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Editor's Corner

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NASA's Earth Science Division is off to a roaring start in 2015! Two new Earth Science missions have already launched, and a third joint mission with NOAA and the U.S. Air Force, which includes two Earth observing instruments that will view the Earth from a never-before-seen perspective, is planned for early February.

A SpaceX Dragon spacecraft successfully carried the Cloud Aerosol Transport System (CATS) payload (along with other cargo) to the International Space Station onboard a Falcon 9 rocket launched from Cape Canaveral Air Force Station in Florida at 4:47 AM EST on January 10, 2015. On January 22, CATS was installed on the space station's Japanese Experiment Module – Exposed Facility (JEM-EF)—the first NASA-developed payload to ever fly on the JEM-EF. Systems have been powered up and preliminary indications are that everything is functioning nominally. The plan moving forward is to work through turn-on/check-out sequences, with a goal of receiving first science data sometime around February 1. Designed to operate for at least six months—with a goal of three years, and the possibility to operate as long as five years—CATS will provide vertical profiles of cloud and aerosol properties at three wavelengths (1064, 532, and 355 nanometers). CATS will serve as a "bridge" between CALIPSO and ESA's EarthCARE mission, helping to extend the CALIPSO data record for continuity of lidar climate observations. More information about CATS is at *cats.gsfc.nasa.gov*.

On January 31, 2015, NASA successfully launched the Soil Moisture Active Passive (SMAP) spacecraft from Vandenberg Air Force Base in California, aboard a United Launch Alliance Delta II *7320-10C*. The SMAP mission is NASA's first Earth-observing satellite mission designed to collect continuous global observations of

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This long exposure photograph shows NASA's SMAP observatory as it successfully launched from Vandenberg Air Force Base in California at 9:22 AM EST on Saturday, January 31. **Image credit:** NASA/ Bill Ingalls

the earth observer

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In This Issue

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

surface soil moisture and freeze/thaw state every 2 to 3 days. We feature a full-length article about the mission—beginning on **page 14**—that provides details on instrumentation, spacecraft design, data acquisition, and a discussion about the societal benefits of SMAP data. We also include a summary of the recent activities of the *SMAP Early Adopters Program*—groups and individuals who have a direct or clearly defined need for SMAP-like soil moisture or freeze/thaw data, and who are planning to apply their own resources (e.g., funding, personnel, facilities, etc.) to demonstrate the utility of SMAP data for their particular system or model. Learn more by reading the summary on **page 24** of this issue.

With the successful launch of CATS and SMAP, five NASA Earth Science launches have taken place in the span of twelve months. In addition to the two launches mentioned here, the GPM Core Observatory, OCO-2, and ISS-RapidSCAT missions have all taken to the skies since February 2014. *The Earth Observer* reported on each of these missions extensively during 2014. For an update on OCO-2 science, see the news story on **page 42** of this issue describing recently released global maps of carbon dioxide and solar-induced fluorescence.

Also, in our last issue, we described the joint NOAA–U.S. Air Force–NASA Deep Space Climate Observatory (DSCOVR), which while not classified as an Earth Science mission, has two the Earth-observing instruments onboard: Earth Polychromatic Imaging Camera (EPIC) and National Institute of Standards and Technology Advanced Radiometer (NISTAR)[1]. DSCOVR is now scheduled to launch no earlier than February 8, from Cape Canaveral Air Force Station onboard a SpaceX Falcon 9 rocket. After launch, the spacecraft will travel 1.5 million km (930,000 mi) from Earth, and enter an orbit around the Sun–Earth Lagrange Point (L1). (Based on the current schedule, this would happen on June 5.) Once in position, DSCOVR's two Earth-observing instruments will begin making the first Earth observations ever obtained from that distant vantage point.

