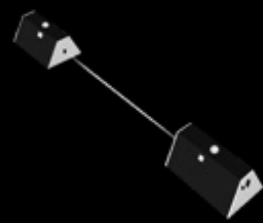
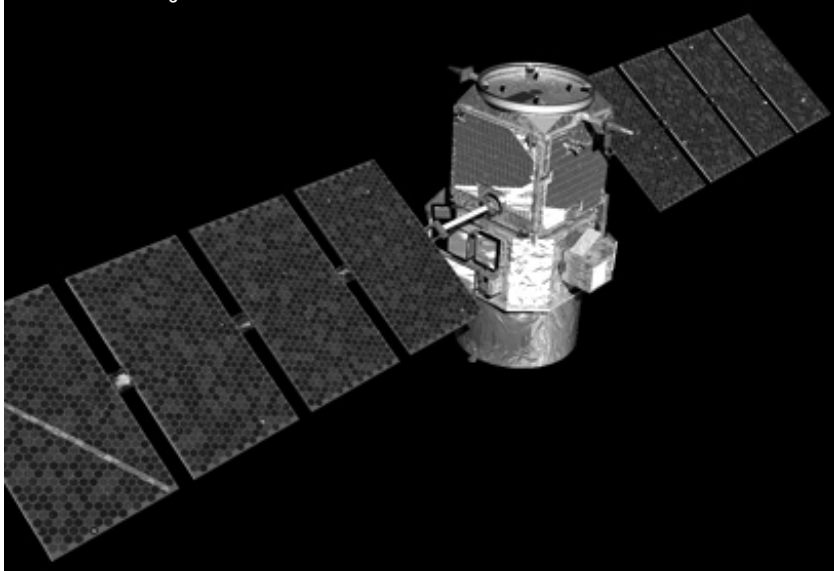
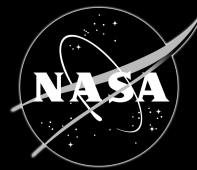


National Aeronautics and Space Administration  
www.nasa.gov



# CALIPSO CloudSat GRACE

## SCIENCE WRITER'S GUIDE

A guide for reporters to understand the mission and purpose of NASA's satellites



NASA'S FIRST THREE EARTH SYSTEM SCIENCE PATHFINDER PROGRAM (ESSP) SATELLITES

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## NASA'S EARTH SYSTEM SCIENCE PATHFINDER PROGRAM (ESSP) SATELLITES

The CALIPSO, CloudSat, and GRACE missions

### WHAT IS THE PURPOSE OF THIS SCIENCE WRITER'S GUIDE?

This publication is intended to be a one-stop resource for science writers and reporters who want to write about any of these three missions. For each satellite, the guide includes a quick reference sheet, Q&A, basics on the science of each mission, public affairs and scientist contact information, explanations of the satellites and their instruments, Web sites and other resources. This guide will also be online under [www.nasa.gov](http://www.nasa.gov) or at <http://earthobservatory.nasa.gov/Newsroom/#> under "Media Resources."

### What Is NASA's ESSP Program?

NASA's Earth System Science Pathfinder (ESSP) Program addresses unique, specific, highly-focused mission requirements in earth science research. These first 3 satellites of the ESSP will help unravel the secrets of climate variability and change.

\* **CALIPSO — Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations** will employ an innovative set of instruments to study the role that aerosols and thin clouds play in regulating earth's weather, climate and air quality. CALIPSO will collect information about the vertical structure of clouds and aerosols unavailable from other earth-observing satellites, and data from CALIPSO will improve our understanding of the human impact on the atmosphere.

\* **CloudSat** is designed to provide the first global survey of cloud profiles and properties with seasonal and geographic variations from space. These are needed to evaluate the way clouds are characterized in global models, thereby enabling research that will lead to improved predictions of weather and climate.

\* **GRACE — Gravity Recovery and Climate Experiment** unravels global climatic issues by enabling a better understanding of ocean surface currents and heat transport, measuring changes in sea-floor pressure, watching the mass of the oceans change, and by monitoring changes in the storage of water and snow on the continents. The primary goal of the GRACE mission is to obtain accurate, global and high-resolution determination of both the mean and time-variable components of earth's gravity field.



RIGHT: SUNRISE  
Credit: NOAA/USDA

# CALIPSO Quick Reference Guide



The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) will fly in formation with four other satellites to provide a global set of data on aerosol and cloud properties, radiative fluxes and atmospheric state to enable new assessments of the radiative effects of aerosols and clouds that will greatly improve our ability to forecast air quality events and to predict climate change.

## PARTNERS:

NASA and the French space agency *Centre National d'Etudes Spatiales* (CNES). Other collaborators include: Ball Aerospace & Technologies Corp.; Hampton University; and the Institut Pierre Simon Laplace.

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NASA Headquarters: Erica Hupp, 202-358-1237

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## CALIPSO RELATED PUBLICATIONS:

- CloudSat / CALIPSO BROCHURE: <http://www-cali-pso.larc.nasa.gov/resources>
- CALIPSO fact sheet: <http://www-cali-pso.larc.nasa.gov/resources>
- CALIPSO-related Games, puzzles and more; <http://calipsooutreach.hampton.edu/arcade.html>

Winker, D. M., J. Pelon and M. P. McCormick, The CALIPSO mission: Spaceborne lidar for observation of aerosols and clouds, SPIE Asia-Pacific Symposium on Remote Sensing of the Atmosphere, Environment and Space, Hangzhou, China, 23-27 October 2002. Volume 4893 Pages 1-11

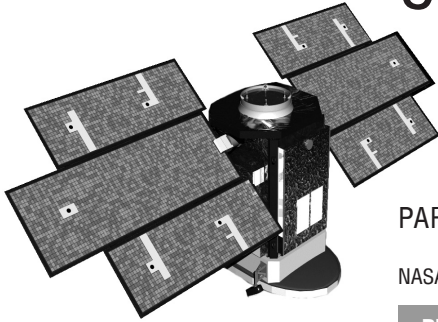
Winker, D., C. Hostetler and W. Hunt, CALIOP: The CALIPSO Lidar, 22nd International Laser Radar Conference (ILRC 2004), Matera, Italy, 12-16 July 2004. ESA SP-561

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- CALIPSO Web site: <http://www.nasa.gov/calipso>
- CALIPSO Instrument Websites: <http://www-cali-pso.larc.nasa.gov>
- CALIPSO Outreach: <http://calipsooutreach.hamptonu.edu>

# CloudSat Quick Reference Guide



CloudSat will provide the first global survey of cloud profiles and properties with seasonal and geographic variations from space. These are needed to evaluate the way clouds are characterized in global models, thereby enabling research that will lead to improved predictions of weather and climate.

## PARTNERS:

NASA, the Canadian Space Agency, the U.S. Air Force, the U.S. Department of Energy, and Colorado State University.

**Please call the NASA Public Affairs Office before contacting individual scientists.**

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NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

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## CLOUDSAT RELATED PUBLICATIONS:

CloudSat Brochure: [http://cloudsat.atmos.colostate.edu/data/general/brochure\\_final.pdf](http://cloudsat.atmos.colostate.edu/data/general/brochure_final.pdf)

CloudSat/CALIPSO Brochure: <http://www-calipso.larc.nasa.gov/resources>

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CLOUDSAT Web site: <http://www.nasa.gov/cloudsat> and <http://cloudsat.atmos.colostate.edu>

Education: Atmospheric Stability and Instability:  
[http://squall.sfsu.edu/courses/metr302/F96/handouts/stability\\_1.html](http://squall.sfsu.edu/courses/metr302/F96/handouts/stability_1.html)

## IMAGES:

Cloud Chart (NASA): <http://asd-www.larc.nasa.gov/SCOOOL/cldchart.html>

NOAA Photolibrary: <http://www.photolib.noaa.gov>

NOAA Cloud Photolibrary: <http://www.photolib.noaa.gov/historic/nws/clouds1.html>

Instrument Website: <http://cloudsat.atmos.colostate.edu/instrument/instrument.html>

Outreach: <http://cloudsat.atmos.colostate.edu/outreach>

Poster: "Reading the Clouds": <http://catalog.core.nasa.gov/core.nsf/item/300.1-56P>

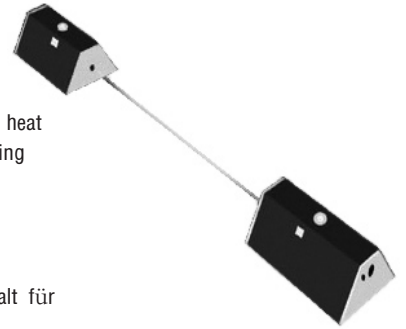
## CLOUDSAT SCIENCE QUESTION LINKS:

Cloud Classification: <http://cloudsat.atmos.colostate.edu/CloudClass.html>

Clouds and the Human Culture: <http://cloudsat.atmos.colostate.edu/CloudCulture.html>

Story of Clouds: <http://cloudsat.atmos.colostate.edu/CloudStory.html>

# GRACE Quick Reference Guide



GRACE unravels global climatic issues by enabling a better understanding of ocean surface currents and heat transport, measuring changes in sea-floor pressure, watching the mass of the oceans change, and monitoring changes in the storage of water and snow on the continents. GRACE was launched on March 17, 2002.

## PARTNERS:

NASA, The University of Texas Center for Space Research (UTCSR), the German Deutsche Forschungsanstalt für Luft und Raumfahrt (DLR), and GeoForschungsZentrum (GFZ) Potsdam.

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NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

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## GRACE RELATED PUBLICATIONS:

Brochure: <http://www.csr.utexas.edu/grace/publications/brochure/cover.html>  
 Educational Activities: <http://www.csr.utexas.edu/grace/education>  
 Fact Sheet: [http://www.csr.utexas.edu/grace/publications/fact\\_sheet](http://www.csr.utexas.edu/grace/publications/fact_sheet)  
 Games: <http://www.csr.utexas.edu/grace/games>  
 Handbook: <http://www.csr.utexas.edu/grace/publications/handbook>  
 Image Gallery: <http://www.csr.utexas.edu/grace/gallery>  
 Lithograph: <http://www.csr.utexas.edu/grace/publications/litho>  
 Posters: <http://www.csr.utexas.edu/grace/gallery/other/posters> and  
[http://www.csr.utexas.edu/grace/gallery/other/posters/GRACE\\_D2001\\_0828\\_C1.html](http://www.csr.utexas.edu/grace/gallery/other/posters/GRACE_D2001_0828_C1.html)  
 and [http://www.csr.utexas.edu/grace/gallery/other/posters/2001-10\\_cast\\_grace.html](http://www.csr.utexas.edu/grace/gallery/other/posters/2001-10_cast_grace.html)  
 and [http://www.csr.utexas.edu/grace/gallery/other/posters/1999-06\\_graceposter.html](http://www.csr.utexas.edu/grace/gallery/other/posters/1999-06_graceposter.html)  
 and [http://www.csr.utexas.edu/grace/gallery/other/posters/2001-06\\_lumpy\\_bumpy.html](http://www.csr.utexas.edu/grace/gallery/other/posters/2001-06_lumpy_bumpy.html)

PDF files of print publications can be obtained at:  
[http://eospsso.gsfc.nasa.gov/eos\\_homepage/for\\_educators/educational\\_publications.php](http://eospsso.gsfc.nasa.gov/eos_homepage/for_educators/educational_publications.php)

To order contact:  
 The EOS Project Science Office, Code 900, NASA/Goddard Space Flight Center, Greenbelt, MD 20771 Tel. 301-867-2037

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GRACE Web site: <http://www.csr.utexas.edu/grace/>  
 GRACE Mission Press Kit: [http://www.jpl.nasa.gov/news/press\\_kits/gracelaunch.pdf](http://www.jpl.nasa.gov/news/press_kits/gracelaunch.pdf)

SCIENCE QUESTION LINKS ON NASA'S EARTH OBSERVATORY WEB SITE:  
 Weighing Earth's Water from Space: <http://earthobservatory.nasa.gov/Study/WeighingWater>  
 Reference Article on GRACE: [http://earthobservatory.nasa.gov/Library/GRACE\\_Revised](http://earthobservatory.nasa.gov/Library/GRACE_Revised)

## WHAT IS NASA'S EARTH SYSTEM SCIENCE PATHFINDER PROGRAM?

NASA's Earth System Science Pathfinder (ESSP) program is a component of NASA's Science Mission Directorate that addresses unique, specific, highly-focused mission requirements in earth science research. These first three satellites of the ESSP: CALIPSO, CloudSat, and GRACE will help unravel the secrets of climate change in the atmosphere, land, and oceans.

The ESSP program offers an innovative approach for addressing global change research by providing periodic "windows of opportunity" to accommodate new scientific priorities and encourage new scientific participation in the Science Mission Directorate.

ESSP missions are the cornerstone of a dynamic and versatile program consisting of multiple earth system science space flights, characterized by small- to medium-sized missions capable of being built, tested, and launched in a short period. These missions support a variety of scientific objectives related to earth science, including the atmosphere, oceans, land surface, polar ice, and solid earth.

The ESSP program is responsible for the management, direction, and implementation of these science investigations. Missions encompass the entire project life-cycle from definition, through design, development, integration and testing, launch, operations, science data analysis, and distribution.

ESSP missions are peer-reviewed science investigations. They consist of a series of low-cost missions led by a Principal Investigator (PI) and at least two ESSP missions are selected from each AO. The PI is responsible for science integrity, assembling the team for complete mission implementation, and ensuring mission success.

The team may include university, industry, government, Federally Funded Research and Development Centers (FFRDC), and international partners as desired by the PI. Costs for each ESSP mission are capped and the project management follows standard industry practices and procedures to the maximum extent possible. For more information on the ESSP missions: <http://earth.nasa.gov/essp/index.html>

## EARTH SYSTEM SCIENCE PATHFINDER MISSION SUMMARIES

**Aquarius** - Aquarius is a focused satellite mission to measure global sea surface salinity. Scientific progress has been limited to date because conventional in situ sea surface salinity sampling is too sparse to give the global view of salinity variability that only a satellite can provide. Aquarius will resolve missing physical processes that link the water cycle, climate, and ocean. (Scheduled Launch Date: 2009) Web site: <http://aquarius.gsfc.nasa.gov>

**Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)** - CALIPSO employs an innovative set of instruments to study the role that aerosols and thin clouds play in regulating earth's weather, climate, and air quality. CALIPSO will collect information about the vertical structure of clouds and aerosols unavailable from other earth-observing satellites, and data from CALIPSO will improve our understanding of the human impact on the atmosphere. (Scheduled Launch Date: 2005) Web site: <http://www.nasa.gov/calipso>

**CloudSat** - CloudSat is a satellite designed to provide the first global survey of cloud profiles and properties with seasonal and geographic variations from space. These are needed to evaluate the way clouds are characterized in global models, thereby contributing to predictions of weather, climate and the cloud-climate feedback problem. (Scheduled Launch Date: 2005) Websites: <http://www.nasa.gov/cloudsat> and <http://cloudsat.atmos.colostate.edu>

**Gravity Recovery and Climate Experiment (GRACE)** - GRACE unravels global climatic issues by enabling a better understanding of ocean surface currents and heat transport, measuring changes in sea-floor pressure, watching the mass of the oceans change, and by monitoring changes in the storage of water and snow on the continents. The primary goal of the GRACE mission is to obtain accurate, global and high-resolution determination of both the mean and the time-variable components of the earth's gravity field. (Launch: March 17, 2002) Web site: <http://www.csr.utexas.edu/grace>

**Hydrosphere State Mission (HYDROS)** - HYDROS will provide the first global views of earth's changing soil moisture and land surface freeze/thaw conditions, leading to breakthroughs in weather and climate prediction and in the understanding of processes linking water, energy, and carbon cycles. (Scheduled Launch Date: 2010) Web site: <http://hydros.gsfc.nasa.gov>

**Orbiting Carbon Observatory (OCO)** - OCO will provide space-based observations of atmospheric carbon dioxide, the principal anthropogenic driver of climate change. This mission will use mature technologies to address NASA's highest priority carbon cycle measurement requirement. (Scheduled Launch Date: 2008) Web site: <http://oco.jpl.nasa.gov>

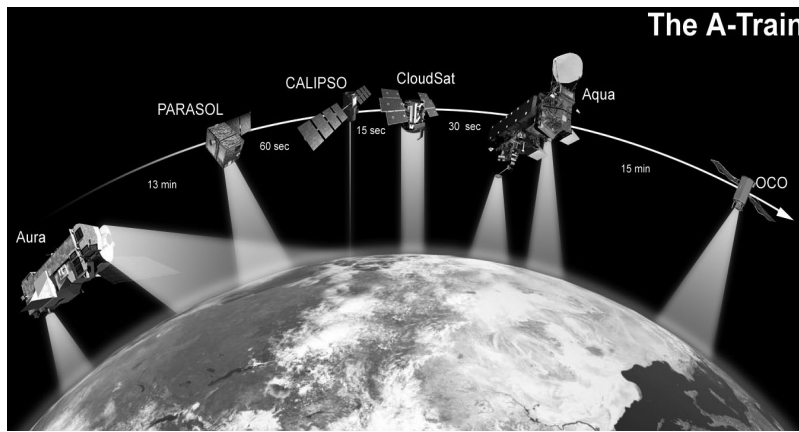


**CALIPSO & CLOUDSAT CATCH THE “A-TRAIN” WITH OTHER SATELLITES**

**WHAT IS THE A-TRAIN OF SATELLITES?**

The A-Train refers to a group of satellites all moving in roughly the same, sun-synchronous orbit. This group includes satellites launched by NASA in the U.S. and a satellite built by the French Space Agency, CNES, in Europe. (One of the satellites, CALIPSO, is a joint NASA/CNES mission, but launched by a NASA rocket.) The reason for all of these satellites being in essentially the same orbit and positioned close to one another on that orbit is so that they can make coordinated science observations. The lead satellite in this group is Aqua, followed by CloudSat, CALIPSO, PARASOL, and lastly Aura.

