National Aeronautics and Space Administration

CERES

Clouds and the Earth's Radiant Energy System

Acknowledgements

CERES Websites
ceres.larc.nasa.gov
jointmission.gsfc.nasa.gov/ceres.html

Special thanks to the CERES Science Team for making this publication possible.

Content: Kristyn Damadeo, Heather Hanson
Design: Debbi McLean

Table of Contents

Understanding the characteristics of clouds (e.g., amount, composition, thickness, cloud particle size), where they form (e.g., height), how they move, and the radiative properties of clouds (i.e., how they reflect, absorb, and emit energy), is key to understanding Earth's energy budget and climate.

Image credit: Frankieleon

Clouds and Earth's Energy Budget

Energy from the sun continuously heats our planet's land surfaces, ocean, and atmosphere, but the heating is unevenly distributed over Earth's surface. The tropics receive more energy than they emit and the polar regions emit more energy than they receive. This imbalance fuels Earth's weather and climate, powers ocean currents, and ignites interactions between Earth's sphere's—the atmosphere, hydrosphere, cryosphere, geosphere, pedosphere, and biosphere.

In addition to redistributing solar heat from the equator to the poles, our planet also maintains a balance between the overall amount of incoming and outgoing energy at the top of Earth's atmosphere—called Earth's *energy budget*. Energy received from the sun is mostly in the visible (or shortwave) part of the electromagnetic spectrum, while the energy that Earth emits back to space is in the infrared (or longwave) part of the spectrum. For Earth's temperature to be stable over long periods of time, incoming energy and outgoing energy have to be equal. In other words, the energy budget at the top of the atmosphere must balance.

Examples of Cloud Feedback

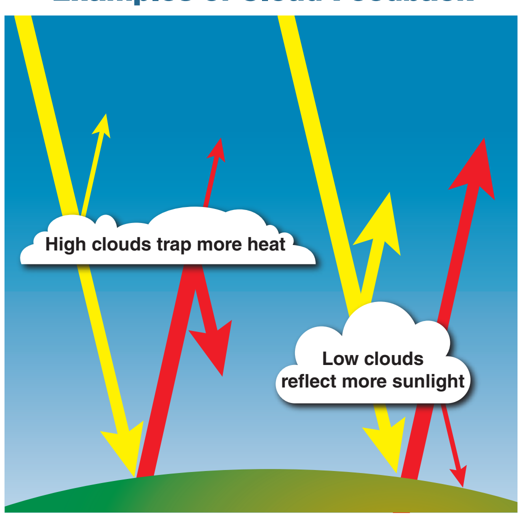


Image credit: NASA

[*Above*] Radiation and clouds strongly influence Earth's energy budget, weather, and climate. Low, thick clouds tend to reflect more sunlight and cool the Earth, while high, thin clouds tend to trap more radiation and warm the Earth.

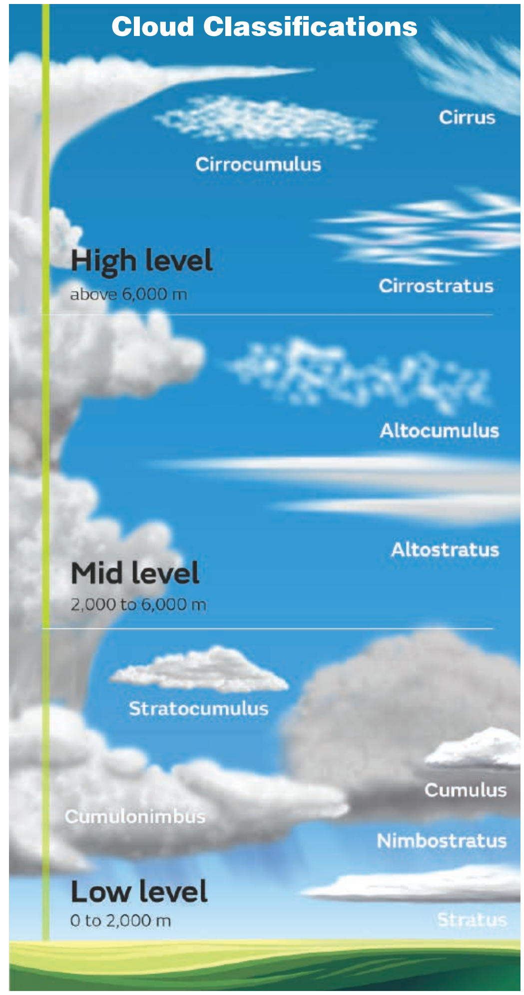


Image credit: World Meteorological Organization

Different types of clouds have varying impacts on Earth's energy budget. For example, low, thick clouds (e.g., stratocumulus clouds) are opaque and do not let as much solar energy reach the Earth's surface, which tends to have a net cooling effect on the Earth. High, thin clouds (e.g., cirrus clouds) are transparent and allow shortwave radiation through to the surface of Earth to produce a net warming effect. Understanding the characteristics of clouds (e.g., amount, composition, thickness, cloud particle size), where they form (e.g., height), how they move, and the radiative properties of clouds (i.e., how they reflect, absorb, and emit energy), is key to understanding Earth's energy budget and climate.

