynthesis chamber attached to a corn leaf.

At midday, we measured the fraction of photosynthetically active radiation absorbed by the corn canopy and leaf chlorophyll content along the 328 ft (100 m) transect. After putting in a long hot day in the field, the work was not yet finished. On the day following the field measurements, we returned to the cornfield to collect sample leaves from where the leaf-level measurements had been made. These leaves were taken to our lab at GSFC where we measured *fluorescence* and *spectral reflectance* and *transmittance*. We also measured leaf area, along with wet and dry weights, and extracted samples of the leaves for chemical analysis to get chlorophyll, carbon, and nitrogen concentrations.

Finally, to expand the results of the field work to the region, we used imaging spectrometer data collected from the *Hyperion* sensor flying on the EO-1 satellite. During the 2008 growing season we were able to get eight clear views of the study site from Hyperion.

Preliminary results show that indices based on the reflectance data have diurnal patterns similar to the *light use efficiency* at both the leaf and canopy level. Further, these *spectral reflectance indices* also track *light use efficiency* through the growing season. Our goal is to develop approaches that will allow us to scale up from leaves to regions, providing robust estimates of *photosynthetic rates* based on models driven

Larry Corp and Yen-Ben Cheng get ready to collect measurements in the corn field.

Yen-Ben Cheng measures corn canopy reflectance early in the growing season before the corn completely engulfs him.

by *spectral reflectance*. We will use these models with existing and future satellite systems, such as the Hyperspectral Infrared Imager (HyspIRI)—a Decadal Survey mission—to monitor photosynthetic rates globally. This will provide improved estimates of ecosystem carbon exchange as well as detect the onset and severity of plant stress events. ■

The USDA ARS flux tower in the cornfield; instruments on the tower continuously measure carbon flux and meteorological variables.

Release of Land Surface Imaging Constellation Portal

The Committee on Earth Observation Satellites (CEOS) Land Surface Imaging (LSI) Constellation Study Team and Working Group on Information Systems and Services (WGISS) recently released *Version 1* of the *Land Surface Imaging Constellation Portal for Mid-Resolution Optical LSI Satellite Information and Enhanced Data Access*.

The web Portal provides users of mid-resolution (10m–100m), optical satellite imagery of Earth's land surfaces with a *single web destination* where they can obtain information about currently and previously operating mid-resolution LSI satellite systems and their data. *Active links* to the data *search and order tools* for all CEOS agency mid-resolution LSI systems that offer user access to data are provided. Links to *free sample data* collected by mid-resolution optical LSI systems operated by CEOS member agencies are also available.

Users of mid-resolution, optical LSI satellite data are invited to use, and review, the *CEOS LSI Constellation Portal for Mid-Resolution Optical LSI Satellite Information and Enhanced Data Access* by visiting *wgiss.ceos.org/lsip*. Input will be used to improve the Portal, expand its content, and enhance functionality in future versions.

featured articles

EOS Faces Growing Risk From Space Debris

Lauri K. Newman, NASA Goddard Space Flight Center, lauri.k.newman@nasa.gov

Introduction

On February 10, 2009, a collision between the active *Iridium 33* satellite and inactive payload *COSMOS 2251* caused the failure of *Iridium 33* and brought international attention to the risk posed by space debris. This incident magnified the concern that has been steadily growing since the Chinese destroyed their *FengYun 1C* weather satellite in an Anti-Satellite weapon test on January 11, 2007. Even many years before these events, the debris environment had been slowly but steadily becoming more crowded. Each year, about 200 debris objects were being added to the ~14,000 objects being tracked by the Space Surveillance Network. The *FengYun* event instantaneously added over 2,000 objects to the catalog, while the *Iridium* event added another ~1,000.

Debris Environment Characterization

The NASA Orbital Debris Program Office (ODPO) at NASA Johnson Space Center (JSC) is chartered with characterizing the debris environment for NASA missions. **Figures 1-3**, produced by the ODPO, provide some visual information about the debris environment. **Figure 1** shows the current debris population by altitude. The most crowded regimes are the geosynchronous orbit and low Earth orbits near 800 km, which is slightly above the 705 km Earth Observing System (EOS) regime. **Figure 2** shows the amount of objects >10 cm in orbit as of 1985 and again 20 years later just after the *FengYun* breakup in 2007. **Figure 3** [*Ref 1*] shows the debris growth since the beginning of the space age**. The ODPO predicts that even if we were to stop launching space missions today, the debris would continue to accumulate before leveling off. One reason for this growth is because, although rules were put in place in the early 1990s to limit the production of space debris, earlier launches routinely left rocket bodies full of unspent fuel on orbit.** After some period of time these rocket bodies can explode, creating new debris. The more debris in the environment, the more likely a collision becomes. Over the years, there have been eight publicly documented collisions in space—see **Table 1**. Three of these collisions involved active satellites.

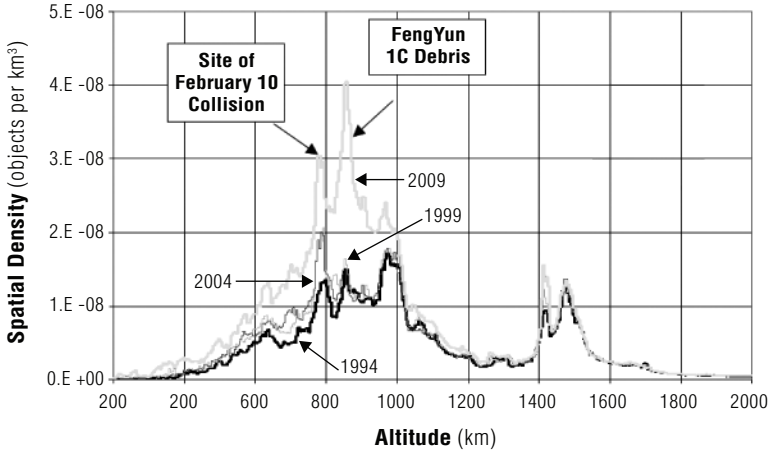

Figure 1. Debris population from ODPO at NASA Johnson Space Center (JSC).

Protection Methods

What can a satellite operator do to protect valuable assets from the threat of collision with space debris? There are several methods used for protection. NASA has requirements on satellite design that mandate the ability to withstand impact from objects less than 1 cm in size. A post-launch process called *Conjunction Assessment* (CA) has been put in place to handle larger objects. In this process, the trajectory of the object is compared to the trajectory of a known spacecraft and any predicted close approaches are identified and later analyzed to determine the threat posed. (CA is often confused with *Collision Avoidance*, which is the act of performing a maneuver to mitigate the threat posed by a conjunction.) However, CA can only be used for objects that have known trajectories.

Although the ODPO is responsible for characterizing the debris environment for NASA, tracking and cataloging each piece of on-orbit debris is the responsibility of the Joint Space Operations Center at Vandenberg Air Force Base in California. Objects larger than 10 cm are tracked by the Space Surveillance Network and their orbits kept in a database at Vandenberg called the *High Accuracy Catalog*. There is publicly-available object trajectory data that may be accessed at *www.space-track.org* among other sources, but the *High Accuracy Catalog* is more appropriate for use in CA. The problem is that while objects greater than 10 cm in size are tracked, objects between 1–10 cm currently are not. **The ODPO estimates that there are 300,000 uncatalogued objects greater than 1 cm in size currently in orbit.** In the next few years, improvements to sensors used to track debris are planned that would allow track-

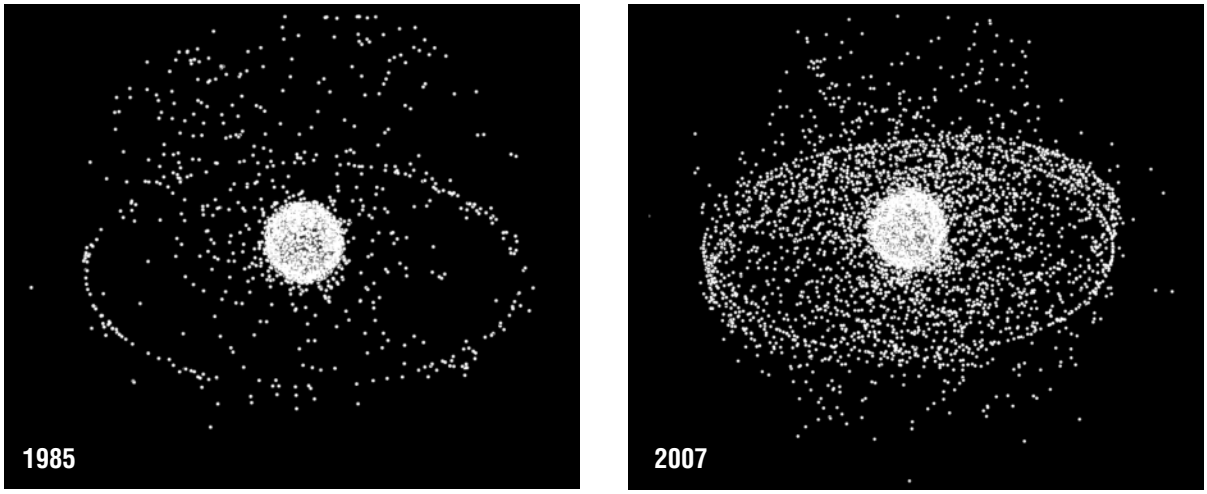

Figure 2. Growth of the Earth Satellite Population over the last 20 years. From NASA JSC ODPO.

ing of these smaller objects in hopes of mitigating this threat. (This effort is external to NASA.) **However, at the present time, the risk that these smaller objects pose can't be predicted or mitigated.**

History of NASA Robotic Conjunction Assessment

In an effort to do as much as possible to mitigate the debris threat, NASA has performed CA since STS-26 (the seventh flight of Space Shuttle *Discovery*) in 1988 for the manned space program. On the other hand, no official requirement for unmanned, or robotic, missions existed until NASA Procedural Requirements (*NPR*) *8715.6* was signed in August of 2007. Many of the Goddard

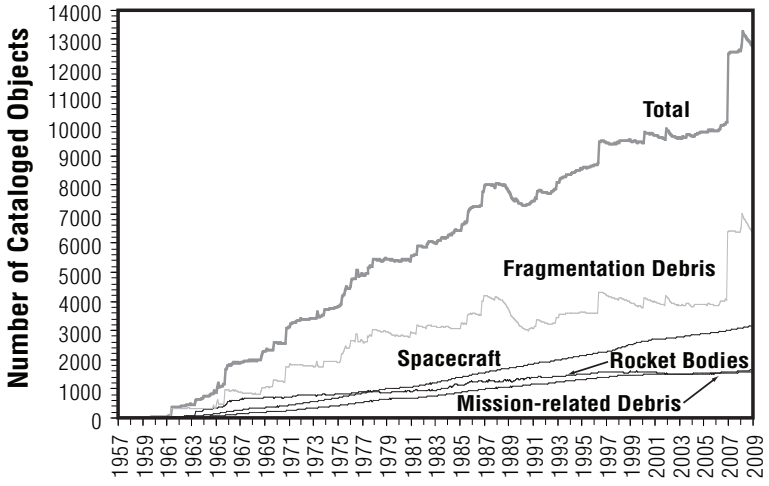

Figure 3. This plot shows how the amount of debris in orbit has increased since the beginning of the Space Age. [Ref 1]

Space Flight Center (GSFC) mission operators were either unaware of the growing debris threat, or were subscribers to the so-called *big sky theory*, which states that the likelihood of a collision is so small that it can be neglected. However, some operators were not so cavalier.

In 2002 EOS *Aqua* Mission Director **Bill Guit** became concerned about the potential debris threat and worked with JSC Human Spaceflight orbital safety experts to define a process to screen the EOS *Aqua* trajectory against the *High Accuracy Catalog* during launch and early orbit. However, deciding what to do with the data once it was provided turned out to be more complicated than anyone had imagined. Simply knowing how close an object would pass to Aqua did not give any indication of the *believability* of the threat, something that the Department of Defense (DoD) didn't provide. **Many long meetings were held to discuss predicted close approaches, but in the end, no action was taken because no credible decision criteria existed to weigh the risk of delaying critically-timed ascent maneuvers against a threat of collision that was not well understood mathematically.**

When EOS *Aura* launched in 2004, I (**Lauri Newman**) was the Flight Dynamics Engineer. In order to make sure the *ascent phase* ran smoothly, I defined a clear decision-making flow for evaluating CA events and increased the amount of data requested from the Air Force. Fortunately, no concerning close approach events were predicted, so the ascent ran smoothly without the need to make decisions based on the close approach data. However, Bill was still concerned about the possibility of conjunctions with on-orbit debris in the mission orbits and desired to implement a routine CA process for all of the EOS missions. He enlisted my technical expertise to develop a process that was appropriate for the EOS missions. I had been supporting the EOS program since 1988 and had designed the trajectories for *Terra*, *Aqua*, and *Aura*,

Table 1. Documented collisions [Ref 2]:

Year	Incident Description
1991	Inactive payload *COSMOS 1934* hit by *COSMOS 296* debris
1996	Active French *CERISE* satellite hit by *Arienne* rocket debris
1997	Inactive payload *NOAA 7* hit by uncatalogued debris, causing orbit change and creation of additional debris
2002	Inactive payload *COSMOS 539* hit by uncatalogued debris, causing orbit change and creation of additional debris
2005	Collision between U.S. and Chinese rocket debris
2007	Active payload *Meteosat 8* experiences orbit change due to collision with uncatalogued debris
2007	Suspected collision between inactive NASA UARS satellite and uncatalogued debris creates additional debris
2009	Active payload *Iridium 33* destroyed by collision with inactive payload *COSMOS 2251*

so I was very familiar with the orbit requirements for the EOS missions. While the human spaceflight CA process was well-established, there were aspects of it that did not apply to the higher altitude, different control capabilities, and restrictive mission orbit requirements that defined the EOS missions. Therefore, we could not just reuse what was already being done at JSC—although we relied on their expertise and used whatever pieces did apply. I found a local contractor, **Matt Duncan** of a.i. Solutions, who had previously performed CA for the Air Force and knew what was needed to establish a process to support EOS. Together, we built a capability for GSFC that has grown to support 28 missions in a state-of-the-art process that includes both autonomous and manual analysis tools used to compute the risk posed by a close approach and determine the best mitigation scenario for threatening events. This growth happened fairly quickly, and we were soon glad we had made the effort.

Current NASA Robotic Conjunction Assessment Process and Statistics

In January 2005, when we started receiving routine close approach prediction data from the Air Force, the number of CA events predicted was startling. For each spacecraft, we saw an average of 1 object per day that entered our largest (±2 x 25 x 25km) defined safety volume, the *Monitor Volume*, which is the trigger that dictates what events we are notified about. We had also defined a smaller volume (±0.5 x 5 x 5 km), the *Tasking Volume*. Objects that were predicted to violate the *Tasking Volume* caused heightened concern and drove the collection of additional data about the other object. We would typically see about 2 objects per month that were predicted to come within 1 km of each spacecraft, a radius we dubbed the *Watch Volume*.

Over the course of the next year, we began performing CA not only for EOS, but for all of the missions flying in constellation with EOS. The large amount of data produced for these missions could not be processed manually. The GSFC CA Team quickly developed an automated software system (based on the *FreeFlyer* and *Matlab* system already being used for Flight Dynamics support in the control center) to capture the data into a database and analyze each event for geometry, quality of the orbit solution, and probability of collision. Skilled orbit determination experts on the CA Team could then evaluate the data and analysis for each close approach event to determine whether that event posed a *credible threat* to a Constellation spacecraft. If the threat was valid, the CA Team would help the Flight Operations Team to develop a mitigation scenario.

To provide an idea of the data we receive and how it is acted upon, selected operations statistics are included here. **Figure 4** shows the monthly statistics for the past year of the number of safety volume violations per spacecraft. Of these violations, about 3–4 per year require avoidance maneuver planning for each spacecraft. **As we trended the data from these close approaches, we learned more about what events were truly a threat and how to make decisions about performing risk mitigation maneuvers.** The goal is always to perform a maneuver that maintains the science requirements of the missions. Over the last four years, the Earth Science Constellation missions have collectively performed seven risk mitigation maneuvers—see **Table 2**—and several other routine maintenance maneuvers have been rescheduled to prevent close approaches predicted to occur following the planned maneuver.

Significant Recent Debris Events Increase the Threat

On January 11, 2007, the Chinese performed a test of an Anti-Satellite weapon, destroying one of their inactive weather satellites, *FengYun 1C*. This event created over 2000 pieces of debris in an 861 km sun-synchro-

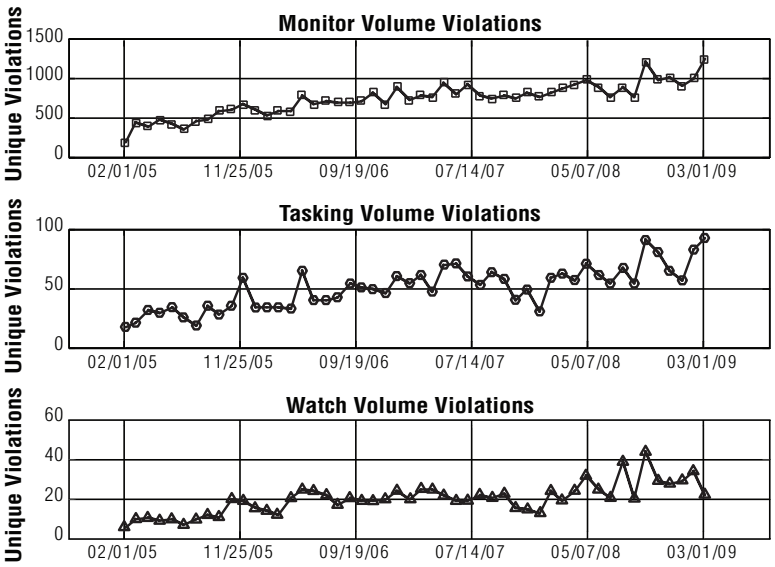

Figure 4. Monthly Conjunction Assessment statistics for Earth Science Constellation Missions (See article text for details.)

nous orbit. The Earth Science Constellation missions began having conjunctions with *FengYun 1C* debris within weeks of the event, so it was very fortunate that the CA process was in place to address the threat. *FengYun* debris made up 10% of the conjunctions for the Constellation, and has since grown to make up about 15%. Detecting these close approaches depends on the debris objects being "catalogued" (by the Joint Space Operations Center at Vandenberg) following the breakup event. This process is labor intensive, and can take weeks or months for a debris cloud of such magnitude. The GSFC CA process can only be used to protect NASA missions once the objects are in the catalog.

The *Iridium 33*/*COSMOS 2251* collision occurred at an altitude of about 788 km, and there are currently about 1000 debris objects associated with this event. **Figure 5** shows the EOS orbit and its relative placement within the debris clouds. The EOS spacecraft began seeing debris from this collision within days of the event as the debris was catalogued. **Figure 5** shows that the collision debris is very close above the EOS orbit, implying that the risk will continue to increase as drag pulls the debris down toward the EOS orbit. The GSFC CA Team will continue to monitor the EOS spacecraft to notify management when a close approach needs to be mitigated.