This group of satellites is also called the Afternoon Constellation because the place on the equator over which they fly moving north, i.e., the ascending node of their orbits, has a mean local time of 1:30 p.m. And because the orbits are all sun-synchronous, this position of the ascending node remains essentially the same over the mission life. So for a ground-based observer on the equator seeing the Afternoon Constellation pass over head, the local time would be 1:30 p.m..



ABOVE: This graphic shows the satellites that make up the Afternoon Constellation – “The A-Train” of satellites. (Credit: Alex McClung, SSAI)

**WHICH SATELLITES ARE INVOLVED IN THE “A-TRAIN”?**

The A-Train consists of: Aqua, Aura, CALIPSO, CloudSat, OCO, and PARASOL. GRACE is not a part of the “A-Train” of satellites. While each satellite has an independent science mission, these complementary satellite observations will enable scientists to obtain more comprehensive information. The OCO satellite will be added to the A-Train in 2008.

**WHAT IS THE PURPOSE OF THE A-TRAIN? HOW WILL THE A-TRAIN OF SATELLITES WORK?**

As a constellation, the synergistic measurements will improve the quality and accuracy of the results by identifying aerosol types, the role of polar stratospheric clouds in ozone loss, and the vertical distribution of water and ice in cloud systems. Scientists plan to perform coincidental observations, by using data from approximately the same time from two or more instruments on the various satellites to investigate a specific area of interest.

**IN WHAT ORDER WILL THE SATELLITES BE FLYING?**

The Aqua satellite was launched in May 2002. In July 2004, NASA’s Aura satellite was put into orbit such that it follows Aqua by 15 minutes. Aura was placed on a different orbital track to cross the equator eight minutes after Aqua, which results in specific synergy between the Aura and Aqua instruments. In 2005, CALIPSO and CloudSat will share a single launch vehicle. Once in orbit, CALIPSO will fly in formation with CloudSat reacting to any changes in CALIPSO’s orbit. CALIPSO will, in turn, react to changes in Aqua’s orbit. This tight formation between CALIPSO and CloudSat enables complementary measurements between the two and with Aqua, which is a key science requirement. In December 2004, the French space agency, *Centre National d’Etudes Spatiales* (CNES) launched PARASOL, which will fly one minute behind CALIPSO. Lastly, the OCO mission, to be launched in 2008, is being designed to fly 15 minutes in front of Aqua.

**IS THERE ANY DANGER OF THE SATELLITES COLLIDING?**

No. Each spacecraft is controlled to stay within an assigned ‘box’ along the orbit. Although each of the satellites is moving at high orbital speeds, the relative velocities with respect to each other are small, i.e., a walking speed, and the distance between even the closest satellites are many miles. Thus, as long as each satellite stays inside its ‘box,’ the constellation is very stable and safe, with no risk of collision.

The operations teams from member satellites communicate regularly between each other and coordinate activities. They

have delegated to the Earth Science Mission Operations Project at NASA's Goddard Space Flight Center (GSFC) the role of communications coordinator for the constellation.

**WHY DO THESE SATELLITES NEED TO FLY SO CLOSE TOGETHER?**

The instruments of the A-Train each have unique measurement capabilities. By combining measurements from the various sensors of the A-Train, we greatly extend and enhance our information about clouds and the atmosphere in which they are embedded. Because the properties of clouds can change rapidly with time, the measurements need to be made at nearly the same time.

**WHAT COUNTRIES ARE INVOLVED IN THE A-TRAIN?**

The A-Train can be thought of as a virtual international science platform of Earth Science missions. It consists of three NASA missions (Aqua, Aura, OCO), one French Centre National d'Etudes Spatiales (CNES) mission (PARASOL), one joint NASA/CSA mission (CloudSat), and one joint NASA/CNES mission (CALIPSO).

**WHAT IS THE NOVELTY OF THE A-TRAIN?**

The novelty of the A-Train is making a variety of measurements from different satellites and combining them to provide insight on earth's atmosphere and water cycle. The satellites are flown in a controlled, on-orbit formation that will minimize the amount of time between successive measurements. The CloudSat data processing system has already taken up the challenge of coregistering a portion of the data sets of CloudSat, CALIPSO, and Aqua/MODIS, and the CloudSat data products are produced using these combined data. We expect that the scientific community will find many ways to exploit the A-Train data.

**WHERE DO ALL THE SATELLITES ORBIT?**

All six satellites orbit at a mean equatorial altitude of 705 kilometers (438 miles) and cross the equator within a few minutes of one another at around 1:30 p.m. local time. Collectively, they are referred to as the Afternoon Constellation because the equator crossings occur in the early afternoon.

**HOW IS THE A-TRAIN BEING COORDINATED FROM NASA?**

The NASA Constellation Coordination System is managed by GSFC and provides a method for facilitating the exchange of information between missions, independently assessing anomalous situations that may arise, and providing recommendations for remedial actions in the event of anomalies.

**OVERVIEW OF THE A-TRAIN SATELLITES**

Satellite	Focus of Mission	Launch Date	Managing Center
<b>Aqua</b>	Water/energy cycle	Launched May 4, 2002	NASA/GSFC
<b>Aura</b>	Atmosphere chemistry	Launched July 15, 2004	NASA/GSFC
<b>CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations)</b>	Aerosols & clouds	2005	NASA/GSFC, LaRC, CNES
<b>CloudSat</b>	Clouds	2005	NASA/JPL
<b>OCO (Orbiting Carbon Observatory)</b>	Carbon cycle	2008	NASA/JPL
<b>PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar)</b>	Aerosols & clouds	Launched December 18, 2004	CNES

**KEY:** CNES – *Centre National d'Etudes Spatiales* (France); GSFC – NASA Goddard Space Flight Center; JPL – California Institute of Technology/NASA Jet Propulsion Laboratory; LaRC – NASA Langley Research Center

**A-TRAIN WEB SITES:**

- Classroom Web Activity – A-Train Express: [http://ali.apple.com/ali\\_sites/ali\\_exhibits/1001347/Web\\_Activity.html](http://ali.apple.com/ali_sites/ali_exhibits/1001347/Web_Activity.html)
- Educator Guide – A-Train Express: [http://ali.apple.com/ali\\_sites/ali\\_exhibits/1001347/Educator\\_Guide.html](http://ali.apple.com/ali_sites/ali_exhibits/1001347/Educator_Guide.html)
- Educator Introduction A-Train Express: [http://ali.apple.com/ali\\_sites/ali\\_exhibits/1001347/Introduction.html](http://ali.apple.com/ali_sites/ali_exhibits/1001347/Introduction.html)
- Education Article – “NASA Connect: The ‘A’ Train Express”: [http://www1.nasa.gov/audience/foreducators/5-8/features/F\\_A\\_Train\\_Express.html](http://www1.nasa.gov/audience/foreducators/5-8/features/F_A_Train_Express.html)
- Fact Sheet: <http://calipsooutreach.hamptonu.edu/download/a-train.pdf>

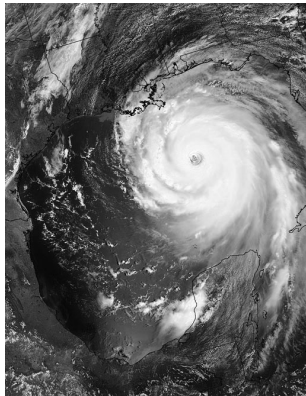
**FEATURE: WHAT’S THE DIFFERENCE BETWEEN WEATHER AND CLIMATE?**

By Rob Gutro, NASA’s Earth – Sun Science News Team/SSAI/NASA GSFC and excerpts from NOAA’s Climate Prediction Center Web site and the U.S. Environmental Protection Agency Web site. 2/2005

The difference between weather and climate is a measure of time. Weather is the conditions of the atmosphere over a short period of time, while climate is how the atmosphere “behaves” over relatively long periods of time.

When we talk about climate change, we talk about changes in long-term averages of daily weather. Today, children always hear stories from their parents and grandparents about how snow was always piled up to their waists as they trudged off to school. Children today in most areas of the country have not experienced those kinds of dreadful snow-packed winters. The change in recent winter snows indicate the climate has changed since their parents were young.

If summers seem hotter lately, then this indicates that the climate may have changed. In various parts of the world, some people have reported that springtime comes earlier now than it did 30 years ago. An earlier start of spring is also indicative of a possible change in the climate.



LEFT: At 10 a.m., CDT on August 29, 2005, the center of Hurricane Katrina moved ashore near the Louisiana–Mississippi border. The center of Hurricane Katrina was located near the mouth of the Pearl River about 35 miles east-northeast of New Orleans, Louisiana, and about 45 miles west-southwest of Biloxi, Mississippi. Katrina was moving toward the north near 16 mph, and maximum sustained winds are near 125 mph, with higher gusts. This image is from NASA’s Moderate Imaging Spectroradiometer (MODIS) instrument that is aboard both NASA’s Terra and Aqua satellites. Katrina, which cut across Florida August 25–27, 2005 leaving nine dead and massive damage, had intensified into a Category 5 storm over the warm waters of the Gulf of Mexico, reaching top winds of 175 mph before weakening as it neared the coast.

Credit: NASA/MODIS Land Rapid Response Team

**WHAT WEATHER MEANS**

Weather is basically the way the atmosphere is behaving, mainly with respect to its effects upon life and human activities. The difference between weather and climate is that weather consists of the short-term (minutes to months) changes in the atmosphere. Most people think of weather in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure.

In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. Climate, however, is the average of weather over time and space. An easy way to remember the difference is that climate is what you expect, like a very hot summer, and weather is what you get, like a hot day with pop-up thunderstorms.

**THINGS THAT MAKE UP OUR WEATHER**

There are a lot of components to weather. Weather includes sunshine, rain, cloud cover, winds, hail, snow, sleet, freezing rain, flooding, blizzards, ice storms, thunderstorms, steady rains from a cold front or warm front, heat waves, and more.

In order to help people be prepared for such changing conditions, the National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service (NWS), the lead forecasting outlet for the nation’s weather, has over 25 different types of warnings, statements, or watches that they issue. Some of these include: flash flood watches and warnings, severe thunderstorm watches and warnings, blizzard warnings, snow advisories, winter storm watches and warnings, dense fog advisories, fire weather watches, tornado watches and warnings, and hurricane watches and warnings. They also provide weather statements and short-and long-term forecasts.

NWS also issues many notices concerning marine weather for boaters and others who dwell near shorelines. They include: coastal flood watches and warnings, flood watches and warnings, high wind warnings, wind advisories, gale warnings, high surf advisories, heavy freezing spray warnings, small craft advisories, marine weather statements, freezing fog advisories, coastal flood watches, and flood statements.



LEFT: "NIGHT-TIME THUNDERSTORM"  
Multiple cloud-to-cloud and cloud-to-ground lightning strokes caught using time-lapse photography during a night-time thunderstorm.  
Credit: NOAA Photo Library; OAR/ERL/NSSL

## WHO IS THE NATIONAL WEATHER SERVICE?

According to their mission statement, "The National Weather Service provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community."

To do their job, the NWS uses radar on the ground and images from orbiting satellites that keep a continual eye on Earth. They use reports from a large national network of weather reporting stations, and they launch balloons in the air to measure air temperature, air pressure, wind, and humidity. They put all these data into various computer models to give them weather forecasts. NWS also broadcasts all of their weather reports on NOAA weather radio and posts them immediately on their Interactive Weather Information Network Web site at: <http://iwin.nws.noaa.gov/iwin/graphicsversion/bigmain.html>.

## WHAT CLIMATE MEANS

In short, *climate* is the description of the long-term pattern of weather in a particular area. Some scientists define climate as the average weather for a particular region and time period, usually taken over 30 years. It's really an average pattern of weather for a particular region.

When scientists talk about climate, they're looking at averages of precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather that occur over a long period.

For example, after looking at rain gauge data, lake and reservoir levels, and satellite data, scientists can tell a summer was drier than average. If it continues to be drier than normal over the course of many summers, then it may indicate a change in the climate.

## WHY STUDY CLIMATE?

Studying climate and a changing climate is important because changing environmental conditions will affect people around the world. Rising global temperatures are expected to raise sea levels, bringing changes in precipitation and other local climate conditions. A changing regional climate can alter forests, crop yields, and water supplies, impacting human health, animals, and many types of ecosystems. Deserts may expand into existing rangelands, and some features of our National Parks and National Forests may be permanently altered.

The National Academy of Sciences, a lead scientific body in the U.S., has determined that the earth's surface temperature has risen by about 1 degree Fahrenheit in the past century, with accelerated warming during the past two decades. There is new and stronger evidence that most of the warming over the last 50 years can be attributed to human activities. Yet, there is still some debate about the role of natural cycles and processes.

Human activities have altered the chemical composition of the atmosphere through the buildup of greenhouse gases, primarily carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. The heat-trapping property of these gases is undisputed although uncertainties exist about exactly how Earth's climate responds to them. According to the U.S. Climate Change Science Program (<http://climatescience.gov>), factors such as aerosols, land use change, and others may play important roles in climate change, but their influence is highly uncertain at the present time.

## WHO STUDIES CLIMATE CHANGE?

Climate prediction started back in the late 1700s with Thomas Jefferson and continues to be studied around the world today.



At the national level, the U.S. Climate Change Science Program (CCSP) integrates federal research on climate and global change, as sponsored by thirteen federal agencies and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council and the Office of Management and Budget.

During the past thirteen years the United States, through the U.S. Global Change Research Program (USGCRP), has made the world's largest scientific investment in the areas of climate change and global change research — a total investment of almost \$20 billion.

Because of the scientific accomplishments achieved by USGCRP and other research programs during a productive "period of discovery and characterization" since 1990, the U.S. is ready to move into a new "period of differentiation and strategy investigation," which is the theme of the President's Climate Change Research Initiative (CCRI). The CCRI focuses on the development of near-term decision-support information and requires close integration with the many existing programs managed under the USGCRP.