Looking toward the future, on November 25, 2014, NASA announced the winners of second Earth Venture Suborbital (EVS-2[2]) AO. According to **Jack Kaye** [NASA Headquarters—Director of Research for the

[1] To learn more about DSCOVR and its Earth-observing instruments, see the Editorial of the November–December 2014 issue of *The Earth Observer*.

[2] *Earth Venture* investigations are regularly solicited, quick-turnaround projects recommended by the National Research Council in 2007, and reported on in the September–October 2010 issue of *The Earth Observer* [**Volume 22, Issue 5**, pp. 15-18]. The first series of five sub-orbital projects (EVS-1, or EV-1) was selected in 2010, has been ongoing over the past few years, and was reported on in the July–August issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 19-32].

Earth Science Division], "these new investigations address a variety of key scientific questions critical to advancing our understanding of how Earth works. These innovative airborne experiments will let us probe inside processes and locations in unprecedented detail that complements what we can do with our fleet of Earth-observing satellites." Congratulations to all the PIs and investigation teams for each of the five new airborne investigations that will tackle climate questions from Africa to the Arctic. To view the suborbital mission details please visit *go.nasa.gov/1H6yR6s*.

As we celebrate new launches, we also recognize the continuing achievements of our existing fleet of Earth science satellites and those who continue to coax new science out of aging hardware. The American Geophysical Union (AGU) Fall Meeting is an opportunity to showcase these accomplishments. As in past years, the NASA Science Program Support Office organized the 2014 AGU exhibit booth on behalf of the Science Mission Directorate. The *Hyperwall*—a high-resolution video wall—was the centerpiece of the exhibit, supplemented by other activities. Many of the presentations at the booth focused on the achievements of one or more of our Earth science missions. In a 37-day span to close out 2014, staff from the support office also traveled to Sydney, Australia to exhibit at the World Parks Congress conference—held once a decade—and Lima, Peru to support the 20th Conference of Parties (COP) to the United Nations Framework Convection on Climate Change (UNFCC) conference. Please turn to **page 20** to read how the Hyperwall was used in these settings to personally communicate NASA Science face-to-face.

During AGU there were also two special sessions organized in conjunction with milestone achievements for two of the EOS "flagship" missions—Terra and Aura. On December 18, 2014, Terra celebrated the fifteenth anniversary of its launch, and there was a session held on December 19, titled "Terra: 15 Years as the Earth Observing System Flagship," consisting of both an oral and poster session. All of the instruments were represented during the poster session with a range of topics including outreach activities, data quality and sensor calibration, surface change, and climate studies. The oral session was dedicated to talks by each of the instrument leads, an overview of the platform, an example of Terra-sensor intercomparisons, and concluding with an overview of Terra data applications. Many of the topics raised during the session are included as part of the article, "15@15: 15 Things Terra has Taught Us in its 15 Years in Orbit," that appears on **page 4** of this issue.

In addition, July 15, 2014 marked the tenth anniversary of the launch of Aura and there was an AGU special session titled, "Observations from Aura: An Integrated Observatory of Atmospheric Composition," held on December 17. Both the oral presentations and posters presented new results from each of Aura's three major themes: ozone depletion, air quality, and climate—similar to those that appear in the feature article published in our last issue [**Volume 26, Issue 6**, pp. 4-17] titled "Aura Celebrates Ten Years in Orbit."

In other news, the CloudSat-CALIPSO Science Team convened November 1-3, 2014, in Alexandria, VA. Attendees represented NASA Centers, universities, and international partners. These two missions have worked closely together from the start, having launched together in 2006 to fly in formation with each other as part of the A-Train to study the three-dimensional structure of clouds and aerosols. One significant topic of discussion was orbital scenarios to accommodate CALIPSO's fuel limitations. Participants agreed that CALIPSO should participate in A-Train inclination-adjustment campaigns through 2017, and then begin to gradually drift eastward across the MODIS swath, providing a sampling of MODIS look-angles—which was an original goal of the CALIPSO ESSP proposal. It was also agreed that formation-flying of the CloudSat and CALIPSO satellites to provide joint radar/lidar data products has proven of such high scientific benefit that it should continue as long as possible. Consequently, CloudSat will "follow" CALIPSO on its eastward drift after the 2017 A-Train inclination-adjustment campaign.