Atmospheric radiation measurements, coupled with surface radiation measurements, are needed to study the absorption and emission of solar radiation within Earth's atmosphere. In the 1970s, NASA recognized the importance of improving understanding of the energy budget and its effects on the Earth's climate. As a result NASA's Langley Research Center was charged with developing instrumentation that could make accurate regional and global measurements of the components of the energy budget. In October 1984, a radiation measurement instrument—called the Earth Radiation Budget Experiment (ERBE)—was launched from the Space Shuttle Challenger (STS-41G) onboard the Earth Radiation Budget Satellite (ERBS). The mission was meant to monitor Earth's average monthly energy budget, the seasonal movement of energy from the tropics to the poles, and the average daily variation in the energy budget on a regional scale for at least one year. The instrument went on to collect data for 15 years. The second and third ERBE instruments were launched on two National Oceanic and Atmospheric Administration (NOAA) weather-monitoring satellites: NOAA 9 and NOAA 10 in 1984 and 1986, respectively. These two instruments operated until 1987 (NOAA 9) and 1989 (NOAA 10).

Data from these three ERBE instruments helped the international scientific community better understand how clouds and aerosols affect the Earth's weather as well as how the amount of energy emitted by the Earth varies from day to night.

To extend the important measurements started by ERBE, NASA developed the Clouds and the Earth's Radiant Energy System (CERES) family of instruments. The first CERES instrument began collecting measurements in 1997. Since then, there has been at least one CERES instrument in orbit, making it a key part of NASA's Earth Observing System (EOS). In recent years, measurements from CERES have indicated that Earth's energy budget is not balanced, and that it absorbs more energy than it emits back to space. This imbalance causes Earth's climate to warm.

The CERES Flight Model 6, or CERES FM6, will fly onboard the Joint Polar Satellite System-1 (JPSS-1)—a joint mission between NASA and NOAA scheduled to launch in 2017. Measurements from CERES FM6 will continue to help quantify changes in Earth's energy budget and clouds, identify the mechanisms that drive those changes, and determine the impacts of these changes on future weather and climate.

Image credit: NASA

[*Above*] Launched from the Space Shuttle Challenger in October 1984, the Earth Radiation Budget Satellite was designed to investigate how energy from the sun is absorbed and re-radiated by the planet, also known as the energy budget.