LEFT: SUNRISE OVER THE EVERGLADES  
Credit: NOAA / DOI National Park Service

**SOME FEDERAL AGENCIES STUDYING CLIMATE**

In the 1980s the National Weather Service established the Climate Prediction Center (CPC), known at the time as the Climate Analysis Center (CAC). The CPC is best known for its United States climate forecasts based on several factors, including El Niño and La Niña conditions in the tropical Pacific.

There are other agencies and organizations that study climate change. Some of the more prominent ones include: NOAA's National Climatic Data Center (NCDC) and Climate Monitoring & Diagnostics Laboratory (NOAA/CMDL), the Climate Diagnostics Center (NOAA/CDC), and the National Center for Atmospheric Research (NCAR). The U.S. Department of Energy (DOE) also has a program called the Atmospheric Radiation Measurement (ARM) Program, DOE's largest global change research program.

CPC was established to give short-term climate prediction a home in NOAA. CPC's products are operational predictions or forecasts of how climate may change and includes real-time monitoring of climate. They cover the land, the ocean, and the atmosphere, extending into the upper atmosphere (stratosphere). Climate prediction is very useful in various industries, including agriculture, energy, transportation, water resources, and health.

NASA has been using satellites to study Earth's changing climate. Thanks to satellite and computer model technology, NASA has been able to calculate actual surface temperatures around the world and measure how they've been warming. To accomplish these calculations, the satellites measure the Sun's radiation reflected and absorbed by the land and oceans.

NASA satellites keep eyes on the ozone hole, El Niño's warm waters in the eastern Pacific, volcanoes, melting ice sheets and glaciers, changes in global wind and pressure systems, and much more.

At the global level, countries around the world have expressed a firm commitment to strengthening international responses to the risks of climate change. The U.S. is working to strengthen international action and broaden participation under the support of the United Nations Framework Convention on Climate Change.

Today, scientists around the world continue to try and solve the puzzle of climate change by working with satellites, computer models, and other tools that simulate and predict the earth's conditions.

**WEB SITES ABOUT WEATHER AND CLIMATE:**

- 2004's Global Temperature Review: [http://www.nasa.gov/vision/earth/lookingatearth/earth\\_warm.html](http://www.nasa.gov/vision/earth/lookingatearth/earth_warm.html)
- Glossary of Weather Terms: <http://www.nws.noaa.gov/glossary>
- NASA's study of earth's climate, please visit: <http://www.nasa.gov/vision/earth/features/index.html>
- National Weather Service, please visit: <http://www.nws.noaa.gov>
- NOAA weather radio station near you, please visit: <http://www.nws.noaa.gov/nwr>
- U.S. Global Change Research Program, please visit: <http://www.usgcrp.gov>
- Weather watches and warnings; please visit the NWS Interactive Weather Information Network: <http://iwin.nws.noaa.gov/iwin/graphicsversion/bigmain.html>

# Q&A on the CALIPSO Mission

## WHAT DOES “CALIPSO” STAND FOR?

Cloud – Aerosol Lidar and Infrared Pathfinder Satellite Observations

## WHAT IS CALIPSO'S PURPOSE AND MISSION?

To help scientists answer significant questions and provide new information about the effects of aerosols (airborne particles) and thin clouds on changes in the earth's climate. Accurate climate model predictions will provide international and national leaders accurate information to make more informed policy decisions about global climate change.

## WHAT TYPES OF THINGS WILL CALIPSO LOOK AT?

CALIPSO provides a new and unique perspective on the amount, height and type of aerosols, and thin clouds — some are even invisible to radar and the human eye. The lidar can tell if a cloud is made of water or ice.

## WHAT 3 STATEMENTS FORM THE BASIS FOR CALIPSO'S OBJECTIVES?

The CALIPSO satellite mission objectives are to determine precisely the altitudes of clouds, aerosol layers and their overlap; identify the composition of clouds and the presence of subvisible (or “invisible” clouds); and estimate the abundance and sources of aerosols. Combining this data with observations from the other A-Train satellites will help scientists to better understand how aerosols and clouds interact and these measurements will ultimately contribute to improved forecasts of air quality and predictions of climate change.

## WHAT QUESTIONS WILL CALIPSO ANSWER?

CALIPSO will give us new 3-D perspectives on earth's clouds and aerosols that will answer questions about how they form, evolve, and affect our weather, climate, water supply, and air quality.

At what altitude do thin clouds and aerosols occur and how much overlap is there between them?

In what quantity do these thin clouds and aerosols occur?

How/to what extent do atmospheric aerosols affect the earth's energy balance?

How/to what extent do aerosols affect cloud properties?

How/to what extent do multilayered clouds affect the balance of solar and thermal energy at the earth's surface?

What is the role of clouds in the climate system?

## THE FEATURE SECTION OF THE WRITER'S GUIDE WILL EXPLORE THESE:

1. “*The Air We Breathe*” — how aerosols and pollutants are transported in the atmosphere. Air quality is a global problem.
2. *Aerosols and Clouds* — the interconnectivity of these two atmospheric features; their effects on air quality, weather, and climate; and the technology (lidar) that NASA uses to observe them.

## WHAT PREVIOUS MISSION DOES CALIPSO CONTINUE AND IMPROVE ON?

LITE (Lidar In-space Technology Experiment) and the ICESat (Ice, Cloud, and Land Elevation Satellite) are two missions that paved the way for CALIPSO in that they both flew space-based lidars.

## WHAT MAKES CALIPSO DIFFERENT FROM PREVIOUS MISSIONS?

LITE was a short-term mission, flying only 10 days on the Space Shuttle Discovery, that showed the possibilities for space-based lidar usage. The ICESat mission, which is currently operating, takes only intermittent lidar measurements, focusing mainly on the polar ice sheets. While ICESat does measure some aerosols and clouds, it does not have the collaboration or complement of a suite of instruments (like those of the A-Train) that is necessary to unlock the mysteries of weather, air quality, and climate change held in aerosols and clouds.

**HOW WILL ACCURACY OF CALIPSO DATA BE ENSURED?**

A number of validation missions are planned in order to ensure the accuracy of CALIPSO’s data. During these missions, ground-based, air-based, and other space-based instruments will make simultaneous readings that will be compared to validate the CALIPSO measurements.

**WHOM DO I CONTACT ABOUT CALIPSO SCIENCE QUESTIONS?**

The Project Scientist or Deputy Project Scientists.

1. Dr. David M. Winker, CALIPSO Principal Investigator, Tel. 757-864-6747 David.M.Winker@nasa.gov
2. Dr. Jacques Pelon, CALIPSO Co-Principal Investigator, Tel. 33-1-44-27-37-79 jacques.pelon@aero.jussieu.fr
3. Dr. M. Patrick McCormick, Co-Principal Investigator, Tel. 757-727-5108 Pat.McCormick@HamptonU.edu
4. Dr. Charles R. Trepte, Deputy Principal Investigator, Tel 757-864-5836, Charles.R.Trepte@nasa.gov

**WHO CAN HELP WITH PRESS RELEASES, INTERVIEWS, VIDEO, AND OTHER RESOURCES?**

Christopher Rink, NASA Langley Public Affairs, Tel. 757-864-6786, E-mail: c.p.rink@larc.nasa.gov; or Lynn Chandler, NASA Goddard Public Affairs, Tel. 301-286-2806, E-mail: Lynn.Chandler-1@nasa.gov

**WHO WILL MANAGE THE CALIPSO MISSION?**

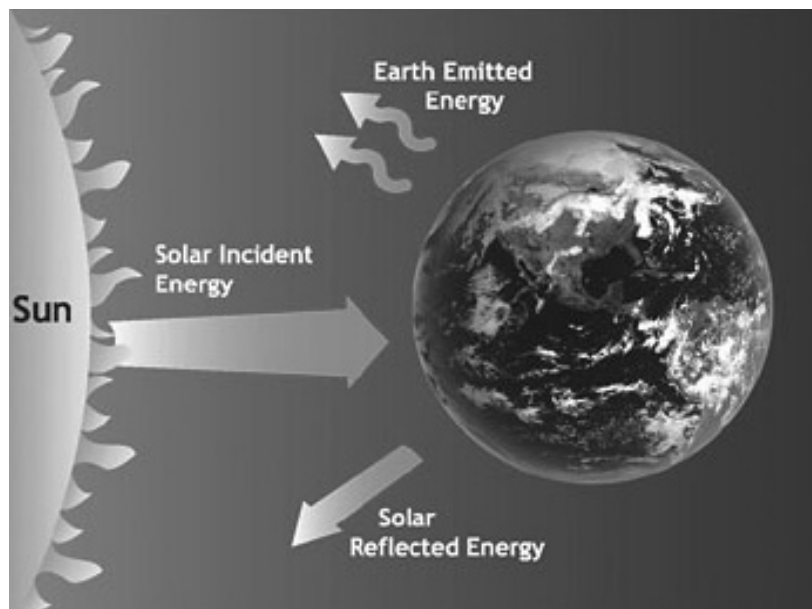
NASA’s Langley Research Center is leading the CALIPSO mission and is providing overall project management, systems engineering, payload mission operations, and validation, processing and archiving of data. NASA’s Goddard Space Flight Center is providing program management, project management support and payload and satellite systems engineering support for the CALIPSO satellite and payload. CALIPSO is being developed through collaboration among NASA and the French space agency, *Centre National d’Etudes Spatiales* (CNES); the *Institut Pierre Simon Laplace*, Hampton University; and Ball Aerospace & Technologies Corp.

**WHAT KIND OF INSTRUMENTS WILL FLY ON CALIPSO?**

CALIPSO will fly a 3-channel lidar with a suite of passive instruments in formation with Aqua to obtain coincident observations of radiative fluxes and atmospheric conditions. This combination of measurements will enable new observationally based assessments of the radiative effects of aerosol and clouds that will greatly improve our ability to predict future climate change.

**WHAT IS THE MAIN WEB SITE FOR CALIPSO?**

[www.nasa.gov/calipso](http://www.nasa.gov/calipso)



EARTH’S RADIATION BUDGET is a balance between incoming and outgoing radiation. CREDIT: NASA

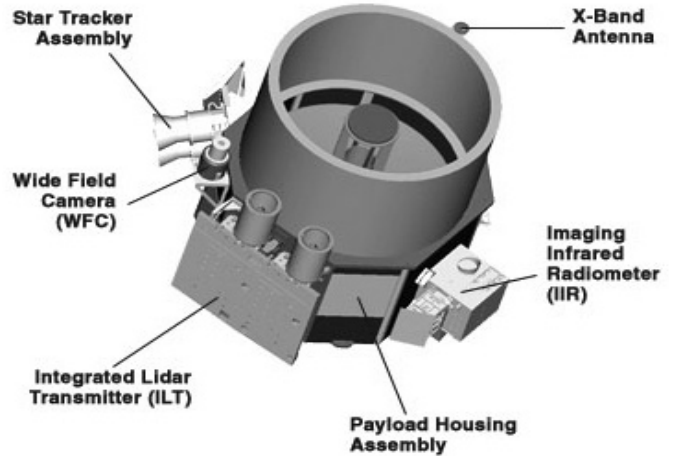
# The Three Instruments on CALIPSO

The CALIPSO spacecraft carries three co-aligned nadir-viewing instruments:

1. The Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP)
2. The Imaging Infrared Radiometer (IIR)
3. The Wide Field Camera (WFC)

These instruments are designed to operate autonomously and continuously, although the WFC acquires data only under daylight conditions. Science Data are downlinked using an X-band transmitter system which is part of the payload of instruments on CALIPSO.

Credit: Ball Aerospace & Technologies Corporation.



INSTRUMENT	DESCRIPTION	HOW IT WORKS	DETAILS
<b>Cloud – Aerosol Lidar with Orthogonal Polarization (CALIOP)</b>	A two-wavelength polarization-sensitive lidar that provides high-resolution vertical profiles of aerosols and clouds	The lidar measures the intensity of light returned by aerosols and clouds as a function of distances from the lidar. Information on size and particles is obtained from the ratio of the measurements at the two different wavelengths.	Vertical Resolution: 30 – 60 meters Footprint Diameter: 70m Footprint Spacing: 333 meters Wavelength: 532 and 1064 nm
<b>Wide Field Camera (WFC)</b>	The WFC is a modified off-the-shelf startracker camera.	The fixed, nadir-viewing imager consists of a single spectral channel covering the 620-670 nm region, selected to match a similar band of the MODIS (MODerate resolution Imaging Spectroradiometer) instrument on Aqua.	Wavelength: 645 nm Swath: 61 km Pixel resolution: 125 meter Pixels outside the central 5-km cross-track swath are averaged to 1 km resolution
<b>Imaging Infrared Radiometer (IIR)</b>	A three-channel IIR is provided by CNES. The IIR is a nadir-viewing imager.	The instrument uses a single microbolometer detector array, with a rotating filter wheel, providing measurements at three channels in the thermal infrared window region at 8.7, 10.6, and 12.0 $\mu\text{m}$ . These wavelengths were selected to optimize joint CALIOP/IIR retrievals of cirrus cloud emissivity and particle size.	Wavelengths: 8.65 $\mu\text{m}$ , 10.60 $\mu\text{m}$ , 12.00 $\mu\text{m}$ Swath: 64 km Pixel resolution: 1 km

**For more information on CALIPSO’s payload,** visit this journal article from the International Society for Optical Engineering: Winker, D. M., W. H. Hunt, and C. A. Hostetler, 2004: Status and Performance of the CALIOP Lidar, Proc. SPIE vol 5575, 8-15. Located at: [http://www-cali-pso.larc.nasa.gov/resources/pdfs/SPIE\\_5575-3.pdf](http://www-cali-pso.larc.nasa.gov/resources/pdfs/SPIE_5575-3.pdf)

**For print quality images of the CALIPSO satellite:** <http://www.ball-aerospace.com/cali-pso.html>



## "The Air We Breathe": Studying Aerosols and Thin Clouds to Improve Forecasts of Weather, Climate, and Air Quality

From hazy days, to hurricanes, to summer heat waves, we have all experienced our complex atmosphere at work. Poor air quality days, catastrophic weather events and long-term changes in climate are all matters that can affect our quality of life, our economy, and even our health. Small particles in the air, called aerosols, together with thin clouds, play a major role in regulating earth's air quality and climate. Scientists are studying both of these atmospheric constituents to answer many difficult questions about our planet and to better predict changes in our weather, climate, and air quality.

Our climate is the product of a delicate and complicated balance of energy [also called heat or radiation] — a balance between energy received from the sun and energy reflected and emitted back to space from earth. Clouds affect the radiation balance directly by reflecting sunlight into space, which prevents energy from reaching the surface, thus cooling both the ground and the atmosphere. Clouds can also absorb heat emitted by the earth, called thermal radiation. When clouds absorb this thermal radiation, less energy escapes to space and the planet warms. The degree to which the energy balance tips in one direction — either warming or cooling — is heavily dependent on the altitude, thickness, and overlapping structure of clouds.

Aerosols can also affect the radiation balance and directly impact climate. Like clouds, aerosols can reflect sunlight back to space and cool the atmosphere. The haze layer that often forms in late summer, produced from industrial pollution, is an example of an aerosol that scatters light back to space. Unlike clouds, however, aerosols can absorb sunlight and warm the atmosphere. "Black carbon," such as soot emitted by diesel engines, is a type of aerosol that can absorb significant amounts of sunlight, particularly when these layers lie over a bright surface like a low-lying cloud.

Aerosols can also change the properties of clouds and indirectly affect our climate. Cloud droplets form around aerosols such as salt from sea-spray, dust blown from the desert, or fine particles from industrial emissions. Changing the characteristics of these aerosols, such as their number and size, can change the characteristics of the cloud droplets and thus the clouds that they form. As an example, scientists have observed that clouds above exhaust plumes from ships are brighter than other clouds in the area. This change in the clouds results from smaller particles in the exhaust that cause more numerous, but smaller, cloud droplets to form. With the smaller cloud droplets, the clouds can also remain intact longer because precipitation in these clouds is slower to form. Conversely, scientists believe that under some circumstances aerosols cause clouds to dissipate faster and some aerosols even prevent clouds from forming in the first place. Unfortunately, how aerosols affect clouds remains a mystery, and we don't know exactly which of these processes is significant enough to effect our weather, climate, and air quality.

