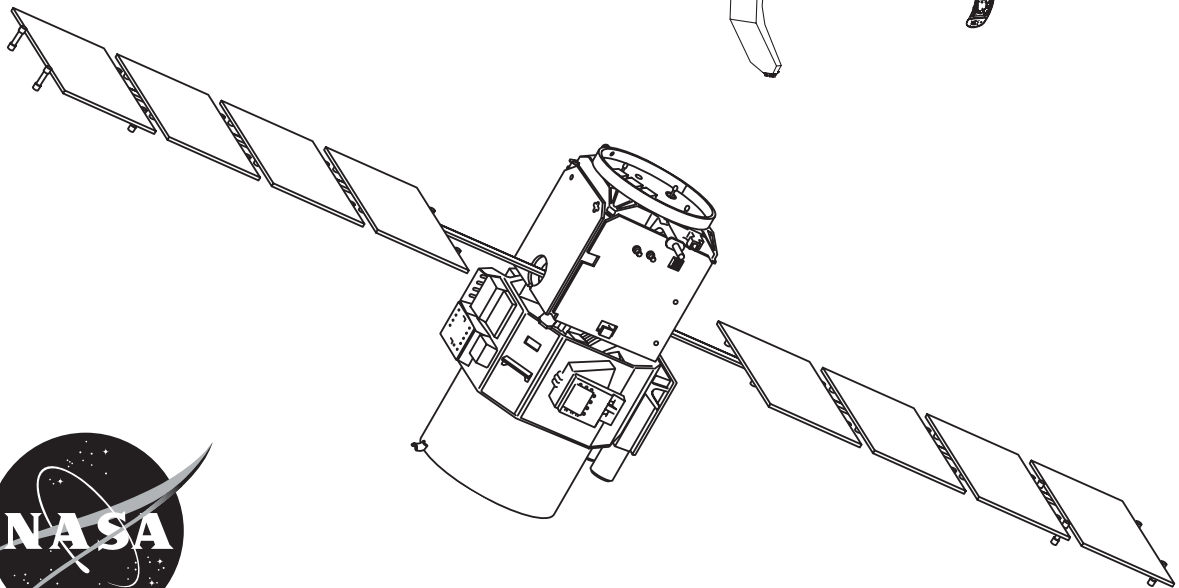
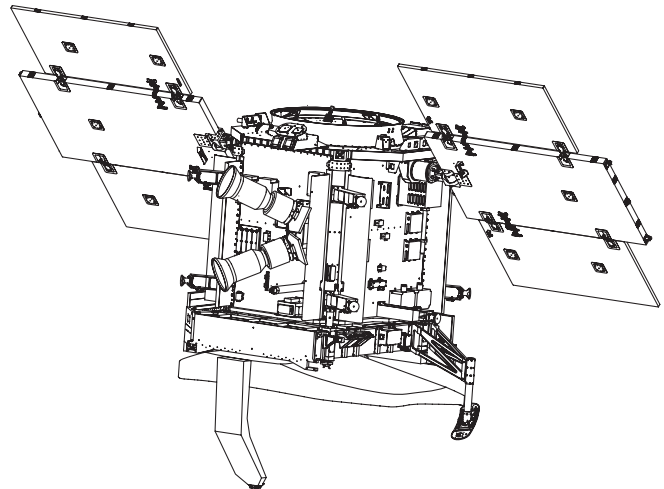


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# CloudSat-CALIPSO Launch

Press Kit  
October 2005





## Media Contacts

Erica Hupp NASA Headquarters, Washington	Policy/Program Management	202/358-1237 erica.hupp-1@nasa.gov
Alan Buis NASA Jet Propulsion Laboratory, Pasadena, Calif.	CloudSat Mission	818/354-0474 alan.buis@jpl.nasa.gov
Emily Wilmsen Colorado State University, Fort Collins, Colo.	Colorado Role - CloudSat	970/491-2336 emily.wilmsen@colostate.edu
Louis Michon Canadian Space Agency, Saint-Hubert, Quebec, Canada	Canada Role - CloudSat	450/926-4338 louis.michon@space.gc.ca
Chris Rink NASA Langley Research Center, Hampton, Va.	CALIPSO Mission	757/864-6786 christopher.p.rink@nasa.gov
Eliane Moreaux Centre National d'Etudes Spatiales, Toulouse, France	France Role - CALIPSO	011 33 5 61 27 33 44 eliane.moreaux@cnes.fr

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## **GENERAL RELEASE:**

### **NASA SATELLITES WILL REVEAL SECRETS OF CLOUDS AND AEROSOLS**

Two NASA satellites, planned for launch no earlier than Oct. 26, will give us a unique view of Earth's atmosphere. CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are undergoing final preparations for launch from Vandenberg Air Force Base, Calif.

CloudSat and CALIPSO will provide a new, 3-D perspective on Earth's clouds and airborne particles called aerosols. The satellites will answer questions about how clouds and aerosols form, evolve and affect water supply, climate, weather and air quality.