Abstracts of the oral and poster presentations are available at *stm.dpc.cira.colostate.edu.*

Lastly, **Dong Wu** [NASA's Goddard Space Flight Center (GSFC)] has been selected as Project Scientist for SORCE/TSIS[3]. Wu has been part of GSFC's Climate and Radiation Laboratory since 2011, and prior to that, since 1994, he was with NASA/Jet Propulsion Laboratory's Aerosol and Cloud Group. Wu has worked with numerous Earth science missions/instrument datasets over the years (e.g., CloudSat, MLS, MISR). His interest in sun-Earth connections includes funding from the Living with a Star program. Wu replaces **Bob Cahalan**, who recently retired from GSFC after a distinguished 40-year career at NASA. Congratulations to Wu on his new role, and best wishes to Cahalan in his future endeavors—and many thanks for his leadership on SORCE and TSIS. ■

[3] TSIS is a solar irradiance instrument planned as a follow-on to the Total Irradiance Monitor (TIM) that flies onboard SORCE.

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 40**.

15@15: 15 Things Terra has Taught Us in Its 15 Years in Orbit

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While Terra has not (yet) broken any records for longevity, it is still operating at near-full capability now nine years beyond its designed six year lifetime, with only slight reductions in its data-gathering capabilities—as described here. The rest of the platform is in fine shape, and scientists and engineers expect it to continue to collect valuable data for almost another decade.

Introduction

Fittingly for NASA's then-nascent Earth Observing System (EOS), the first of what would become three "flagship" satellite missions was named *Terra.* Beginning with the prosaic designation of AM-1—because of its sun-synchronous polar orbit, with a descending-node 10:30 AM equator-crossing time—Terra, launched in December 1999, forged paths of science goals, design, and implementation that subsequent platforms have continued, with wonderful success. While Terra has not (yet) broken any records for longevity, it is still operating at near-full capability now nine years beyond its designed six-year lifetime, with only slight reductions in its data-gathering capabilities—as described here. The rest of the platform is in fine shape, and scientists and engineers expect it to continue to collect valuable data for almost another decade.

Terra's Origins and Mission

In the late 1980s and into the early 1990s, as EOS began to travel the long and difficult road from concept to reality[1], there was as yet no unified plan to explore the phenomena that together make up the Earth system. The concept of studying the Earth as a system of systems was a new paradigm—one that required new ways of exploring these phenomena.

It was clear from early investigations, and often from simple observation, that the Earth was in a constant state of flux, with data that showed that humans could have an effect on such phenomena. Furthermore, the success of pioneering programs such as Nimbus and follow-on missions (e.g., the Upper Atmosphere Research Satellite (UARS), Landsat, the Ocean Topography Experiment (TOPEX)/Poseidon, and the series of Total Ozone Mapping Spectrometer (TOMS) instruments[2]) had shown that satellites could be useful tools for studying Earth-system phenomena. Think, for example, of the historical underpinnings of the formation and causes of the Antarctic ozone "hole" that led to the 1987 Montreal Protocol that banned stratospheric ozone-depleting substances (ODS).

In this light, thousands of scientists, engineers, administrators, and managers worked to bring EOS into being, with plans to begin a systematic exploration of our home planet[3]. The first of the planned series of probes was Terra—an international mission, with major contributions from the U.S., Japan, and Canada.

Terra was to explore the state of and changes in specific phenomena—and interactions between them—in the atmosphere, in and over the ocean, on and over land masses, precipitation as snow and ice, land and sea ice, and Earth's energy budget.