Aerosols often have some serious impacts on society — posing a threat to public health and safety. On hot, humid, stagnant summer days, the air quality over urban areas often reaches unhealthy levels and aerosols are a primary culprit. Tiny aerosol particles can work their way deep into the lungs and aggravate or cause breathing problems. The risk is particularly high for the elderly and the very young. Aerosols can also threaten the safety of aviation. They reduce visibility over heavily polluted areas, and during volcanic eruptions, planes have to reroute around the eruption to prevent particles from being taken into their jet engines.

To improve predictions of climate change, to help devise strategies for limiting pollution, and to improve forecasts of harmful air quality conditions, we need better information on aerosol sources and how aerosols enter the atmosphere and interact with circulation patterns. Obtaining better information on the height of clouds is also needed. At present, scientists have considerable difficulty predicting the effects of aerosols and clouds on our weather, climate and air quality, and inaccuracies in these parameters can lead to large errors in estimates of precipitation and the effects of aerosols and clouds on atmospheric circulation patterns and climate.

## CALIPSO Studies Aerosols and Clouds Using Innovative Observation Methods

Scientists have been observing clouds and aerosols globally from space for many years using passive imagers sensors that measure the amount of radiation reflected and emitted by the earth. These sensors observe how clouds and aerosols vary with latitude and longitude, but provide, at best, limited information on how they vary with altitude. CALIPSO combines an innovative combination of an active lidar (light detection and ranging) instrument with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols over the globe.

The CALIPSO lidar satellite provides vertical profiles of aerosols and clouds on a global scale. The lidar is an active sensing technique, where pulses of light are sent from the satellite toward the atmosphere and the amount of light that is reflected, or scattered back to the spacecraft from thin vertical segments of the atmosphere is measured. It is similar to radar in operation; however, lidar uses short pulses of laser light instead of radio waves to probe the atmosphere. The lidar data from CALIPSO allows scientists to identify the composition of clouds, to estimate the abundance and sizes of aerosols and to determine precisely the altitudes of clouds and aerosol, layers and the extent of layer overlap.

Each lidar measurement is a 100-meter wide snap-shot or profile of the atmosphere. The profiles can be streamed together to paint a picture of what a vertical slice of our atmosphere looks like. If you could envision the observations from other satellites appear like X-ray images of the human body, then lidar would provide a view like a CAT scan — an advanced 3-D imaging technique that shows the spatial relations between different objects as well as their relative depth. With an X-ray, you can see inside the human body, but you can't tell how things are layered. The CAT scan, and thus the lidar, is a breakthrough because it allows us to see the layers beneath other layers. The CAT scan sees layers of human organs and tissues, while the lidar sees layers of aerosols and clouds. Lidar measurements are also unique because the slices of the atmosphere taken from multiple orbits can be combined to create a 3-D view of aerosols and clouds over the entire globe.

Complementing CALIPSO's lidar is a sensor called the Imaging Infrared Radiometer, or IIR. The IIR is provided by the French *Centre National d'Etudes Spatiales* (CNES), one of CALIPSO's partner institutions. This instrument has a swath of 64 kilometers (about 40 miles) across the satellite ground track, and measures, at three different wavelengths, the outgoing thermal radiation emitted toward space from the atmosphere. Its design allows scientists to estimate the size of ice cloud crystals and helps to estimate the amount of heat clouds absorb and emit. The lidar measurement aids our interpretation of the IIR observations with concurrent measurements of the altitudes of these clouds.

A third instrument that CALIPSO carries is a high-resolution digital camera. This camera, called the wide-field camera, or WFC, provides a large-scale view of the atmosphere surrounding the thin column of air probed by the CALIPSO lidar, providing a context for interpreting the observations. From these images, scientists will be able to tell whether a cloud feature seen by the lidar is a small, isolated or one that is part of a larger field of clouds. Together, the innovative combination of the lidar, the IIR and the WFC will strengthen our understanding of cloud properties like never before.

CALIPSO uses an innovative method to explore our atmosphere and study aerosols and thin clouds. CALIPSO will provide us with global 3-D perspectives on earth's aerosols and clouds that will answer questions about how they form, evolve, and affect our weather, climate, and air quality. Especially exciting about CALIPSO is its ability to collect information about the vertical structure of clouds and aerosols unavailable from other Earth observing satellites. These observations, when combined with coincident data from other missions, will greatly enhance our understanding of how clouds and aerosols interact, the quantity of aerosols produced world-wide, how they are transported, and how long the aerosols remain in the atmosphere. CALIPSO measurements will ultimately contribute to improved predictions of weather, climate, and air quality.

# Who is on the CALIPSO Science Team?

**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Langley Research Center: Chris Rink, 757-864-6786

NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

**David M. Winker, Principal Investigator (PI), NASA Langley Research Center**

Leads the project from both scientific and mission perspectives and is responsible for achieving the objectives of the mission including scientific integrity; instrument design and performance; spacecraft; launch vehicle; ground system; mission planning and operations; data processing, analysis and validation; and data distribution. Also responsible for the development of the scientific aspects of CALIPSO, for assuring that the science data products are effectively utilized, for coordinating science requirements, plans, and field experiments with other national and international organizations, and for leading an international science team.

**Jacques Pelon, Co-Principal Investigator, Institut Pierre Simon Laplace**

Scientific objectives in the frame of CALIPSO and the A-train are related to aerosol radiative forcing and surface energy budget analysis. This includes aerosol direct and semi-direct forcing near source regions or after long range transport as well as indirect effect, looking to cloud life cycle modification.

**M. Patrick McCormick, Co-Principal Investigator, Hampton University**

Works with the PI on all aspects of the mission. His project team at Hampton University is responsible for CALIPSO Quid-Pro-Quo validation, outreach and Level- 2 production code development. Research objectives for CALIPSO center mainly on the effects of aerosols, cirrus clouds and polar stratospheric clouds on global climate, air quality, and polar processes. He will use data from multiple satellite platforms (such as Aura, CALIPSO, Aqua, CloudSat, GLAS, SAGE III) in these studies.

**Steven A. Ackerman, Co-Investigator, University of Wisconsin-Madison**

Focuses on the remote sensing of cirrus cloud properties. Recent research addresses combining observations from lidar, imager, and sounder instruments to retrieve cloud radiative and microphysical properties. Also develops visualization systems to view these observations and explore their relationships.

**François-Marie Bréon, Co-Investigator, Laboratoire des Sciences du Climat et de l'Environnement**

Focuses on the remote sensing of surface, cloud, and aerosol properties, as well as their interaction. Particularly interested in the synergistic use of the many sensors of the A-Train to better constrain the retrievals. The retrieved parameters are then used to evaluate global models and to understand several aspects of the human impact on climate.

**Thomas P. Charlock, Co-Investigator, NASA Langley Research Center**

Uses satellite and meteorological data to compute the surface and atmosphere radiation budget as a global record of stacked vertical profiles for both the energy from the sun and the thermal infrared emitted by the earth. Systematically compares the computations with independent ground-based and space-based measurements, putting the results online at the "CERES CAVE" URL. Diagnoses the effects of clouds, aerosols, and the surface on these energy flows.

**Robert J. Charlson, Co-Investigator, University of Washington**

Performs correlative measurements, validation and experiment design.

**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Langley Research Center: Chris Rink, 757-864-6786

NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

**Tad Anderson, Research Assistant Professor, University of Washington**

A primary thrust of the research is the development of instruments for *in-situ* measurement of climatically relevant, integral aerosol properties. For CALIPSO, focuses on methods of coupling spaceborne lidar observations to these measurements. The efforts include the invention of an instrument for the *in-situ* measurement of the lidar ratio and helping to design and coordinate a high-latitude research program focused on application of CALIPSO observations. In addition, he is currently studying the integral of the CALIPSO lidar return signal as a potential proxy for planetary albedo.

**James A. Coakley, Co-Investigator, Oregon State University**

Focuses on the effects of haze on clouds. Haze pollution increases the number of particles around which water condenses to form cloud droplets. Particulate pollution has been shown to increase the number of cloud droplets and to also increase the amount of sunlight reflected by polluted clouds. Plans to use CALIPSO observations to characterize haze particles in the vicinity of clouds and Aqua-MODIS observations to characterize the properties of clouds under various levels of haze pollution. The effects of haze on clouds and the consequent effect on the amount of sunlight reflected by clouds is among the largest sources of uncertainty in predictions of climate change caused by human activity.

**Raymond M. Hoff, Co-Investigator, University of Maryland, Baltimore County**

Research centers on the study of optical properties of aerosols and gases in the lower atmosphere using lidar as a tool. With urban and regional pollution issues as a focus, has developed ground networks of lidars to provide ground validation and context for the CALIPSO measurements as they relate to air quality. Plans to work with the flight teams from NASA Langley's HSRL group to provide validation measurements during the early mission operation with students focusing on analyzing air quality measurements from CALIPSO in coordination with other sensors such as MODIS, AIRS, and OMI.

**Chris A. Hostetler, Co-Investigator, NASA Langley Research Center**

Interested in satellite remote sensing. Focuses on lidar remote sensing of clouds and aerosols with applications in the areas of climate, atmospheric chemistry, and air quality research. Developed and deployed lidar systems from aircraft and is currently working on a combined active+passive (lidar+radiometric) aircraft-based instrument suite designed to investigate the power of combined instrument retrievals in measurements of aerosol macro- and microphysical properties.

**Michael C. Pitts, Co-Investigator, NASA Langley Research Center**

Research focuses on the role of aerosol and clouds in the earth's climate system. Serves as the Wide Field Camera (WFC) Instrument Scientist for CALIPSO and will utilize the WFC data to study cloud properties. Interested in using CALIPSO data to improve our understanding of the formation, evolution, and lifetime of polar stratospheric clouds, which play a crucial role in the annual springtime loss of ozone in the polar stratosphere.

**Yoram J. Kaufman, Co-Investigator, NASA Goddard Space Flight Center**

Working on a joint mathematical inversion of CALIPSO lidar data together with the spectral MODIS data to get the vertical profiles of aerosol. By using MODIS data in the inversion, the lidar does not have to assume backscattering ratio and derives two separate profiles: fine aerosol (smaller than 1 micron) and coarse aerosol (larger than 1 micron). Since the fine aerosol is related to pollution and smoke generated by human activity and coarse particles to dust and salt that are mainly natural, the procedure will allow observation of contribution of human produced and natural aerosol sources.

**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Langley Research Center: Chris Rink, 757-864-6786

NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

**Ali H. Omar, Co-Investigator, NASA Langley Research Center**

Research activities for CALIPSO are focused on the determination of the aerosol extinction-to-backscatter ratios for the lidar inversion algorithms. Research interests include: (1) characterization of the physical and chemical properties of aerosols using field measurements and model simulations, and (2) determination of optical properties of aerosols using remote sensing techniques with a goal of improving estimates of the optical properties of tropospheric aerosols.

**C. Martin R. Platt, Co-Investigator, Colorado State University**

Chief scientific interest is in the field of clouds and their effects on radiative flows and climate. Concentrated recently on cirrus ice clouds and mixed phase midlevel clouds. Uses lidar and radiometry, both from the ground and from satellite data. Role on the Science Team has been to develop, along with his colleagues, optimum retrieval and analysis methods to study clouds from CALIPSO data. High cirrus and midlevel clouds are usually visible in satellite data and he will use CALIPSO data to study their optical properties for a better understanding of their role in climate.

**Lamont R. Poole, Co-Investigator, NASA Langley Research Center**

Work focuses on the interpretation of remote sensing data on aerosols and clouds, and their effects on atmospheric chemical processes. Especially interested in the validation and analysis of CALIPSO polar stratospheric cloud (PSC) data and using these data to further the understanding of the formation of large solid PSC particles that play an important role in polar ozone chemistry.

**John A. Reagan, Co-Investigator, University of Arizona**

Reagan's role/research objectives for CALIPSO are development, validation and application of: on-orbit lidar calibration techniques, and lidar aerosol retrieval approaches — particularly aerosol backscatter and extinction profile retrievals and the associated aerosol extinction-to-backscatter ratio. Reagan will also use CALIPSO aerosol retrievals and associated A-Train aerosol related observations to investigate/characterize the various types of aerosols that are observed and their radiative forcing impacts.

**Ken Sassen, Co-Investigator, University of Alaska**

Research includes remote sensing with lidar and radar, atmospheric optics, and the study of cloud physics and related instrumentation.

**Graeme L. Stephens, Co-Investigator, Colorado State University**

Studies clouds and the connections to aerosols in affecting the earth's climate system. Focuses on use of A-Train data, combining lidar, radar and MODIS data to determine cloud properties and their relation to the environmental factors that control them. Stephens also serves as the PI of CloudSat.

**Didier D. Tanré, Co-Investigator, Laboratoire d'Optique Atmosphérique**

Focuses on aerosol remote sensing from satellite as well as from ground-based measurements. His research experience includes radiative transfer modeling, both theory and applications. He is the PI of the PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar) mission, which is part of the A-Train. Aerosols and clouds properties derived from PARASOL and CALIPSO will be used for estimating and modeling the direct and indirect aerosol effects.

**Charles R. Trepte, Deputy Principal Investigator, NASA Langley Research Center**

Research interests for CALIPSO are focused on obtaining a better understanding of the evolution and transport of aerosols. Combines the A-Train observations to determine aerosol and cloud properties and their relationship to the environment. Also serves as a primary contact for validation activities.

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 NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806  
 NASA Headquarters: Erica Hupp, 202-358-1237

**Bruce A. Wielicki, Co-Investigator, NASA Langley Research Center**

Research focuses on the role of clouds and radiation in climate sensitivity. Serves as the PI for the CERES radiation budget experiment on Aqua and Terra. Interested in A-train combinations of CERES, CALIPSO, and Cloudsat data in helping to understand ways to improve clouds and radiation in climate models. Clouds have remained for decades one of the most vexing problems in climate modeling.

**BACKGROUND SCIENCE: SOURCES OF AEROSOLS**

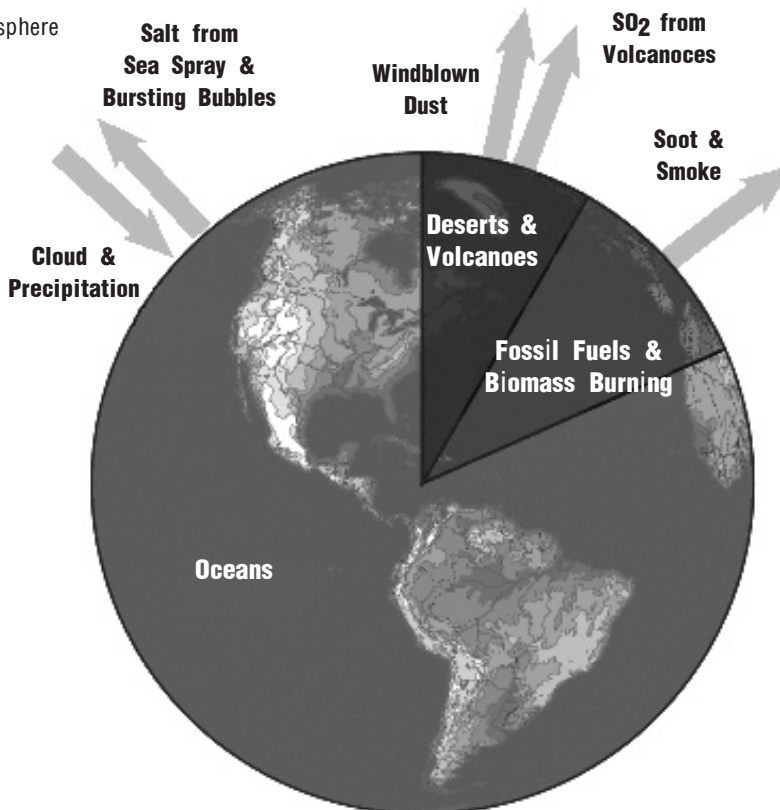
Aerosols are small particles suspended in the atmosphere. They have natural sources such as desert dust, sea salt, volcanic eruptions, and smoke from forest fires. They are also produced from the burning of coal, oil, and other fossil fuels; manufacturing chemicals; and from driving cars and trucks.