CloudSat and CALIPSO employ revolutionary tools that will probe Earth's atmosphere. Each spacecraft carries an "active" instrument that transmits pulses of energy and measures the portion of the pulses scattered back to the instrument.

CloudSat's cloud-profiling radar is more than 1,000 times more sensitive than typical weather radar. It can detect clouds and distinguish between cloud particles and precipitation. "The new information from CloudSat will answer basic questions about how rain and snow are produced by clouds, how rain and snow are distributed worldwide and how clouds affect the Earth's climate," said Dr. Graeme Stephens, CloudSat principal investigator at Colorado State University, Fort Collins, Colo.

CALIPSO's polarization lidar instrument can detect aerosol particles and can distinguish between aerosol and cloud particles. "With the high resolution observation that CALIPSO will provide, we will get a better understanding of aerosol transport and how our climate system works," said Dr. David Winker, CALIPSO principal investigator at NASA's Langley Research Center, Hampton, Va.

The satellites will be launched into a 438-mile circular, sun-synchronous polar orbit, where they will fly in formation just 15 seconds apart as members of NASA's "A-Train" constellation with three other Earth Observing System satellites. The A-Train includes NASA's Aqua and Aura satellites and France's PARASOL satellite.

The usefulness of data from CloudSat, CALIPSO and the other A-Train satellites will be much greater when combined. The combined set of measurements will provide new insight into the global distribution and evolution of clouds that will lead to improvements in weather forecasting and climate prediction.

CloudSat is managed by NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. The radar instrument was developed at JPL, with hardware contributions from the Canadian Space Agency. Colorado State University provides scientific leadership and science data processing and distribution.

Other contributions include resources from the U.S. Air Force and the U.S. Department of Energy. Ball Aerospace and Technologies Corp. designed and built the spacecraft. A host of U.S. and international universities and research centers provides support to the science team. Some of these activities are contributed as partnerships with the project.

CALIPSO was developed through collaboration between NASA and the French Space Agency, Centre National d'Etudes Spatiales (CNES). NASA's Langley Research Center leads the CALIPSO mission and provides science team leadership, systems engineering, payload mission operations, and validation, processing and archiving of data. Langley also developed the lidar instrument in collaboration with the Ball Aerospace and Technologies Corp., which developed the onboard visible camera.

NASA's Goddard Space Flight Center, Greenbelt, Md., provides project management, system engineering support and overall program management. CNES provides a PROTEUS spacecraft developed by Alcatel, the imaging infrared radiometer, payload-to-spacecraft integration and spacecraft mission operations. The Institut Pierre Simon Laplace in Paris provides the imaging infrared radiometer science oversight, data validation and archival. Hampton University provides scientific contributions and manages the outreach program.

For more information on CloudSat and CALIPSO on the Internet, please visit:

**<http://www.nasa.gov/cloudsat>**

and

**<http://www.nasa.gov/calipso>**

- End of General Release -

# Media Services Information

## NASA Television

NASA Television is carried on the Web and on an MPEG-2 digital signal accessed via satellite AMC-6, at 72 degrees west longitude, transponder 17C, 4040 MHz, vertical polarization. It is available in Alaska and Hawaii on AMC-7, at 137 degrees west longitude, transponder 18C, at 4060 MHz, horizontal polarization. A Digital Video Broadcast compliant Integrated Receiver Decoder is required for reception.

The schedule for television transmissions for CloudSat-CALIPSO activities is available on the Internet at <http://www.nasa.gov/ntv>.

## Audio

Audio of the pre-launch news conference and launch coverage will be available on "V-circuits" that may be reached by dialing 321/867-1220, -1240, -1260 or -7135.

## Webcast

NASA will host a live webcast on the mission from Vandenberg Air Force Base on launch minus two days. The live webcast will be available at <http://www.ksc.nasa.gov>.

## Briefings

An overview of the CloudSat-CALIPSO mission will be presented in a news briefing broadcast on NASA Television originating from NASA Headquarters in Washington on Sept. 15, 2005, at 1 p.m. EDT. The pre-launch briefings will be held at 1 p.m. and 2 p.m. EDT in the main conference room of the NASA Resident Office, Building 840, Vandenberg Air Force Base, Calif., on launch minus two days.

## Launch Media Credentials

News media interested in attending the launch should contact Staff Sgt. Rebecca Danet, U.S. Air Force 30th Space Wing Public Affairs Office, Vandenberg Air Force Base, Calif., phone 805/606-3595, fax 805/606-8303. Foreign nationals must submit accreditation requests not later than 30 days before launch. Please include full legal name, news organization, address, nationality/citizenship, passport number and date of birth.

## News Center/Status Reports

The CloudSat-CALIPSO News Center at the NASA Vandenberg Resident Office will be staffed beginning launch minus four days and may be reached at 805/605-3051. Recorded status reports will be available beginning launch minus three days at 805/734-2693.