Next Steps

As we move into the future, the space community will continue to face the increasing threat of orbital debris. The GSFC CA Team will continue to seek ways to improve our operational process through automation and analysis. Per direction from the Acting Administrator, beginning this summer, all NASA robotic assets will be screened against the *High Accuracy Catalog* to predict close approaches, not just the maneuverable spacecraft. Relationships between NASA and DoD will be strengthened in the hopes of implementing a government-wide solution that takes advantage of all available capabilities. In addition, processes need to

Table 2. Risk Mitigation Maneuvers Performed by the Earth Science Constellation Missions

Asset	Secondary	Maneuver Date	Minimum Predicted Total Miss Distance (m)	Collision Probability
Terra	14222 (*SCOUT G-1*)	21-Oct, 2005	37	6.82×10^{-2}
PARASOL	81257 (*Analyst SAT*)	16-Jan, 2007	43	1.51×10^{-3}
SAC-C	14345 (*SL-8 DEB*)	16-Feb, 2007	57	3.40×10^{-6}
Terra	31410 (*FENGYUN 1C DEB*)	22-Jun, 2007	18	1.58×10^{-1}
CloudSat	28893 (*SINAH 1*)	04-Jul, 2007	38	2.24×10^{-2}
Aura	1399 (*TRIAD 1 Debris*)	26-Jun, 2008	11	4.80×10^{-1}
CloudSat	8542 (*Delta I Debris*)	20-Jul, 2008	90	1.77×10^{-3}
PARASOL	31293 (*FENGYUN 1C DEB*)	19-Oct, 2008	82	2.11×10^{-2}

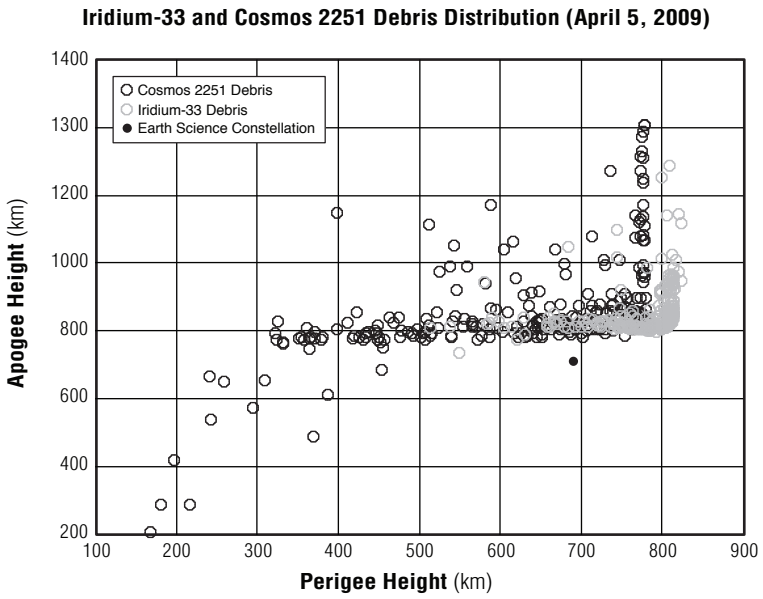

Figure 5. Iridium/COSMOS debris relative to EOS orbit

be put in place by the DoD to enable the commercial space operators to obtain the accurate data they need to prevent collisions. Some researchers are attempting to develop feasible ways to clean up the existing debris. **The bottom line is that each operator's actions affect the environment that all other space operators need to share, so it is important to take actions to limit debris as much as possible.**

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New Version of NAALSED Now Available

NASA's Jet Propulsion Laboratory (JPL) announces the release of the *North American ASTER Land Surface Emissivity Database (NAALSED)*, *Version 2*. The database provides the average summertime and wintertime emissivity derived from ASTER data for much of North America with a spatial resolution of 100 m in five spectral channels. The product also includes a land water mask, average Normalized Difference Vegetation Index (NDVI) image, and average temperature image. The product is described in:

Hulley, G. C., S. J. Hook and **A. M. Baldridge**, 2008. ASTER Land Surface Emissivity Database of California and Nevada. *Geophysical Research Letters*, vol. 35.

The product can be ordered from the following website: *emissivity.jpl.nasa.gov*. The website provides examples of the product as *jpgs* and *kmls* together with a validation database. The data are available in *HDF5* or *binary*. Contact *simon.j.hook@jpl.nasa.gov* with questions.

Arctic Sea Ice News & Analysis: Arctic Sea Ice Younger, Thinner as Melt Season Begins

Walt Meier, National Snow and Ice Data Center, walt@nsidc.org
Introduction by Walt Meier and Stephanie Renfrow, National Snow and Ice Data Center, srenfrow@nsidc.org

Arctic sea ice reflects sunlight, keeping the polar regions cool and moderating global climate. According to scientific measurements, Arctic sea ice has declined dramatically over at least the past thirty years, with the most extreme decline seen in the summer melt season.

The National Snow and Ice Data Center (NSIDC) provides an update of sea ice conditions during the first week of each month, or more frequently as conditions warrant. NSIDC scientists provide Arctic Sea Ice News & Analysis, with partial support from NASA.

The images shown in Arctic Sea Ice & News Analysis are derived from the Sea Ice Index data product. The basis for the Sea Ice Index is the data set, "Near Real-Time Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) Daily Polar Gridded Sea Ice Concentrations" and the NASA-produced "Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I Passive Microwave Data".

Arctic sea ice extent has begun its seasonal decline towards the September minimum. Ice extent through the winter was similar to that of recent years, but lower than the 1979–2000 average. More importantly, the melt season has begun with a substantial amount of thin first-year ice, which is vulnerable to summer melt.

Sea ice extent averaged over the month of March 2009 was 5.85 million mi^2 (15.16 million km^2)[1]. This was 282,000 mi^2 (730,000 km^2) above the record low of 2006, but 228,000 mi^2 (590,000 km^2) below the 1979–2000 average.

At the end of last summer's melt season, extensive areas of open water froze up quickly, once air temperatures cooled in the fall. By February 28, ice extent had reached its annual maximum. Although the maximum ice extent occurred slightly earlier than usual, ice extent remained close to the maximum level through much of March.

Including March 2009, the past six years have all had ice extent substantially lower than normal. The linear trend indicates that for the month of March, ice extent is declining by 2.7% per decade, an average of 16,000 mi^2 (43,000 km^2) of ice per year.

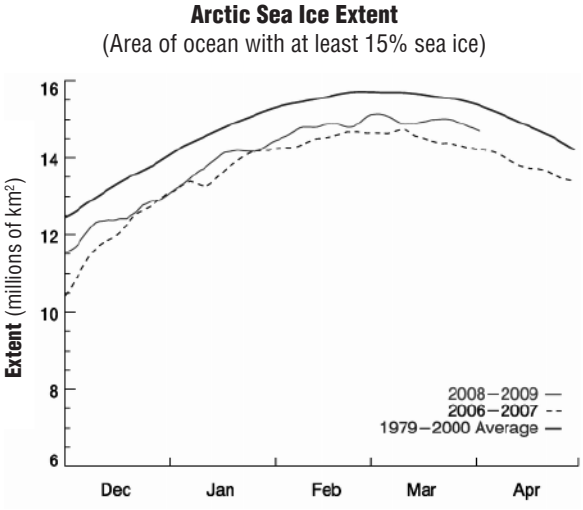
Overall, it was a fairly warm winter in the Arctic. Air temperatures over the Arctic Ocean were an average of 1.8–3.6°F (1–2°C) above normal, with notable regional variations. The Barents Sea region was over 7.2°F (4°C) warmer than average this winter. This warmth probably stemmed from unusually low sea ice extent in the region throughout much of the winter, which allowed the ocean to pump heat into the atmosphere. The Bering Sea, in contrast, experienced a cool winter, with temperatures 1.8–3.6° F (1–2°C) below average. The cooler conditions were consistent with the above-average sea ice extent in the Bering Sea through much of the winter.

How vulnerable is the ice cover as we go into the summer melt season? To answer this question, scientists also need information about ice thickness. **Indications of winter ice thickness, commonly derived from ice age estimates, reveal that the ice is thinner than average, suggesting that it is more susceptible to melting away during the coming summer.**

Sea Ice Extent March, 2009

Arctic sea ice extent for March, 2009, was 5.85 million mi^2 (15.16 million km^2). The black line shows the 1979–2000 median extent for that month. The black cross indicates the geographic North Pole. Sea Ice Index data. **Credit:** National Snow and Ice Data Center

[1] Original measurements were made in metric units, then converted to English units.



The graph above shows daily sea ice extent. The thin solid line indicates 2008–2009; the thin dashed line shows 2006–2007 (the record-low summer minimum occurred in 2007); and thick solid line indicates average extent from 1979–2000. Sea Ice Index data. **Credit:** National Snow and Ice Data Center

As the melt season begins, the Arctic Ocean is covered mostly by first-year ice, which formed this winter, and second-year ice, which formed during the winter of 2007–2008. First-year ice in particular is thinner and more prone to melting away than thicker, older, multi-year ice. This year, ice older than two years accounted for less than 10% of the ice cover at the end of February. From 1981–2000, such older ice made up an average of 30% of the total sea ice cover at this time of the year.

While ice older than two years reached record lows, the fraction of second-year sea ice increased compared to last winter. Some of this second-year ice will survive the summer melt season to replenish the Arctic's store of older ice; however, in recent years less young ice has made it through the summer. To restore the amount of older ice to pre-2000 levels, large amounts of this young ice would need to endure through summer for several years in a row.

But conditions may not always favor the survival of second-year and older ice. Each winter, winds and ocean currents move some sea ice out of the Arctic ocean. This winter, some second-year ice survived the 2008 melt season only to be pushed out of the Arctic by strong winter winds. Since the end of September 2008, 150,000 mi^2 (390,000 km^2) of second-year ice and 73,000 mi^2 (190,000 km^2) of older (more than two years old) ice moved out of the Arctic (*Maslanik et al.*, 2007; *Fowler et al.*, 2004).

To view images from this story in color, please visit: *nsidc.org/arcticseaicenews/2009/040609.html.* For continuing updates on Arctic sea ice, please go to: *nsidc.org/arcticseaicenews/.*

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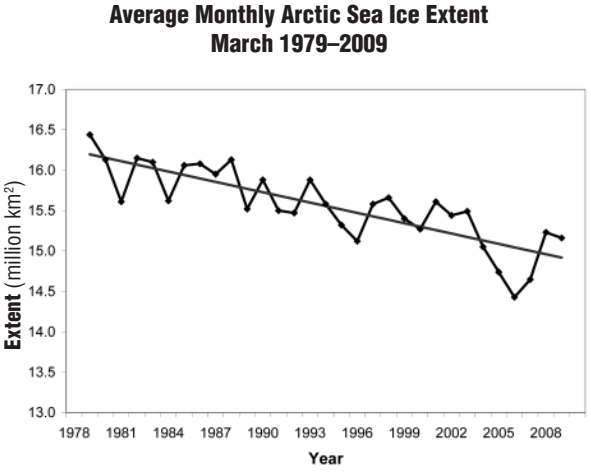

Monthly March ice extent for 1979–2009 shows a decline of 2.7% per decade. **Credit:** National Snow and Ice Data Center

Arctic and Antarctic-themed Activities to Bring a Breath of Polar Air to Baltimore

Peter West, National Science Foundation, pwest@nsf.gov
Modified for ***The Earth Observer*** *by Alan Ward, NASA Goddard Space Flight Center, award@sesda2.com*

The Maryland Science Center in Baltimore was the focal point for a range of public events April 4–5, 2009, that highlighted federally funded Arctic and Antarctic research programs. These public events were held the weekend before a two-week-long Antarctic Treaty Consultative Meeting (ATCM) convened at the Baltimore Convention Center. Delegates from more than 40 countries attended the ATCM to discuss ongoing international cooperation and scientific research in Antarctica.

This year marked the 50th anniversary of the Antarctic Treaty. Signed in the U.S. in 1959, the treaty begins with the words "*recognizing that it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes* ..." It uniquely guarantees freedom of scientific investigation on the southernmost continent. Treaty protocols also prohibit such activities as oil and gas and mineral exploration. The Treaty was also the first multilateral arms-control agreement, banning nuclear explosions and military activity.

This year's Treaty meeting was also unusual because senior diplomats and scientists from the Arctic Council nations were also in attendance. (Many of the nations from the Arctic Council are also signatories of the Antarctic Treaty.) The date of the Baltimore meeting is also historically significant, as it convened a century to the day after Maryland-born Arctic explorer **Matthew Henson**, an African-American, became the first person to reach the North Pole.

The meeting also marked the official close of the International Polar Year (IPY) that ran from 2007–2009. During IPY, scientists embarked on a comprehensive effort to study the Polar regions and learn more about how climate is changing at the Poles and what impacts this may have on the rest of the world; more than 60 nations participated. The National Science Foundation (NSF) was the lead U.S. agency for IPY, but many organizations including NASA and the National Oceanic and Atmospheric Administration (NOAA) participated.

NASA provided an Antarctic-themed exhibit to the Baltimore Convention Center during the two-week meeting. The self-contained display featured imagery from the Landsat Image Mosaic of Antarctica (LIMA). NASA also presented *Polar-Palooza* and *Frozen* (see descriptions below) to the Antarctic Treaty delegates the evening of April 7.

The U.S. Department of State organized the Baltimore meeting—the 32nd since the Treaty was signed, but only the first in the U.S. since the 1970s.

The Science Center public outreach events included an unprecedented exhibit of collected art, film, poetry, and prose created by world-class artists to interpret the nation's Antarctic heritage, the public unveiling of a unique film that shows the global importance of the world's Polar Regions to multimedia, and hands-on demonstrations of polar science and cultures.

The exhibit and many of the related events are funded jointly by NSF Office of Polar Programs (OPP) and its Education and Human Resources Directorate's Informal Science Education (ISE) program. NSF manages the U.S. Antarctic program, which coordinates all U.S. research on the southernmost continent. NSF's director also chairs the Interagency Arctic Research Policy Committee (IARPC).

The programs are designed to give the public, including young children, a glimpse into both the lives of those who make their homes in the Polar Regions and those who conduct cutting-edge science there. They also focus attention on the importance of U.S. government-supported polar research in fields as diverse as climate sciences, oceanography, and astrophysics—in a global context. NSF worked with NASA and NOAA to plan and execute the public-outreach events.

Highlights of the weekend at the Maryland Science Center included:

Interactive demonstrations and displays: The science center staff provided hands-on demonstrations of polar clothing to show visitors what it takes to work safely in the harsh conditions of the world's coldest, highest and driest continent. A separate display showed visitors how a typical Antarctic field camp is set up. A large floor mural using the latest space-based satellite imagery of Antarctica (from LIMA) allowed visitors to get to the know the continent's geography. High-resolution, ground-level panoramic images of the McMurdo Dry Valleys, the only ice-free region of the Antarctic, complimented the LIMA mural. Two IMAX films, *Antarctica* and *Shackleton's Antarctic Adventure,* were also shown.

An exhibit of works by participants in NSF's Antarctic Artists and Writers program: NSF annually invites artists to apply for the opportunity to visit the southernmost continent to gather information or to actually work in the field to interpret the Antarctic experience and to celebrate the nation's Antarctic heritage for the general public. Internationally acclaimed director **Werner Herzog** was a recent program participant. His Antarctic documentary *Encounters at the End of*

the World, was nominated for a 2009 Academy Award. Other previous participants include **Kim Stanley Robinson**, author of the science fiction work *Antarctica* and the Mars trilogy, installation artist **Lita Albuquerque,** and the late nature photographer **Galen Rowell**. More than 40 world-class photographers, sculptors, and painters in various media, filmmakers, writers, poets, historians and others, who are selected for the opportunity through a merit-review system have participated in the program. Only a small fraction of applicants are selected to visit Antarctica. Their work continues a unbroken tradition of artists' involvement in Antarctic science that stretches back to the so-called "Heroic Age" of exploration at the turn of the 20th century. The early explorers included photographers and artists on their teams and themselves often wrote lucid and timeless accounts of their struggles and discoveries on the frozen continent. This was the first such exhibit ever mounted in one single venue in the history of the Artists and Writers program.

A series of presentations by *Polar-Palooza*: *Polar-Palooza* is a jointly NSF- and NASA-funded project, that brings Polar researchers to science museums around the country, often to institutions where young people never would otherwise meet a Polar scientist. Since the Fall of 2007, *Polar-Palooza* has taken its *Stories from a Changing Planet* presentation on tour to more than 25 science centers and museums all over the country, featuring a diverse cast of Polar researchers (the cast varies at each tour stop), high-definition video shot on location in the Arctic and Antarctic, and authentic artifacts such as ancient ice cores and NSF's special cold weather gear. Presentations include opportunities for personal interaction between the public and Polar researchers, with questions about both Polar research and climate change, as well as hands-on experiences. On hand for the show in Baltimore were:

- **Mike Castellini** [University of Alaska Fairbanks] seal and penguin expert;
- **Kathy Licht** [Indiana University–Purdue University] geologist and Antarctic explorer;
- **Sean Topkok** [Alaskan Native Knowledge Network] a native Alaskan; and
- **Bob Bindschadler** [NASA Goddard Space Flight Center] a glaciologist.

Educators for Grades K-12 attended a workshop on the morning of April 4, and there was a special session for an invited student audience on the morning of April 6.

NSF-funded *Polar Weekend*: This event offered more hands-on activities for children and their parents as well as the chance to meet polar researchers face-to-face. The *Polar Weekend*, organized by **Stephanie Pfirman**, a researcher at Columbia University's Barnard College, has been staged successfully at New York's American Museum of Natural History three times, most recently in January 2009. The main goal of this project is to enhance public understanding of science through a focus on the polar regions. This program design deliberately allows and encourages people to learn in several different ways: listening and viewing as well as interaction with scientists through one-on-one question and answer, demonstrations, and personal participation. The Baltimore version included both local and international flavor. There were contributions by local institutions, including the Baltimore Zoo and NASA Goddard, as well as a collection of Siberian children's paintings documenting local climate change, indigenous singers from Norway, and a hands-on demonstration that allows children to drill an ice core.

The premiere of *Frozen*—a new NASA-developed multimedia presentation: This presentation was developed for NOAA's *Science on a Sphere®* multimedia display system. *Science on a Sphere®* is a room-sized, global display that uses computers and video projectors to show planetary scale environmental data on a six-foot diameter sphere, like a giant animated globe. Researchers at NOAA developed *Science on a Sphere* as an educational tool to help illustrate Earth system science to people of all ages. As part of the weekend events, NASA unveiled a new movie called *Frozen* that explores the Earth's coldest regions from a truly global perspective. *Frozen* is a spherical movie, designed specifically for *Science on a Sphere®*, and showcases global ice and snow cover in ways that simply have not been displayed before. *Frozen* is only the second major film of its kind. It uses moviemaking processes and techniques developed at Goddard. Turning in space, images on the screen become a portal onto a virtual planet, complete with churning, swirling depictions of huge natural forces moving below. *Frozen* showcases the global *cryosphere*—those places on Earth where temperatures don't generally rise above water's freezing point. To learn more please visit the *Frozen* website at: *www.nasa.gov/frozen*. (The Maryland Science Center is one of fewer than 30 venues around the world with access to the *Science on a Sphere®* technology.)