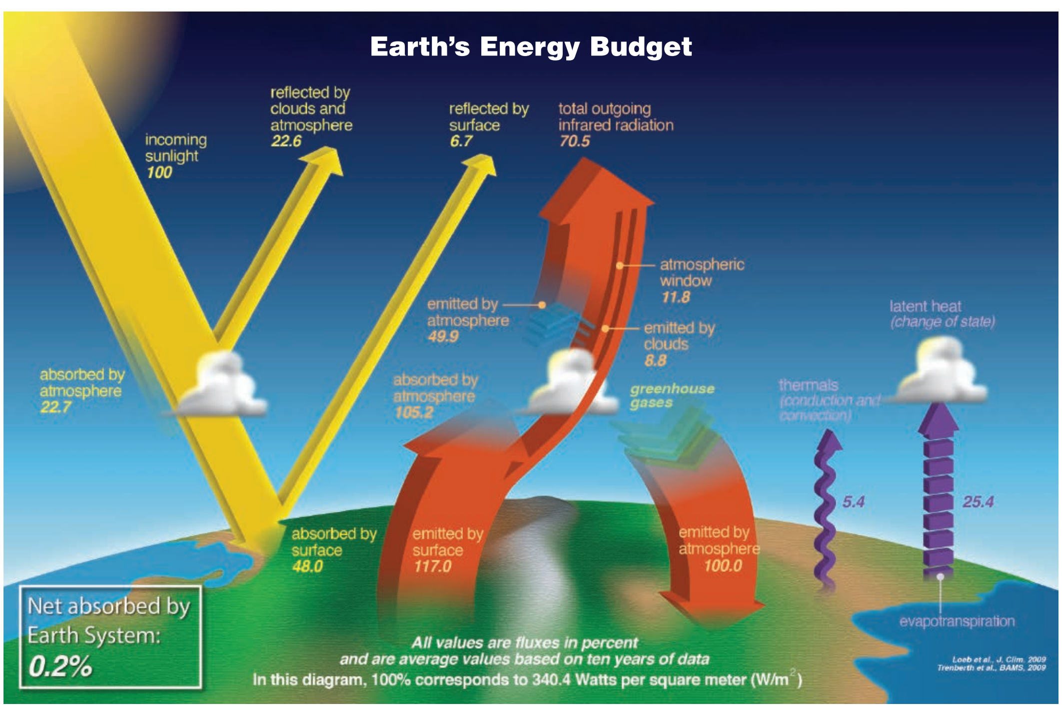


Image credit: NASA

[*Left*] The radiation entering, reflected, absorbed, and emitted by the Earth system are the components of the Earth's energy budget. Based on the physics principle of conservation of energy, Earth's energy budget represents the accounting of the balance between incoming radiation, which is almost entirely solar radiation, and outgoing radiation, which is partly reflected solar radiation and partly radiation emitted from the Earth system, including the atmosphere. Data from CERES indicate that the Earth system has a net absorption rate of 0.2%, meaning that Earth absorbs more energy than it emits back to space. This energy imbalance causes the temperature of the atmosphere to increase and Earth's climate to warm.

Instrument Overview

Image credit: Ball Aerospace & Technologies Corp.

The CERES FM6 instrument was delivered to the JPSS-1 spacecraft integration facility on June 17, 2014.

The Clouds and the Earth's Radiant Energy System, or CERES, instrument measures reflected sunlight and thermal radiation emitted by the Earth. Data products from CERES include both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. These measurements, called *radiative fluxes*, represent the amount of energy radiated through a given area within a given time range. CERES provides the only global top of atmosphere energy budget dataset. In addition, the CERES science team uses measurements from a high spatial resolution visible/infrared imager flying alongside CERES to infer a variety of cloud properties, including cloud amount, altitude, thickness, and the size of cloud particles.

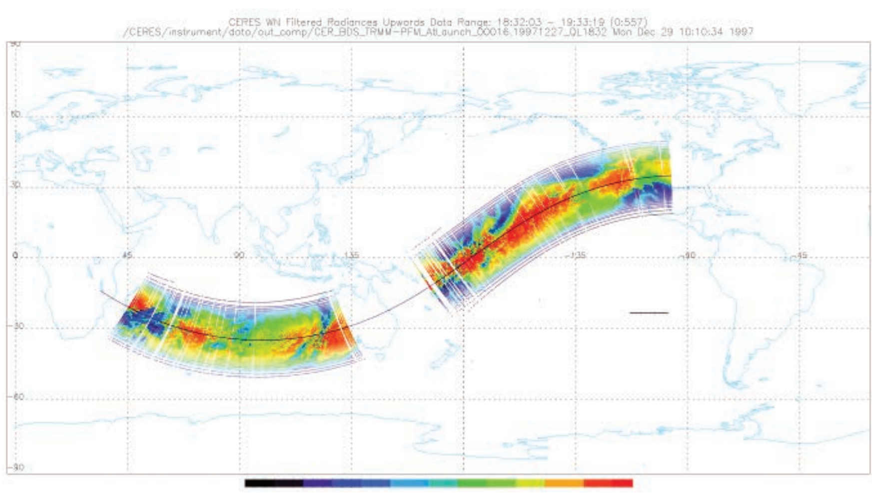
CERES Characteristics	
Spectral Coverage	PFM-FM5: 0.3 to 5 microns 8 to 12 microns 0.3 to 200 microns FM6: 0.3 to 5 microns 5 to 35 microns 0.3 to 200 microns
Nadir Resolution	PFM: 10 kilometers FM1-FM4: 20 kilometers FM5-FM6: 24 kilometers
Accuracy	0.3 to 1 percent
Average Data Rate	10,520 bits per second
Average Power	55 Watts
Mass	54 kilograms

CERES has several important science goals:

1. Provide a continuation of the ERBE record of radiative fluxes at the top of Earth's atmosphere for climate change analysis.
2. Increase the accuracy of estimates of radiative fluxes at the top of the atmosphere and the Earth's surface.
3. Provide the long-term global estimates of the radiative fluxes within the Earth's atmosphere.
4. Provide cloud property estimates that are consistent with the radiative fluxes at the top of the atmosphere.