## Internet Information

More information on the CloudSat-CALIPSO missions, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, can be found at <http://www.nasa.gov/cloudsat> and <http://www.nasa.gov/calipso>.

# Quick Facts

## CloudSat

Dimensions: Main structure approx 2.54 meters (100 inches) by 2.03 meters (80 inches) by 2.29 meters (90 inches); wingspan of deployed solar array approx 5.08 meters (200 inches)

Weight: 848 kilograms (1,870 pounds), fully fueled

Power: 570 watts average from solar array

Science instrument: Cloud-profiling radar

## CALIPSO

Dimensions: Main structure about 1.9 meters (6.25 feet) by 1.6 meters (5.25 feet) by 2.46 meters (8 feet); wingspan of deployed solar array 9.7 meters (31.9 feet)

Weight: 587 kilograms (1,294 pounds), fully fueled

Power: 550 watts from solar array

Science instruments: Cloud-aerosol lidar, imaging infrared radiometer, wide-field camera

## Mission

Launch: No earlier than Oct. 26, 2005, at 3:01:05 a.m. Pacific Time from Launch Complex 2W, Vandenberg Air Force Base, Calif.

Launch vehicle: Boeing Delta II 7420-10C launch vehicle with dual payload attachment fitting

Launch opportunity: One daily instantaneous launch window

Launch period: Oct. 26 to Nov. 22, 2005

Primary mission: CloudSat 22 months; CALIPSO 36 months

Orbit path: Circular, sun-synchronous orbit at altitude of 705 kilometers (438 miles), 98.2-degree inclination, orbiting Earth once every 99 minutes and repeating the same ground track every 16 days

## Program

CloudSat Cost: NASA \$175 million, consisting of \$29 million launch vehicle, \$146 million for satellite development and science and mission operations; plus contributions from Canadian Space Agency for instrument development (U.S. \$15 million, estimated), U.S. Air Force (\$5 million, plus ground stations and uniform personnel), U.S. Department of Energy (\$12 million, estimated)

CALIPSO Cost: NASA \$200 million, consisting of \$29 million launch vehicle, \$171 million for satellite development and science and mission operations; plus contributions from France for hardware and operations (U.S. \$75 million, estimated)



# Mission Overview

CloudSat and CALIPSO were selected under NASA's Earth System Science Pathfinder program's announcement of opportunity released in 1998. Overseen by NASA's Science Mission Directorate, the Earth System Science Pathfinder program sponsors missions designed to address unique, specific, highly focused scientific issues, and provide measurements required to support Earth science research.

Missions are small- to- medium-sized, and are capable of being built, tested and launched quickly. They support a variety of scientific objectives related to Earth science, including studies of the atmosphere, oceans, land surface, polar ice regions and solid Earth.

The CloudSat mission will provide the first global survey of cloud properties that are critical for understanding their effects on both weather and climate. These cloud properties are not obtainable from current satellite measurement systems. CloudSat's primary mission is scheduled to continue for 22 months, to allow more than one seasonal cycle to be observed, although the satellite system is equipped with sufficient propulsion to allow at least three years of on-orbit operation.

The CALIPSO mission is a multi-sensor satellite experiment that uses an innovative method to explore our atmosphere and study aerosols and thin clouds. CALIPSO will provide, from space, the first global survey of cloud and aerosol profiles and physical properties, with seasonal and geographical variations. CALIPSO will 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. CALIPSO's primary mission is scheduled to continue for three years.

CloudSat and CALIPSO will fly in formation with each other and in concert with the other satellites of what scientists and engineers call the "A-Train," a constellation of several Earth-observing satellites. The combination of data from the CloudSat radar with measurements from CALIPSO and NASA's Aqua satellite provides a rich source of information that can be used to assess the role of clouds in both weather and climate.

## Launch Site and Vehicle

CloudSat and CALIPSO will be launched together from Space Launch Complex 2W at Vandenberg Air Force Base, Calif., on a two-stage Delta 7420-10C launch vehicle with a dual payload attachment fitting. The Delta II launch vehicle has a history of more

than 300 successful launches, with a 98 percent success rate. Delta II payload capabilities range from 2.7 to 5.8 metric tons (6,020 to 12,820 pounds) to low Earth orbit.

The Delta launch vehicle features a liquid-fueled first stage with four strap-on solid fuel boosters and a second-stage liquid-fueled engine. With its payloads, the vehicle will stand 39 meters (128 feet) tall.

The first stage of the Delta II uses a Rocketdyne RS-27A main engine. The engine provides nearly 920,782 newtons (207,000 pounds) of thrust by reacting RP-1 fuel (thermally stable kerosene) with liquid oxygen. The four solid rocket motors are 102 centimeters (40 inches) in diameter and fueled with enough hydroxyl-terminated polybutadiene solid propellant to provide about 431,478 newtons (97,000 pounds) of thrust apiece.