Terra's Manifest

The Terra platform is approximately the size of a small school bus—6.8 m (22.3 ft) long by 3.5 m (11.5 ft) across, weighing just under 5190 kg (11,442 lbs). It orbits Earth at an altitude of 705 km (438 mi) at an inclination of 98.5°. This gives it an orbital period of 99 minutes, for 16 orbits per day. As mentioned earlier, it crosses the equator at 10:30 AM (and also at 10:30 PM). (In contrast, Aqua, the second "flagship" mission, crosses the equator at 1:30 PM (and also at 1:30 AM)—and was originally called PM-1.)

[1] For an excellent compendium on the origins of EOS, download the special "Perspectives on EOS" issue of *The Earth Observer* found at *eospso.gsfc.nasa.gov/earthobserver/new-perspectives-eos*.
[2] TOMS flew onboard Nimbus-7 [1978-93], the Russian Meteor-*3M* satellite [1991-94], the Japanese Advanced Earth Observing Satellite (ADEOS) [1996-97], and Earth Probe [1996-2006]; QuikTOMS also carried a TOMS instrument onboard, but failed to reach orbit in 2001.
[3] For more information on the process, refer to the March-April 2014 issue of T*he Earth Observer* [**Volume 26**, **Issue 2**, pp. 4-13].

To meet the scientific mission requirements, Terra was outfitted with five instruments designed to explore phenomena at or near Earth's surface. These are the:

- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), provided by the Japan Aerospace Exploration Agency (JAXA);
- Clouds and Earth's Radiant Energy System (CERES), provided by NASA;
- Multi-angle Imaging Spectroradiometer (MISR), provided by NASA;
- Moderate Resolution Imaging Spectroradiometer (MODIS), provided by NASA; and
- Measurements of Pollution in the Troposphere (MOPITT), provided by the Canadian Space Agency

In addition, NASA provided the spacecraft and launch vehicle, an Atlas II-*AS*[4].

While the instrument manifest is still largely operational, the short-wave infrared (SWIR) data from ASTER became unavailable after that subsystem's design life. The robust array of similar and extended-capability instrumentation currently in orbit on other Earth-observing platforms—both in the A-Train[5] and elsewhere—can make up for this small lack of data.

For more than 15 years, the marvelous piece of technology called Terra has enabled new discoveries in Earth System Science. Dedicated engineers and scientists work together to calibrate instruments, process and store the vast quantities of data returned, validate results, and continue to coax cutting edge science out of aging hardware.

Terra's Data

A window into the scientific planning that formed the core of its implementation in *Terra* is provided by noting that together, the five instruments generate 79 data products, designed to provide their own information and to work in concert with other data products to further expand our knowledge of Earth's systems. The data are provided in *hierarchical data format* (HDF), a commonly used system across many disciplines and that has available many tools to search, browse, and display the resulting files.

Key to the success of EOS was the implementation of the EOS Data and Information System (EOSDIS[6]), with data repositories located at the Goddard Earth Sciences Data and Information Services Center and several discipline-specific Distributed Active Archive Centers (DAACs). Specifically, these include the Atmospheric Science Data Center (ASCD) Level 1 and Atmosphere Archive and Distribution System; the Land Processes DAAC; and the National Snow and Ice Data Center (NSIDC). Users with appropriate facilities may also access MODIS via *direct broadcast* capabilities. Additional information on Terra's data and acquisition and analytical capabilities is found at *terra.nasa.gov/data*.

Terra's Findings

For more than 15 years, the marvelous piece of technology called *Terra* has enabled new discoveries in Earth System Science. Dedicated engineers and scientists work together to calibrate instruments, process and store the vast quantities of data returned, validate results, and continue to coax cutting edge science out of aging hardware. The results are manifold and too many to describe here. However, in an effort to provide at least a sense of what Terra has provided us, in the rest of this article we will explore 15 findings—on an instrument-by-instrument basis, listed alphabetically—that are interesting and useful in their own right, and that serve as examples of what Terra (and its follow-on EOS and international-partner missions) have accomplished and will continue to accomplish for years to come. Short descriptions of each instrument's observational capabilities will precede example findings. The order of the examples is in no way indicative of prioritization of relative importance.