Some aerosols are emitted directly into the atmosphere while others are formed in the atmosphere.

After formation, the aerosols are mixed and transported by atmospheric motions and are primarily removed by cloud and precipitation processes.

A key piece of information that is not provided by currently operating observational satellites is the altitude of aerosol layers in the atmosphere. Aerosols confined to the lowest part of the atmosphere are likely to be removed quickly by rain. On the other hand, those that are transported to higher altitudes are much more likely to travel long distances and affect air quality in distant countries. CALIPSO will provide this vital missing piece of information.

Credit: NASA Earth Observatory



# Q&A on the CloudSat Mission

**WHAT IS CLOUDSAT'S PURPOSE AND MISSION?**

CloudSat seeks to overcome shortcomings in the treatment of cloud processes in climate and weather forecast models. The CloudSat Mission will provide the first global survey of the synoptic (large scale) and seasonal variations of cloud vertical structure and frequency of occurrence. It will provide quantitative information on cloud-layer thickness, cloud base and top altitudes, cloud optical thickness, cloud water and ice contents, and the heating of the atmosphere by clouds. These measurements are a significant advance over present observing capabilities.

**CLOUDSAT'S SCIENCE GOAL**

To improve our understanding of the indirect effect of aerosols on clouds by investigating (in cooperation with other satellites) the effect of aerosols on cloud formation and cloud processes.

**CLOUDSAT'S PRIMARY SCIENCE OBJECTIVES:**

1. Quantitatively evaluate the representation of clouds and cloud processes in global atmospheric circulation models, leading to improvements in both weather forecasting and climate prediction;
2. Quantitatively evaluate the relationship between the vertical profiles of cloud liquid water and ice content and the radiative heating by clouds.
3. Improve and validate cloud information derived from other satellite systems, especially Earth Observing Systems.

**CLOUDSAT SECONDARY SCIENCE OBJECTIVES:**

Improve our understanding of the indirect effect of aerosols on clouds by investigating (in cooperation with other satellites) the effect of aerosols on cloud formation and cloud processes.

**WHAT QUESTIONS WILL CLOUDSAT ANSWER?**

**THE FEATURE SECTION OF THE WRITERS GUIDE WILL EXPLORE THESE:**

1. Improving climate prediction accuracy
2. Improving weather forecasts

**WHAT PREVIOUS MISSION DOES CLOUDSAT CONTINUE AND IMPROVE ON?**

CloudSat is unique. All previous observations of clouds from space are limited to the information at the top of the cloud layer or limited vertical observations in broken cloud fields.

**HOW WILL ACCURACY OF CLOUDSAT DATA BE ENSURED?**

A number of specific activities are planned to characterize and ensure the quality of the CloudSat data products. Some activities are carried out prior to launch whereas other activities are conducted throughout the course of the mission. The CloudSat radar is calibrated both prior to launch and in flight via calibration associated with surface returns from the ocean. Direct measurement comparisons will be made with independently calibrated airborne radar that underfly the spaceborne radar.

**WHOM DO I CONTACT ABOUT CLOUDSAT SCIENCE QUESTIONS?**

Deborah Vane, NASA Jet Propulsion Laboratory: Deborah.G.Vane@jpl.nasa.gov Tel. 818-354-3708 OR  
Richard Austin, Colorado State University: austin@atmos.colostate.edu Tel. 970-491-8587

**WHO CAN HELP WITH PRESS RELEASES, INTERVIEWS, VIDEO, AND OTHER RESOURCES?**

Alan Buis, Media Relations, NASA Jet Propulsion Laboratory, Pasadena, Calif. Alan.d.buis@jpl.nasa.gov Tel. 818-354-0474

**WHAT ORGANIZATIONS ARE INVOLVED IN CLOUDSAT?**

The CloudSat Mission is a partnership between NASA, the Canadian Space Agency, the U.S. Air Force Space Test Program, and the U.S. Department of Energy Atmospheric Radiation Measurements Program. CloudSat is managed for NASA by the Jet Propulsion Laboratory. Science leadership and data processing are conducted at Colorado State University. The U.S. Air Force conducts satellite ground control. Ball Aerospace built and tested the spacecraft.

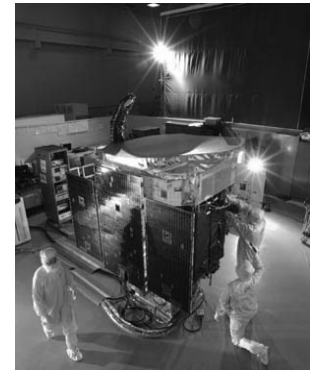
# The Instrument on CloudSat

## The CloudSat spacecraft carries one instrument: Cloud Profiling Radar (CPR)

INSTRUMENT	DESCRIPTION	HOW IT WORKS	DETAILS
The Cloud Profiling Radar (CPR)	A 94-GHz nadir-looking radar	It measures the power backscattered by clouds as a function of distance from the radar	Vertical Resolution: 500 meters; Cross-track Footprint: 1.2 km; Along-track Footprint (including orbital motion): 3.5 km

### BACKGROUND INFORMATION ON THE TECHNOLOGY BEHIND THE INSTRUMENT:

Most of the design parameters and subsystem configurations are nearly identical to those for the Airborne Cloud Radar, which has been flying on the NASA DC-8 aircraft since 1998. The design of the CPR is driven by the science objectives. The original requirements on CPR were: sensitivity defined by a minimum detectable reflectivity factor of -30 dBz (Decibels of Reflectivity), along-track sampling of 2 km, a dynamic range of 70 dB, 500 m vertical resolution and calibration accuracy of 1.5 dB. The minimum detectable reflectivity factor requirement was reduced to -26 dBz when the mission was changed to put CloudSat into a higher orbit for formation flying.



(RIGHT: Technicians inspect the CloudSat satellite after arrival at the Astrotech facility at Vandenberg AFB)

To achieve sufficient cloud detection sensitivity, a relatively low frequency (i.e. <94 GHz) radar would require an enormous antenna and high peak power. At frequencies much greater than 100 GHz, a large antenna and high peak power are also needed due to rapid signal attenuation through cloud absorption. Furthermore, technologies at such high frequencies are less well developed. The 94-GHz frequency chosen by CPR offers the best compromise, meeting performance within the spacecraft resources. In fact, most existing airborne cloud radars operate at 94 GHz. These airborne radars provide extensive heritage for CPR on instrument design and technology, data processing, and retrieval algorithms. A primary frequency allocation of 94 GHz for spaceborne cloud radar sensing has been formally approved at the 1997 World Radio Conference.

The CPR capitalizes on existing radar expertise and experience at JPL. Other radars already flown successfully or being developed by JPL include the SeaSat SAR, SIR-A, SIR-B, SIR-C, SRTM, Cassini Radar, NSCAT, QuikSCAT, and SeaWinds.

### ORBIT AND SPACECRAFT

The CloudSat mission was designed with a two-year lifetime to enable more than one seasonal cycle to be observed, although radar lifetime data indicates that the radar is expected to operate for 3 years with a 99% probability. The desired orbit is that of the Aqua satellite; which is a sun-synchronous, 705 km altitude orbit. CloudSat is designed around the Ball Aerospace RS2000 spacecraft bus that is being used for both QuikSCAT and ICESat. Communications is accomplished via an S-band transceiver using a nearly omni-directional patch antenna. The wet mass of the commercial spacecraft with the radar is 848 kg and the spacecraft subsystems and payload will require an orbital average power level of 572 W.

### LAUNCH

The launch scenario of CloudSat is for launch on a Delta 7420-10 launch vehicle co-manifested with CALIPSO via the dual payload attachment fitting (DPAF). The combined launch mass is 1295 kg with an additional 360kg of reserve.





# CloudSat: Improving Weather Forecasts

Modern technology, especially computers, weather satellites and data from coordinated meteorological observing networks, has resulted in enormous improvements in the accuracy of weather forecasting.

To make weather forecasts, meteorologists today rely largely on sophisticated computer models that make a forecast of the future state of the atmosphere by solving complex equations that describe the evolution of variables, such as temperature, wind speed, humidity and pressure. But, these computer-generated forecasts are only as accurate as the input that goes into them. The process begins by analyzing the current state of the atmosphere using observational data. The data are used to adjust a previous short range forecast to arrive at a best guess on the current, true condition of the atmosphere. This information is then fed into the computer model to make a prediction about future conditions. In general, detailed observations, with few gaps in data, make for more reliable model forecasts.

The National Weather Service and similar agencies around the world have traditionally relied on observations taken from weather stations, ships, buoys, weather balloons, and aircraft to gather a wealth of observational data to feed into their models. Satellite data are also becoming an increasingly valuable tool for weather forecasting by providing details on weather systems around the world not generally captured by more traditional atmospheric instruments.

Today's satellites not only provide detailed visual images, they also give data that allows the calculation of atmospheric temperature and moisture profiles and other environmental variables used for weather forecasting, including ozone concentration, soil moisture, sea surface temperature and winds, and precipitation estimates. This information can be used to fill in gaps between weather ground stations, especially in remote regions of the globe, where stations may be hundreds of miles apart.

What's been missing up until now is detailed information about clouds around the world. Clouds have a large influence on the climate and weather, so in order to make better forecasts, scientists need an improved picture of what clouds do, where they are, and how their structure varies.

CloudSat will provide a never-before-seen perspective on clouds. Its unique, powerful radar system is much more sensitive than weather radar and will allow scientists to "see" the water droplets and ice crystals inside the large cloud masses that make our weather.

CloudSat will also conduct the first global survey of cloud vertical structure and physical characteristics. Unlike current observations of clouds from space that are limited to the information at the top of the cloud layer, CloudSat will assess the entire vertical structure of a cloud to better understand how it forms and evolves.

Additionally, CloudSat will give information on the thickness of clouds, their altitude, and the occurrence of multiple cloud layers. All of these measurements represent a significant advance over present observing capabilities and have many applications, especially in weather forecasting.

CloudSat will also give new details to increase the accuracy of predictions of potential climate change. It will also link climate conditions to hydrological processes that affect occurrences of drought and water availability, helping to improve water resource management.

## CloudSat: Improving Climate Prediction Accuracy

Clouds exert an enormous influence on our weather and climate; they are the key element of the earth's water cycle that carries precipitation and redistributes fresh water over the planet's surface. Perhaps more importantly, clouds are the primary regulator of the earth's radiation balance.

Earth's radiation balance refers to the balance between the sunlight (also called shortwave radiation) that the land, oceans, clouds, and aerosols capture or reflect back to space and the heat released to space by the earth's surface and atmosphere (also called longwave radiation). The balance between incoming sunlight and outgoing energy determines the planet's temperature and ultimately its climate.

Clouds exert such a major influence on climate because they directly regulate the amount of the Sun's energy that reaches the earth's surface and the heat that leaves the earth's surface. Some clouds reflect sunlight to space, which has a net cooling effect on the earth's atmosphere. Other clouds absorb outgoing radiation from the earth, creating a warming effect on the climate system. In general, high, thin, ice-crystal clouds like cirrus contribute to surface heating, whereas low, thick clouds like stratocumulus tend to have a cooling effect because they block incoming sunlight.

But, which of these two opposing processes dominates? The answer is still not well known and is an important research topic for NASA. The answer depends on many factors that CloudSat will help scientists investigate, including:

- \* the height of clouds in the sky
- \* the size of the tiny particles that make up the cloud
- \* the physical structure of the cloud
- \* the amount of cloud cover present
- \* the amount of water and ice in the cloud
- \* the extent to which clouds at different altitudes overlap each other

These factors all affect how heat is distributed in the atmosphere and at the earth's surface, influencing the circulations of the atmosphere and oceans that largely regulate our climate. While scientists currently have excellent information from existing satellite measurements about how radiation is distributed at the top of the atmosphere, they lack good sources of information on the processes at work on the inside of clouds and how energy is actually distributed within the atmosphere.

This lack of understanding of cloud processes is widely believed to be the major obstacle that prevents credible prediction of climate change. Even small changes in the amount of global cloud cover can cause a significant change in earth's radiation balance. Because of this sensitivity, many scientists believe that the biggest unknown in climate change prediction is the response of clouds to increased heating caused by greenhouse gases like carbon dioxide. CloudSat is an exciting and timely opportunity to increase our understanding of this important issue.

CloudSat's powerful radar will "see" into clouds allowing scientists to study their interior with a level of detail greater than ever before and provide never-before-seen global vertical cross sections showing how clouds form, evolve, and affect weather and climate. CloudSat will also give global measurements of cloud thickness, height, and water and ice content, and will retrieve a wide range of precipitation data, essential in understanding cloud development. All of this new information provided courtesy of CloudSat will ultimately be incorporated into computer simulations used to predict climate change and should improve our understanding of the role clouds play in regulating climate.

# Who is on the CloudSat Science Team?

**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Jet Propulsion Laboratory: Alan Buis, 818-354-0474

NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

The CloudSat Science Team is an international science team, with membership from the United States, Canada, United Kingdom, France, Germany, Japan, and the Netherlands.

**Graeme L. Stephens, Principal Investigator, Colorado State University**

Graeme Stephens studies clouds and the connections to aerosol in affecting the Earth’s climate system. He focuses on use of A-Train data, combining lidar, radar and MODIS data to determine cloud properties and their relation to the environmental factors that control them. Graeme Stephens also serves as the PI of CloudSat.

**Tom Ackerman, University of Washington**

Focuses on the role of radiative transfer (RT) in climate problems, in particular the interaction of RT with clouds and aerosols. Current research involves the use of ground-based instrumentation such as millimeter radar and lidar to determine cloud properties remotely, linking such properties to changes in the surface radiation budget and representing these linkages in climate studies.

**Howard Barker, Meteorological Service of Canada**

Studies RT for realistic cloudy atmospheres and the representation of clouds and radiative transfer in large-scale atmospheric models.

**Jean-Pierre Blanchet, University of Quebec**

Research activities have centered on the study of Arctic aerosols and climate issues and developing radiation and cloud parameterizations in the Canadian General Circulation Model (GCM) and Northern Aerosol Regional Climate Model.

**Dave Donovan, KNMI, Netherlands**

Conducts experimental studies examining the radiative effects of tropospheric clouds and aerosols and is interested in developing new remote sensing systems and techniques to conduct cloud micro-and-macrophysical property studies.

**Frank Evans, University of Colorado**

Research is centered on remote sensing and RT within clouds, with special interest in the effects of cloud inhomogeneities on RT and developing techniques for remote sensing of cirrus clouds using passive submillimeter-wave radiometers.

**Jurgen Fischer, Free University of Berlin**

Major interests include RT modeling and remote sensing of atmospheric and oceanic properties.

**David Hudak, Meteorological Service of Canada**

Expertise is in the use of radar in weather forecasting, weather modification and climate applications.

**Anthony Illingworth, University of Reading, United Kingdom**

Research focuses on the measurement of clouds and aerosol properties using radar and lidar.

**Hiroshi Kumagai, Communications Research Laboratory, Japan**

Studies applications involving microwave remote sensing of precipitation and the atmosphere.



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**Fuk Li, Jet Propulsion Laboratory**  
 Expertise in radar remote sensing.

**Zhanqing Li, University of Wyoming**  
 Research activities include the remote sensing of radiative and terrestrial environments, development of inversion algorithms, the interaction between clouds and aerosols, and the radiation budget of earth's climate.

**Gerald Mace, University of Utah**  
 Researches issues important to representing clouds in climate models, including the maintenance of cloud fields by the large-scale circulation, the development and verification of data analysis techniques applied to wind profiler, radiosonde, and surface-based and satellite-observed data.