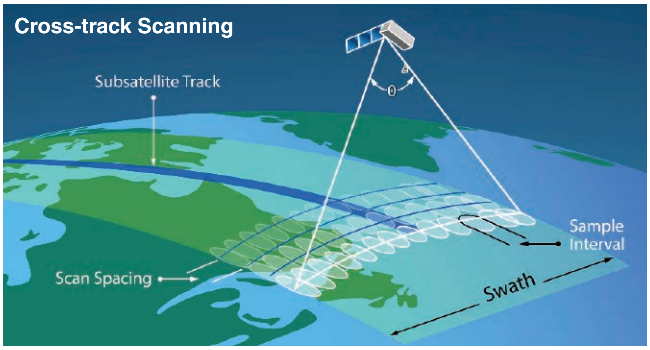
CERES has had seven Flight Models (FM), meaning seven "copies" of the same instrument have been built over the years, all by Northrup Grumman. Proto-Flight Model (PFM) flew onboard the now defunct Tropical Rainfall Measuring Mission (TRMM); FM1 and FM2 currently fly onboard the Terra satellite; FM3 and FM4 fly onboard the Aqua satellite; and FM5 flies onboard the Suomi National Polar-orbiting Partnership (NPP) satellite. Because of how important the CERES measurements are to the scientific community and how crucial it is to have a continuous record of CERES data, plans were made to launch another CERES instrument, on JPSS-1, before the instruments currently on orbit have the chance to fail.

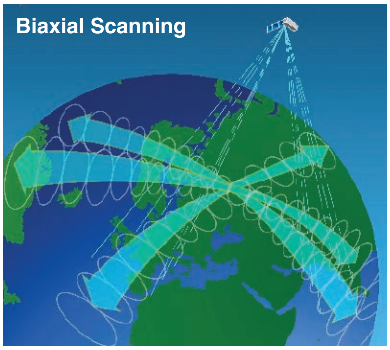
[*Right*] This plot depicts data from the first time CERES onboard TRMM collected a swath of data between 35° north and south latitude after being powered on at 1:32 PM EST on December 27, 1997. Satellite-altitude measurements from the window channel (8-12 microns) are expressed as filtered radiance in watts per square meter per steradian.



Credit: NASA/NOAA/CERES Team

Image credit: NASA





[*Left*] All CERES instruments have the capability to provide both a static scanning path (i.e., cross-track scan mode) and a back and forth scanning path (i.e., biaxial scan mode). A cross-track scan mode allows CERES to measures a straight, continuous swath of data 25 kilometers across, while a biaxial scan mode allows CERES to measure in 360 degrees for 20 kilometers. Combined, these two swath modes provide nearly total coverage of the Earth.

CERES PFM on TRMM

The first CERES instrument was launched onboard TRMM[1] from Japan in November 1997. TRMM was a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) to study rainfall for weather and climate research. While the TRMM satellite operated until April 2015, the CERES instrument on TRMM stopped collecting data in March 2000. The TRMM satellite provided coverage over tropical and subtropical regions, from approximately 35° north latitude (e.g., the Mediterranean Sea) to 35° south latitude (e.g., the southern tip of South Africa). CERES data from TRMM helped validate the accuracy of Earth energy estimates and gain confidence in the proper operation of the instrument and the data interpretation algorithms.

CERES FM1 and FM2 on Terra

Still in orbit today, NASA's Terra mission[2] launched from Vandenberg Air Force Base in December 1999, carrying the second and third copies of CERES (FM1 and FM2). The Terra satellite operates in a sun-synchronous, or near-polar, orbit crossing the equator from north to south at 10:30 AM local time every 99 minutes. This orbit extends the coverage of CERES PFM provided by TRMM, allowing CERES FM1 and FM2 on Terra to observe the entire Earth's surface (from pole to pole) every one to two days. CERES FM1 mainly operates in a cross-track scan mode and FM2 mainly operates in a biaxial scan mode. The FM1 cross-track scanning data built on the measurements taken by CERES PFM on TRMM by adding mid-latitude and polar observations. The additional measurements help to increase the accuracy of the data on the diurnal cycle of radiation from day to night. The FM2 biaxial scan mode provides observations of the angular radiation fields in order to improve the accuracy of the fluxes of solar and thermal energy used to derive the Earth's radiation balance.

CERES FM3 and FM4 on Aqua

NASA's Aqua[3] spacecraft, launched from Vandenberg Air Force Base in May 2002, also carries two CERES instruments (FM3 and FM4), the fourth and fifth CERES instruments to fly in space. Similar to Terra, Aqua operates in a sun-synchronous orbit crossing the equator from south to north at 1:30 PM local time; therefore, the CERES instruments on Terra and Aqua collect data at the equator approximately three hours apart. CERES FM4 experienced an anomaly on March 30, 2005, after which the shortwave channel could no longer be used to obtain daytime observations. Thus, only data from FM3 are used for flux comparisons.