Related Websites

The Maryland Science Center: *www.mdsci.org/*
The Polar-Palooza Web site: *passporttoknowledge.com/polar-palooza/pp01.php*
NSF's Antarctic Artists & Writers Program Guidlines: *www.nsf.gov/funding/pgm_summ.jsp?pims_id=12783&org=NSF&sel_org=NSF&from=fund*
Past Participants in NSF's Antarctic Artists & Writers Program: *www.nsf.gov/od/opp/aawr.jsp*
The U.S. Department of State's Antarctic Treaty Consultative Meeting Site: *www.atcm2009.gov/*

Applications Showcase Summary at GSFC

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An Applications Showcase took place on March 9, 2009 at Goddard Space Flight Center (GSFC).

Fritz Policelli [GSFC Office of Applied Sciences—*Technical Manager of Applications Division*] welcomed all and introduced **Franco Einaudi** [GSFC Earth Sciences Division (Code 610.0)—*Director*].

Einaudi opened the meeting. He stressed the importance of the applications of Earth science research. *"What we do in Earth sciences has major impacts on society and we need to publicize the linkage between our research and various societal applications."* Einaudi stressed how important it is to know specifically how our NASA data are being used by other agencies.

Shahid Habib [GSFC Office of Applied Sciences (Code 610.4)—*Chief of Applications Division*] again stressed the importance of applications; the recent Earth Science Decadal Survey specifically states that new missions should take into consideration socioeconomic needs. The purpose of this forum is to publicize existing applications so that others can learn about them and that these discussions might possibly lead to ideas for new applications. Habib showed a diagram of the six Research Themes and stressed their interdependence. The goal is to use our research results and apply them to respond to the needs of society. The Applied Sciences Division is also organized into themes. Previously there were 12 themes but the division has been reorganized around seven themes: Agriculture, Air Quality, Ecosystems, Natural Disasters, Public Health, Water Management, and Weather.

Habib pointed out that all of the seven applied sciences themes are interrelated or *crosscutting*. He also illustrated the idea that *hazards feed hazards*—i.e., a single natural disaster such as a hurricane could create impacts in all seven areas.

Habib also pointed out that most Applied Science applications are applied on a regional scale. The challenge is to take our research (often involving global scale satellite observations) and apply it to specific situations. The interface of research and applications is called *applied research*.

Habib also stressed the importance of partnerships and the interactions between science, management, and engineering.

Habib reviewed the structure of the Applied Sciences Program at NASA Headquarters (HQ), and also mentioned a number of *crosscutting* programs that cover a variety of themes. He also discussed the Applied Science Program Structure at Goddard, including a brief review of some of the applied sciences work going on at Goddard.

Robert Adler [University of Maryland, College Park/GSFC—*Senior Scientist*] discussed *Global Flood and Landslide Detection and Prediction Using Satellite Observations*. Data from the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA) are a key input to flood and landslide analysis and prediction, with *Real-time Heavy Rain Maps* updated every three hours, with a lag of about six hours behind real time.

The TRMM team has extended this information to come up with a *Global Flood Monitor* (GFM) that produces a global map of flooding every three hours at 0.25º resolution, using the satellite rain information as input to a global hydrological model. Adler showed an example from March 8, 2009, at 1200 Greenwich Mean Time (GMT). He also showed the flooding calculations for the extensive flooding in Burma on May 5, 2008, as compared to an after-the-fact Moderate Resolution Imaging Spectroradiometer- (MODIS-) based flood inundation map.

A member of the team has also developed a *Landslide Susceptibility Map*, a global map that gives an idea *where* landslides are most likely. An ability to know *when* a landslide would occur—i.e., how much rain it would take to set off a landslide—has also been developed. The final product combines the *where* and *when* information and forecasts where landslides are likely to occur in near real-time. Adler showed some analysis of the *Relative Skill of the Landslide Algorithm*. There are areas of "over-forecasting" as well as "under-forecasting" and Adler suggested some reasons for the errors and plans for improvement to reduce the errors.

Adler also briefly mentioned *Flood Modeling for SERVIR-Africa*. (**Fritz Policelli** will discuss SERVIR.) Global products to use in East Africa are being adapted.

Adler also discussed efforts to incorporate *Numerical Weather Prediction* precipitation data into the flood and landslide predictions for up to five days in advance.

Fritz Policelli gave background on the SERVIR (servir being the Spanish word for *to serve*) project jointly funded by NASA and United States Agency for International Development (USAID). The project was original-

ly implemented in Mesoamerica, and has been recently expanded to Africa—*www.nasa.gov/mission_pages/servir/index.html*. After consultations with colleagues and other sources, contact was sought with remote sensing organizations in Africa. NASA representatives attended the African Association of Remote Sensing of Environment conference in Cairo in 2006, making several presentations, hosting a town hall meeting, and staffing a NASA booth at the conference. The SERVIR team then began discussions with several different remote sensing centers in Africa. The Regional Center for Mapping of Resources for Development (RCMRD) (Nairobi, Kenya) was most responsive and the SERVIR team jointly developed a project with this regional remote sensing center. SERVIR identified RCMRD's top priorities as forecasting and monitoring of flooding in the Lake Victoria Basin and monitoring risk of Rift Valley Fever.

Policelli discussed the main products and showed some examples. Additionally, early in the project, RCMRD representatives traveled to the SERVIR office in Panama to join their Mesoamerican SERVIR colleagues in receiving training on using and requesting tasking of the EO-1 data products. The SERVIR project has a web developer and has started developing a website for SERVIR Africa. Policelli showed the *NASA Global Food Potential* map, developed by SERVIR partners from the NASA TRMM science team, for Africa projected on *Google Earth* along with reports for severe flooding potential (>125 inches of standing water.)

Policelli showed a flood map based on MODIS data which was produced by SERVIR partners at the Dartmouth Flood Observatory (DFO). To illustrate the utility of the flood potential maps, he also showed the (model-derived) NASA *Global Flood Potential Product* compared with the (observed) DFO Product.

Policelli also showed near-real-time-, near-daily-MODIS flood maps recently developed in partnership with the DFO. The SERVIR team would like to automate this process and extend it to cover the SERVIR Africa region, and eventually, beyond.

Policelli also showed *Rift Valley Fever Risk Maps*. Normalized Difference Vegetation Index (NDVI) data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) have been used for this product to date, but in the future NASA MODIS data will be used.

There was a ribbon-cutting ceremony in Nairobi in November 2008 to officially kickoff SERVIR Africa. There was actual flooding going on in the Lake Victoria region at the time, and NASA was able to provide several remote sensing products to its colleagues in Kenya for this flooding event.

Policelli ended by discussing some next steps for SERVIR Africa.

Antti Pulkkinen [GSFC Community Coordinated Modeling Center (CCMC)—*Research Scientist*] discussed *Solar Shield—Forecasting and Mitigating Space Weather Effects on High-Voltage Power Transmission Systems*. This is an experimental system to forecast space weather effects on the North American Power Grid. NASA/GSFC/CCMC partners with the Electric Power Research Insitute (EPRI) on this effort.

Solar activity such as *coronal mass ejections* can impact Earth's magnetosphere. *Aurora borealis* is the best known impact but there are others that are important to understand such as ge*omagnetically induced currents* (GICs). GICs can cause saturation of power transformers, which can lead to transformer damage, and in some cases, electric blackouts. The worst impact of a GIC was a storm that hit North America in 1989, causing a total blackout in Quebec Province in Canada.

Solar Shield seeks to give prior warning of GICs with a *two-level* forecasting system. Pulkkinen discussed some of the system requirements and explained the physics behind the *Level 1* and *Level 2* GIC forecasts. He then showed a *Level 2* forecast example. The product seems to be able to accurately predict the duration and intensity of the GIC event.

Pulkkinen also discussed how Solar Shield data are incorporated in the SUNBURST Decision Support Tool.

John Schnase [GSFC Office of Computational and Information Science and Technology (CISTO/Code 606)—*Information Science and Technology Research Lead*] discussed the the *Invasive Species Forecasting System* (ISFS) project. A partnership with the U.S. Geological Survey (USGS), ISFS uses NASA satellite data and NASA technology to help resource managers predict the spread of invasive plants on lands managed by the Department of Interior.

Schnase provided some background on *invasive species*—one of the top environmental issues of the 21st century—and showed photos of *tamarisk* growth in Colorado. *Tamarisk* is an invasive species that has dramatically altered the landscape in Colorado and other areas in the west.

The ISFS focuses on producing *habitat suitability* maps for plants of management concern. He described the computing and remote sensing techniques required to do this as well as the project's science accomplishments to date. *Phase I* of the project focused on engineering development—assembling and testing the tools, data, and methods needed for habitat suitability modeling. In *Phase II*, the focus is on operational deployment—coming up with ways of making the forecasting system available to the user community.

USGS is developing an online, Web-based version of the ISFS. NASA is working primarily on "light-weight", simple-to-use versions of the ISFS that can run on laptop computers, smart phones, and other mobile devices. He closed by demonstrating the real-time creation of a habitat suitability map for *cheatgrass* for Grand Staircase-Escalante National Monument.

Ken Pickering [GSFC Atmospheric Chemistry and Dynamics Branch—*Senior Physical Scientist*] discussed *Emission Inventories for Air Quality Modeling*. The two projects discussed use data from the Aura/Ozone Monitoring Instrument (OMI.)

In one project [collaborative with Greg Carmichael (University of Iowa) and Dave Streets (Argonne National Laboratory)] they are comparing "bottom-up" (i.e., ground-based) emissions and "top-down" (e.g., satellite) emission estimates and using results to update and improve various air quality emissions inventories.

One experiment involves studying nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) data from OMI to determine how emissions reductions made in China in the time leading up to and during the 2008 Olympics in Beijing impacted air quality in the region. NO_2 definitely seems to have improved in the immediate Beijing area during the Olympic timeframe, but SO_2 results are not as clear. There was a longer-term, nation-wide effort to reduce SO_2 emissions over China so this makes it more difficult to determine the impact level of the short-term SO_2 reductions for the Olympics.

The second project is monitoring the air quality (AQ) impacts of ongoing oxides of nitrogen (NOx) emissions reductions in the U.S. using a combination of OMI data and a regional air quality model. Pickering discussed why it is important to include NOx emissions from lightning into the Environmental Protection Agency's (EPA) Community Multiscale Air Quality (CMAQ) model. Prior to adding in the impact of lightning NOx, CMAQ seemed to be "missing" much of the NO_2 aloft. Pickering went on to describe the lightning parameterization for CMAQ.

In addition, the project studies NOx emissions from soil. This is also done using OMI data. Results suggest that the EPA soil NOx emission algorithm is probably underestimating NOx emissions from soil. Once the lightning and soil emissions are properly specified in the model, it can be used together with OMI NO_2 data to study NOx emissions reductions from power plants and motor vehicles.

Richard Kiang [GSFC Code 610.2—*Earth Science Data Operation Group Leader*] discussed *Malaria Modeling and Surveillance*. Malaria is just one example where satellite data can be used to predict the spread of infectious diseases. Kiang gave some of the sobering statistics about malaria. He discussed project objectives (risk detection, risk prediction, and risk reductions), benefits of each, and modeling techniques developed for each.

Research has been done in Thailand, Indonesia, and Afghanistan. Thailand is the epicenter of multi-drug resistant forms of malaria. Most provinces endemic with malaria are border provinces. In Indonesia, 40% of the population (245 million) live in malaria-infested areas. It is the only country where all three types of malaria have shown drug resistance. In Afghanistan, 60% of the population live in an endemic area, partly due to the military conflicts and instability in the last three decades. Kiang also showed a map for risk in Afghanistan broken down by province.

Kiang showed some of the satellite data and results for risk detection, prediction, and reduction.

Christina Hsu [GSFC Laboratory for Atmospheres, Sciences and Exploration Directorate—*Senior Scientist*] discussed infusing satellite products from MODIS and the OMI into the EPA's CMAQ model.

Hsu wants to add two new modules to the model: 1) a chemical data ingest and assimilation mode; MODIS Aerosol Optical Depth (AOD); and particulate matter (PM) surface and 2) NASA Land Information System—rainfall/snowfall event (soil moisture).

Hsu described the progress in model advancements of the CMAQ Data Assimilating Version and in the information delivery of the model data (i.e., automobile navigation systems could include data on visibility in smoky regions).

The goal of Hsu's work is to advance air quality forecast capabilities through model improvements. This would improve operational decision support for numerous clients. Hsu is working with partners at Baron Advanced Meteorological Systems (BAMS) to deliver air quality information to different groups, such as end-user forecasters.

Molly Brown [GSFC Biospheric Sciences Branch (Code 614.4)—*Research Scientist*] discussed *Farming, Food Security, and Climate Change*. Global monitoring of food resources needs global observations, and satellites are ideal for making these observations. Remote sensing provides an objective analysis of hazards, is the earliest identifier of the problem source, and is the least controversial method of data retrieval.

The Famine Early Warning Systems Network (FEWS NET) gathers information on food security in 23 countries and compiles it into country reports, alert statements, and other documents for decision makers.

In turn, the decision makers work through the United Nations and other groups to deliver aid.

Brown discussed some new statistical models being used for aid determination. These models make projections of rainfall, vegetation index, and precipitable water 1–3 months in advance and give estimates of the length of growing season. She also said that a new *Early Warning Explorer* web tool is in development. As more countries are added to the FEWS NET network, there will be additional emphasis on accurate and reliable global satellite data for agriculture monitoring.

Matt Rodell [GSFC Hydrological Sciences Branch (Code 614.3)—*Hydrologist*] discussed *Integrating Enhanced GRACE Water Storage into the U.S. and North American Drought Monitors*. The U.S. and North American Drought Monitors are two of the premier operational drought assessment products currently available. Currently, they rely heavily on precipitation indices (percentage of normal rainfall in the past week, month, etc.) which do not fully represent the weather and land conditions that contribute to droughts. There is great potential for improvement through the incorporation of NASA's satellite-based Earth observations.

Rodell explained that by integrating terrestrial water storage observations from the Gravity Recovery and Climate Experiment (GRACE) mission and other data into the Drought Monitors, more accurate and objective assessments of drought conditions can be made. Terrestrial water storage includes groundwater, soil moisture, surface water, and snow/ice.

GRACE measures variations in the storage of water at all depths—from the top of the land surface down through the aquifers—by measuring the gravity field rather than emitted or reflected light. In contrast, other Earth observing satellites, such as Aqua, can only sense water on or within the first few cm of the soil.

Jeanne Behnke [GSFC Earth Science Data and Information System (ESDIS)—*Science Operations Manager*] discussed *EOSDIS and Near-Real Time Processing*. She explained that the ESDIS Project is responsible for the Earth Observing System Data and Information System (EOSDIS)—the largest civilian science information center in the world. EOSDIS has over 3,700 unique data products.

Behnke explained that NASA launched a Near-Real Time Processing Effort (NRTPE) in response to the September 11, 2001 attacks. NRTPE is a risk reduction effort that distributes Earth Observing System (EOS) data to users prior to the launch of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) and NPOESS. Data from the Terra and Aqua MODIS, Aqua Atmospheric Infrared Sensor (AIRS) and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) are available three hours after processing with NRTPE.

Patrick Coronado [GSFC Direct Readout Laboratory (DRL)—Manager] discussed *Direct Readout Laboratory: Providing Earth Science Direct Readout Mission Continuity to the Broad User Community*. NASA's DRL provides access to Earth remote sensing data. Coronado explained that Direct Broadcast (DB)—the real-time transmission of satellite data to the ground—and Direct Readout (DR)—the process of acquiring freely transmitted live satellite data—empower people to "see" and make decisions about environmental issues.

DR has enabled mapping of forest fires, including associated hotspots and wind direction in fire areas. Sea-ice monitoring, polar wind vectors for navigational utility, and tornado/severe storm tracking are all possible with DR data.

Shahid Habib closed the showcase and thanked everyone for attending. ■

Landsat Science Team Meeting Summary

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Meeting Overview

The U.S. Geological Survey (USGS)- and NASA-sponsored Landsat Science Team held its winter meeting from January 6-8, 2009. The U.S. Department of Agriculture (USDA) Forest Service in Fort Collins, CO hosted the meeting.

Tom Loveland [USGS—*Landsat Science Team Co-Chair*] and **Jim Irons** [NASA Goddard Space Flight Center (GSFC)—*Landsat Science Team Co-Chair*] reviewed the objectives of the fifth meeting. The objectives included:

1. Reviewing recent USGS and NASA Landsat Data Continuity Mission (LDCM) implementation progress and of the status of Landsats 5 and 7.
2. Reviewing the research and application activities within the Fort Collins area remote sensing community.
3. Identying requirements for, and technical issues associated with, future operational Landsat products.
4. Identifying the science and applications drivers for future missions.

Desired outcomes from the meeting included establishing priorities for future Landsat products, identifying advances needed in processing, and developing an improved understanding of the requirements and paths for future Landsat missions.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] challenged the team to evaluate new opportunities for Landsat applications, such as the global forest monitoring requirements associated with the United Nations Framework Convention on Climate Change (UNFCCC) initiative, Reducing Emissions from Deforestation in Developing Countries (REDD). Woodcock commented that the recent USGS action to make all Landsat data available at no cost will create many new opportunities, but to meet the needs of emerging applications there must also be improvements in product quality that will make it easier for people to use Landsat data more effectively. He also stressed the urgency to focus attention on the authorization and planning for Landsat 9 and beyond.

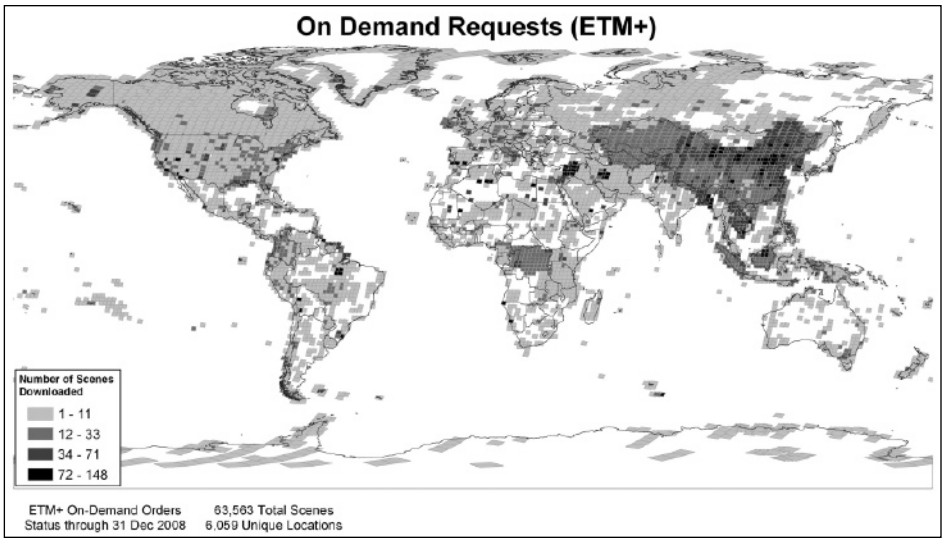
Bryant Cramer [USGS—*Associate Director for Geography*] challenged the group to contribute to the establishment of a national land imaging program. He also reiterated Woodcock's comments on the importance of Landsat for climate science applications, including carbon crediting and treaty verification.