[4] A complete description of the Terra mission, including its five instruments and data products, can be found in the *2006 Earth Science Reference Handbook* (*eospso.gsfc.nasa.gov/sites/default/files/publications/2006ReferenceHandbook.pdf*), pp. 225-237.

[5] For a description of the A-Train, refer to the January-February 2011 issue of *The Earth Observer* [**Volume 23**, **Issue 1**, pp. 12-23].

[6] For perspective on the development of EOSDIS, see "EOSDIS: Where We Were and Where We Are—Parts I and II" in the July–August 2009 [**Volume 21**, **Issue 4**, pp. 4-11] and September–October 2009 [**Volume 21**, **Issue 5**, pp. 8-14] issues of *The Earth Observer*.

ASTER

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a high-spatial-resolution instrument—the only such on Terra—at resolutions ranging from 15 m (~49 ft) to 90 m (~194 ft). It images Earth in 14 wavelengths across visible and infrared wavelengths, to take measurements of land surface temperature, emissivity, reflectance, and elevation.

1. ASTER Global Digital Elevation Model (GDEM):

In 2009 the ASTER GDEM was completed, revealing the topography of the land surface of Earth at the highest spatial resolution then available. Instead of loading up equipment and supplies and then trekking into the most remote parts of the world (e.g., Siberia) and then repeating this task over every 30-m (~98-ft) section of land on Earth, many such trips are no longer necessary with the completion of the ASTER GDEM. Indeed, data from ASTER were used to create the most detailed inventory of topography on Earth. The map in **Figure 1** shows the resulting topography for Earth's land surfaces.

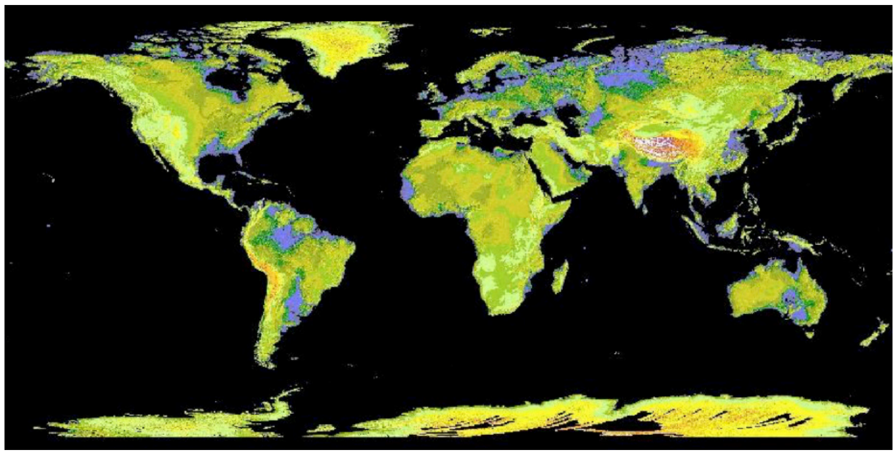

Figure 1. Blue and dark green areas are lower elevations than yellow areas. Red areas are higher elevations. These are highest over the Himalayas, the highest land elevations in the world. **Image credit:** NASA/Goddard Space Flight Center/METI/Japan Space Systems, and U.S./Japan ASTER Science Team

Such in-depth knowledge of Earth's topography is important in understanding climate impact studies that study how control factors such as evaporation, water flow, mass movement, and forest fires can impact climates and further change Earth's surface; the ASTER GDEM supports these studies. In addition, hydrologists use the information from the ASTER GDEM to understand the movement of water, glaciers, and ice over Earth's surface. Further, more accurate models of Earth's land surface leads to improvements in weather forecast models.