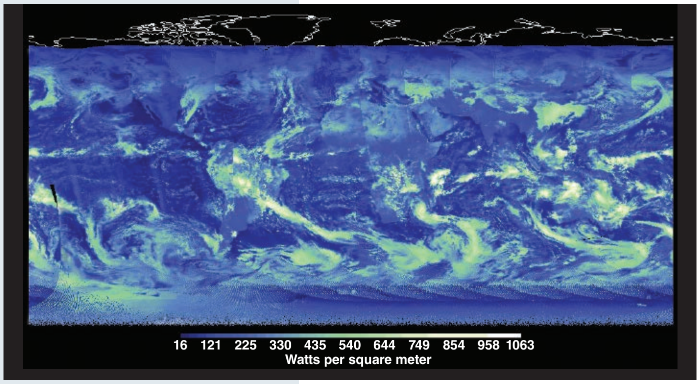
Because of how important the CERES measurements are to the scientific community and how crucial it is to have a continuous record of CERES data, plans were made to launch another CERES instrument, on JPSS-1, before the instruments currently on orbit have the chance to fail.

[1] Along with CERES, TRMM carried four other instruments: the Precipitation Radar (PR), the TRMM Microwave Imager (TMI), the Visible and Infrared Scanner (VIRS), and the Lightning Imaging Sensor (LIS).

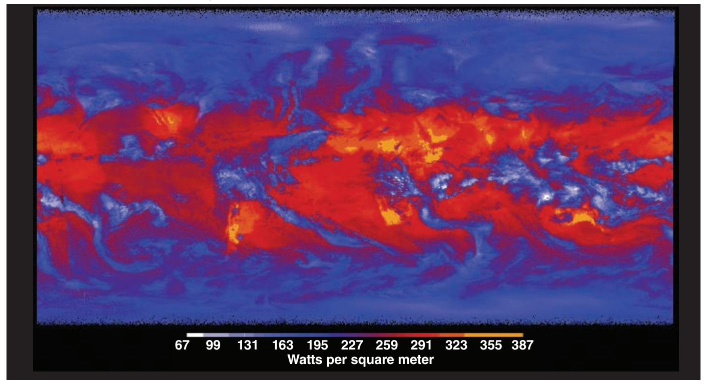
[2] In addition to CERES, Terra is home to the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), the Multi-angle Imaging Spectroradiometer (MISR), Measurements of Pollution in the Troposphere (MOPITT), and the Moderate Resolution Imaging Spectroradiometer (MODIS).

[3] Aqua, designed to study Earth's water cycle and all of its components, has five instruments onboard in addition to CERES: the Atmospheric Infrared Sounder (AIRS), the Advanced Microwave Sounding Unit (AMSU-A), the Humidity Sounder for Brazil (HSB), the Advanced Microwave Scanning Radiometer for EOS (AMSR-E), and a second MODIS instrument.

Shortwave Top of the Atmosphere Flux



Longwave Top of the Atmosphere Flux



Credit: NASA/NOAA/CERES Team

[*Above*] Created using initial data from CERES FM5 on Suomi NPP, these maps show the amount of incoming, shortwave radiation [*left*] and outgoing, longwave radiation [*right*] at the top of Earth's atmosphere on January 27, 2012. Comparison between these maps shows that thick cloud cover tends to reflect a large amount of incoming solar (i.e., shortwave) energy back to space, represented as white (brightest clouds) and green shades in the shortwave map, but at the same time, reduce the amount of outgoing (i.e., longwave) energy lost to space, represented as white, purple, and blue shades in the longwave map. Bright orange on the longwave map represents the areas emitting the most energy out to space (i.e., areas with little cloud cover), while bright white, purple, and blue shades represent areas emitting the least energy (i.e., areas with clouds).

Having pairs of CERES instruments on Terra and on Aqua provide both missions with the possibility of samplings from both scanning paths (i.e., cross-track and biaxial), enhancing the quality of the final data products.

CERES FM5 on Suomi NPP

CERES FM5 launched from Vandenberg Air Force Base in October 2011 onboard the Suomi National Polar-orbiting Partnership (NPP) satellite. Suomi NPP[4] operates in the same orbit as Aqua but at a higher altitude, 824 kilometers above Earth as opposed to 438 kilometers. The mission was part of the National Polar-orbiting Operational Environmental Satellite System (NPOESS), a joint effort of NASA, the U.S. Department of Defense (DOD), and NOAA to extend the measurement series initiated with NASA's EOS missions (i.e., TRMM, Terra, and Aqua). The NPOESS Preparatory Project (NPP) was renamed to Suomi National Polar-orbiting Partnership (NPP) and became the first satellite in the Joint Polar Satellite System (JPSS) series—see *Getting Into Space* on the next page.