The opening session closed with meeting attendees applauding Landsat Science Team member **Sam Goward** [University of Maryland, College Park] for his selection as the 2008 Pecora Award winner.

All presentations used during the Fort Collins meeting are available online at: *landsat.usgs.gov/science_january 2009MeetingAgenda.php*.

Landsat Status and Activities Report

Kristi Kline [USGS—*Landsat Project Manager*] updated the team on the status of Landsats 5 and 7. Land-



Landsat ETM+ scenes obtained since the opening of the Landsat archive to no-charge access (October 1, 2008 –December 31, 2008).

sat 7 is now 9.5 years past launch. Enhanced Thematic Mapper Plus (ETM+) data are affected by the 2003 scan line corrector failure, and technical issues associated with spacecraft attitude control, solid state recorders, and other components require close monitoring. However, these issues have not had a negative impact on the Landsat 7 Long Term Acquisition Plan and the mission is continuing to aggressively collect global coverage. Landsat 5 is now nearly **25 years** past its March 1984 launch and operational acquisitions are continuing—a remarkable achievement! Landsat 5 has no solid state recorders and can only relay data to ground stations, limiting the volume of international coverage flowing into the USGS Landsat archive. A battery anomaly that occurred in late-2007 affected available power, resulting in seasonal reductions in acquisitions (i.e., high latitude coverage was eliminated during the Southern and Northern Hemisphere summer solstice) due to sun angle constraints. With both Landsats 5 and 7 past their design life, there is an increasing chance of mission-ending failures. However, both satellites have sufficient on-board fuel to continue operating for several years. Barring catastrophic system failure, the USGS has a goal to operate both satellites through 2012.

Kline reported that as of December 8, 2008, all 2.3 million scenes in the USGS Landsat archive are now available over the Internet at no cost. Landsat 7 data were released for no cost access on October 1, 2008. Since October 1, over 200,000 scenes have been downloaded—see distribution map on previous page. As an indication of the demand, during the month of October, over 60,000 scenes were downloaded. (The largest number of scenes distributed in any single year prior to the opening of the archive was in 2001, when approximately 21,000 scenes went out.) The interest in free Landsat data has led to a new global phenomenon with investigators from 137 countries downloading scenes through early January 2009. The highest demand has been from the U.S. and China.

Kline also reported that duplicates of nearly all scenes in the USGS Landsat archive have been shipped to a National Archives and Records Administration (NARA) managed limestone cave near Kansas City, MO. She also reported on discussions with Landsat International Cooperators (i.e., Landsat ground stations) regarding USGS planning for a consolidated global Landsat archive. In discussion, the Landsat Science Team members stressed that global Landsat archive consolidation is a high priority that would result in major benefits for science and applications. The team offered to work closely with the USGS to develop a prioritization strategy that identifies those areas and temporal periods where consolidation of data holdings is most urgent.

Kline and **John Dwyer** [USGS—*Landsat Project Scientist*] gave an update on the Global Land Survey (GLS) initiative. The GLS involves providing periodic epochs of global Landsat coverage that have been consistently processed for use in monitoring land-cover change. Kline reported that production of the GLS 2005 data set is nearly complete with only isolated continental land areas and small islands remaining. A status map of the GLS 2005 processing is available at *landsat.usgs.gov/science_GLS2005.php*.

Dwyer gave an update on the status of GLS 2010 planning. GLS 2010 is again a collaborative development between NASA and the USGS. Landsat 5 Thematic Mapper (TM) and Landsat 7 ETM+ data will be used in GLS 2010 and the USGS is working to augment Landsat coverage by establishing campaign stations in areas where their coverage is limited (e.g., northern Russia, east Africa, Mexico). In addition, efforts are underway to involve the Committee on Earth Observation Satellites Land Surface Imaging Constellation Working Group on Regional Data Set Compilation in order to make GLS 2010 an international multi-source initiative that includes Landsat-class data from India, China, Brazil, France, and other international providers.

Natalie Sexton [USGS—*Survey Scientist*] gave an update on a survey of Landsat data users designed to document societal uses and benefits of moderate resolution imagery. The goal of the survey is to better understand the uses of moderate resolution imagery, including those previously not captured or detailed. To meet this goal, the survey team first used a *snowball survey approach*—where one person is surveyed and then is invited to identify others who should be surveyed—to identify and classify users. This has resulted in the establishment of a sample group of nearly 3,800 data users that will soon be contacted to understand how and why moderate resolution imagery are being used and to qualitatively and quantitatively measure societal benefits associated with the use of the imagery. Plans are to distribute the survey to those identified in the first phase once approval is received from the Office of Management and Budget.

The final Landsat-related topic involved the status of planning for a Landsat *data gap*. There is a strong probability that Landsat 5 and 7 will cease operation prior to the launch of LDCM. **Tom Holm** [USGS—*Data Management Advisor*] reviewed the analysis of international moderate resolution candidates that could fill a *data gap* and the steps ahead to implement a *data gap* activity. Previously, an interagency Landsat *data gap* study team established radiometric, spectral, spatial, and geographic criteria that replacement data sources should ideally meet (*see calval.cr.usgs.gov/documents/LDGST_Technical_Report_Final.pdf*). The group concluded that no single source would meet all of the criteria but that the leading candidates are the instruments on the Indian Remote Sensing ResourceSat-1 and the Chinese–Brazilian Earth Resources Satellites. It is clear that additional sources (e.g., the French Système

Pour l'Observation de la Terre (SPOT) satellites and the German *RapidEye* system) are also candidates and that some other data sources are still being evaluated. The USGS will develop a detailed implementation plan by mid-2009 that addresses technical and policy/programmatic issues. Holm requested input from the Landsat Science Team on data requirements for operational and scientific purposes.

LDCM Status

Bill Ochs [NASA GSFC—*LDCM Project Manager*] and **David Hair** [USGS—*LDCM Project Manager (Acting)*] updated the team on the LDCM development status. **Ochs** led off with the news that in September 2008, the NASA Program Management Council gave approval for LDCM to proceed into *Phase B* of the project life cycle. *Phase B* is the system preliminary design phase of the mission. This decision follows the May 2008 System Requirements Review/Mission Definition Review/Preliminary Non-Advocate Review. The review findings included the determination that the original LDCM launch readiness date of July 2011 was excessively aggressive and added risk to the mission because of the conclusion that there was less than a 20% chance that the 2011 launch date could be achieved. Because NASA mission schedules must reflect a 70% chance of achieving the launch readiness date, five independent schedule assessments were made. Based on those assessments, the LDCM launch readiness date approved by the NASA Program Management Council was December 2012. The conclusion was that the revised date provided an appropriate level of confidence and that it resulted in sufficient schedule reserve on the mission critical path.

Ochs next reviewed the status of the Operational Land Imager (OLI). Ball Aerospace & Technologies Corp. (BATC) successfully conducted the OLI critical design review in October 2008. There are a few issues that have been discovered recently. Analysis of the OLI optical model showed reflections from the focal plane assembly window onto adjacent bands on the focal plane module. BATC has adjusted the baseline design to tilt the focal plane assembly window 16.7º based on results of the refined ghosting analysis. The second concern is that the OLI engineering design unit focal plane module has surface leakage. If not corrected, it could lead to degraded detector response. The NASA LDCM and Ball engineers are developing *decision milestone* dates regarding options for solving the problem. This issue could have a potential impact on the OLI delivery date.

Ochs also reported that the spacecraft system requirements review was held in September 2008. As a result of this review, NASA and the spacecraft vendor (General Dynamics) are concentrating on instrument interfaces [both OLI and the Thermal Infrared Sensor (TIRS)—see discussion on TIRS below] and resolution of open requirements. Ochs mentioned that The Hammer Company received the mission operations element award to provide capabilities for controlling and managing the spacecraft.

Finally, **Ochs** provided a detailed update on the status of TIRS. While thermal imaging capabilities are currently not authorized, there is still significant congressional and scientific interest in adding thermal imaging capabilities to LDCM. In July 2008, NASA initiated a *Phase A* Study to proactively investigate the implementation of a TIRS for LDCM and provide risk mitigation to the December 2012 launch readiness date. This included assessing all requirements, creating a concept design, and assessing the programmatic implementation, including the schedule and required early procurements needed. The concept developed is based on the use of Quantum Well Infrared Photodetector (QWIP) technology. At this point, TIRS is still not authorized but it has been fully integrated into the LDCM planning process.

David Hair summarized USGS LDCM accomplishments. The USGS is in the final stages of completion of the ground system preliminary design and elements of the ground system critical design have been initiated. The full ground system preliminary requirements review is scheduled for May 2009. Hair also reported on a USGS investigation of the need for access to *Level 0R* (L0R) format data for historical Landsat data. The investigation included an evaluation of the potential frequency and volume of requests for L0R data and whether there were expectations on the need to provide processing software. Results of the study were inconclusive and there was relatively little interest in low-level Landsat products, especially if there would be a cost associated with access to L0R products.

The LDCM status discussion continued on the final day of the meeting when the Landsat Science Team traveled to Boulder, CO for a detailed briefing on OLI status by the BATC team. During that session, **Charlie Vanhouten, Ed Knight,** and other BATC engineers and scientists provided a comprehensive overview and tour of OLI development. They gave the Team an in-depth tour of the development labs and showed flight hardware including the optical bench, telescope mirrors, and other components. They also introduced the Team to their testing facilities and other capabilities used in the OLI development process.

Remote Sensing Science and Applications

As the host of the Fort Collins meeting, Landsat Science Team member **Eileen Helmer** [U.S. Forest Service] organized a technical session to showcase selected Fort Collins remote sensing activities.

Helmer's U.S. Forest Service team is involved in tropical vegetation assessments in the Caribbean. **Bonnie Ruefenach** [USFS Remote Sensing Applications Center] provided a detailed introduction to a set of image analysis tools that she has developed for vegetation characterization. **Tom Ruzycki** [Colorado State University] gave an overview of the methods used to create cloud-free Landsat time series mosaics for use in modeling of Puerto Rico and the Virgin Islands forest characteristics. In addition, he described a geospatial framework that uses remote sensing and other inputs along with regression tree analysis to predict tropical species occurrences. **Helmer** provided an overview of their research on the interactions between the spatial patterns of tropical forest disturbance and biomass in Puerto Rico. The research documents the changes in tropical forest types and an analysis of the shifting of the Puerto Rican economy from agriculture to industry and services. It also estimates the total biomass of forest cleared for land development from 1991–2000 based only on forest type and also based on both forest type and age class.

Jeff Morisette [USGS—*Research Biologist*] summarized the USGS Fort Collins Science Center remote sensing of invasive species program. Satellite data provide predictor layers for habitat modeling that is used to estimate where species will thrive. There has been considerable effort at the Center to use satellite data to enhance habitat modeling. Initial work was with Landsat 5, using tasseled cap transformations. Recent work has been with national-level mapping using the Moderate Resolution Imaging Spectroradiometer (MODIS). Potential future work includes using disturbance mapping to anticipate invasion (e.g., predicting the likelihood of invasion as a function of burn severity.)

John Gross [National Park Service Inventory and Monitoring Program—Fort Collins] described efforts to establish inventory and monitoring as a standard practice throughout the National Park Service. This program emphasizes inventorying natural resources, monitoring park ecosystems, and integrating natural resource information into planning, management, and decision making. In addition to providing an overview of the program, Gross reviewed the role of remote sensing in contributing to the spatial and temporal scales of analysis that form the basis for the inventory and monitoring framework. A key requirement for the program is long-term data continuity from which change products can be derived. MODIS, Landsat, and *IKONOS* imagery are current inputs to the integrative land-cover change element. A particular interest for the future is the establishment of tools for detecting change in long Landsat time series. In addition, the Inventory and Monitoring Program is working toward a tighter link to climate change issues.

Products Discussion

The morning of the second day was dedicated to discussing future products. **Brian Markham** [NASA GSFC] reviewed the LDCM *Level-1* product. The *Level-1* product will be 16-bit integers, radiometrically and geometrically corrected, and scaleable to reflectance or radiance with linear scaling factors that will be provided with the product. The reflectance product will be for a scene-center zenith sun and will include the Earth-Sun distance correction. The Team agreed to the use of a scene-center angle as long as information for all four corners will be provided in the metadata.

Dennis Helder [South Dakota State University] discussed ongoing calibration work for Landsat TM and Multispectral Scanner (MSS) sensors. *Pseudo-invariant* calibration sites (sites with non-changing surface properties such as non-vegetated desert sites) have been used for radiometric trending and to help cross-calibrate TM and MSS sensors. Cross-calibration of TM4 to TM5 is complete and Helder is currently expecting to incorporate the new calibration for Landsat 4 TM by May 2009. Radiometric calibration of the MSS 1-5 showed good stability over time and cross-calibration validation showed good consistency between sensors. Cross-calibration for MSS/TM is more difficult due to differences in the spectral bands and his team is looking at developing a spectral-based cross-calibration technique.

Pat Scaramuzza [Stinger Ghaffarian Technologies (SGT) Inc.] showed results from the Cloud Cover Assessment algorithms developed for LDCM. Scaramuzza's task was to create an Automated Cloud Cover Assessment (ACCA) that does as well or better than the current Landsat ACCA, but without the use of a thermal band and with minimum processing time. The *See5* algorithm correctly identified 89% of the cloud/non-cloud pixels and outperformed the current ACCA. The final system may include several algorithms with intermediate masks that will be merged to create a final cloud cover mask.

David Roy [South Dakota State University] presented his Web-enabled Landsat Data (WELD) project. The goal is to generate 30-m mosaic temporally composited products over the continental U.S. Similar to MODIS. Roy's team will create monthly, seasonal, and annual products such as surface reflectance, brightness temperature, and Normalized Difference Vegetation Index (NDVI). In some areas they are having difficulty getting enough data to create monthly and seasonal mosaics due to the USGS data policy restricting the automated processing of Landsat to scenes that have 40 percent or less cloud cover.

Warren Cohen [USDA Forest Service] presented work on tools that use Landsat's long-term archive for large-

scale monitoring. *LandTrendr* analyzes Landsat time series using automated algorithms to track trends in disturbance and recovery, and can also create composites removing SLC-off gaps and clouds. *Timesync* uses Landsat's rich archive to validate time-series maps by allowing a visual interpretation of what has been automatically detected.

Future Missions Discussion

The Landsat Science Team devoted an afternoon to a discussion of the future of the Landsat Program. The Future of Land Imaging Plan recommended by the White House Office of Science and Technology Policy called for the establishment of a National Land Imaging Program (NLIP) with an operational Landsat program as a central part of NLIP. Thus far, there has been little congressional support for NLIP and as a result, planning for Landsat 9 and beyond is not underway.

Tony Willardson [Western States Water Council (WSWC)—*Deputy Director*] led off the discussion. The WSWC has been a strong advocate for Landsat data, and in particular, thermal infrared imagery. Willardson reviewed the information needs for western state's water resources management with emphasis on the importance of Landsat. Issues being addressed by western state's water managers include:

- general lack of data on water needs and past, present, and future uses;
- climate change and variability;
- endangered species and other in-stream water uses;
- outflows to bays and estuaries;
- increasing energy needs; and
- unquantified Native American water rights.

These issues are further complicated by population growth in the West, which has created even greater demands for water and is threatening water-dependent agricultural practices. Landsat data are being used throughout the West to provide data and information needed to manage these issues. For example, five court cases that WSWC is currently involved in are using Landsat thermal data in the deliberations. Because of the importance, the WSWC is working with western congressional delegations to advocate for Landsat thermal data continuity.

The Landsat Science Team spent the remainder of the session identifying the issues and steps that need to be taken to establish an operational Landsat program. There was strong agreement that the future of Landsat must be viewed as a two stage process with the first stage being the authorization and development of Landsat 9, and the specification and development of the long-term operational configuration starting with Landsat 10 and beyond. The need for continuity that extends the Landsat record without periods of observation gaps is the most urgent driver for Landsat 9. Given the extended lead time required for authorization, planning, and development of each Landsat mission, there is real urgency to embark on a course for Landsat 9 that has a shortest possible development time. The team generally agreed that the current LDCM specifications, plus a thermal imaging capability, were appropriate for planning Landsat 9. The technology improvements incorporated into LDCM (e.g., pushbroom scanner) and improved capabilities (e.g., 12-bit quantization, additional spectral channels, and expanded acquisition capabilities), were sufficiently demonstrated in the Earth Observer-1 mission to suggest that the current LDCM specifications and design be used for Landsat 9. While the specific cost and schedule savings associated with reuse are not known, the Team expected that this approach was the most logical short-term strategy.

While the Landsat Science Team considered Landsat 9 progress to be the most urgent issue, they also remain committed to an operational Landsat program as envisioned in NLIP. NLIP is clearly the long-term solution to mid-resolution imaging and authorization of the program remains an important need.

Discussions focused on three issues associated with an operational Landsat program as summarized below.

1. **Definition of what an operational program involves**. **Bryant Cramer** suggested the Team consider the operational threshold for *data gaps* by considering the length of time that is permissible between the failure of one mission and the launch and operation of a follow-on. This could also be addressed through an expression of what probability of a *data gap* is acceptable to the user community. In other words, how much risk can users tolerate—and why?
2. **Definition of the Landsat 10 mission… and beyond**. The definitions must address the purpose of an operational Landsat program and express the fundamental mission requirements. Landsat Science Team members agreed that the long-standing mission definition to detect land changes at the scales relevant to human activities remains valid but that climate change and emerging operational environmental monitoring applications will necessitate evolutionary changes. There was general agreement that future missions must include additional science data products such as land-cover change, fraction of absorbed photosynthetic radiation, albedo, fire products, and others.
3. **The importance of periodic technology missions to test new capabilities or technologies for future Landsats.** An operational program must have a strong research and development component to test and evaluate new capabilities.

In general, the Team agreed that Landsat missions must continue to serve as the "gold standard" that is used to maintain calibration between constellations of international missions. However, there was also agreement that miniaturization of instruments to lower mission costs and enable faster development-to-launch schedules is needed. It is also important to work through the international community and coordinate acquisition schedules.

Summary

The primary topics addressed during the January 2009 meeting were Landsat products and future Landsat missions. While there was considerable discussion of options associated with each topic, many issues were not resolved and have to be carried over to the summer meeting. Six working groups were established to study the unresolved issues and each was tasked with identifying and evaluating options and presenting them for discussion and resolution when the Team meets in June 2009. The six working groups and a brief summary of the responsibilities of each follows.