**Sergey Matrosov, NOAA-ETL**  
 Research activities focus on developing remote sensing techniques for retrieving cloud properties from combined passive and active measurements, including the application of polarimetric cloud and precipitation radars in determining characteristics of atmospheric hydrometeors.

**Teruyuki Nakajima, University of Tokyo, Japan**  
 Research interests surround processes in the Earth's atmosphere system, which are important for evaluating the climate impacts of external forcing such as the effects of human-produced aerosols and greenhouse gases.

**Steven Platnick, NASA Goddard Space Flight Center**  
 Research focuses on the remote sensing of cloud optical and microphysical properties from MODIS, and the relationship between passive cloud retrievals and those derived from active radar on CloudSat. Platnick also serves as Deputy Project Scientist of Aqua.

**Markus Quante, GKSS, Germany**  
 Research activities in the role of clouds in the climate system and the role of clouds in the transport and modification of atmospheric constituents. He operates a ground-based cloud radar to assess cloud layer properties. The main expertise is in the field of cloud dynamics.

**David Randall, Colorado State University**  
 Focuses on numerical simulation of cloud processes in the global circulation of the atmosphere. Research includes embedding high-resolution cloud-resolving models inside coarser-resolution global models. Model results are compared with observations, including satellite data.

**Bill Rossow, NASA-Goddard Institute for Space Studies**  
 Research interests are cloud physics, atmospheric RT, atmospheric dynamics, and satellite remote sensing of earth's climate.

**Ken Sassen, University of Alaska**  
 Research includes remote sensing with lidar and radar, atmospheric optics, and the study of cloud physics and related instrumentation.

**Steve Sekelsky, University of Massachusetts**  
 Research focuses on development of airborne and ground-based radar systems. Research interests include atmospheric remote sensing, digital signal processing, embedded computing, and wireless networking.

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**Jim Spinhirne, NASA – Goddard Space Flight Center**

Specializes in atmospheric remote sensing, instrument development, and atmospheric radiation.

**Ron Stewart, McGill University, Canada**

Research activities are mainly focused on understanding water cycle issues, regional climate, the structure of frontal systems, and the role of these cloud systems on climate.

**Jacques Testud, Centre d’Etude des Environnements Terrestre et Planétaires (CETP), FRANCE**

Conducts extensive research in the retrieval algorithms of combined cloud radar/lidar data.

**Alexander Trishchenko, Canada Centre for Remote Sensing (CCRS)**

Researches remote sensing of earth’s radiation budget, cloud and aerosol radiative effects, and surface albedo.

**Deborah Vane, NASA Jet Propulsion Laboratory**

Current role is Deputy PI for the CloudSat Mission. She is the JPL resident representative of the Principal Investigator. Develops science requirements for the mission and participates as a member of the Project Management Team and the Science Team. Manages contracts with the Co-Investigators. Plans the execution of the science program and validation activities within the resources of the Project. Participates in the Education and Public Outreach activities.

**Tom Vonder Haar, Colorado State University**

Expert in satellite meteorology.

**Steve Walter, Surveillance and Remote Sensing**

Develops passive microwave and millimeter-wave instrumentation for atmospheric remote sensing.

**Bruce Wielicki, NASA Langley Research Center**

Researches the role of clouds and radiation in climate sensitivity and is the Principal Investigator of the CERES radiation budget experiment on Aqua and Terra. Interested in A-train combinations of CERES, CALIPSO, and Cloudsat data in helping understand ways to improve clouds and radiation in climate models, a major obstacle in climate modeling.

**Dave Winker, NASA Langley Research Center**

Principal Investigator for the CALIPSO mission. Research involves clouds and aerosols.

# CloudSat: Cloud Glossary

Source: Colorado State University

[http://cloudsat.atmos.colostate.edu/outreach/pbl-s\\_clouds.php](http://cloudsat.atmos.colostate.edu/outreach/pbl-s_clouds.php)

**AEROSOLS** can be natural like sea salt or dust, or man-made like smoke or soot. Although aerosols that act as cloud condensation nuclei are abundant, ice nuclei are much rarer.

**ALTOSTRATUS** is lower and thicker than cirrostratus clouds and follow cirrostratus in an overrunning situation.

**ALTOCUMULUS** is either a stable cloud like stratocumulus, or an unstable cumulus cloud with a high base (above 2,000 meters or 6561 feet).

**ALTUS** is the root word found in middle-level clouds.

**CIRRUS** is the wispy tail-type cloud usually associated with pleasant weather. Condensation trails (contrails) are a type of cirrus caused by aircraft. All high clouds contain the word cirrus.

**CIRROCUMULUS** is a cumulus type cloud based high in the atmosphere. They indicate great instability at that level.

**CIRROSTRATUS** is a thin sheet-like cloud of ice crystals; usually the first clouds to precede a warm front in an overrunning situation and are indicative of eventual rain or snow.

**CLOUDS** are made up of billions and billions of tiny liquid water droplets and/or ice crystals suspended in the air.

**CLOUD CLASSIFICATIONS** Clouds are divided into four major groups and ten major types. The names of clouds are usually some combination of the following words: cirrus (wispy); cumulus (heap); altus (middle); stratus (layer); nimbus (rain). The four cloud groups include low, middle, and high clouds (depending on the height of their bases), and clouds that develop vertically.

**CLOUD CONDENSATION NUCLEI** is a particle such as dust, or a grain of sand, that ice or water form around.

**CLOUD FORMATION** For clouds to form, moisture is needed in the form of water vapor; also needed are very small particles for the water vapor to condense around. When water vapor condenses on the particles in its liquid phase, these tiny solid or liquid particles are called cloud condensation nuclei (CCN). The particles are called ice nuclei if water vapor directly sublimates onto them in the form of ice. This usually happens when the temperature is well below zero degrees Celsius (32 degrees Fahrenheit). Both the condensation and ice nuclei consist of small particles called aerosols. A typical size for an aerosol particle is on the order of 1/1,000,000th of a centimeter in diameter. Clouds form when the temperature and dew point are equal, and then either cooling occurs or moisture is added. (The dew point is a measure of how much moisture is in the air).

**CONVECTIVE LIFTING** This occurs when warm air near the ground rises. (When air tends to rise on its own, the atmosphere is unstable.) As it rises, it cools until saturation and then condensation takes place. Clouds that form in this manner are cumulus-type clouds, sometimes called clouds of vertical extent. They include the fair weather cumulus, as well as the thundercloud known as cumulonimbus.

**CUMULUS** or heap clouds. They are flat-based with a dome created by ordinary convection. The base forms at the condensation level of the rising warm current.

**LOW-LEVEL CONVERGENCE** When air is forced together at earth's surface, it can only go up. Clouds that form can be of different types as with orographic lift. Like orographic clouds, the types of clouds that form depend on the stability of the atmosphere.

**NIMBOSTRATUS** although based low, can extend to great heights. It follows altostratus in an overrunning situation and usually produces rain or snow.

**OROGRAPHIC LIFTING** When air is pushed up a mountainside or any rise in terrain, it also cools. If sufficient cooling occurs, clouds will form. These clouds can be of the cumulus type, if the air is unstable or of the stratiform type if the air is stable. Stratiform clouds include cirrostratus (high), altostratus (middle), and stratus (low). They form by spreading out in the horizontal and do not exhibit vertical development like cumuloform clouds.

**OVERRUNNING** Sometimes a dome of cold air exists near earth's surface. Because this air is so dense, any warm air trying to replace it is forced over the top, a process called overrunning.

**STRATOCUMULUS** also forms beneath rain clouds as rain evaporates.

**STRATUS** is a low cloud very similar to fog. When stratus rises during the day, it transforms into stratocumulus. Low clouds contain the word stratus.

# Q&A on the GRACE Mission

**WHAT DOES GRACE STAND FOR?**

The Gravity Recovery And Climate Experiment

**WHAT IS GRACE'S PURPOSE AND MISSION?**

The primary goal of the GRACE mission is to obtain accurate, global, and high-resolution determination of both the mean and the time-variable components of the earth's gravity field. The high-resolution mean gravity field enables scientists to use TOPEX-Poseidon altimetry data to measure ocean surface currents and heat transport within the oceans with unprecedented accuracy. The time-variable components of the gravity signals sensed by GRACE are due to mass exchange, mostly of water, within and between the earth's atmosphere, oceans and land areas. The gravity variations that GRACE studies are due to effects that include: changes due to deep currents in the ocean; runoff and ground water storage on land masses; and exchanges between ice sheets or glaciers and the oceans, and variations of mass within the solid earth. A secondary goal of the mission is to provide measurements of the temperature and water vapor in the earth's atmosphere.

**WHAT QUESTIONS WILL GRACE ANSWER?**

1. In combination with Topex-Poseidon and Jason altimeter measurements, the highly accurate GRACE mean gravity field has allowed the most accurate independent determinations of currents associated with general ocean circulation.
2. GRACE and satellite radar altimeter measurements of oceans and ICESat measurements over the ice contribute to an understanding of the global sea level rise, i.e., what part of the rise is due to polar ice melt and what part is due to a warming of the ocean water. These are important factors in understanding the consequences of global warming. Actually, GRACE will sense all water run off and separate global warming from global runoff.
3. GRACE has provided the first global measurements of changes in the deep ocean currents.
4. In the area of hydrology, GRACE measurements of the seasonal water variations provide the capability for improving predictions through calibrated land-surface model inputs to weather models. In the basic equation;  $Evapotranspiration = Precipitation - Runoff - Change\ in\ Stored\ Surface\ Water$ , Precipitation and Runoff are measured, and the seasonal gravity measurements by GRACE provides the change in stored water to allow determination of Evapotranspiration.
5. GRACE time-varying gravity signals measure seasonal variations in underground aquifers.

**THE FEATURE SECTION OF THE WRITERS GUIDE WILL EXPLORE:**

1. Tracking water movement on and beneath earth's surface
2. Tracking changes in ice sheets and global sea level
3. Tracking ocean currents both near the surface and far beneath the waves
4. Tracking changes in solid earth
5. Measuring parameters of the atmosphere using GPS Occultations

**WHAT PREVIOUS MISSION DOES GRACE CONTINUE AND IMPROVE UPON?**

GRACE is the first mission devoted to measuring the earth's gravity field with a spatial and temporal resolution that contributes to climate research. GRACE will expand and continue the gravity measurements initiated by the Lageos, Starlette, GFZ-1, and CHAMP satellites, but these satellites measure only the very long wavelength components of the gravity field.

**WHAT MAKES GRACE DIFFERENT FROM PREVIOUS MISSIONS?**

The high measurement accuracy and the high spatial resolution of the mean earth Gravity field: and for the first time, GRACE will provide accurate maps of the month-to-month variation in the global gravity field.

**HOW WILL ACCURACY OF GRACE DATA BE ENSURED?**

The individual inter-satellite measurements are evaluated through ground assessment. The overall gravity products are evaluated through calibration campaigns and through assessment of the overall science products derived from the application of the GRACE measurements.

**WHAT IS THE MAIN WEB SITE FOR GRACE?**

<http://www.csr.utexas.edu/grace>

**WHERE CAN I FIND THE GRACE MISSION PRESS KIT?**

[http://www.jpl.nasa.gov/news/press\\_kits/gracelaunch.pdf](http://www.jpl.nasa.gov/news/press_kits/gracelaunch.pdf)

**WHOM DO I CONTACT ABOUT GRACE SCIENCE QUESTIONS?**

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**WHAT PUBLICATIONS ARE AVAILABLE ON GRACE?**

1. GRACE Brochure — NP-2002-2-427-GSFC — Provides a thorough overview of the GRACE mission and the science areas it will study.
2. Lithograph: “*Studying Earth’s Gravity Field from Space*”— LG-2001-12-038-GSFC REV —Shows image of earth’s gravity anomalies (departures from average gravity values) and briefly describes the GRACE mission, including planned applications for the data.
3. ASA Facts: “*Studying Earth’s Gravity Field from Space: The Gravity Recovery and Climate Experiment*”— FS-2002-1-029-GSFC— Gives a general introduction to the subject of gravity studies, then proceeds to more detailed information on the GRACE mission, including details how GRACE works, key components of the spacecraft, and information on the management of the GRACE mission.
4. *GRACE Interactive* CD-ROM— NP-2002-2-432-GSFC —Provides a comprehensive overview of the mission; includes numerous video and animation loops.

**WHERE CAN I GET PDFS OF THE PRINT PUBLICATIONS?**

[http://eospsso.gsfc.nasa.gov/eos\\_homepage/for\\_educators/educational\\_publications.php](http://eospsso.gsfc.nasa.gov/eos_homepage/for_educators/educational_publications.php)

**HOW DO I ORDER THESE PUBLICATIONS?**

Contact the EOS Project Science Office, Code 610, NASA/Goddard Space Flight Center, Greenbelt, Md. 20771, Tel. 301-867-2037

**WHAT ARE SOME WEB SITES ADDRESSING GRACE SCIENCE QUESTIONS?**

- 1) *Weighing Earth’s Water from Space* — <http://earthobservatory.nasa.gov/Study/WeighingWater>
- 2) *Reference Article: The Gravity Recovery and Climate Experiment* — [http://earthobservatory.nasa.gov/Library/GRACE\\_Revised](http://earthobservatory.nasa.gov/Library/GRACE_Revised)

**WHO ARE THE PARTNERS ON THE GRACE MISSION?**

NASA, The University of Texas Center for Space Research (UTCSR), German Deutsches Zentrum für Luft und Raumfahrt (DLR), and GeoForschungsZentrum (GFZ), Potsdam, Germany.

**WHEN DID GRACE LAUNCH?**

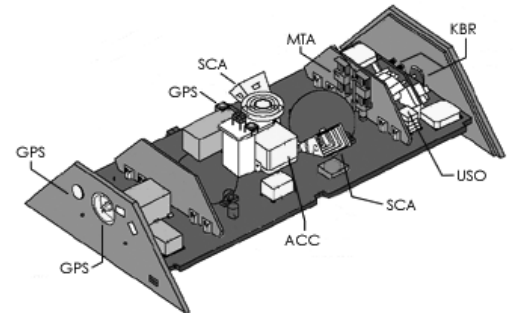
NASA and the German Center for Air and Space Flight successfully launched the Gravity Recovery and Climate Experiment, or “GRACE” mission into Earth orbit at 1:21:27 a.m. Pacific time March 17, 2002 from Russia’s Plesetsk Cosmodrome.





# The GRACE Instrument

Unlike most missions the twin GRACE satellites are not platforms for independent remote-sensing instruments. Instead, the satellites themselves act in unison as the primary science instrument. Spatial and temporal variations in the earth's gravity field, due to inhomogeneities in the mass distribution, cause changes in the distance between the satellites. Changes in distance between the satellites are measured in order to determine the earth's gravitational field. The satellites are spaced about 220 kilometers (137 miles) apart- approximately the distance between Los Angeles and San Diego.



In addition to the satellites themselves, there are four primary components to the GRACE measurement system. These are the High Accuracy Intersatellite Ranging System (HAIRS), the Superstar accelerometer, the Star tracker (SCA) and the GPS tracking system.

At the heart of the HAIRS, there is a dual frequency K- Ka-band ranging link (KBR) which measures changes in the range between the ends of twin GRACE spacecraft with an accuracy approaching 1  $\mu\text{m}$ . Anything beyond the effects of the gravity that causes the center of mass of either satellite to change, or to mimic such a change is a source of error in the measurement.

Accelerometers (ACC) on each satellite measure the effects of atmospheric drag, solar radiation pressure, attitude control thruster forces, etc. to better than one ten-billionth of the acceleration of gravity. The measured accelerations are used to correct KBR measurements for these effects, which are not caused by gravity.

The instrument processor unit (IPU) digitizes and determines metric observables from three GPS antennas and the K-band ranging assembly (KBR) system, as well as determining the satellite attitude from star camera (SCA) images. From GPS alone, the IPU's acquire the data that allows time synchronization of the two independent telemetry streams for the GRACE twins to better than 150 pico-sec and determination of their position in space to better than 2 cm.