Data from CERES FM5 have been crucial in continuing data collection of solar energy reflected and absorbed by Earth, the heat the planet emits, and the role of clouds in that process.

CERES FM6 on JPSS-1

CERES FM6 was the seventh CERES instrument built by Northrop Grumman Aerospace Systems. The instrument was delivered to Ball Aerospace and Technologies Corporation in Boulder, Colorado in 2012 for integration onto the JPSS-1 satellite and integrated environmental testing. FM6 was developed using many existing parts from previous CERES instrument builds. Just as all CERES instruments have been designed to do in the past, FM6 will be able to operate in both cross-track and biaxial (360 degree) scan modes, measuring radiances in three broadband channels: a shortwave channel (0.3 to 5 microns), a longwave channel (5 to 35 microns) with an accuracy of 0.3 to 1%, and a total channel (0.3 to 200 microns), which is a combination of the shortwave and infrared. JPSS-1 will operate in the same orbit as Suomi NPP, just 50 minutes apart. Onboard JPSS-1, CERES FM6 will fly alongside four other instruments: the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite (OMPS), and the Visible Infrared Imaging Radiometer Suite (VIIRS). Data from CERES FM6 will help scientists further develop a quantitative understanding of the links between the Earth's energy budget and the properties of atmosphere and surface that define it.

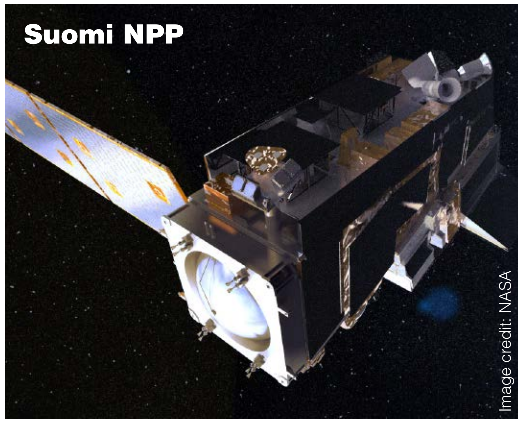
Data from CERES FM6 will help scientists further develop a quantitative understanding of the links between the Earth's energy budget and the properties of atmosphere and surface that define it.

[4] In addition to CERES, Suomi NPP carries the Advanced Technology Microwave Sounder (ATMS), Cross-track Infrared Sounder (CrIS), Ozone Mapping and Profiler Suite (OMPS), and Visible Infrared Imaging Radiometer Suite (VIIRS).

Getting into Space

CERES FM6 will fly onboard the Joint Polar Satellite System-1, or JPSS-1. The Joint Polar Satellite System (JPSS) is a collaborative program between NOAA and NASA. JPSS is the civilian component of the former National Polar-orbiting Operational Environmental Satellite System (NPOESS), which was reorganized in 2010. Today, JPSS supports the latest generation of U.S. polar-orbiting, environmental satellites. Suomi NPP is the first satellite in the series (which carries CERES FM5). Like Suomi NPP, JPSS-1 will circle the Earth from pole-to-pole, crossing the equator about 14 times daily in the afternoon orbit—providing full global coverage twice a day. JPSS-1 is designed for an operational lifetime of seven years; the spacecraft will launch from Vandenberg Air Force Base on a Delta II 7920-10C rocket, consisting of a booster stage, hypergolic second stage, nine solid rocket motors, and a 10-foot diameter payload fairing.

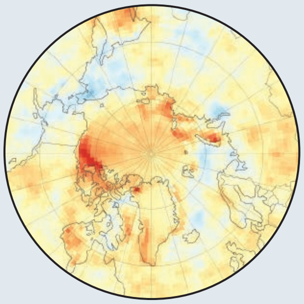
For more information about JPSS missions and their instruments, visit *http://www.jpss.noaa.gov.*



Satellites in the JPSS constellation will gather global measurements of atmospheric, terrestrial, and oceanic conditions to help improve weather forecasting. JPSS-2, JPSS-3, and JPSS-4 are planned to join the JPSS constellation in the future. To continue the data record from CERES, the JPSS-2, JPSS-3, and JPSS-4 satellite missions will fly the Radiation Budget Instrument (RBI).

At launch, the satellite will weigh 4850 pounds, or 2200 kilograms. It was manufactured by Ball Aerospace & Technologies Corporation. The total height of the launch vehicle is approximately 128 feet.