Data Gap Working Group

The Data Gap Working Group will contribute a science and applications perspective to the development of a USGS operational plan for acquiring data during a Landsat *data gap* period. In particular, the group should contribute to the strategy and preparations associated with acquiring replacement moderate resolution remotely sensed data as soon after the failure of Landsat as possible. Specific topics that the working group must address include: (1) confirmation of the technical and programmatic specifications for data gap candidates; (2) evaluation and validation of candidates; and (3) assessment of the science and applications potentially associated with both individual and integrated multi-source data sets.

Future Missions Working Group

The Future Missions Working Group will develop and recommend to the USGS and NASA operational mission standards, requirements, and characteristics for future Landsat missions. This includes determining the meaning of an "operational" Landsat program, suggesting a long-term mission definition including the purpose of an operational Landsat program, providing recommendations on what the key technical elements of an operational program are, and identification of the key innovations needed in the Landsat program over the next 5-10 years.

Global Consolidated Landsat Archive Group

The Global Consolidated Landsat Archive Group will develop and recommend a prioritization strategy for acquiring data from International Ground Stations to the USGS. Some of the topics for the team to address are: (1) where are there data gaps in the USGS Landsat archive; (2) which data gaps are most important to fill and where is the data held; (3) which stations hold the highest volume of unique data; and (4) what are other mechanisms for acquiring data? Each of the station's holdings and the importance of the data should be documented for the USGS.

Cloud and Shadow Masking Group

The Cloud and Shadow Masking Group will identify and evaluate methods for improving cloud and shadow masking. The team will develop and assess algorithms to create a *Level 2* cloud and shadow mask. The team will also evaluate and determine the feasibility of implementing additional algorithms as part of the Cloud Cover Assessment for the LDCM Image Processing Element.

Gridded Data Sets

The Gridded Data Set Working Group should provide recommendations to the USGS Landsat and LDCM projects on the specifications for standard product generation to ensure the highest levels of product quality and usability. The Working Group should address issues related to the map projections, resampling methods, and pixel coordinate referencing schemes for Landsat and LDCM data products to ensure the consistency in image geometry and geolocation necessary to support large area and time-series research and applications. Particular consideration should be given to the geometric registration and georeferencing across the multiple Landsat and LDCM sensors and spectral bands.

Surface Reflectance and Temperature

The Surface Reflectance and Temperature Working Group should provide recommendations to the USGS Landsat and LDCM projects on the specifications for standard product generation with particular emphasis on the derivation of geophysical parameters from calibrated at-sensor radiance data. These recommendations will be considered in the design and implementation of algorithms used for ground processing and standard product generation. The Working Group should address issues associated with radiometric calibration, data processing algorithm and scaling parameters, product metadata, and data usability to support the needs of the research and applications community.

Next meeting

The next meeting of the Landsat Science Team is tentatively scheduled for June 22-24 in Rochester, NY. Landsat Science Team member **John Schott** from the Rochester Institute of Technology will host the meeting.

TES Science Team Meeting Summary

Annmarie Eldering, NASA Jet Propulsion Laboratory, annmarie.eldering@jpl.nasa.gov

The 32nd Tropospheric Emission Spectrometer (TES) Science Team meeting was held February 23-25, 2009, at the National Center for Atmospheric Research (NCAR) Foothills Laboratory in Boulder, CO.

The morning of the first day focused on status and validation, while the afternoon focused on air quality. The second day had a session on chemistry, climate, and dynamics, followed by one on intercomparisons, and ended with presentations on tropospheric chemistry. The third day focused on hydrology and science use of isotope measurements.

Reinhard Beer [NASA Jet Propulsion Laboratory (JPL)—*TES Principal Investigator* (PI)] provided a welcome and brief instrument status. The instrument is performing well, although there are signs of aging. A graph of the motor current was shown for the life of the mission, showing that it has been reduced since changes to the global survey were made in Summer 2008.

Mark Schoeberl [NASA Goddard Space Flight Center (GSFC)—*Aura Project Scientist*] spoke briefly, primarily on the Senior Review and progress on preparing that proposal. He touched on the future of NASA Earth Science, both the positive (more funding likely), and more concerning (aging satellites and instruments).

Jay Al-Saadi [NASA Headquarters (HQ)—*Tropospheric Chemistry Program Manager*] also presented a brief talk. Jay highlighted the Research Opportunities in Space and Earth Sciences (ROSES) Solicitation and pointed out that the selections for some earlier calls are still pending. Potentially, 26 elements are being solicited this year. There is a new Interdisciplinary Research in Earth Science (IDS) solicitation this year—growing emphasis to use an interdisciplinary approach for science analysis. Also, there is a placeholder for an upcoming Field Mission that will be added in an update to ROSES.

Doug Shepard [JPL—*TES Project Manager*] talked about performance of the instrument, and data processing. In the last 12 months, 172 Global Surveys and 1237 Special Observations were collected. Over the summer, changes were made to the global survey to remove observations above 70°N and below 50°S latitude (reduced number of footprints by 30%). The TES Science Investigator Processing System (SIPS) is now processing TES data *Version 4* (V4).

Annmarie Eldering [JPL—*TES Deputy PI*] discussed the status of senior review proposal preparation. A draft has been prepared; continued collaboration with the larger Aura team will be needed to get to the final proposal in late March.

Greg Osterman [JPL—*TES Validation Lead*] provided an update on the validation status of TES data, providing some details on *Version 3* (V003) data (a complete record of V003 exists) and V4 (V004) data (being processed currently). The nadir measurements have been well validated, and limb validation is underway, with a plan to complete it by the middle of 2009. The first version of the V004 TES Validation Report should be available on the Distributed Active Archive Center (DAAC) in April 2009.

Vivienne Payne [Atmospheric and Environmental Research, Inc. (AER)] discussed updates to the TES forward model and impacts on the data products. Her work is focused on the analysis of new spectroscopy, impacts on the radiance residuals, and consistency between bands. Significant improvements to the temperature retrievals were achieved by using new line coupling, line strengths, and line positions for carbon dioxide (CO_2). Water vapor spectroscopy may result in significant decreased (5-7%) in line strengths for strong lines, but further analysis is needed to assess the impact on TES retrievals. Ozone spectroscopy is unlikely to undergo significant changes, but methane line coupling may be implemented and impact TES retrievals.

Chris Boxe [JPL] discussed his analysis of TES retrieval and ozonesonde measurements, which used Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) ozonesondes and TES special observations data that were very closely paired in time (less than 30 minutes). His analysis showed that the TES error estimates are in good agreement with the difference between sondes and TES measurements, and the biases are well characterized.

Vivienne Payne discussed TES methane retrievals in detail. Her key findings are that V004 has a slightly higher bias (4.5%) than V003 (3.5%). Comparisons are being made against National Snow and Ice Data Center (NSIDC) Network for the Detection of Atmospheric Composition Change (NDACC) ground based columns, and a collaboration with Aaron Goldman and Jim Hannigan will let them compare just the tropospheric column, starting with measurements from Thule, Greenland.

Susan Sund Kulawik [JPL] discussed research retrievals of CO_2. She is using the TES infrared radiances to retrieve profiles of CO_2, with most of the sensitivity in the mid-troposphere. She finds that TES retrievals are biased about 5 parts per million [ppm] low relative to Mauna Loa measurements. In the Northern Hemisphere, the data have a correlation coefficient of 0.92. The year-to-year increases seen in the TES data match those of the ground-based measurements.

Karen Cady-Pereira [AER] presented a talk on additional trace species that can be retrieved from TES radiance measurements, specifically ammonia. With ROSES funding, she and AER colleagues are working in collaboration with JPL, University of Colorado, Environmental Protection Agency (EPA), and Clough Associates to develop these trace gas retrievals. A prototype retrieval code at AER is being used. Initial simulations show that there is sensitivity to ammonia, peaking at 850 mb, with a layer thickness of about 2 km. In the near future, they will be doing retrievals of ammonia with TES measurements made over ground-based sites that the EPA is operating.

Daven Henze [NCAR/University of Colorado at Boulder (UC Boulder)] discussed ammonia in the context of the relationship of gas phase and aerosol, and on-going efforts to constrain the ammonia emission inventory using measurements and inverse models. Henze is performing inverse analysis using an adjoint model, and his long-term goal is to use TES ammonia measurements to further constrain emissions over the U.S.

Mark Parrington [University of Toronto] presented his results of assimilation of TES ozone measurements into the Goddard Earth Observing System (GEOS)-Chem model. He found that assimilating TES data reduces the negative bias in the modeled free tropospheric ozone, enhancing the flux of background ozone into the boundary layer. TES assimilation is providing a best estimate of North American background ozone of 20-40 parts per billion by volume [ppbv]. Parrington, of **Dylan Jones's** group, wishes to understand how errors in the GEOS-Chem model estimates of emission of ozone precursors-the atmospheric constituents that are needed to enable the formation of ground level ozone-impact the model ozone fields. They are integrating top-down emissions estimates of nitrogen oxides (NO_X) and isoprene derived from Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) nitrogen dioxide (NO_2) as well as formaldehyde measurements from the Ozone Monitoring Instrument (OMI), and quantifying how ozone fields are changed by the inclusion of these new emission estimates.

Greg Osterman [JPL] spoke on the topic of analysis of the wildfires of Northern California in 2008, which were measured by TES. In collaboration with **Brad Pierce** [National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS)], Osterman is verifying that the Real-Time Air Quality Monitoring System (REAMS) can capture the influence of wildfires on air quality, as observed by TES.

Yunsoo Choi [California Institute of Technology (Caltech)/JPL] discussed summertime tropospheric composition over North America using satellite remote sensing data and the Regional Chemical Transport Model (REAM). He investigated the migration of enhancements of NO_2 and ozone (O_3) concentration, outgoing longwave radiation, and radiative forcing associated with the onset of the North American Monsoon in July 2005 using satellite data [from Aura (TES and OMI), and NOAA-16] and REAM. This study shows that lightning-generated NO_X exerts a larger—by up to a factor of three—impact on outgoing longwave radiation (OLR) and radiative forcing than anthropogenic NO_X via enhancement of O_3 in the convective outflow regions. This is despite the fact that the lightning-generated tropospheric NO_2 and O_3 are much smaller than anthropogenic NO_X emissions.

At the end of the first day, **Susan Sund Kulawik** and **Greg Osterman** presented a discussion for new TES data users, providing copies of the TES data user's guide found at the Langley DAAC (*eosweb.larc.nasa.gov/PRODOCS/tes/UsersGuide/TES_L2_Data_Users_Guide.pdf*) and the new quick start guide that is under development. These guides can help the new user quickly identify the data of interest and some common manipulations.

The second day of the meeting began with **Helen Worden** [NCAR]. Worden discussed how instantaneous radiative forcing from tropospheric ozone (in W/m^2) derived from TES ozone profiles and *radiance Jacobians* (change in radiance due to a change in the species concentration) varies with season and observation type (clouds, ocean, land, day, night) in a selected region (15°–45°N, 20°–60°E). She also showed that the effective radiative forcings due to tropospheric ozone differences between TES measurements and the AM2-Chem model for this region are as large as the term for anthropogenic forcing from tropospheric ozone in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (0.35 W/m^2).

Jennifer Logan [Harvard University] discussed comparisons of TES, Microwave Limb Sounder (MLS), and OMI measurements to the Global Modeling Initiative (GMI) Combined Stratosphere-Troposphere (COMBO) model. She concluded that TES and OMI/MLS products show similar variability, but over South America and South Africa, the maximum convection in GEOS-*Version 4* (GEOS-4) appears to be a month too late. To understand this more fully, the convective mass fluxes in the model need to be analyzed. Also, TES reveals interannual variability in tropical ozone, but the model has problems matching this in the South Atlantic, likely due to lightning NOx.

Dale Allen [University of Maryland, College Park] presented results from an analysis of a July 9-11, 2007, U.S. east coast pollution event by Allen and graduate

student **Elena Yegorova**. They compared the Weather Research and Forecast (WRF) model coupled with Chemistry (WRF-Chem) calculated lower tropospheric ozone columns with TES columns and found that TES detected elevated lower tropospheric ozone off of the coast, in agreement with WRF-Chem. This illustrates continental outflow of a polluted air mass that had originated over the Great Lakes and Ohio River Valley.

Ben Ho [NCAR] discussed a comparison of carbon monoxide (CO) profiles and column amounts from TES and Measurements of Pollution In The Troposphere (MOPITT). In this study, he compared CO products from MOPITT and TES and investigated the possible causes of the differences between retrievals for these two datasets. After accounting for the combined effects of instrument noise, *a priori* constraint and measurement weighting functions in TES and MOPITT retrievals, comparison results show that TES CO profiles are biased 1 ppbv lower near the surface and 4-9 ppbv lower in the troposphere. The mean absolute TES and TES-equivalent CO column difference is less than 6.5%. The remaining CO bias is primarily due to the combined effects of radiance biases, forward model errors, and the spatial and temporal mismatches of TES and MOPITT pixels.

Lin Zhang [Harvard University] showed an intercomparison of tropospheric ozone measurements from TES and OMI. Using a variety of comparison methods (sonde–satellite, satellite–satellite, and model–satellite), he found that independent and concurrent measurements of tropospheric ozone from TES and OMI show consistent evaluations on the ozone simulation from the GEOS-Chem 3-D chemical transport model, which indicates consistency of tropospheric ozone information from thermal infrared (IR) and backscattered ultraviolet (UV) radiance measurements.

Juying Warner [University of Maryland, Baltimore County (UMBC)] presented the comparison of the global Atmospheric Infrared Sounder (AIRS) and TES CO profiles over a period of three years (2005–2008). Warner pointed out that, in majority of the cases, the two sensors agree to within 10-20 ppbv in the free troposphere especially in the Northern Hemisphere.

Curt Rinsland [NASA Langley Research Center (LaRC)] presented time series of methanol (CH_3OH) and carbonyl sulfide (OCS) concentrations as determined from Kitt Peak solar absorption spectra. For CH_3OH, the season cycle has been characterized, but no trend is found over the 22 year record of data. The OCS time series was updated using new spectroscopic parameters.

Anne Thompson [Pennsylvania State University] presented her results of ozone budget calculations during the ARCTAS campaign. She presented analysis of ozonesondes during the Arctic Intensive Ozonesonde Network Study (ARCIONS) campaign in the Summer of 2008. Thompson and colleagues quantified the impact of a number of ozone sources, and saw significant impacts of the fires in Siberia, California, and Western Canada on the ozone measured with these sondes.

Murali Natarajan [LaRC] discussed the bromine catalyzed ozone loss observed during the ARCTAS campaign. Using the Regional Air Quality Modeling System (RAQMS), he tried to reproduce the ozone losses that were observed during the campaign. He found that, while the comparison of the lowest model level ozone with observed surface ozone time series is good, the model does not show the extreme decreases seen in the data. Further investigation will focus on the boundary layer mixing and the resulting bromine influence in the model.

Jennie Moody [University of Virginia] discussed the derivation and validation of a Multi-sensor Upper Tropospheric Ozone Product (MUTOP) based on TES Ozone and Geostationary Operational Environmental Satellites (GOES) Water Vapor. With this product, she derives maps of ozone that show clear evidence of dynamical events.

Ming Luo [JPL] discussed trends in ozone and carbon monoxide as seen in the TES dataset. She has created time series for a number of regions of the world. Behavior such as *tape recorders* (a term used to describe the way that gases move from the surface to upper altitudes over time—the same gases are seen high in the atmosphere a few weeks to months after they were observed lower down) and annual cycles are clearly seen in the data.

David Noone [University of Colorado at Boulder] spoke on the use of deuterated water vapor (HDO) observations for understanding processes controlling the water vapor feedback. He and his students are using TES HDO to rethink atmospheric hydrology. They have begun to quantify the rainfall efficiency across the globe with the TES measurements.

John Worden [JPL] presented an intercomparison of *in situ* measurements of water vapor and its isotopes from Mauna Loa with satellite measurements of water vapor and its isotopes from the TES.

Jim Lawrence [University of Houston] is trying to determine if there is a record of changes in the *jet stream* over Greenland in the isotopic composition of snow and *firn* at the Dye 2 and Dye 3 ice core sites. Tropical cyclones produce water vapor with an unusually low hydrogen isotope ratio as indicated by the TES instrument on the Aura satellite as well as by ground and aircraft studies. Therefore, a record of tropical cyclones that have deposited precipitation in southern Greenland

may exist. The main control on the paths of tropical cyclones as they transition into extratropical cyclones and go over southern Greenland is the *jet stream*. A record of past changes in the *jet stream* therefore may be present in the isotopic record of the uppermost part of the Greenland ice cap.

Kei Yoshimura [Scripps Institute of Oceanography] shared his results on nudged isotope Atmospheric General Circulation Model (AGCM) simulation and its comparison with TES and SCIAMACHY isotope retrievals. He showed a number of comparisons of the nudged model with ground based *Fourier Transform Spectrometer* measurements, and TES and SCHIAMACHY satellite measurements, revealing some significant differences in the spatial features of the fields. Finally, Yoshimura discussed the potential for *Ensemble Kalman Filtering* data assimilation approaches that will be used with the isotope general circulation model (GCM).

Jeonghoon Lee [Caltech/JPL] discussed preliminary results of quantitative comparisons of water vapor and the isotopic composition of water vapor between TES and two isotope-enabled GCMs [NCAR Community Atmosphere Model (CAM) and Goddard Institute for Space Studies (GISS)]. After applying the TES observation operator, there are some noticable differences in the latitudinal distribution of water vapor isotopes between the TES measurements and model simulations. Further work is needed to identify the model process representations that result in these differences. ■

NASA Honor Awards Recipients

The Earth Observer would like to congratulate the 2009 Goddard Space Flight Center (GSFC) Sciences & Exploration Directorate (SED) recipients of the NASA Honor Awards. The recipients listed are involved in GSFC Earth Science activities.

NASA's most prestigious honor awards are approved by the Administrator and presented to a number of carefully selected individuals and groups of individuals, both Government and non-Government, who have distinguished themselves by making outstanding contributions to the Agency's mission. For a complete description of each award, please visit: *nasapeople.nasa.gov/awards/nasamedals.htm.*

Exceptional Achievement Medal
Robert Wolfe [Terrestrial Information Systems Branch (Code 614)]
H. Jay Zwally [Cryospheric Sciences Branch (Code 614)]

Exceptional Scientific Achievement Medal
Anne Douglass [Atmospheric Chemistry and Dynamics Branch (Code 613)]

Exceptional Service Medal
Jack Richards [Earth Sciences Division (Code 610)]
James Irons [Biospheric Sciences Branch (Code 613)]
Matthew McGill [Mesoscale Atmospheric Processes Branch (Code 613)]
Dorothy Hall [Cryospheric Sciences Branch (Code 614)]
Douglas Rabin [Solar Physics Branch (Code 671)]

Outstanding Leadership Medal
Shahid Habib [Office of Applied Sciences (Code 610.4)]
David Starr [Mesoscale Atmospheric Processes Branch (Code 613)]

Group Achievement Award
Ozone Monitoring Instrument (OMI) Team [Code 613]—Aura mission
Geoscience Laser Altimeter System (GLAS) Laser On Orbit Analysis and Advisory Team [Code 690]—Ice, Cloud, and land Elevation Satellite (ICESat)
Gravity Recovery and Climate Experiment (GRACE) Science Team [Code 698]
Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL) Development Team [Code 698]

Public Service Group Achievement Award
Science Outreach Support Team (Science Mission Directorate and Earth Observing System) [Code 610]

2008 CLARREO Workshop

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Meeting Overview

The Second Community Workshop supporting the Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission was held October 21-23, 2008, at the L'Enfant Plaza Hotel in Washington, D.C. CLARREO is a *Tier 1* mission defined in the 2007 National Research Council's (NRC) report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. This workshop was open to all interested members of the scientific community and industry for the purpose of soliciting feedback on the draft CLARREO science objectives and *Level 1* Requirements to ensure optimal science return from the mission. The feedback obtained at the workshop is being used to guide activities conducted in support of the *pre-Phase A* mission formulation of CLARREO during Fiscal Year 2009. **David Young** [NASA Langley Research Center (LaRC)—*CLARREO Mission Formulation Project Scientist*] led the meeting. The full presentations are available on the CLARREO web site at: *clarreo.larc.nasa.gov/workshop2008/workshop2008-agenda.html*.