The Delta's second stage is powered by a restartable Aerojet AJ10-118K engine, which produces about 42,703 newtons (9,600 pounds) of thrust. The engine uses a fuel called Aerozine 50, which is a mixture of hydrazine and dimethyl hydrazine, reacted with nitrogen tetroxide as an oxidizer.

### **Launch Timing**

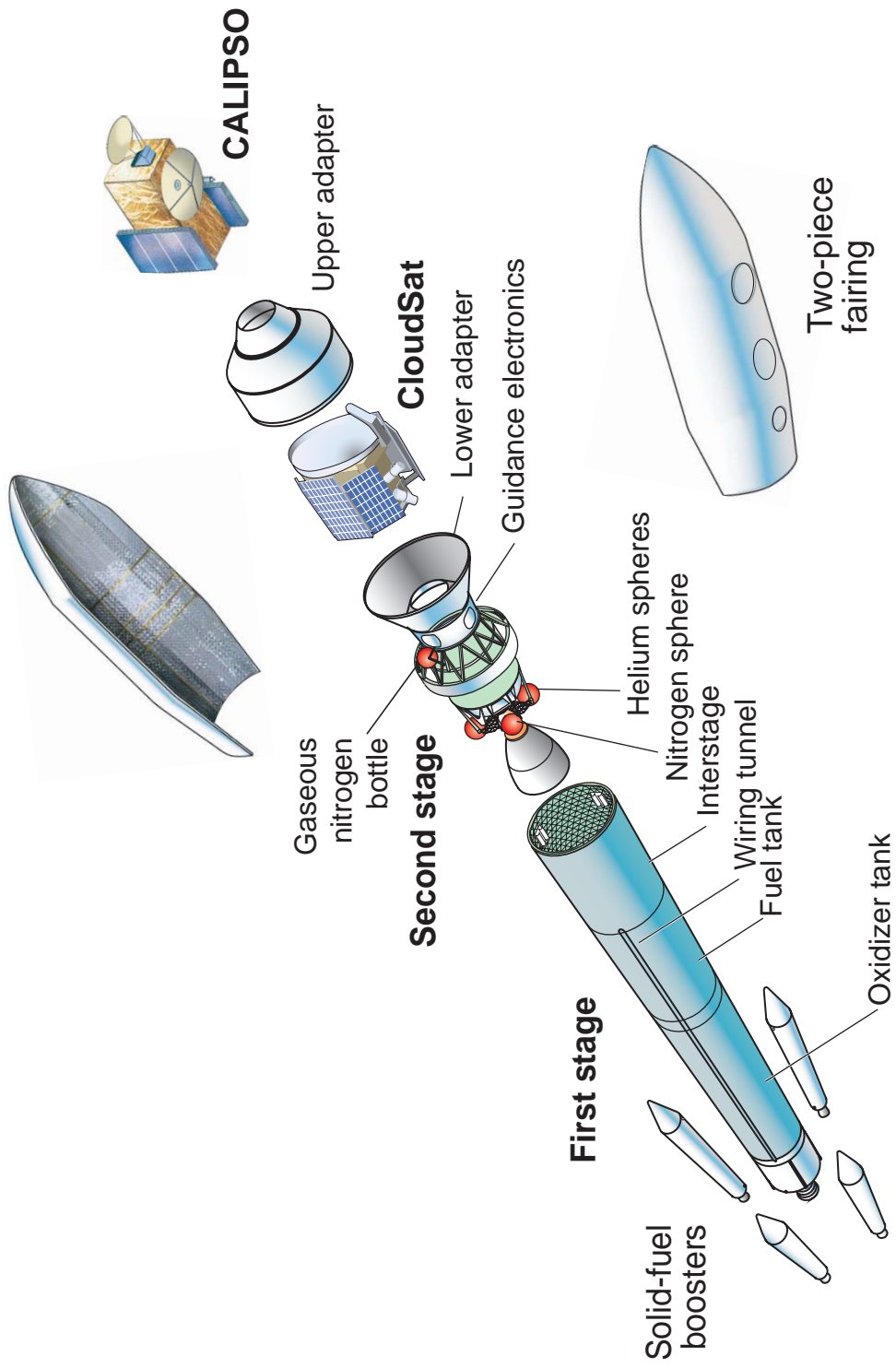
Unlike spacecraft sent to other planets, comets or asteroids, the launches of Earth-orbiting satellites such as CloudSat and CALIPSO do not need to be timed based on the alignment of the planets. The launch date is based only on the readiness of the satellites, the Delta launch vehicle and the launch range at Vandenberg Air Force Base.

Earth-orbiting satellites do, however, need to be launched during particular windows within any given 24-hour day in order to get into the proper orbit around Earth. CloudSat and CALIPSO will assume what is called a "sun-synchronous" orbit flying close to Earth's north and south poles. Because they need to adjust to the even more precise A-Train constellation orbit, the launch vehicle must be launched during a daily nearly instantaneous launch window. Launch is currently scheduled for 3:01 a.m. Pacific Time no earlier than Oct. 26, 2005.