Data Products



[*Above*] This map shows the net change in solar radiation absorbed by the atmosphere over the Arctic from 2000 to 2014. NASA satellite instruments have observed a marked increase in the amount of solar radiation absorbed by the Arctic since the year 2000, a trend that aligns with the steady decrease in Arctic sea ice during the same period. Measurements for this image were made by the CERES instruments on NASA's Terra and Aqua satellites. Credit: NASA's Earth Observatory

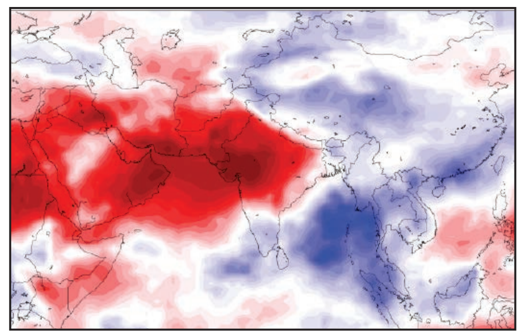
CERES provides global radiative flux and cloud property datasets. The temporal resolutions range from Level 2 instantaneous measurements to Level 3 hourly, daily, and monthly averages. The spatial resolutions range from Level 2 satellite field-of-view footprint measurements to Level 3 gridded regional, zonal, and global averages.

Global CERES data allow scientists to validate models that calculate the effect of clouds in driving planetary heating or cooling. CERES data also help improve seasonal climate forecasts, including cloud and radiative aspects of large-scale climate events like El Niño and La Niña.

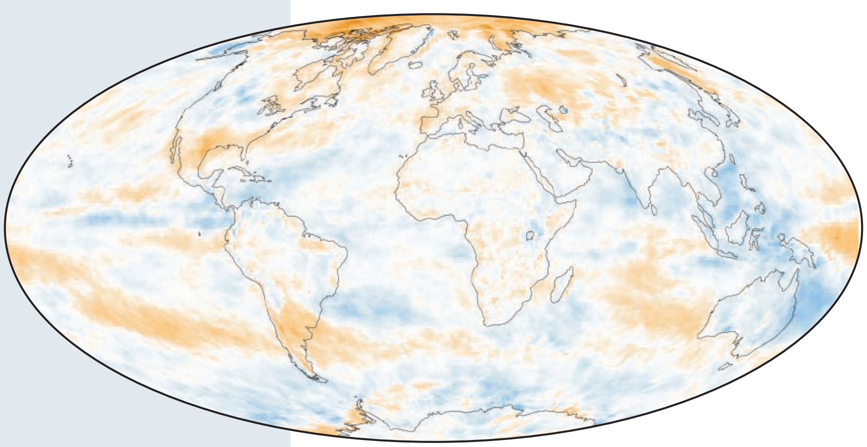
The CERES science team also uses high spatial resolution visible/infrared imager data to determine cloud properties including the amount, height, thickness, particle size, and phase of clouds using simultaneous measurements by other instruments, such as the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard Suomi NPP. These measurements are critical for understanding cloud-radiation climate change and improving the prediction of global warming using climate models.

Data from CERES can also be used for assessing the radiative effects and climatic impact of natural disasters like volcanic eruptions, major floods, and droughts. The long-term data record from CERES will provide a basis for scientific understanding of cloud and climate feedback that determines climate variations and trends.

Like all NASA Earth science data, CERES data are freely available to the public through the CERES website (*https://ceres.larc.nasa.gov/order_data.php*) and the Atmospheric Sciences Data Center (*https://eosweb.larc.nasa.gov/project/ceres/ceres_table*).



[*Above*] This map of India and the Middle East and Asia shows how much outgoing longwave radiation left Earth's atmosphere between May 15-27, 2015, while the region was experiencing a heatwave. Measurements for this image were made by the CERES instrument on NASA's Terra satellite. The image was created using the CERES SSF1deg data product. Credit: NASA's CERES Science Team



[*Left*] This map shows how the amount of sunlight reflected back into space changed between March 1, 2000, and December 31, 2011. Shades of blue mark areas that reflected more sunlight and orange areas denote less reflection over the 12-year time period. At the North Pole, reflectivity decreased markedly. At the South Pole reflectivity was down around West Antarctica and up slightly in parts of East Antarctica. Visible on the right and left ends of the map is the signature of the El Niño–Southern Oscillation (ENSO) pattern in the Pacific Ocean. An increase in reflectivity in the western tropical Pacific and reduced reflectivity in the central Pacific reveal patterns that are consistent with a shift from El Niño to La Niña. Measurements for this image were made by the CERES instruments on NASA's Terra satellite. Credit: NASA's Earth Observatory

Education and Outreach

Since 1997, students and citizen scientists across the globe have been comparing CERES data with their own cloud observations. The Students' Cloud Observations On-Line (S'COOL) program, established in 1997 and run by the Science Directorate education team at NASA's Langley Research Center, involves participants from age five and up in real-world science experiences, collecting and reporting observations of clouds from the ground to assist in the validation of NASA's CERES satellite instruments. These observations establish ground-truth data, where a person on the ground (or in an airplane) makes the same observation at the exact time the satellite does. The two observations are then compared to help evaluate how well the satellite instrument and the scientific analysis methods are performing. When patterns of disagreement are found, they can lead to improvements in the analysis methods.