The primary goals of the workshop were to:

- discuss and refine the CLARREO science objectives (*Level 1* Requirements document);
- present results from on-going NASA-funded trade studies for community comment;
- define and refine the links between the identified science objectives and the measurement requirements;
- present CLARREO-related Instrument Incubator Proposal (IIP) selections;
- identify requirements for technological development to enable mission success; and
- recommend studies needed to further the readiness of the CLARREO mission.

CLARREO Background

The NRC recommended the initiation of long-term climate records to detect decadal-scale trends in key climate feedbacks and forcings and to test and improve climate model predictions. Measurements of high accuracy that are tested for systematic errors on-orbit, and are tied to irrefutable standards such as those maintained in the U.S. by the National Institute of Standards and Technology (NIST) are envisioned as the critical basis for advancing climate science and acceptable public policy. This is the impetus behind the CLARREO mission. The combination of high spectral resolution and verifiable calibration also enables the use of CLARREO as a means for intercalibrating key elements of the Earth observing system.

NASA and NOAA share responsibility for CLARREO. The NOAA component involves the continuity of measurements of incident solar irradiance and the Earth energy budget by flying the Total Solar Irradiance Sensor (TSIS) and the Clouds and the Earth's Radiant Energy System (CERES) sensors that were originally planned for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). **This workshop focused on the NASA portion of CLARREO**.

Bruce Wielicki (LaRC) kicks off the Workshop with a discussion of the key climate questions to be addressed by CLARREO.

The foundation for CLARREO is the ability to produce irrefutable climate records through the use of exacting on-board traceability of the instrument accuracy and systematic sampling of the Earth for climate records. Spectral reflected solar and infrared radiance and Global Positioning System Radio Occultation (GPSRO) refractivity measured by CLARREO will be used to initiate an unprecedented, high accuracy record of climate change that is tested, trusted, and necessary to provide sound policy decisions. This record of direct observables will have the high accuracy and information content necessary to detect decadal-scale climate change trends and to test and systematically improve climate predictions.

Pre-Phase A Activities

NASA formed a *pre-Phase A* science team in May 2008 to define rigorous science objectives and instrument and mission requirements in anticipation of a Mission Concept Review (MCR) in Fall 2009. Key studies are focused on high-level science questions concerning the use of benchmark radiances for testing and improving climate models. A major element of the studies is the use of climate Observing System Simulation Experiments (OSSE). Simulated CLARREO infrared and solar reflected radiances will be generated from three leading climate models to test the utility of CLARREO data for evaluating climate models. Sampling studies will determine optimal orbits for unbiased long-term trends. Finally, the team is performing studies using simulated CLARREO data from existing infrared (IR) and ultraviolet (UV)/visible sensors to establish the limitations of intercalibration accuracy. The study plan and initial results were presented at the October workshop.

Welcome / Introduction

Steve Volz [NASA Headquarters (HQ)—*Associate Director, Flight Programs, Earth Science Division*] explained that NASA has been asked to take the lead in implementing fifteen of the NRC Decadal Survey Missions (NOAA is responsible for the others.) To date, NASA has, focusing most of its effort on developing the first four missions (known as *Tier 1* missions because they have the highest priority) in the queue. Volz noted that both CLARREO and Deformation, Ecosystem Structure and Dynamics of Ice (DESDynI) are directed science missions with individual budget lines, managed out of the Earth Systematic Missions (ESM) Program Office. Langley Research Center (LaRC) leads the CLARREO mission, with support from Goddard Space Flight Center. Volz outlined his expectations for CLARREO during the *Pre-Phase A* period.

Dave Young provided an overview of the CLARREO mission. He discussed both the CLARREO societal objectives and imperatives. He emphasized that CLARREO is a new type of mission focused on decadal time scales—i.e., it is intended to measure trends and test climate model predictions. The mission will be an integral part of future research, i.e., moving beyond the Earth Observing System and operational systems for characterizing climate.

John Bates [National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC)] reviewed the options developed by NOAA and NASA to minimize the impacts on climate research of the Nunn–McCurdy Certification for National Polar-orbiting Operational Environmental Satellite System (NPOESS) through 2026. As recommended by the NRC Decadal Survey (and also through the President's FY 2009 budget request) NOAA will participate in CLARREO by flying CERES on the NPOESS Preparatory Project (NPP) satellite, and both TSIS and CERES on NPOESS C1. Bates also noted that NOAA is interested in exploring with NASA the need for operational continuity of CLARREO.

Climate Benchmarking and S.I. Traceability

Gerald Fraser [National Institute of Standards and Technology (NIST)] emphasized that climate measurements require a new strategy. What is truly required is a dedicated satellite program to provide benchmark climate-quality measurements with: (1) low uncertainties known throughout the mission; (2) the ability to serve as a reference for other satellite measurements; and (3) the ability to serve as a benchmark measurement for future generations. The key to achieving this goal is *traceability* [e.g., the measurement can be related to a national or international standard (based on the International System of Units—*systeme internationale* (S.I.)) through an unbroken chain of comparisons all having stated uncertainties.]

Jim Anderson [Harvard University] reviewed the CLARREO Societal Objectives Imperative, and a subset of the draft Science Questions. He discussed the need for an unprecedented, high-accuracy record of climate change to enable sound policy decisions. Anderson suggested that the need for CLARREO is more urgent due to the rapid increase in climate forcing from carbon release. He then discussed what measurements will form the basis of a climate record and noted that there is an important distinction between the S.I. traceable, on-orbit measurements and derived quantities. He stressed the importance of determining the time-dependent bias on-orbit and reviewed potential CLARREO instrument subsystems designed to address each of these on-orbit sources of error.

Hank Revercomb [University of Wisconsin-Madison] began with a discussion on why the nation needs CLARREO. He referred to the serious gaps in capability of existing systems to unequivocally detect long-

term climate trends with high sensitivity. Revercomb outlined his view of high-level requirements for climate benchmark IR measurements, including recommendations for spectral coverage and resolution, spatial footprint and angular sampling, temporal resolution and sampling, orbit selection, validation on-orbit, and cross-calibration with other systems.

Climate Prediction and Climate Model Testing

Bill Collins [University of California at Berkeley] began by reviewing Intergovernmental Panel on Climate Change (IPCC) forcing scenarios for the 21st century. **He noted that the reflected solar portion of CLARREO is critical because current models do not agree on the sign or magnitude of forcing in the shortwave.** A benchmark in the solar irradiance is needed to better understand how the models should behave. In addition, measurements must be sensitive enough to determine the sign of expected changes in cloud radiative effects. Collins then outlined the overall goals of the CLARREO OSSEs, which are to: (1) test the detection and attribution of radiative forcings and feedbacks from the CLARREO data, [i.e., determine the feasibility of separating changes in clouds from changes in the rest of the climate system, and examine the feasibility of isolating forcings and feedbacks]; and (2) quantify the improvement in detection and attribution skill using CLARREO data relative to existing instruments. He noted that the group plans to conduct the OSSEs using three models analyzed in the IPCC Assessment Report (AR) 4. He then discussed the major steps of the OSSEs, potential issues, and key questions to be addressed.

Stephen LeRoy [Harvard University] began with a brief overview of climate feedbacks, the uncertainty in those feedbacks, and the impact on climate prediction. He then transitioned to a discussion of GPSRO measurements for climate studies. LeRoy introduced the concept of optimal fingerprinting and multi-pattern regression and how the technique can be used to determine the minimum amount of time required to detect a climate trend using GPSRO data. Additional benchmarks, such as thermal infrared spectra, used in combination with GPSRO data can reduce the overall time required to detect a trend. Furthermore, trends in the outgoing longwave spectrum can be used to monitor longwave forcing and constrain longwave feedbacks observationally. Work is ongoing and includes simulations in cloudy skies and shortwave trends.

Michael Mishchenko [NASA Goddard Institute for Space Studies (GISS)] focused on the importance of polarimetry for absolute measurements in the shortwave (SW) region. He compared fully collocated cloud-free, pixel-level Moderate Resolution Imaging Spectroradiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR) aerosol retrievals that showed significant disagreement in both optical depth and Angstrom exponent. Mishchenko noted that these systems measure only intensity, which is just one of the four *Stokes parameters*. Polarization is more sensitive to particle size and refractive index than intensity alone. He concluded by recommending that CLARREO include a polarimeter if the mission requires intercalibration of other sensors.

Venkatachalam Ramaswamy [NOAA Geophysical Fluid Dynamics Laboratory (GFDL)] presented the results from Yi Huang's doctoral thesis, which demonstrates the use of IR spectra for climate model validation. He showed the sensitivity of spectrally resolved outgoing long wave (LW) radiation to the temperature and composition of the atmosphere at the level from which the radiation mainly emerges, as quantified by its partial derivatives which appear to provide a computationally low-cost method for climate feedback analysis and model diagnosis. Ramaswamy concluded by discussing the spectral signatures of climate change (i.e., long-term change versus natural variability.)

Peter Pilewskie [University of Colorado, Laboratory for Atmospheric and Space Physics (LASP)] presented an overview of his work on defining the information content of the CLARREO solar reflected record. This work included an examination of establishing a "benchmark" of current Earth's climate using visible and near-IR observations, along with extending CLARREO climate measurements using other Earth-viewing visible/near-IR instruments through intercalibration. He then discussed some of the challenges associated with establishing a benchmark climate data record for reflected solar spectral radiance.

Kevin Bowman [NASA/Jet Propulsion Laboratory (JPL)] began his presentation by referring to a recent article[1] that envisions a new approach for prediction—where data are not only used to define the initial conditions for decadal projection but also to refine estimates of key internal model parameters that influence climate sensitivity. He then noted that the largest source of uncertainty for climate prediction is cloud feedbacks. Clouds and water vapor are distributed on scales not currently consistent with Global Climate Model (GCM) scales—regional climate models could help. Water vapor, *"the ties that bind",* has strong absorption features in the far-IR, IR, and visible regions. In order to improve overall climate predictions, the uncertainty in the radiative response of the hydrological cycle must be reduced. The spatial scales over which water vapor is distributed and clouds are formed are much less than 100 km (Bowman showed several examples); therefore the impact of finer spatial resolution of observations on predictability must be investigated.

[1] Cox and Stephenson, "Changing Climate of Prediction", *Nature*, 2007.

Sampling

Robert Knuteson [University of Wisconsin-Madison] began by summarizing the random error assessment method they utilized. Atmospheric Infrared Sounder (AIRS) radiance observations averaged over the five year period 2003–2007 were used to create an annual mean infrared spectrum. The radiances were measured on global, zonal, and regional latitude/longitude grids to give a range of footprint sizes. They used a linear fit to determine the trend of the resulting mean spectra. The inter-annual variability can then be used to estimate the number of years required to detect a trend, which is relevant to mission lifetime. He concluded that there is little difference (≤ ~2%) in the inter-annual mean and standard deviation for CLARREO fields of view (FOV) ranging from 13.5 km and 100 km.

Alex Ruzmaikin [JPL] discussed the fact that climate variables are random functions of space and time. Some general causes of sampling biases are: (1) uneven sampling of a symmetric probability distribution function (PDF); (2) non-symmetric PDF sampled evenly; and (3) non-stationary PDF sampled evenly. He cautioned against having too few samples which can lead to an inaccuracy in the mean. Ruzmaikin stated that decreasing the field of view (FOV) to 20 km and using a 10-FOV wide swath increases the number of samples by a factor of 50, allowing for the 0.1 K accuracy using daily data averaged over 12 latitude zones.

Daniel Kirk-Davidoff [University of Maryland, College Park] presented results from his orbital sampling studies. He estimated sampling errors (e.g., diurnal sampling bias, seasonal sampling bias, spatial sampling bias, and random weather noise) by sampling both real and modeled brightness temperature error using virtual orbiters in a variety of orbits. Using these data, he determined what accuracy could be achieved in spectrally resolved brightness temperature at a given spatial and temporal resolution.

Dave Doelling [NASA LaRC] evaluated the diurnal component in the inter-annual variability of radiative fluxes and implications for CLARREO sampling requirements. There is a large diurnal component in radiative fluxes over maritime stratus and convection regions; however, the diurnal cycle might be very consistent inter-annually. Doelling compared the two data sets over a 5-year period and determined that at the global scale the diurnal effect was much smaller than the mean field changes. He concluded that the time to detect climate change trends at the level of anthropogenic forcing is shortest for global scales (~15 years) and is considerably longer for zonal/regional scales.

Zhonghai Jin [Science System and Applications, Inc. (SSAI)] simulated the variability expected in CLARREO solar reflected radiance spectra in order to clarify sampling requirements for the mission. Monthly average atmospheric and surface properties from CERES for years 2000–2005 were used as inputs to the *MODTRAN* radiative transfer model to calculate monthly mean outgoing solar spectra over different latitude regions. The results clearly showed the effects of regional differences and inter-annual variability in aerosol, clouds, water vapor, ozone, and surface properties on the reflected spectrum. Consequently, the modeled inter-annual variability in solar reflectance spectra was thought to be realistic.

Applied S.I. Traceability [and Instrument Incubator Proposals]

John Dykema [Harvard University] chaired a session on achieving S.I.-traceability for CLARREO. Dykema discussed the systematic errors present in existing models/sensors and the importance of S.I. traceability on-orbit. S.I. traceability is critical to making an accurate record of the response of the climate to anthropogenic forcing. He stressed the importance of linking satellite measurements to S.I. base units (e.g,, Kelvin, second, mole, kilogram.) GPSRO is an excellent example of a model that does this; in fact it requires only one of the base S.I. units (second) for calibration. He then gave a brief overview of the CLARREO measurement approach in the IR, highlighting the importance of NIST in this process.

The next few presentations discussed technology development for CLARREO funded by the Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP).

- **Fred Best** [University of Wisconsin-Madison] reviewed the proposed technologies and the program milestones for the UW–Harvard Instrument Incubator Proposals (IIP) that focused on IR measurements.

Tony Mannucci (JPL) and **John Dykema** (Harvard University) lead a discussion of the GPS radio occultation measurements for CLARREO.

- **Marty Mlynczak** [NASA LaRC] reviewed the proposed technologies and the program milestones for Langley's IIP—Calibrated Observations of Radiance Spectra from the Atmosphere in the Far-Infrared (CORSAIR.).
- **Greg Kopp** [LASP] reviewed the LASP IIP, which included technology development for achieving the calibration goals in the solar reflected measurement.

Brian Cairns [NASA GISS] discussed multiple approaches for measuring polarization. He concluded by stating that the Glory Aerosol Polarimetry Sensor (APS), which uses a Wollaston approach, is expected to demonstrate highly accurate polarimetric measurements on-orbit.

Tony Mannucci [JPL] began with a description of how the Global Positioning System (GPS) can be utilized via radio occultation (RO) techniques to obtain profiles of atmospheric refractivity, which is a function of temperature, pressure, and water vapor pressure. Dykema also presented an update on the Traceable Radiometry Underpinning Terrestrial- and Helio-Studies (TRUTHS) instrument on behalf of **Nigel Fox** [National Physical Laboratory, U.K.] who could not attend the meeting.

Intercalibration of Operational Instruments Using CLARREO

Tom Pagano [JPL] presented an overview of CLARREO studies performed by JPL concerning requirements for the IR measurements, including: (1) a definition of expected sources of error; (2) determination of the spatial resolution required for cross-calibration; and (3) investigation of how validation might be performed. He described the study approach which involved using existing AIRS, Infrared Atmospheric Sounding Interferometer (IASI), and MODIS cross-calibration methods. He then estimated the number of clear and Dome C (Antarctic) observations possible versus spatial resolution. The results from the study suggest that insufficient cloud free and Dome C Automated Weather Station observations are available for cross-calibration and validation at 100 km. The study suggests that in order to achieve sufficient samples for cross-calibration of CLARREO MW/LW it would be necessary to have an instrument field of view of <20 km with a 100 km swath.

Dave Tobin [University of Wisconsin-Madison] introduced his talk with the question, *"Given a CLARREO mission optimized to produce climate benchmark data, how well can CLARREO meet its objective to serve as an intercalibration reference for the operational IR sounders?"* Tobin described the study approach which consists of finding Simultaneous Nadir Overpasses (SNOs) of a simulated CLARREO (three 90º polar orbits separated by 120º in longitude, with 100-km FOV) and Aqua for 2006, and for each SNO using MODIS radiances to estimate the spatial and temporal sampling differences between CLARREO and the Cross-track Infrared Sounder (CrIS), AIRS or IASI. He presented results for multiple MODIS bands, showing that the assumed CLARREO radiometric noise level (1 K NEDT)—not spatial and temporal variability—is the dominant contributor to monthly intercalibration uncertainty. Each of the FOVs evaluated (i.e., 100 km, 50 km, 25 km diameter) demonstrated less than 0.03 K intercalibration uncertainty at the assumed CLARREO radiometric noise level.

Dave MacDonnell [NASA LaRC] discussed orbital analyses performed to support intercalibration by CLARREO. He noted that this is an 8-dimensional problem (the dimensions being latitude, longitude, altitude, time, wavelength, viewing zenith angle, viewing azimuth angle, and solar zenith angle). MacDonnell examined the *trade space* attempting to optimize the number of viewing angle matches with several operational sounders (i.e., Aqua MODIS, CERES, AIRS cross track scan). MacDonnell found that adding pointing capability to CLARREO would increase the number of intercalibration matches by a factor of 10 over nadir-only values. The lower threshold on the altitude trade space is ~600 km because below that altitude satellite lifetime is compromised due to drag.