The ASTER GDEM is also used to help aircraft guidance systems locate potential risks in areas where there may be an unsupported airstrip, such as in military actions, or when assistance is being sent to areas affected by catastrophic events.

The ASTER GDEM is a collaboration between the Ministry of Economy, Trade, and Industry (METI) of Japan and NASA. The data are free to all users.

For more information about the ASTER GDEM, visit *asterweb.jpl.nasa.gov/gdem.asp*.

2. ASTER and Advanced Industrial Science and Technology (AIST) Global URban Area Map [AGURAM]:

AGURAM is the only high spatial resolution map of the extent of urban areas for the 3750 cities whose population is greater than 100,000.

While it's fun to look for notable landmarks in these images, these are more than just "pretty pictures;" there are a number of important applications. At a high resolution of 15 m (~49 ft) per pixel, these data give a unique view of human impact on the otherwise "natural" world, and help city planners and scientists better understand how these local impacts contribute to changes globally. For example, by looking at the image, it is easy to identify areas of permeable versus impermeable surfaces and to identify the effects these surfaces have on watersheds. AGURAM also allows scientists to study *urban heat islands* and their effects on biodiversity.

Not only are such data being used to track changes in and around cities, they are also used to compare city structure and to support planning for cities of similar size.

For an example of how ASTER/AIST AGURAM is being used, visit *cesa.asu.edu/urban-systems/100-cities-project*.

3. ASTER Global Emissivity Database (GED):

Emissivity is defined as how well Earth's surface emits radiation. Higher emissivity materials emit more radiation at a given temperature than low emissivity materials. Emissivity is directly related to the composition of Earth's surface; unlike surface temperature, it does not depend on weather conditions or the angle of the sun in relationship to Earth.

The ASTER GED is a global, 90-m (~295-ft) spatial resolution, emissivity map of Earth. Other orbiting instruments—e.g., the Moderate Resolution Imaging Spectroradiometer (MODIS), Tropospheric Emission Spectrometer (TES) onboard Aura, and Advanced Infrared Sounder (AIRS) onboard Aqua—used the ASTER GED to validate and improve their data products, e.g., atmospheric gas composition. Such information is also crucial for accurate retrieval of land surface temperature, a component of Earth's energy budget (see also CERES, following).

For more information about the ASTER GED, visit *emissivity.jpl.nasa.gov/aster-ged*.

CERES

There are two Clouds and the Earth's Radiant Energy System (CERES) instruments onboard Terra, designed to explore Earth's radiation budget and the roles that clouds play in modulating radiative fluxes from the surface to the top of the atmosphere by examining solar-reflected and Earth-emitted radiation. As of this writing, there are also operational CERES instruments on two other satellites: Aqua and Suomi National Polar-orbiting Partnership (NPP).

4. CERES measurements of Earth's albedo:

As is frequently the case in just about any kind of research, early results can change over time. In the early days of CERES data, Earth's *albedo*—the ratio of reflected radiation from the Earth to the incoming solar radiation—was thought to be in decline. Albedo is a function of the reflectivity of Earth's surface (land and ocean) and atmosphere, which makes it a key variable in understanding how Earth's energy balance is controlled. **Figure 2** shows by how much the amount of sunlight reflected into space changed between March 1, 2000 and December 31, 2011. This global picture of reflectivity (also called albedo) appears to be a muddle, with different areas reflecting more or less sunlight over the 12-year record. Based on these data, Earth's albedo didn't change much in 12 years—although there were substantial inter- and intrannual differences, particularly over specific regions, such as described in module #5, "Increased absorption of solar energy in the Arctic."