The star camera assemblies (SCA's) are used for attitude control and provide the data to allow accelerometer measurements to be transformed into an inertial frame of reference.

Because in the GRACE mission the satellites themselves act as the "proof masses" by which the gravitational field is sensed, the satellites are carefully designed for mass balance, mass stability, dimensional stability, and aerodynamic configuration. The body-fixed solar panels are rigid and insulated on the back side. The design prevents thermal warping of the solar panels and isolates the internal structure from the varying heat input from the sun. With the exception of the small solenoid thruster valves, there are no moving parts on the satellite in the science mode.

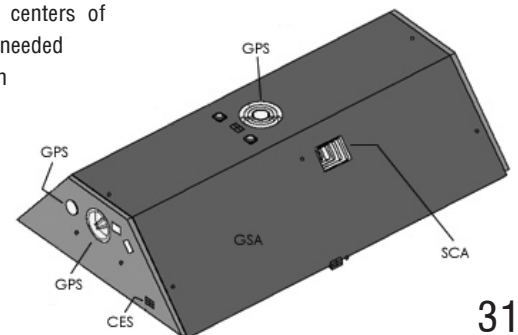
To minimize aerodynamic forces the GRACE satellites have a high mass and low frontal area. To minimize aerodynamic torques, they are shaped to keep the total aerodynamic force acting as close as possible through the center of mass of the satellite.

Changes in the temperature of the electronics and the structure can mimic gravity signals. Structure and instrumentation temperatures are controlled at 72 points in each satellite. Critical structural elements are fabricated using materials with a low coefficient of thermal expansion.

Attitude variations can create signals that mimic non-gravitational force in both the ACC and KBR data.

This effect in the ACC data is minimized by accurately co-locating the ACCs and satellite centers of mass. An on-orbit calibration maneuver is performed periodically to measure and define needed adjustment of each satellite's centers of mass. Center-of-mass trim assemblies (MTAs) on each satellite are then adjusted. The MTA system is composed of six motor-driven masses on each satellite.

The attitude error effect in the KBR data is minimized by calibrating the alignment of the K-band boresight with the star cameras using an on-orbit maneuver. Each satellite attitude is then biased to minimize the residual errors.



Researchers worldwide will use information obtained from the Gravity Recovery and Climate Experiment (GRACE) to assist in the study of a variety of scientific problems that link directly to important societal issues. This section highlights some of those applications.

GRACE FEATURES: 1

## Tracking Water Movement on and Beneath Earth's Surface

Our home planet is a world of water. So much water is present on earth's surface that it appears blue when viewed from outer space. Water is everywhere on earth over, under, and above earth's surface in solid, liquid, and gaseous form. The earth's water is in continual motion — moving from one area to another. As the water moves, the mass associated with the water is redistributed. This movement is one of the primary causes of gravity field variations. The twin GRACE satellites have been measuring the resulting month-to-month changes in the earth's gravity field since April 2002.

The measurement of gravity that GRACE obtains is a powerful new tool for hydrologists to study water movement. GRACE data are being combined with data from other NASA satellites, aircraft, and ground-based measurements to study the movement of liquid water over our home planet at a level of detail never before possible.

Scientists today use numerical models to help them mimic, and thus understand, how nature works. The models can simulate water exchange between the ocean and land surfaces including such processes as rainfall, deep soil moisture, and runoff at both the continental and regional scale of only a few hundred kilometers. But to remain realistic, these models need real data. The information from GRACE allows for much more detailed verification of the output from these models. This verification, in turn, allows improvements to these models, which then result in increasingly realistic portrayals of water movement, making the simulations more useful for predicting future conditions. These improvements will allow for increasingly accurate and longer-range forecasts of changes in water storage, giving water resource planners access to more dependable information and allow for better regulation of water resources to meet the needs of society including irrigation for agriculture, municipal supplies, and industry. Better monitoring of water storage on a global scale should also help scientists improve our ability to predict, plan for, and respond to extreme events, such as floods and drought.

## Tracking Changes in Ice Sheets and Global Sea Level

The question of whether polar ice sheet volume is shrinking or growing is important for climate change studies. If polar ice sheet volume is shrinking, then where does the water end up — in the oceans, or on land in surface and ground water? Scientists are using monthly earth gravity data from GRACE to study how the mass of ice sheets is changing and how the mass of water in the oceans is changing. When GRACE data are combined with height variations measured by ground-based, aircraft, and satellite instruments, like the Geoscience Laser Altimeter System (GLAS) on NASA's Ice, Clouds, and Land Elevation Satellite (ICESat), computations of ice sheet mass balance become more accurate. Scientists are also combining the GRACE gravity field measurements with ocean surface elevation measurements (such as from radar altimeters on the U.S./French Topography Experiment for Ocean Circulation (TOPEX)/Poseidon and Jason satellites). The GRACE data make it possible to separate changes in sea level due to thermal expansion from those caused by the redistribution of water, whether the water was 'piled up' by the wind, or brought from the land to the oceans. Thermal expansion is caused by a change in the heat content of a column of ocean water, helping scientists measure changes in the rate at which heat is transported in the oceans.

Scientists are using monthly earth gravity fields from GRACE to correct estimates of the melting of polar ice and the rise of sea level for a phenomenon known as *post glacial rebound (PGR)*. PGR refers to the slow rebounding of earth's crust that is still occurring since the weight of the ice from the last Ice Age is no longer present. The rebounding of the crust at the coastline can affect tide-gage

GRACE FEATURES: 2

measurements of relative sea level in a manner that could be mistakenly linked to sea-level rise. Estimates of the mass of water in the polar ice that rely on measurement of ice volume are similarly vulnerable to errors in knowledge of ice density and where the ice-to-rock-surface interface is located. The mass distribution data from GRACE is helping scientists understand what affects the global and regional sea level change. For example, how much of the overall observed change in sea level is actually caused by thermal expansion of the oceans and how much is due to ice melt resulting from global warming.

GRACE FEATURES: 3

## Tracking Ocean Currents Both Near the Surface and Far Beneath the Waves

On a calm day the ocean surface looks level to us, but not to the GRACE satellites. Even if there were no other forces acting on it, the ocean surface would still have hills and valleys 100 meters (328 feet) high and 50 to thousands of kilometers across that are created by variations in the density and proximity of the solid earth beneath the oceans. Scientists call this *static topography* because it exists in the absence of any forces other than gravity. By measuring the variations in the earth's gravity everywhere at a spatial scale of 200 km (124 miles), GRACE data has been used to create the world's most accurate maps of the ocean's static topography.

But of course, there are strong forces acting on earth's oceans. The oceans are swept by winds, heated by the sun, cooled by the atmosphere, and influenced by the rotation of earth. These forces give rise to gigantic circulating currents and gyres. These motions also influence the shape of the ocean surface creating a certain *dynamic topography* that combines with static topography. Although the dynamic topography only causes small variations to the overall topography of the ocean — about 1% of the total shape is from dynamic topography — scientists are very interested in studying such changes since they contain important information about the speed and direction of ocean currents.

Historically, it has been difficult to study dynamic topography from space, but GRACE and other NASA satellites are providing more clues than ever. To measure dynamic topography scientists require two pieces of information: sea-surface height measurements, converted into a mean ocean surface and a model for earth's *geoid*. A geoid is a map of the static topography of the ocean. Since the impact of dynamic topography on the shape of the ocean surface is quite small compared to the impact of the static gravity field, the map of static topography must be extremely precise and of high resolution. GRACE data have provided the map of static ocean topography that has been desired by oceanographers for over two decades. Satellite altimeter measurements from TOPEX/Poseidon and Jason have provided the required level of accuracy for sea surface height measurements since 1992. Now, with GRACE data at their disposal, scientists can finally use all of the accumulated sea-surface height data from the last 12 years to better understand the ocean currents and the role ocean they play in regulating earth's climate.

Ninety-seven percent of the earth's water is in the oceans. The water in the oceans itself is in constant motion. Surface currents transport water and heat energy around the major ocean basins. Heat energy from the sun is absorbed by the oceans in the equatorial regions and lost to the atmosphere as it is transported toward the poles. As the water enters the polar regions it cools and sinks, feeding deep ocean currents that act as massive "conveyor belts" in a continual process of redistribution of heat over the surface of earth.

So, currents play a pivotal role in regulating earth's climate. Consequently, scientists want to study ocean currents in detail. Any changes in these "conveyor belts" could significantly change climate. Scientists are particularly interested in using GRACE to learn more about deep ocean currents. Until now, deep ocean currents have remained shrouded in mystery because they have been very difficult to measure. However, the deep ocean currents give rise to gradients in ocean bottom pressure. Bottom pressure is directly related to the total mass of water and air above the region in the ocean affected

by the deep ocean currents. The GRACE twins are measuring changes in this total mass above the ocean bottom. This ability gives GRACE the distinction of being the first satellite that can see ‘through’ the full ocean depth to the seafloor, allowing scientists to track deep ocean currents from space and conduct detailed studies of their impact on global climate.

Earth’s oceans essentially serve as huge heat reservoirs, and GRACE, by helping us see the strong surface currents and the weak bottom currents as well as the amount of heat stored in a column of ocean water, has the potential to improve early predictions of broad climate patterns.

## Tracking Changes in Solid Earth

Scientists are also using GRACE data to help them better understand the structure of the solid earth. More precise measurements of earth’s long-term average gravity field, such as those provided by GRACE, allow scientists to study the dynamics of the inner structure of the earth like never before. Scientists still disagree over the exact characteristics of the continental lithosphere, for example. There are a number of competing theories. Data from GRACE may help scientists resolve these questions. As it does for most of its applications, GRACE observes the solid earth indirectly, by measuring either density changes from one location to a neighboring location, or by measuring changes in time in the total mass at a single location, since those changes in mass or density change the gravitational attraction. One especially intriguing example is that by better estimating the rate of postglacial rebound, one can estimate the viscosity of the earth’s mantle. The mantle is the layer of the earth between the crust and the core.

More than a century of ground-based gravity measurements collected across the globe have been available to scientists studying the earth. These measurements of widely differing vintage and accuracy will now be given a new lease on life with new gravity models derived from GRACE. In some areas, ground-based measurements contain vastly more detailed information on the fine structure of the Earth than do the GRACE models. However, they also suffer from large errors on the broader spatial scales due to the age of the data, differing sophistication of measurement campaigns, and from limited regional coverage. Accurate new models of the gravity field from GRACE help knit these data together into a unified picture, thus making historical data valuable for understanding regional variations within the earth.

## Measuring Parameters of the Atmosphere Using GPS Occultations

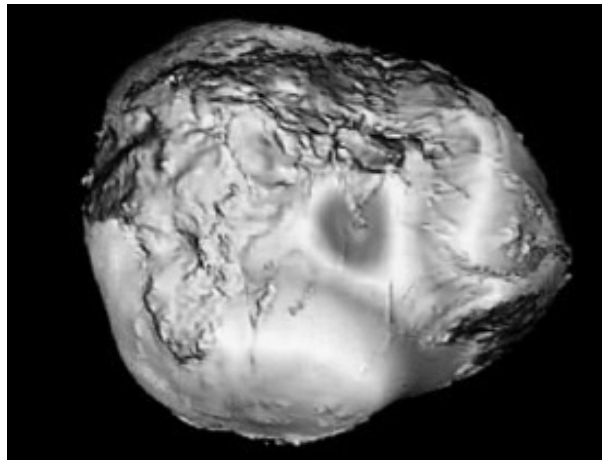
While measuring earth’s gravity is the primary objective for the GRACE mission, a secondary objective is to provide data to improve knowledge of the distribution of pressure, temperature, and moisture in earth’s atmosphere.

Astronomers have used a technique known as *occultation* to help them study the properties of planetary atmospheres. Occultation involves using the passage of stars behind moons and planets. The first experiment using a radio-signal occultation involved the atmosphere of the planet Mars. Launched in 1964, the Mariner-4 spacecraft projected a radio signal through the thin Martian atmosphere. As the line of sight for the spacecraft descended into the Martian atmosphere from top to bottom, the path of the radio frequency signal was bent more and more until finally the signal was blocked by the surface (also called the *limb*) of Mars. The bending of the signal had the effect of increasing the length of the signal path and therefore increased the time it took for the signal to travel from the Mariner-4 spacecraft to earth. Scientists back on earth used the information they received to work backwards and construct a model of the Martian atmosphere.

A satellite orbiting the earth that is equipped with a precision Global Positioning System (GPS) receiver is capable of making occultation measurements of the earth's atmosphere similar to those made by Mariner-4 on the Martian atmosphere. A GPS-equipped satellite can track the NavStar GPS satellites as they set on the limb of the earth. This was first demonstrated in 1996 by an NSF-sponsored mission called GPS-MET. This demonstration was followed by inclusion of NASA-provided GPS receivers on two more mission - Challenging Minisatellite Payload (CHAMP), which is sponsored by the DLR, and Satellite de Aplicaciones Cientificas (SAC)-C, which is sponsored by CONAE. GPS receivers on each of these satellites have been obtaining over 200 atmospheric occultation measurements per day since they were launched.

In 2006, GRACE will join these missions in routinely using GPS satellites to make near-vertical top-to-bottom soundings of the earth's atmosphere. Each GRACE satellite is equipped with a GPS receiver that is capable of making occultation measurements and tests of the capability have been successful. In the future, a mission led by UCAR, called COSMIC, will launch a small constellation of satellites each equipped with GPS receivers with occultation capability.

The data from all of these satellites equipped to track NavStar GPS occultations will be supplied to global weather services such as the National Weather Service and the European Centre for Medium-range Weather Forecasting (ECMWF) for use in their weather forecasting models. Assimilation of GPS occultation data, along with other data, will improve the accuracy of the temperature, pressure, and wind fields that are produced by the weather services. This in turn, will improve knowledge of the distribution of mass in the atmosphere and enable more accurate monthly maps of the earth's gravity field to be produced from GRACE data.



LEFT: A LUMPY EARTH: Due to an uneven distribution of mass inside the Earth, the Earth's gravity field is not uniform — that is, it has “lumps.” By far the largest is a flattening at the poles, called the earth's oblateness, but in this model we've greatly exaggerated the scale so that many smaller features can be seen. The GRACE Mission will map out the precise location and size of these lumps, enabling greater understanding of the structure of the earth. Additionally, GRACE will monitor the mass and location of water as it moves around on the surface of the earth, cycling between the land, oceans, and polar ice caps.  
Credit: NASA

# Who is on the GRACE Science Team?

**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Jet Propulsion Laboratory: Alan Buis, 818-354-0474

Texas Space Grant Consortium: Margaret Baguio, 512-471-6922

NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806

NASA Headquarters: Erica Hupp, 202-358-1237

The GRACE Science Team consists of a large number of scientists around the world due to GRACE's international nature. Below we provide a representative subset of NASA funded investigators. Additional information is available from the GRACE Project.

**Byron Tapley, Principal Investigator, University of Texas at Austin, Center for Space Research**

All aspects of GRACE, including precision gravity field determination and applications to solid earth science and climate studies.

**Christoph Reigber, Co-Principal Investigator, GeoForschungsZentrum, Potsdam, Germany**

All aspects of GRACE, including precision gravity field determination and applications to solid earth science and climate studies.

**Michael Watkins, Project Scientist, NASA Jet Propulsion Laboratory, California Institute of Technology**

All aspects of GRACE, including precision gravity field determination and applications to solid earth science and climate studies.

**Srinivas Bettadpur, Center for Space Research**

Gravity field determination and science applications.

**Michael Bevis, University of Hawaii at Manoa**

Geodetic and geodynamic studies of postglacial rebound in Patagonia.

**Don Chambers, University of Texas Austin**

Application of GRACE data to improving ocean heat storage estimates from satellite altimetry.

**Benjamin Chao, NASA's Goddard Space Flight Center**

Geophysical validation for GRACE time-variable gravity.

**Jianli Chen, University of Texas Austin**

GRACE validation: discrete harmonics and covariance properties of time-variable gravity using earth rotation and climate models.