Bruce Wielicki [NASA LaRC] identified and presented many of the challenges associated with measuring Earth reflected solar fluxes, including detection of cloud feedback trends, spectral darkening of solar optics, and visible channel calibration changes on the order of 2–3% per year. He then discussed recent work examining intercalibration matching. He noted that due to the anisotropy effects, viewing angle match requirements are more stringent for solar measurements than for the IR. He presented a study of intercalibration opportunities using the nominal CLARREO mission from the Decadal Survey. He concluded that: (1) a 100-km FOV appears to minimize both angle and spatial matching error; (2) the nominal NRC Decadal Survey CLARREO mission (i.e., 3 satellites, 90º orbits, and nadir-viewing) is sufficient for IR Low Earth Orbit (LEO) intercalibration, but not for Geosynchronous Orbit (GEO); and (3) two CLARREO satellites with pointing capability are key to meeting the solar intercalibration goals.

Costy Lukashin [SSAI] began his talk by reviewing the CLARREO intercalibration goal—at least 0.2% (2σ) relative accuracy for SW broadband. He then reviewed the SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) high spectral resolution dataset used for the simulation (i.e., channels, spectral ranges, resolution, and uncertainties). The advantage of using SCIAMACHY data is that

Tim Hewison [EUMETSAT] presents EUMETSAT's plans for calibration of operational sensors during lunch.

it permits simulation of the natural ensemble of scene types to be sampled by CLARREO and provides spectra with known radiometric accuracy. The simulation includes effects due to differences in instrument offset and gain, as well as shifts and degradation in instrument relative spectral response (RSR) functions. The results (CLARREO/CERES/MODIS intercalibrations) demonstrated the advantage of using spectra from various scene types to separate effects due to offset/gain error from those due to RSR changes.

Jack Xiong [NASA GSFC] discussed several potential intercalibration approaches for CLARREO, including: (1) lunar observations (VIS/NIR/SWIR only); (2) simultaneous nadir observations (SNO); and (3) ground-based observations—e.g., observations from Dome-C in Antarctica have been used to intercalibrate Terra and Aqua MODIS data and could be used for CLARREO. Xiong then showed examples of each of the intercalibration approaches using real-world data, and outlined advantages and disadvantages of each approach.

Tim Hewison [European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)] presented an invited talk on EUMETSAT's plans for the Intercalibration of Meteosat/IASI for the Global Space-based Intercalibration System (GSICS). He focused in particular on how CLARREO could help provide climate calibration accuracy for operational sensors.

The Way Forward

Mary DiJoseph [Earth Systematic Missions (ESM) Program Office] began by stating that it is NASA's goal to have all of the *Tier 1* missions either in or ready for *Phase A* activities by October 2009. The ESM Program Office provides oversight and assistance—as needed or requested, develops performance standards, and provides independent assessments for all DS missions. She outlined the elements of a project's life cycle, focusing on how a project transitions from *Pre-Phase A* to *Phase A*. She noted that while *Pre-Phase A* is an iterative process, it is crucial that realistic mission objectives and their flow down to science and measurement requirements are documented at the end of the study phase. She then referred the attendees to NASA Space Flight Program and Project Management Requirements documents (*NPR 7120.5D* and *NPR 7123*) that discuss the entrance criteria and products required for a Mission Concept Review.

Mike Gazarik, [NASA LaRC—*CLARREO Mission Formulation Chief Engineer*] began by discussing the importance of a partnership between science and engineering as being critical to mission success. He emphasized the need for a well-defined set of *Level 1* Requirements with supporting rationale(s) as soon as possible. The remainder of Gazarik's presentation focused on the roadmap to a MCR. He defined the major mission trades associated with CLARREO (e.g., number of satellites and orbit selection, instrument redundancy, spatial sampling, spectral resolution, etc.) and outlined the tasks the systems engineers plan to perform over the next several months to assist the science team. He concluded with a summary chart outlining what the systems engineers need from the CLARREO Study Science Team.

Dave Young [NASA LaRC] reviewed key questions and results presented during the workshop and discussed the next steps for the science team. He then reviewed the goals outlined at the outset of the workshop and assessed whether or not the team had met those goals. He concluded that a majority of the workshop goals had been met, but that additional work is still required to refine the science objectives, and link them to the appropriate measurement requirements. He then highlighted some of the remaining actions for the CLARREO team prior to the next workshop tentatively scheduled for Summer 2009:

- finalize and prioritize science questions;
- answer key questions related to sampling and the solar component of CLARREO through on-going studies; and
- emphasize the use of OSSE results to define CLARREO science requirements.

Young concluded his presentation by outlining a plan of action to get from the October workshop to MCR in the Fall of 2009. ■

Ice Bridge Supporting Wilkins Ice Shelf Collapses

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Ted Scambos, National Snow and Ice Data Center, teds@icehouse.colorado.edu

An ice bridge connecting the Wilkins Ice Shelf on the Antarctic Peninsula to Charcot Island disintegrated in early April 2009. The event continued a series of breakups that began in March 2008 on the ice shelf, and highlights the effect that climate change is having on the region.

Images from the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on the *Terra* and *Aqua* satellites showed the shattering of the ice bridge between March 31, 2009 and April 6, 2009. The loss of the ice bridge, which was bracing the remaining portions of the Wilkins Ice Shelf, will now allow a mass of broken ice and icebergs to drift into the Southern Ocean.

Scientists at the National Snow and Ice Data Center (NSIDC) and around the world have been watching the ice bridge since last March, anticipating its collapse. Now that it has broken up, researchers are closely monitoring the remaining portion of the Wilkins Ice Shelf to see if the loss of the ice bridge allows the ice shelf to collapse further.

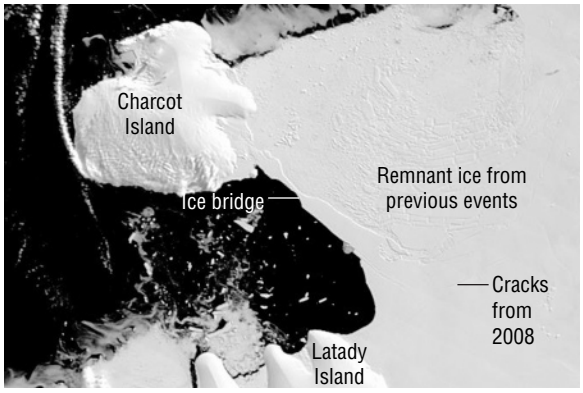
The Wilkins is following a pattern of instability and rapid collapse that many Antarctic Peninsula ice shelves have experienced in recent years. Scientists think that the dramatic loss of these ice shelves, which have existed for hundreds to thousands of years, is an important sign of climate change in the Southern Hemisphere. The loss of an ice shelf can also allow the glaciers that feed into it to start flowing ice into the ocean at an accelerated rate, contributing to a rise in global sea levels.

The Wilkins Ice Shelf first began to break up in the mid-1990s. Last March, the Wilkins lost another 160 mi^2 (400 km^2)[1] in a rapid retreat (see *nsidc.org/news/press/200803 25_Wilkins.html*), and the ice shelf continued to form new cracks over the winter.

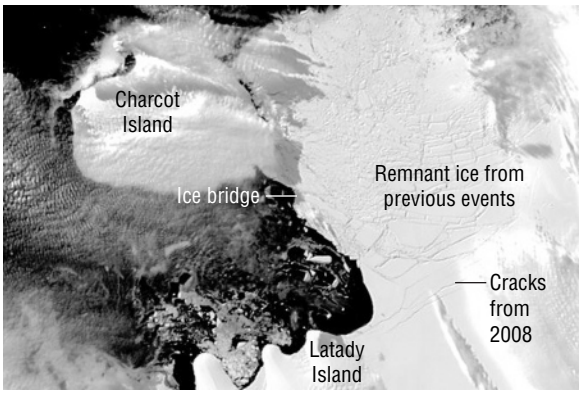
The Wilkins Ice Shelf is located on the southwestern Antarctic Peninsula, the fastest-warming region of the Earth. In the past 50 years, the Antarctic Peninsula has warmed by 4°F (2.5°C). In the early 1990s, the Wilkins Ice Shelf had a total area of 6,700 mi^2 (17,400 km^2). Events in 1998 and the early years of this decade reduced that to roughly 5,280 mi^2 (13,680 km^2). In 2008, a series of *disintegrations*—rapid repeated calvings in which the ice shelf pieces are small enough to topple over—and *break-up events*—rifting of large sections of the shelf, leading to large tabular iceberg calvings—shrunk the area of stable shelf to roughly 4,000 mi^2 (10,300 km^2), a net loss within a year of approximately 1,400 mi^2 (3,600 km^2).

For updates and links to other news on the Wilkins Ice Shelf, see *nsidc.org/news/press/wilkins.* ■

[1] Original measurements were made in metric units, then converted to English units.



On March 31, 2009, the MODIS instrument on *Terra* shows the ice bridge still intact. The ice appears to be a smooth, unbroken surface.



Less than a week later, on April 6, the MODIS instrument on *Aqua* shows the smooth bridge gone, replaced by chunks of ice. The breakup was initially observed in radar imagery by the European Space Agency. To view both these images in color, visit *earthobservatory.nasa.gov/IOTD/view.php?id=37806.*

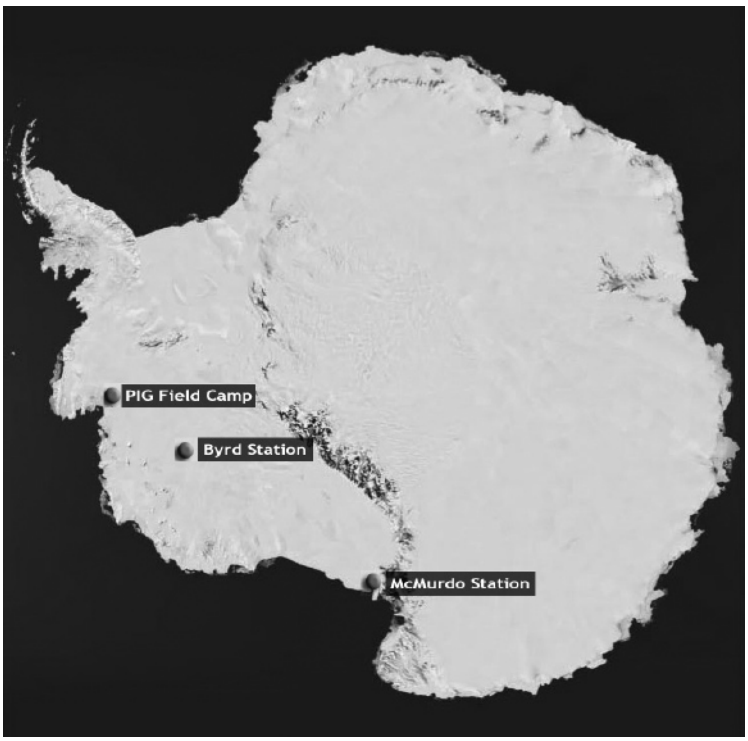
in the news

Try, Try Again: Scientists Prepare for Return to Pine Island Glacier

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

In January 2008, a small *Twin Otter* airplane outfitted with skis touched down on the icy edge of Antarctica's Pine Island Glacier (P.I.G.), carrying NASA glaciologist **Robert Bindschadler** and a crew of scientists and technicians. It was the first time anyone had landed a plane on this ice shelf floating on the edge of the West Antarctic ice sheet. It will also probably be the last.

Bindschadler and colleagues set out to take the first-ever look beneath the ice shelf, which polar scientists believe to be thinning because of warm ocean waters below. But shortly after setting down on the ice, the team discovered the landscape was too rough and the possible runways too short for the multiple takeoffs and landings needed to transport their equipment to the field site. The team constructed a weather station and deployed global positioning system (GPS) units as close to the ice shelf as possible, and headed home.[1]



Researchers plan to establish a field camp on the ice shelf off the Pine Island Glacier (P.I.G.) and begin drilling through the ice during the 2011-2012 field season. Meanwhile, scientists this year will practice drilling though ice at McMurdo Station, and plan for staging P.I.G. field camp materials at Byrd Station.

"This expedition is like landing on a different planet," said Bindschadler, a scientist at NASA's Goddard Space Flight Center. Like astronauts exploring Mars, the researchers have to anticipate and carry everything they need to survive. Satellites, such as the Ice, Cloud and land Elevation Satellite (ICESat), Terra and Landsat, provide a broad look at Antarctica, but scientists don't know exactly what the remote environment will look like until they get there. But now they know and they are going back!

In a project that started under the auspices of the International Polar Year (IPY), Bindschadler and crew are now planning the next steps for research on Pine Island Glacier. They will go back to Antarctica for the 2009-2010 field season to work out the *choreography* required of drilling a 5 in (13 cm) diameter hole though 1,800 ft (550 m) of ice. The goal is to deploy water-profiling instruments and cameras in the sea below the ice shelf in 2011-2012.

Not unlike setting up for future human expeditions of the Moon and Mars, this expedition to most remote reaches of Earth also requires preparation. It will take two years to turn a section of the remote ice sheet into a *village* for research because transportation and setup of field camps can happen only during the short Antarctic summer (late October though late January). They will need a place to eat, sleep, work, and bathe; a generator for electrical power; a safe location for helicopter landings; and lots of food and fuel. That's tens of thousands of pounds of equipment.

NASA and the National Science Foundation, which is co-funding the expedition, are now planning to fly the equipment about 1,000 mi (1,600 km) from McMurdo Station to Byrd Station, and then slowly drive across the remaining 400 mi (640 km) of snow and ice to Pine Island Glacier.

"It's like flying from Washington to Kansas City in an aircraft, and then driving to Denver at lawn-mower speeds," Bindschadler said.

When the team returns to the ice shelf in 2010, the logistical operation and dress rehearsals will be over and

[1] To learn about the details on this first visit to Pine Island Glacier please see the article entitled "Christmas Among Crevasses: How a Goddard Scientist Spent His Holiday Season", in the March–April 2008 issue of the *Earth Observer* [**Volume 20, Issue 2**, pp. 10–21.]

First contact: NASA Goddard scientist Bob Bindschadler standing on the P.I.G. Ice Shelf in West Antarctica. To view Antarctica video footage provided by Polar-Palooza/Passport to Knowledge please visit: *svs.gsfc.nasa.gov/vis/a010000/a010200/a010202/index.html*. **Credit:** NASA's Goddard Space Flight Center

Bindschadler gives an update on the wait to get *boots on the ground* on the remote Pine Island Glacier in Antarctica. NASA scientists are anxious to begin deploying high tech drills and sensors on the quickly-moving glacier in an effort to better understand how global warming is affecting the continent. To view video please visit: *svs.gsfc.nasa.gov/vis/a010000/a010400/a010412/index.html* **Credit:** NASA's Goddard Space Flight Center

the real deployment will begin. It will be the first sustained look at how water and ice interact beneath this fragile ice shelf.

NASA's researchers are eager to return so they can understand what is accelerating changes to the ice shelf —25 mi (40 km) long and 12 mi (20 km) wide— which extends from the Pine Island Glacier and floats on the Amundsen Sea. It is the leading edge of one of the two major glaciers that drain the West Antarctic Ice Sheet. Scientists have calculated that ice flowing from the shelf has accelerated from 2.3–2.6 mi per year (3.7–4.2 km) since Bindschadler's visit just a year ago.

"We want to get a sustained look at what's going on under the ice and figure out why the ice shelf is sliding more swiftly into the Amundsen Sea," Bindschadler said.

He believes the acceleration is caused by warm ocean water melting the glacier from below. Warmer waters may be welling up from about 2,000–3,300 ft depth (600–1,000 m) and circulating on the continental shelf. This warm ocean water is thinning the base of the ice shelf and gradually reducing the pressure that holds the ice sheet on the continent.

Polar scientists are puzzled: *Where is the warm water coming from and how fast is it moving?* Does the upwelling change by season, and exactly how is the ice shelf responding?

"We still don't have any consistent, direct measurements in the ocean," Bindschadler said. "Consistent measurements will give us better quantitative handle on how much melting is taking place."

Despite the initial setbacks, the science goals for the research expedition have not changed. "If anything, this additional time and extra planning is making us bolder," Bindschadler said. "We're daring to go to where the field challenges may be greater, but where the scientific return is also greater." ■

in the news

CALIPSO Makes Successful Switch to Backup Laser, Keeping Important Data Stream Alive

Patrick Lynch, NASA's Langley Research Center, patrick.lynch@nasa.gov

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite has resumed operations after switching from its primary to its backup laser nearly three years after the launch of a satellite that is helping scientists solve the puzzle of how clouds and aerosols affect Earth's climate.

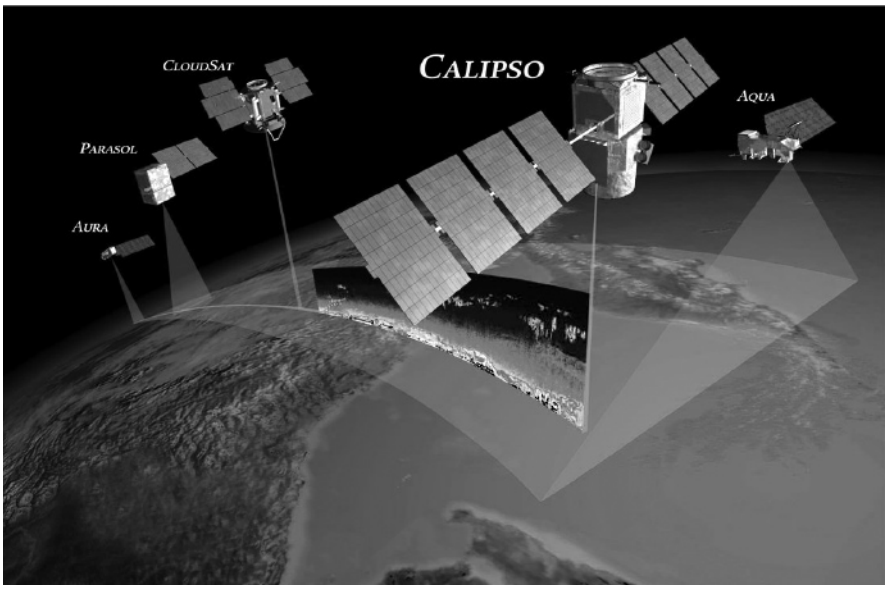
The backup laser was designed into CALIPSO to make it robust, in case the primary laser became unreliable. The value of the planning came to the forefront early this year as the primary laser began to behave erratically, due to a slow pressure leak in the laser's canister. The leak was known about since prior to launch, and likely came about during fabrication. The CALIPSO team, a joint effort between NASA and Centre National d'Etudes Spatiales (CNES), worked together to start up the backup laser, which hadn't been used in three years. It provided its "first light" aerosol and cloud vertical profiles on March 12, 2009. The instrument then resumed normal operations and is undergoing a calibration review now. The release of standard data products should resume in mid-May, and once data is re-processed the total gap due to the switch will be about 10 days.

CALIPSO provides a unique vertical profile measurement of clouds and aerosols using space-borne Light Detection and Ranging—or, lidar. Integrated with other measurements from a constellation of five satellites, one from France and four from NASA, called the *A-Train*, CALIPSO's observations are improving our understanding of two poorly understood variables in Earth's changing climate: aerosols and clouds and their interactions. CALIPSO's near-simultaneous measurements with the other instruments can be integrated with and also enhance data gathered by satellites such as CloudSat.