### **Launch Sequence**

When the Delta II launches, its first-stage engine and its four strap-on boosters ignite at the moment of liftoff and the rocket rises vertically from the launch pad and then heads south over the Pacific Ocean. Sixty-four seconds after liftoff the strap-on boosters will burn out, and their spent casings will be jettisoned approximately 83 seconds after liftoff.

About four minutes and 24 seconds into the flight, the main engine will cut off. About 14 seconds later, the second stage will ignite, and five seconds later, the nose cone, or



*Delta II launch vehicle*

"fairing" will fall away. At about 11 minutes and 10 seconds after liftoff, the second-stage engine will temporarily stop firing.

At about 59 minutes and 56 seconds after liftoff, the second stage will restart, burning 11 seconds before shutting down. At this point, the spacecraft with the second stage of the Delta still attached will be in a circular parking orbit 695 kilometers (375 nautical miles) above Earth. CALIPSO satellite separation occurs approximately 62 minutes after liftoff, and CloudSat will separate approximately 97 minutes after liftoff.

After separation from the launch vehicle, CALIPSO's thermal control is activated. Final orbit is achieved within six weeks, but commands to the science instruments may begin as soon as two days after launch. About 12 to 30 days after launch, CALIPSO will be maneuvered into its operational circular, sun-synchronous orbit about 705 kilometers (438 miles) above Earth. This period, up to approximately 45 days after launch, is dedicated for on-orbit checkout; normal science operations begin shortly after that.

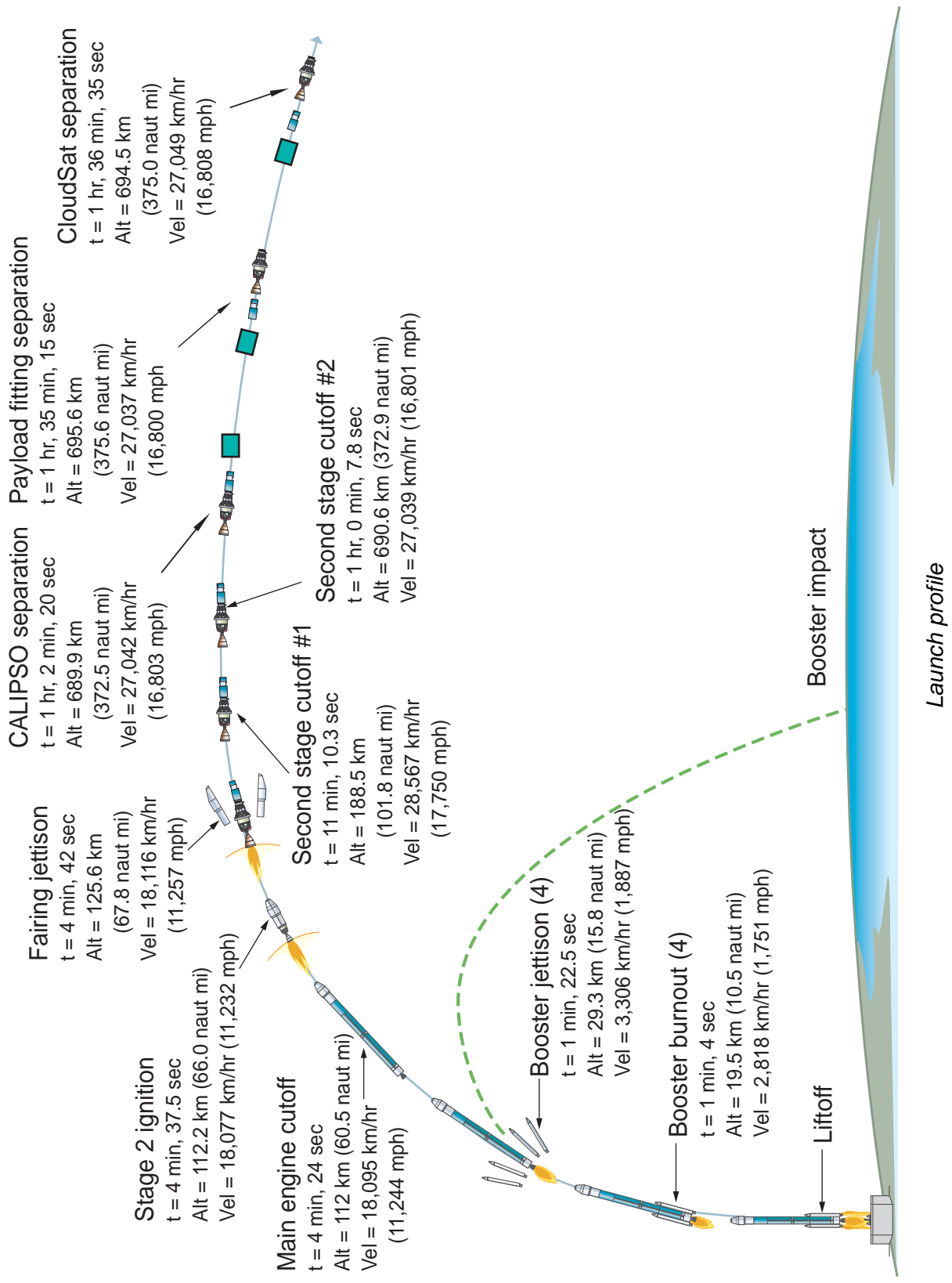
After separation, CloudSat will deploy its solar arrays, and point the spacecraft at Earth using three-axis attitude control. All sensors and units will be checked, and about 12 to 30 days after launch, CloudSat will be maneuvered into its operational circular, sun-synchronous orbit about 705 kilometers (438 miles) above Earth.