**Francis Condi, Center for Space Research**

Separation of GRACE data into atmospheric and oceanic geoid components.

**James Davis, Smithsonian Astrophysical Observatory**

Constraints on melting, sea-level, and paleoclimate from GRACE.

**James Famiglietti, University of California Irvine**

Terrestrial water storage variations using GRACE: estimation, uncertainty, and validation.

**Richard Gross, NASA Jet Propulsion Laboratory**

GRACE, mass displacements, and the earth's rotation.



**Please call the NASA Public Affairs Office before contacting individual scientists.**

NASA Jet Propulsion Laboratory: Alan Buis, 818-354-0474  
 Texas Space Grant Consortium: Margaret Baguio, 512-471-6922  
 NASA Goddard Space Flight Center: Lynn Chandler, 301-286-2806  
 NASA Headquarters: Erica Hupp, 202-358-1237

**Erik Ivins, NASA Jet Propulsion Laboratory**

Geodetic signatures of cryospheric change and interaction with the lithosphere, mantle, and ocean.

**Steven Jayne, Woods Hole Oceanographic Institution**

An *in-situ* ocean comparison for the Gravity Recovery and Climate Experiment (GRACE).

**Christopher Jekeli, Ohio State University**

Validation of GRACE level 2 data products and development of high-resolution regional gravity field models.

**Kristine Larson, University of Colorado Boulder**

Short and long-term stability of the GRACE ultra stable oscillator.

**Frank G. Lemoine, NASA Goddard Space Flight Center**

Unique approaches to addressing time variable gravity for GRACE.

**Erricos Pavlis, University of Maryland Baltimore County**

Current and future satellite mission data analysis for global gravity field modeling and reference frame implementation.

**Nikolaos Pavlis, Raytheon ITSS Corporation**

Analysis of surface gravity and satellite altimetry data for validation of and combination with GRACE information.

**Richard Ray, NASA Goddard Space Flight Center**

Tides for and from GRACE.

**David Salstein, Atmospheric and Environmental Research, Inc.**

Atmospheric mass and motion signals in GRACE and earth rotation measurements.

**C.K. Shum, Ohio State University**

Validation of GRACE data products: characterization of roles of ice sheet and oceanic mass variations in global sea level change.

**Isabella Velicogna, University of Colorado Boulder**

Geopotential heights for GRACE de-aliasing: comparison of SAC-C, CHAMP, and GRACE occultation data with global circulation models.

**John Wahr, University of Colorado Boulder**

Hydrological and oceanographic applications of GRACE.

**Xiaoping Wu, NASA Jet Propulsion Laboratory**

Ice mass variations and Earth rheology — A global inverse approach using gravity, topography, and sea level history data combination.

**Victor Zlotnicki, NASA Jet Propulsion Laboratory**

GRACE applications to ocean circulation: Horizontal pressure gradients, the dynamic balance of wind stress and bottom pressure torques, and ocean data validation.

# Background Science: GRAVITY 101

We can think of gravity as the invisible force that pulls two masses together. When we speak of mass, we're talking about the amount of matter in a substance. Density is a measure of how much mass is concentrated in a given space. Sir Isaac Newton discovered that as an object's mass increases or the distance between attracting objects decreases, the gravitational attraction of that object increases. For example, a container filled with a more dense material like granite rock has more mass and thus more gravitational attraction than that same container filled with water. The earth's Moon has considerably less mass than the earth itself. Not only is the Moon smaller than the earth, but it is only about 60 percent as dense as earth. Thus, the gravitational attraction on the Moon is much less than it is here on earth, and a person weighs less on the Moon. This weaker gravity is why we have the famous images of the Apollo astronauts taking "One giant leap for mankind" on the Moon's surface.



CAPTION: This famous photograph of an astronaut taking a "giant leap for mankind" demonstrates the effect of the moon's lower gravity on a person's weight. Because the moon is smaller than the earth and about 60 percent as dense, the astronaut's weight is only about one-sixth of what it would be on earth. Although they are not as dramatic as the earth-moon difference, slight variations in the mass and density across the earth's surface do create differences in earth's gravity field.

On planet earth, we tend to think of the gravitational effect as being the same no matter where we are on the planet. We certainly don't see variations anywhere near as dramatic as those between the earth and the moon. But the truth is the Earth's topography is highly variable with mountains, valleys, plains, and deep ocean trenches. As a consequence of this variable topography, the density of earth's surface varies. These fluctuations in density cause slight variations in the gravity field, which, remarkably, GRACE can detect from space.

## A Closer Look at the Gravity Field

Although the earth's surface is not uniform, for the most part, the variations are constant over very long time intervals. In other words, if a mountain was at a given location last month, it's probably going to be at that same location this month as well, and for all intents and purposes the mass of the mountain is unchanged. This means that the gravity influence of these larger features is pretty much the same over a very long time and is known as the mean (or long-term average) gravity field.

There are other mass variations, however, that occur on much smaller time scales. These are mostly due to variations in water content as it cycles between the atmosphere, oceans, continents, glaciers, and polar ice caps. These shorter-term mass fluctuations contribute to what is known as the time-variable gravity field.

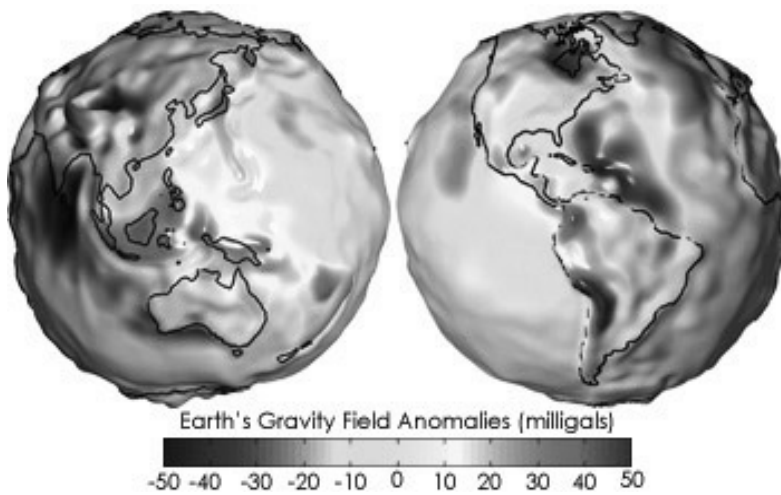
Both the mean gravity field and the monthly maps of the time-variable gravity field are useful tools for scientists as they study the earth's changing climate. The mean gravity field helps scientists better understand the structure of the solid earth and learn about ocean circulation. Likewise, scientists use time-variable gravity to study ground water fluctuations, sea ice, sea level rise, deep ocean currents, ocean bottom pressure, and ocean heat flux.



# Gravity Anomaly Maps and the Geoid

The Earth's gravity field is depicted in two principal ways: gravity anomaly maps and maps of the earth's geoid.

*Gravity anomaly maps* (see globes below) show how much the earth's actual gravity field differs from the gravity field of a uniform, featureless earth surface. The anomalies highlight variations in the strength of the gravitational force over the surface of the earth. Gravity anomalies are often due to unusual concentrations of mass in a region. For example, the presence of mountain ranges will usually cause the gravitational force to be more than it would be on a featureless planet — positive gravity anomaly. Conversely, the presence of ocean trenches or even the depression of the landmass that was caused by the presence of glaciers millennia ago can cause negative gravity anomalies.



These “gravity anomaly” maps show where models of the earth's gravity field based on GRACE data differ from a simplified mathematical model that assumes the earth is perfectly smooth and featureless. Shaded areas are areas where the actual gravity field is larger than the featureless-earth model predicts—such as the Himalayan Mountains in Central Asia (top left of the left-hand globe)—while the progressively darker shades of blue indicate places where the gravity field is less—such as the area around Hudson Bay in Canada (top center of right-hand globe).

Credit: UTCSR

Spatial features on the globe (excluding the large flattening of the earth) correspond to a maximum of around 80-100 parts per million variations of the  $\sim 9.8$  meters squared (105 sq. feet) standard gravitation acceleration. The time-varying seasonal water variations would be around 10 parts per million of the 9.81 meters per second squared (32.2 ft per second squared) standard acceleration.

The *geoid* is a hypothetical earth surface that represents the mean sea level in the absence of winds, currents, and most tides. The geoid is a useful reference surface. It defines the horizontal everywhere and gravity acts perpendicular to it. A carpenter's level aligns itself along the geoid and a carpenter's plumb bob points down the vertical or perpendicular to the geoid. Water will not flow in aqueducts if the pipes are perfectly aligned along the geoid. Surveyors use knowledge of the geoid and the horizontal when they lay out highways and boundaries.

Producing a precise model of the geoid has proven to be a challenge. Until recently, there was no single source for producing a geoid map. Data from several dozen satellites, along with surface measurements over land and from ships at sea, had to be combined to produce a model of the gravitational field. Traditionally, the models have done a fairly good job reproducing large-scale features of the gravity field, but have fallen short when it comes to reproducing finer-scale features or accurately describing time-variable gravity effects like those associated with the hydrologic cycle.

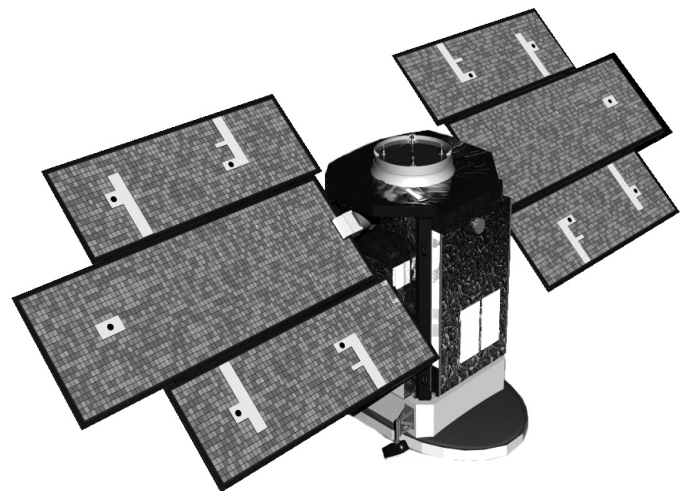
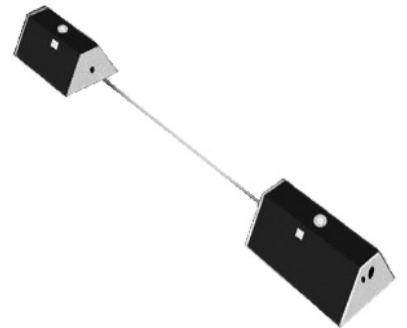
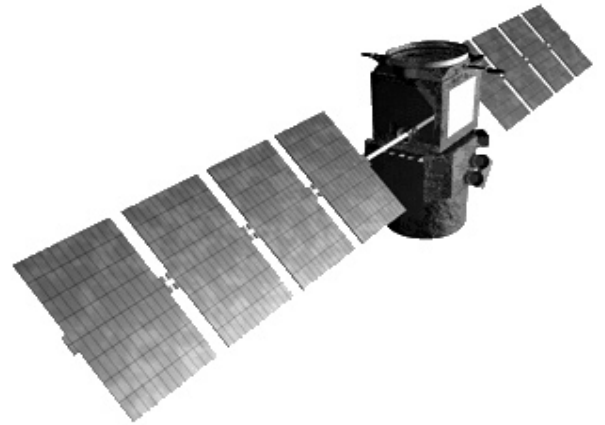
GRACE provides, for the first time, global coverage of the earth's gravity field every 30 days from a single source. GRACE is already able to measure the gravity field with a level of precision that is at least 100 times greater than any existing measurement, and continued improvements are expected as the mission progresses. The finer details of the geoid that have evaded scientists for so long are on the verge of being revealed. GRACE also gives us our best opportunity to date to study time-variable gravity effects. As the mission progresses and more data are added to the model, the resolution of the geoid will improve even further.

For more information about the Geoid and Earth's Gravity, please visit on the Internet:  
[http://www.csr.utexas.edu/grace/gravity/gravity\\_definition.html](http://www.csr.utexas.edu/grace/gravity/gravity_definition.html)

## ACRONYM LIST

AAAS	American Association for the Advancement of Science	HAIRS	High Accuracy Intersatellite Ranging System
ADEOS	Japan's Advanced Earth Observing Satellite	HSRL	High Spectral Resolution Lidar
AGU	American Geophysical Union	HYDROS	Hydrosphere State Mission
AIAA	American Institute of Aeronautics and Astronautics	ICESat	Ice, Cloud, and land Elevation Satellite
AIRS	Atmospheric Infrared Sounder	IIR	The Imaging Infrared Radiometer
AO	Announcements of Opportunity	JPL	NASA's Jet Propulsion Laboratory
CAC	Climate Analysis Center	LITE	Lidar In-space Technology Experiment
CALIOP	The Cloud – Aerosol Lidar with Orthogonal Polarization	MLT	mean local time
CALIPSO	Cloud – Aerosol Lidar and Infrared Pathfinder Satellite Observations	MODIS	Moderate Resolution Imaging Spectroradiometer
CCN	Cloud Condensation Nuclei	MOWG	Mission Operations Working Group
CCRS	Canada Centre for Remote Sensing	NOAA	National Oceanic and Atmospheric Administration
CERES	Clouds and the Earth's Radiant Energy System	NOAA-ETL	NOAA Environmental Technology Laboratory
CETP	<i>Centre d'Etude des Environnements Terrestre et Planétaires</i> (or: Center Terrestrial Study of the Environments and Planets)	NSCAT	NASA Scatterometer, a microwave radar scatterometer that measured near-surface wind vectors (both speed and direction) over the global oceans on Japan's ADEOS satellite
CHAMP	Challenging Mini-satellite Payload	NWS	National Weather Service
CNES	<i>Centre National d'Etudes Spatiales</i> [French Space Agency]	OCO	Orbiting Carbon Observatory
CPC	Climate Prediction Center	OMI	Ozone Monitoring Instrument
CPR	Cloud Profiling Radar	PGR	Post Glacial Rebound
dBz	Decibels of Z, where Reflectivity is designated by the letter Z. "Reflectivity" is the amount of transmitted power returned to the radar receiver	PI	Principal Investigator
dB	Decibels	PSC	Polar Stratospheric Cloud
DLR	The German Deutsche Zentrum für Luft und Raumfahrt	QuikSCAT	A polar orbiting satellite that measures winds on the earth's surface.
DPAF	Dual payload attachment fitting	RT	Radiative Transfer
ECMWF	European Centre for Medium-Range Weather Forecasts	SAC-C	Argentina's Satellite de Aplicaciones Cientificas-C Satellite
EPA	U.S. Environmental Protection Agency	SAGE III	Stratospheric Aerosol and Gas Experiment III
ESMO	Earth Science Mission Operations	SAR	Synthetic Aperture Radar
ESSP	Earth System Science Pathfinder program	SeaSat	SeaSat was the first satellite designed for remote sensing of the earth's oceans with synthetic aperture radar (SAR)
FFRDC	Federally Funded Research and Development Centers	SeaWinds	A specialized microwave radar instrument on the QuikSCAT satellite that measures near-surface wind speed and direction under all weather and cloud conditions over earth's oceans.
GCM	General Circulation Model	SIR-A, SIR-B, SIR-C:	Shuttle Imaging Radar series: SIR-A; SIR-B; and SIR-C
GFZ	GeoForschungsZentrum, Potsdam, Germany	SRTM	Shuttle Radar Topography Mission
GHz	Gigahertz: One billion radio waves, or cycles, per second	SSS	Sea Surface Salinity
GLAS	Geoscience Laser Altimeter System	TOPEX	Topography Experiment for Ocean Circulation
GLOBE	Global Learning by Observations to Benefit the Environment Program	USGCRP	U.S. Global Change Research Program
GPS	Global Positioning System	UTCSR	University of Texas Center for Space Research
GRACE	The Gravity Recovery And Climate Experiment	WFC	Wide Field Camera
GSFC	NASA's Goddard Space Flight Center		

NOTES



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NP-2005-8-709-GSFC