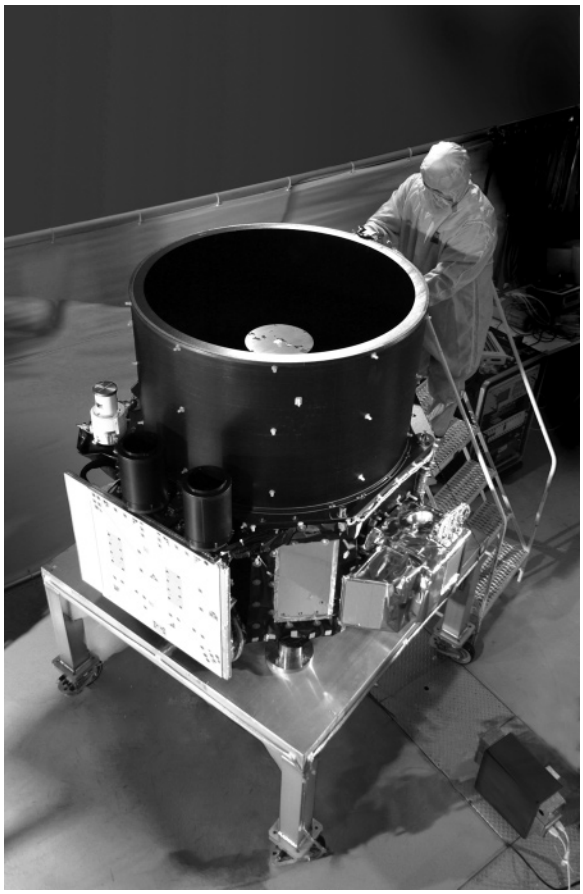
"This mission continues to be a success," said **Chip Trepte**, CALIPSO's project scientist, based at NASA's Langley Research Center. "We completed the objectives of the prime mission, which were to determine the location and frequency of clouds and aerosol layers over the globe and some of their properties, through at least three years. CALIPSO is filling a measurement gap that other satellite missions are unable to provide."

After an April 2006 launch, CALIPSO's primary laser began operating in June 2006, soon demonstrating the ability to observe and track clouds and aerosols as they change over time. The primary laser collected nearly three years, i.e., 12 seasons, of data. The backup laser appears to be healthy and able to last at least that long, barring unforeseen problems.

"Even though we are on each side of the Atlantic, we work as a single, integrated NASA–CNES team," said **Nadège Quéruel**, mission operations manager with the CNES team. CNES and NASA worked together to successfully manage the problems with the first laser and to transition to the second laser with only minor effect on the CALIPSO data record.



Flying in the *A-Train* constellation of Earth-observing satellites, CALIPSO's lidar instrument makes unique vertical profile measurements of clouds and aerosols. These two important climate variables remain as some of the least understood influences on Earth's climate system. **Credit:** NASA Langley Research Center.



In the early stages of CALIPSO's construction at Ball Aerospace, the primary and backup laser canisters are easily visible in the foreground. CALIPSO switched to its backup laser in early March, after nearly three successful operating years with the primary laser. **Credit:** Ball Aerospace.

Trepte said the CALIPSO team was aware before launch that the laser canister was losing pressure. But the leak was so slow, it was expected that the primary laser could still complete much of the three-year, prime mission. "We were not surprised," Trepte said. "The good news is, we turned on the second laser that had been idle three years, and it's working. We built a redundant system to make sure we'd be able to continue making these important measurements."

The lidar instrument was built by Ball Aerospace & Technologies Corporation and the laser transmitters were manufactured by Fibertek Inc.

With humankind's burning of fossil fuels and other activities altering Earth's atmosphere and climate, scientists are using satellites such as CALIPSO to better understand the complexities of the atmosphere's structure and composition, its behavior and our impact on it as well as its impact on society. CALIPSO has expanded that quest by providing measurements to compare with models and thereby become an essential component of improving climate models.

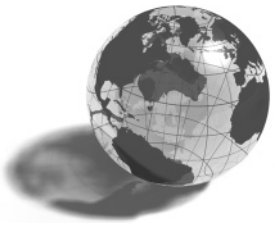
CALIPSO provides a curtain of profile measurements along the satellite track and can measure aerosols and clouds during day and night. Aerosols are tiny suspended liquid or solid particles that appear to the human eye as dust, smoke and haze. Many natural sources produce aerosols: the oceans send sea salt into the air, winds kick up dust clouds, and wildfires create massive smoke and haze plumes. Industrial processes and agricultural burning by humans also create aerosols in large enough quantity to alter clouds, precipitation, the earth's energy budget and, ultimately, the climate. A NASA-led report released earlier this year determined that we still do not have a good handle on how much human-produced aerosols are contributing to global climate change, and stressed the need for scientists to work to reduce the uncertainty by improving our understanding of how aerosols influence Earth's climate. Scientists around the world have also used CALIPSO data to learn more about air quality and pollution, illuminating air quality conditions such as the summer smog that blankets the Tibetan Plateau.

"We're seeing rivers of aerosols and dust coming and going," Trepte said. "Not only are we making important aerosol measurements, we've been able to map very thin clouds that affect how sunlight is absorbed or reflected, on a global basis."

While nearly three years of measurements have been a great start, the backup laser allows the mission to continue and build on a record that becomes more helpful the longer it gets. "It's one thing to get the measurements. It's another to capture the variability," Trepte said.

CALIPSO's primary laser generated more than 1.6 billion laser pulses and more than 20 terabytes of data. CALIPSO observations have been used to characterize the large effects of smoke located over clouds in warming the atmosphere. Conventional satellite instruments are unable to measure aerosols located above clouds and their effects were only estimated before this. The mission's data have been used to test measurements of clouds from conventional satellite sensors and improve the accuracy of these data, which will lead to advances in weather forecasting and climate prediction. CALIPSO observations have given us a greatly improved knowledge of polar stratospheric clouds—clouds which form high in the atmosphere over the poles during the winter and play a major role in the formation of the ozone hole over Antarctica.

"The performance of CALIPSO's lidar instrument is also a benchmark in and of itself," Trepte said. "It's the first laser system that has operated in space this long, continuously, for atmospheric measurements." ■



EOS Scientists in the News

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

NASA Celebrates Landsat 5 Anniversary, March 2; *United Press International*. NASA celebrated the 25th anniversary of the Landsat 5 satellite, and Landsat project scientist **Darrel Williams** (NASA GSFC) explains that the mission's length—22 years beyond its three-year primary mission lifetime—averted a gap in a continuous record of images of Earth's land surface that dates back to 1972.

Earth Seen 'Healing' After Big Quake, March 5; *Los Angeles Times*. Geophysicist **Eric Fielding** (NASA/JPL) led a new study that provides the clearest picture yet of the subtle, slow-motion warping of Earth's surface that can happen after an earthquake on a buried fault.

Aging Satellites Threaten Climate Research Future, March 6; *National Public Radio*. Climate scientist **Bruce Wielicki** (NASA LaRC) speaks to the importance of having a continuous record of satellite-based Earth observations for monitoring climate change.

Sea Rise 'To Exceed Projections', March 10; *BBC News*. Scientists at a climate change summit in Copenhagen said earlier UN estimates were too low and that sea levels could rise by a meter or more by 2100. **Eric Rignot** (NASA/JPL) notes that research since the UN's Intergovernmental Panel on Climate Change (IPCC) 2007 Fourth Assessment Report shows that the contribution from melting and ice loss can not be overlooked.

Life Could Have Survived Earth's Early Pounding, March 10; *New Scientist*. Scientists at the University of Colorado in Boulder found that microbes living deep underground could have survived the massive barrage of impacts that blasted the Earth 3.9 billion years ago, according to a new analysis that **Kevin Zahnle** (NASA ARC) described as "reasonable."

Urban Sprawl, Climate Change Fueled Atlanta Tornado, March 13; *Wired*. In a NASA-funded study, climatologists **Dev Niyogi** (Purdue University) and **Marshall Shepherd** (University of Georgia) used state-of-the art satellite data to *reverse-model* a tornado that ripped through Atlanta last March and found it was likely fueled by a recent drought and unstable microclimates formed by the city's vast sprawl.

Study: West Antarctic Melt a Slow Affair, March 18; *The New York Times*. University researchers ran a five-million-year computer simulation of the West Antarctic Ice Sheet showing that a collapse would take thousands of years, but **Eric Rignot** (NASA/JPL) cautioned that the new findings lacked the precision needed to know what will happen over short periods.

NASA: Environmental Disaster Avoided on Ozone Loss, March 19; *Associated Press*. Atmospheric scientist **Paul Newman** (NASA GSFC) describes the "bizarre world" that would be planet Earth today if the world didn't agree 22 years ago to cut back on chlorofluorocarbons, which cause a seasonal ozone hole to form near the South Pole.

'Halo Effect' Explains Brightest Patches of Sky, March 30; *New Scientist*. Clear sky up to several miles away from clouds appears brighter than cloud-free sky elsewhere, and research by **Tamas Varnai** (NASA GSFC) and **Alexander Marshak** (NASA GSFC) shows that the effect is due to light reflected off the cloud and bouncing off the particles, and not due to varying levels of tiny particles in the air as previously believed. This potentially impacts the way scientists model climate change.

Arctic Sea Ice Thinnest Ever Going into Spring, April 6; *Associated Press*. NASA and the National Snow and Ice Data Center in Colorado announced that Arctic sea ice is thinner and more vulnerable than at anytime in the past three decades, and **Tom Wagner** (NASA HQ) notes that sea ice is important because it reflects sunlight away from Earth—the more it melts, the more heat is absorbed by the ocean, heating up the planet even more.

NASA: Aerosols May Cause Arctic Warming, April 8; *United Press International*. Researchers, led by climate scientist **Drew Shindell** (NASA GISS), used a coupled ocean-atmosphere model to investigate how sensitive different regional climates are to changes in levels of carbon dioxide, and found the mid and high latitudes are especially responsive to changes in the level of aerosols, which likely account for 45 percent or more of the warming that has occurred in the Arctic during the last three decades.

The Birds, the Bees, the Plane Over Greenland, April 9; *Earth Pub, Discovery's Global Science Blog*. **Tom Wagner** (NASA HQ) explains why measurements of sea ice thickness are important for understanding changes in

the Arctic—the primary focus of a month-long series of flights over Greenland this spring led by **William Krabill** (NASA Wallops).

NASA has Better Cyclone Forecasting Model, April 14; *Asian News International*. In the wake of last year's Cyclone Nargis, which was one of the most catastrophic cyclones on record, a team of NASA researchers led by **Oreste Reale** (GSFC/GEST) re-examined the storm as a test case for a new data integration and mathematical modeling approach that could improve weather forecasting and save more lives when future cyclones develop.

Jet Propulsion Laboratory's Patzert Talks about Recent Weather, April 20; *KPCC, California Public Radio*. Temperature records are falling all over Southern California, a good time to check in with **Bill Patzert** (NASA/JPL), who watches the weather for JPL.

Ozone Layer Faces Bumpy Return to Health, April 23; *Discovery News*. Earth's ailing ozone layer will probably recover, but it will never look exactly like it used to, according to a new study led by **Feng Li** (GSFC/GEST), which found that greenhouse gasses are interfering with ozone's rebound in complicated ways.

Slide Show: What Does Climate Change Science Look Like? April 23; *Scientific American*. Climatologist **Gavin Schmidt** (NASA GISS) and photographer Joshua Wolfe offer an inside look at the seemingly abstract phenomena of climate change science in their new book *Climate Change: Picturing the Science*, with the goal of conveying the causes and effects of climate change as well as attempts to mitigate and adapt to it.

Interested in getting your research out to the general public, educators, and the scientific community? *Please contact* ***Kathryn Hansen*** *on NASA's Earth Science News Team at* ***khansen@sesda2.com*** *and let her know of your upcoming journal articles, new satellite images, or conference presentations that you think the average person would be interested in learning about.* ■

North American ASTER Land Surface Emissivity Database (NAALSED) *v2* Now Available

The North American ASTER Land Surface Emissivity Database, *v2* provides the average summertime and wintertime emissivity derived from ASTER data for much of North America with a spatial resolution of 100 m in five spectral channels. The product also includes a land water mask, average NDVI image, and average temperature image.

The product is described in:

Hulley, G. C., S. J. Hook and A. M. Baldridge, 2008. ASTER Land Surface Emissivity Database of California and Nevada. *Geophysical Research Letters*, Vol. 35.

The product can be ordered from the following website: *emissivity.jpl.nasa.gov.*

The website provides examples of the product as *jpegs* and *kmls* together with a validation database. The data are available in *hierarchical data format (HDF5)* or *binary*.

Contact information: Simon J. Hook [JPL] *simon.j.hook@jpl.nasa.gov*

NASA Science Mission Directorate – Science Education Update

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Frozen: New Science on a Sphere Movie

Frozen brings Earth to life, projecting images of the planet onto completely spherical movie screens hanging in the center of darkened theaters. Turning in space, images on the screen become a portal onto a virtual planet, complete with churning, swirling depictions of huge natural forces moving below. *Frozen* showcases the global cryosphere, those places on Earth where temperatures don't generally rise above water's freezing point. As one of the most directly observable climate gauges, the changing cryosphere serves as a proxy for larger themes.

For more information about the film and a partial list of *Science On a Sphere* theaters, visit *www.nasa.gov/centers/goddard/multimedia/frozen/index.html*.

Why Is Earth's Core So Hot? New Podcast on Space Place

A new podcast entitled "Why is Earth's core so hot?" is now available on the *Space Place* Web site for elementary-aged children. Blistering hot molten rock bursts through weak places in Earth's crust. What is down there and why is it so hot? Earth's core may seem as mysterious and remote as outer space, but scientists have actually learned a great deal about it. Listen to a scientist explain. To listen to this and previous podcasts on your computer, or to read the transcripts, visit *spaceplace.jpl.nasa.gov/en/educators/podcast/*.

Understanding Climate: 2009 Earth Science Week Kits

The American Geological Institute (AGI) annually hosts Earth Science Week (ESW) in cooperation with sponsors including NASA, the U.S. Geological Survey, National Park Service and other geoscience groups.

"Understanding Climate" is the theme for the 2009 ESW, which will be held Oct. 11–17. NASA will again contribute educational resources to the ESW kits; AGI plans to distribute the kits beginning in Summer 2009. For more information on ESW, go to *www.earthsciweek.org*.

Climate Discovery Online Courses for Educators

Early Registration deadline: May 31, 2009

The National Center for Atmospheric Research (NCAR) offers a series of seven week online courses for middle and high school teachers that combine geoscience content, information about current climate research, easy to implement hands-on activities, and group discussion. There is a $225 fee per course (save $25 if you register by May 31). The courses run concurrently from June 18-August 9, 2009.

For complete course schedule and registration information, visit *ecourses.ncar.ucar.edu.*

Middle School Teacher Workshop: Using NASA Observations to Study Changes in Chesapeake Bay

July 7–9, 2009; NASA Goddard, Greenbelt, MD

Aided by NASA's remote sensing missions, scientists studying the Chesapeake Bay have made fascinating discoveries that have unlocked the unique history of the Bay and that can inform strategic plans for improving its future.

Cutting edge science observations from space will be integrated with classroom-ready lessons in this three-day workshop for middle school teachers. An overarching theme of the Bay's place in space, time, and the Earth system will tie together lessons in geology (impact craters), land use change, air quality, and water cycle while looking at the long-ago past and into the future. Education specialists with NASA missions will provide a rich experience and a multitude of resources for learning more.

Limit 30 participants. No cost for participating in the workshop itself, but all must cover own expenses for travel, meals, and hotel. 10 rooms are being held until June 10 at Holiday Inn, Greenbelt.

Please register at this URL: *education.gsfc.nasa.gov/bay.* With other issues please send e-mail message with "Chesapeake Bay" in Subject Field to: *Trena.M.Ferrell@nasa.gov.* ■

EOS Science Calendar

June 22–24
NASA Earth System Science at 20: Accomplishments, Plans, and Challenges. Washington, D.C. URL: *dels.nas.edu/osb/nasa.shtml*

June 22–24
Landsat Science Team Meeting, Rochester, NY

July 19–29
SORCE Science Team Meeting, Montreal, Canada. URL: *iamas-iapso-iacs-2009-montreal.ca/e/99-home_e.shtml.* (NOTE: This meeting is being held in conjunction with the IAMAS Meeting described in the *Global Change Calendar*)

September 14–17
Aura Science Team Meeting, Netherlands. URL: *aura.gsfc.nasa.gov/*

Global Change Calendar

June 16–19
Air & Waste Management Association's 102nd Annual Conference & Exhibition, Detroit, MI. URL: *www.awma.org/ACE2009/*

July 12–17
2009 IEEE International Geoscience & Remote Sensing Symposium, Cape Town, South Africa. URL: *www.igarss09.org/*

July 19–29
International Association of Meteorology and Atmospheric Sciences 2009, Montreal, Canada. URL: *iamas-iapso-iacs-2009-montreal.ca/e/99-home_e.shtml*

August 16–19, 2009
Wilhelm and Else Heraeus Seminar on Determination of Atmospheric Aerosol Properties Using Satellite Measurements, Bad Honnef, Germany URL: *http://www.iup.uni-bremen.de/eng/events/*

August 16–20
238 American Chemical Society National Meeting and Exposition: Chemistry and Global Security: Challenges and Opportunities, Washington, DC. URL: *portal.acs.org/*

August 31–September 4
World Climate Conference-3, Geneva, Switzerland. URL: *www.wmo.int/wcc3/*

September 15–20
Land Cover Land Use Change Science Team Meeting, Almaty, Kazakhstan. URL: *lcluc.umd.edu/*

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: *http://cimss.ssec.wisc.edu/goes_r/meetings/guc2009*

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

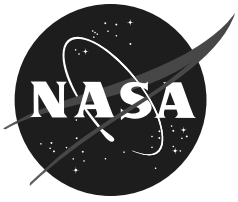
December 14–18
American Geophysical Union Fall Meeting, San Francisco, CA. URL: *www.agu.org/meetings/fm09/*

CloudSat Data Processing Center Releases New Product

The CloudSat Data Processing Center (DPC) has released the *R04* versions of the *2B-CWC-RVOD* and new *2C-PRECIP-COLUMN* products to the general science community. Radar plus Visible Optical Depth (RVOD) is the version of the *Cloud Water Content* product that is generated following the production of the *Visible Optical Depth* retrieval. *PRECIP-COLUMN* is the first of a set of precipitation products from CloudSat. This product provides a number of precipitation-related fields, including the presence of surface precipitation, and its intensity—based on CloudSat Cloud Profiling Radar (CPR) observations (at this time only ocean and inland water scenes are considered).

All data users are asked to review the updated documentation and report any anomalies or questions to the DPC at: *cloudsat@cira.colostate.edu.* The on-line product specifications for this updated product are located at: *www.cloudsat.cira.colostate.edu/dataSpecs.php*. To access the released data, use the DPC data ordering system interface found at: *cloudsat.cira.colostate.edu/data_dist/OrderData.php*.

If you have any questions concerning the ordering process, contact the DPC at *cloudsat@cira.colostate.edu*.



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