First acquisition of CloudSat's signal occurs approximately 97 minutes after launch. First acquisition of CALIPSO's signal occurs 8 hours after liftoff, at which time its in-orbit checkout begins. In-orbit checkout of CloudSat begins at launch plus 15 days, concluding at launch plus 45 days. In-orbit checkout of CALIPSO concludes at the launch plus 45 day mark. The actual conclusion of CloudSat and CALIPSO launch checkout will depend on the launch date. The time for the satellites to integrate into the A-Train constellation depends on the actual launch date. The orbit insertion time could vary by as much as plus or minus 10 days, from about 30 days after launch to 45 days after launch. Science operations will begin at launch plus 46 days for CALIPSO and launch plus approximately 30 to 45 days for CloudSat.

## **Formation Flying**

Formation flying enables CloudSat to track CALIPSO in a very precise way. After launch, maneuvers within the first 30 to 45 days of the mission will bring the CloudSat satellite in formation with CALIPSO and following Aqua. The CloudSat orbit will be adjusted and monitored to hold the CloudSat satellite at a fixed distance from CALIPSO. The satellite will be controlled so that both sets of sensors, along with those of Aqua, view the same ground track for the majority of the time.

As the satellites that are apart of the A-Train circles Earth, about 8 minutes passes between the time the first satellite (Aqua) and the last (Aura) passes over any given spot. Overall the string of satellites stretches across 3,000 kilometers (1,864 miles) in space, with each traveling about 7 kilometers per second (4.3 miles per second). The



CloudSat radar trails Aqua by an average of about 60 seconds. CloudSat will fly approximately 460 kilometers (286 miles) behind Aqua and much closer to CALIPSO—only around 93.8 kilometers (58.3 statute miles), which corresponds to 12.5 seconds average delay between lidar and radar measurements.

The chosen delay is a compromise between the desire to minimize the time delay between the radar and lidar measurements and the need to reduce the complexity in the implementation of formation flying. In this way, the radar footprint will overlap the lidar footprint more than 50 percent of the time, creating coordinated and essentially simultaneous measurements. Maneuvers to maintain this circulation orbit will be carried out approximately weekly.

All five of the A-Train satellites will cross the equator within a few minutes of one another at around 1:30 p.m. local time. Since these missions will all fly in tandem, the set of satellites is referred to as a constellation, or formation. Since this constellation is composed of missions with equator crossings in the early afternoon and also in the middle of the night, at about 1:30 a.m., it is referred to as the Afternoon Constellation—to distinguish it from the Morning Constellation, consisting of Terra, Landsat-7, Satellite de Aplicaciones C and the New Millennium Program's Earth Observing-1 spacecraft.

The term "A-train" comes from an old jazz tune, "Take the A-train," composed by Bill Strayhorn and made popular by Duke Ellington's band, and has become a popular nickname for the Afternoon Constellation because Aqua is the lead member of the formation and Aura is in the rear.

### **CloudSat Satellite Operations**

CloudSat mission data are transmitted via the spacecraft S-band downlink to the Air Force Satellite Control Network and then to the Research, Development, Test and Evaluation Support Complex at Kirtland Air Force Base in Albuquerque, New Mexico. Science data are then sent to the Cooperative Institute for Research in the Atmosphere for science processing. Mission and state-of-health information is examined and archived at the U.S. Air Force ground operations center and NASA's Jet Propulsion Laboratory, Pasadena, Calif.

### **CALIPSO Satellite Operations**

The CALIPSO mission S-band system is used for both spacecraft and payload commanding and for downlink of spacecraft and critical payload health and status data to France's Spacecraft Operations Control Center in Toulouse. The X-band telemetry system is used for downlink of the payload high rate science data and all payload engineering, health and status data to United Space Network ground stations in Alaska and Hawaii, and on to NASA's Langley Research Center's Atmospheric Sciences Data Center, Hampton, Va.