In 2016, S'COOL began to merge its program with the Global Learning and Observation to Benefit the Environment (GLOBE) program and helped launch the GLOBE Observer app initiative. Continuing the work of S'COOL, GLOBE Observer invites citizen scientists all over the world to make sky observations and take pictures that can be compared with NASA satellite images to help scientists understand the sky from above and below.

To date, more than 200,000 observations from 97 different countries have been submitted from teachers, students, and the general public, engaging in authentic science through the S'COOL and GLOBE Observer programs, opening possibilities of pursuing careers in science, technology, engineering, and mathematics (STEM).

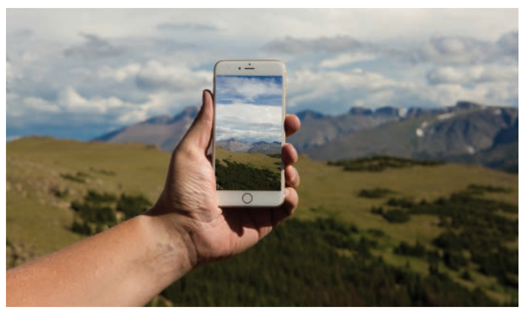


Image credit: NASA GLOBE Observer

The NASA GLOBE Observer app allows anyone to become a citizen scientist by collecting observations of clouds.

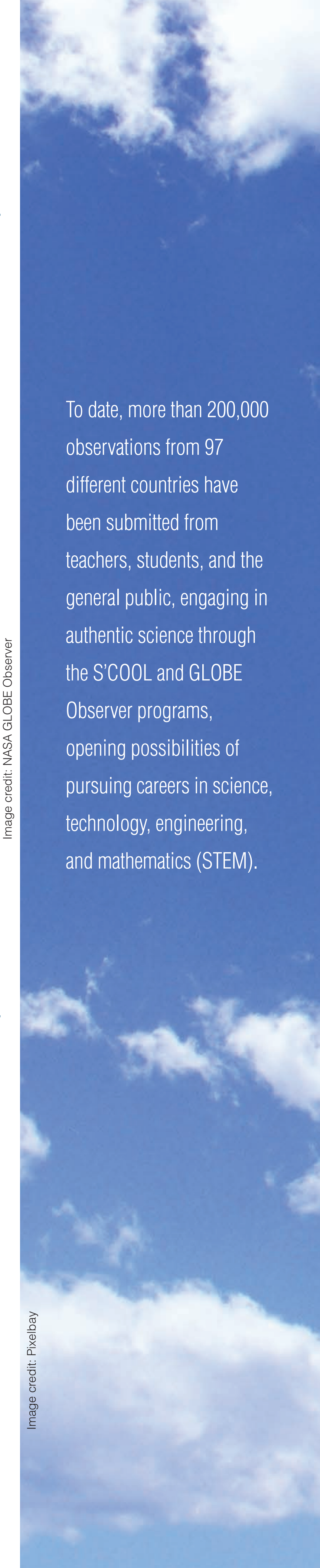


Image credit: Pixelbay

Benefits to Society and Technology

NASA has been studying the Earth for nearly 60 years, increasing understanding of our planet so we can better protect our home. CERES FM6 represents a continuation of NASA's ever-improving measurement capabilities that help to inform policy makers and benefit the economy.

These data are being used to validate and improve seasonal forecasts, which have a major economic benefit to both the agricultural and energy industry. In addition to improving climate models and long-term weather forecasting, CERES data supports commercial applications by providing surface meteorology and solar energy data for the renewable energy industry via an innovative, easy to use, website (*http://eosweb.larc.nasa.gov/sse*). Users include major energy companies, financial institutions, and federal agencies.

Long-term, accurate data are critical to understanding the energy balance. Scientists create this long measurement record by combining data from a series of instruments that has been launched over the past 30 years and continue with CERES FM6 and future radiation budget instruments. A gap in measurements would greatly decrease the accuracy of the overall data record and significantly impact our ability to observe changes in Earth's energy budget and climate.

National Aeronautics and Space Administration

www.nasa.gov

NP-2017-7-044-GSFC