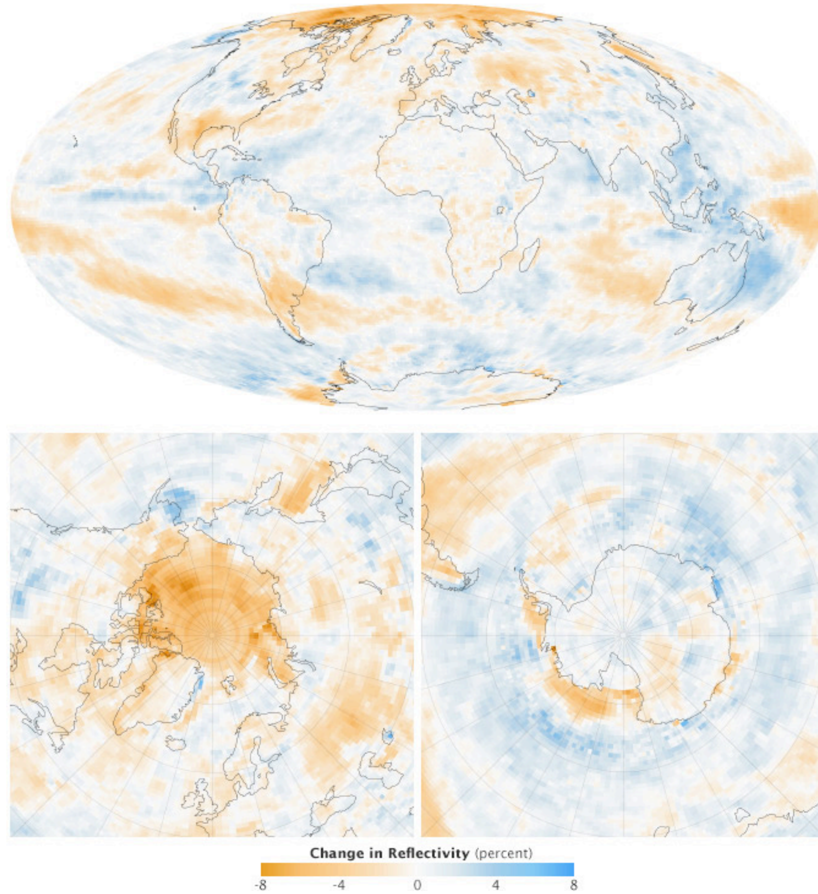

Figure 2. *Change in Earth's reflectivity as measured by CERES between March 1, 2000 and December 31, 2011 from three different viewpoints.* Shades of blue indicate areas that reflected more sunlight over time (indicating increasing albedo), while orange areas denote less reflection over time (decreasing albedo). **Image credit:** NASA's Earth Observatory and Robert Simmon

For more information, visit *terra.nasa.gov/news/measuring-earths-albedo*.

5. Increased absorption of solar energy in the Arctic:

Researchers using CERES data from Terra (and the Aqua and Suomi NPP platforms) have found a 5% increase in absorption of solar energy over the Arctic Ocean between 2000 and 2014. This increase is attributed to increased melting of surface ice in the region, with consequent decrease in albedo and increase in absorbance by the newly exposed darker ocean waters. The Arctic is presenting significant sensitivity to climate change, so data such as these are yet another "arrow" in the research quiver that may further allow greater insight into climate change phenomena.

For more on this finding and for a graphic representation of the data, see the News Story on **page 44** of this issue, and visit *www.nasa.gov/press/goddard/2014/december/nasa-satellites-measure-increase-of-sun-s-energy-absorbed-in-the-arctic/#.VJhm8kCbQg*.

MISR

Unlike many instruments that point in one direction—usually straight down (or *nadir*) or through the atmosphere at Earth's *limb*—Terra's Multi-angle Imaging SpectroRadiometer (MISR) points in nine different angles. Each camera takes measurements in four wavelengths across the visible and into the infrared. Its capabilities allow measurements of natural and human-caused particulate matter in the atmosphere, various cloud parameters, and the types and extent of land surface cover.

6. Eighty percent of the world's population breathes polluted air:

Data from MISR and MODIS have been combined to show that significant numbers of the world's population breathe polluted air. Before Terra, there was no method to use satellites to distinguish aerosols close to the ground from aerosols further up in the