## CloudSat Data Products

The CloudSat Data Processing Center is located at the Cooperative Institute for Research in the Atmosphere on the Foothills Campus of Colorado State University in Fort Collins, Colo. The CloudSat Data Processing Center will produce two types of products for archiving and distribution to the science community. The first is a set of standard data products and the second is a set of auxiliary data products that are mapped to the CloudSat Cloud Profiling Radar profile locations.

CloudSat's standard data products include calibrated cloud-profiling radar reflectivity data, as well as cloud geometric profile, cloud classification, cloud optical depth by layer, cloud liquid water content, cloud ice water content, atmospheric radiative fluxes and heating rates, cloud geometrical profile with lidar input from CALIPSO, and cloud classification with lidar input from CALIPSO.

CloudSat standard data products are produced at each CloudSat profile location. Profiles consist of 125 vertical "bins," each approximately 240 meters (787 feet) deep. With orbital motion, the footprint of the radar beam at the surface of Earth is approximately 1.4 kilometers (0.9 miles) wide by 2.5 kilometers (1.6 miles) long.

A "granule" of CloudSat data is defined as one orbit, consisting of approximately 39,400 profiles. A granule begins at the descending node of an orbit, which occurs at the (southbound) equator crossing on the night side of the planet.

Detailed specifications for each of these products can be found at the CloudSat Data Processing Center website at <http://cloudsat.cira.colostate.edu>.

CloudSat also archives and distributes complementary data from other satellites in the A-Train constellation as they fly over cloud fields at nearly the same time. Included are data from the CALIPSO lidar and the Moderate Resolution Imaging Spectroradiometer instrument on NASA's Aqua satellite, as well as meteorological data of relevance to CloudSat's measurements.

In addition to these standard and auxiliary products, the CloudSat project encourages the development of a class of experimental data products providing supplementary information enhancing the science of the mission. These products are expected to be less mature than the standard products but potentially of high value. Examples of experimental products under development by the current CloudSat team are precipitation estimates including snow, discrimination of ice and liquid and droplet size profiles and number concentrations. The science team will consider the transition of selected experimental products to standard products at the time of data reprocessing (planned after the first year of operations).

## **CALIPSO Data Products**

CALIPSO products will be produced and archived at NASA's Langley Research Center's Atmospheric Sciences Data Center. As the payload consists of a two-wavelength backscatter lidar, a visible channel wide-field camera, and an imaging infrared radiometer flown in formation in the A-Train constellation, CALIPSO will provide a comprehensive suite of nearly simultaneous measurements of atmospheric state, aerosol and cloud optical properties, and radiative fluxes.

During day and night segments of the orbit, CALIPSO's lidar will acquire vertical profile data that will provide information on the distributions of aerosols and clouds, cloud particles, and a classification of aerosol size. Vertical profiles will be measured from -2 to +40 kilometers (-1.24 to +24.85 miles) on one channel while the other two channels cover the -2 to +26 kilometers (-1.24 to +16.15 miles), with the cloud and aerosol measurement region with polar stratospheric clouds occurring toward the top of that range.

The imaging infrared radiometer provides medium spatial resolution nadir viewing images with information on cirrus cloud particle size and infrared emission activity. The wide field camera digital camera collects daytime high spatial resolution imagery in the 620- to 670-nanometer wavelength range and is used to ascertain cloud composition, aid in cloud clearing, and to provide meteorological information

Cloud products will be reported at a horizontal resolution of 5 kilometers (3.1 miles); i.e., at the fundamental averaging resolution of the processing scheme. Cloud boundaries, which can be detected at higher resolution, will be reported at that resolution. To account for weaker backscatter signals from aerosols, the Level 2 aerosol profile products will be reported at a uniform horizontal resolution of 40 kilometers (24.85 miles) at all altitudes.

## **CloudSat Data Access**

During the operations phase, CloudSat data will be stored and distributed by the Cooperative Institute for Research in the Atmosphere, which will provide an on-line data access system that will allow users to view browse images and order data by date/time interval and geographic location. Ordered data will be placed on an ftp server for retrieval by the requestor.

Several features of the data ordering system will allow users to request subsets of the larger CloudSat data product list-thus minimizing the volume of data that they will pull over to their local system. Users will be allowed to specify specific fields within a data product that they need for their research. They will also be able to create "custom products" that will combine fields from multiple standard data products into a single file. In addition, users will be able to set filters on the data to select, for example, orbits that contain a higher percentage of water (vs. land) points, or granules that contain less than 30 percent cloud cover, etc.



Following data checkout by the algorithm developers, data will be made available to the CloudSat science team for evaluation for a period of two months. The first release of data to the general scientific community will occur no later than nine months after launch. Reprocessing of the first year of data will begin one year after launch and will be completed before the end of the nominal mission. All data products will be available via the Cooperative Institute for Research in the Atmosphere's online data ordering system.

### **CALIPSO Data Access**

CALIPSO data will be processed, archived and distributed from NASA's Langley Research Center's Atmospheric Sciences Data Center as the facility responsible for NASA Earth science data in the areas of radiation budget, clouds, aerosols and tropospheric chemistry.

Various levels of data products will be made available to the public anywhere from 45 days after the post launch check-out phase, to a 1-year validation period to ensure the release of high-quality data products.

A CALIPSO data products catalog will provide an overview of the data products that are used or produced by the data management system -- production software that converts CALIPSO instrument data into scientific data products. All data are available to the public via the web. Detailed information about the data products, including documentation, ordering tools, and tools for working with the data, are available for each project the center supports. Some of the data products include web interfaces that allow direct access to data holdings for immediate downloading, for placing media orders or for ordering prepackaged CD-ROMs and videocassettes.

More information about NASA's Langley Research Center's Atmospheric Sciences Data Center is available on its website, <http://eosweb.larc.nasa.gov>, by email from [larc@eos.nasa.gov](mailto:larc@eos.nasa.gov) or by telephone at 757/864-8656.

### **CloudSat Mission Operations**

The U. S. Air Force will provide ground operations and manage communications. It is expected that the data will be downlinked up to about eight times per day, providing a data latency of about four to six hours. The Cooperative Institute for Research in the Atmosphere at Colorado State University will process the data into scientific data products, archive, and distribute the data to the international research community. Some portion of the data will be processed and distributed to operational centers for use in near-real-time assimilation and cloud forecast evaluations. NASA's Jet Propulsion Laboratory is responsible for mission management during mission operations.

## **CALIPSO Mission Operations**

Once operational, mission operations are conducted at the NASA's Langley Payload Operations Control Center and France's Spacecraft Operations Control Center. Science and complete spacecraft operations data will be transmitted to the Poker Flats, Alaska, ground station twice times a day. Raw science and engineering data will be transmitted to NASA's Langley Research Center's Atmospheric Sciences Data Center via a dedicated digital communication link. The spacecraft will send satellite and critical payload status/health information to the Spacecraft Operations Control Center five times daily, seven days a week.

The CALIPSO team consists of NASA's Langley Research Center, industry partner Ball Aerospace & Technologies Corp. and, as international partner, France's Centre National d'Etudes Spatiales. France's industry partner is Alcatel. NASA's Langley Research Center has the overall responsibility for the mission. France is contributing the Proteus spacecraft bus, the imaging infrared radiometer instrument, payload to spacecraft bus integration and testing, and spacecraft operations for the three-year mission. Ball built the payload including the lidar, wide field camera and the X-band transmitter. Validation of CALIPSO products will be based primarily upon comparisons with airborne lidar, sun photometers and other aerosol and cloud particle measurements obtained by various NASA field research campaigns and international research facilities.

## **CloudSat Outreach**

The CloudSat Education Network is part of CloudSat education and public outreach program, and is a partnership with the Global Learning to Benefit the Environment program. The goal of the network is to provide the opportunity for schools to partner with the CloudSat science and education teams. The main focus of the knowledge development component of the project is to help students better understand how scientists predict changes in the weather as well as long-term climate change and the climatic processes that maintain Earth's energy balance.

This school network provides an opportunity for students and teachers from around the world to partner with CloudSat scientists and each other by reporting atmospheric measurements during the satellite's overpasses, providing scientists with "ground truth" data. The atmospheric measurements include but are not limited to cloud cover, cloud type, precipitation and temperature. Training in taking the measurements is supported through the network. In addition, the students will be given the opportunities to continue designing and developing activities in support of the mission.

Communication with the scientists and other members will be promoted electronically through emails, web chats, video and teleconferencing, forums and possible site visits. The network will be international in nature, targeting up to 100 schools.

## **CALIPSO Outreach**

CALIPSO supports a strong educational and public outreach effort aimed at formal (K-14) education, informal education opportunities outside of formal school environments and public awareness. The CALIPSO outreach effort is implemented by one of the mission partners, Hampton University.

Activities such as a February 2005, CALIPSO and CloudSat live video-conference are part of a program to teach students about clouds, aerosols, weather and climate through the missions. The CALIPSO outreach program strives to provide information on global climate change to the public to develop scientifically literate citizens. The Hampton University outreach website offers an on-line learning community committed to providing information, activities and lessons centered on the research of the CALIPSO mission. Educators, students and the general public may access the site at **<http://calipsooutreach.hamptonu.edu>**.

Hampton University's outreach team, in collaboration with the CloudSat mission, will host national and regional workshops in order to provide teachers with an opportunity to integrate the latest atmospheric research data into curricula and provide students with an opportunity to participate in current atmospheric research. CALIPSO students will report visual observations of clouds and aerosol haze conditions and collect measurements of column optical depth for comparison with CALIPSO mission observations.

Hampton University is also establishing partnerships with science and technology centers and museums and national parks to develop demonstrations, education programs and exhibits for children and adults that are focused on the CALIPSO mission.

# CloudSat Satellite

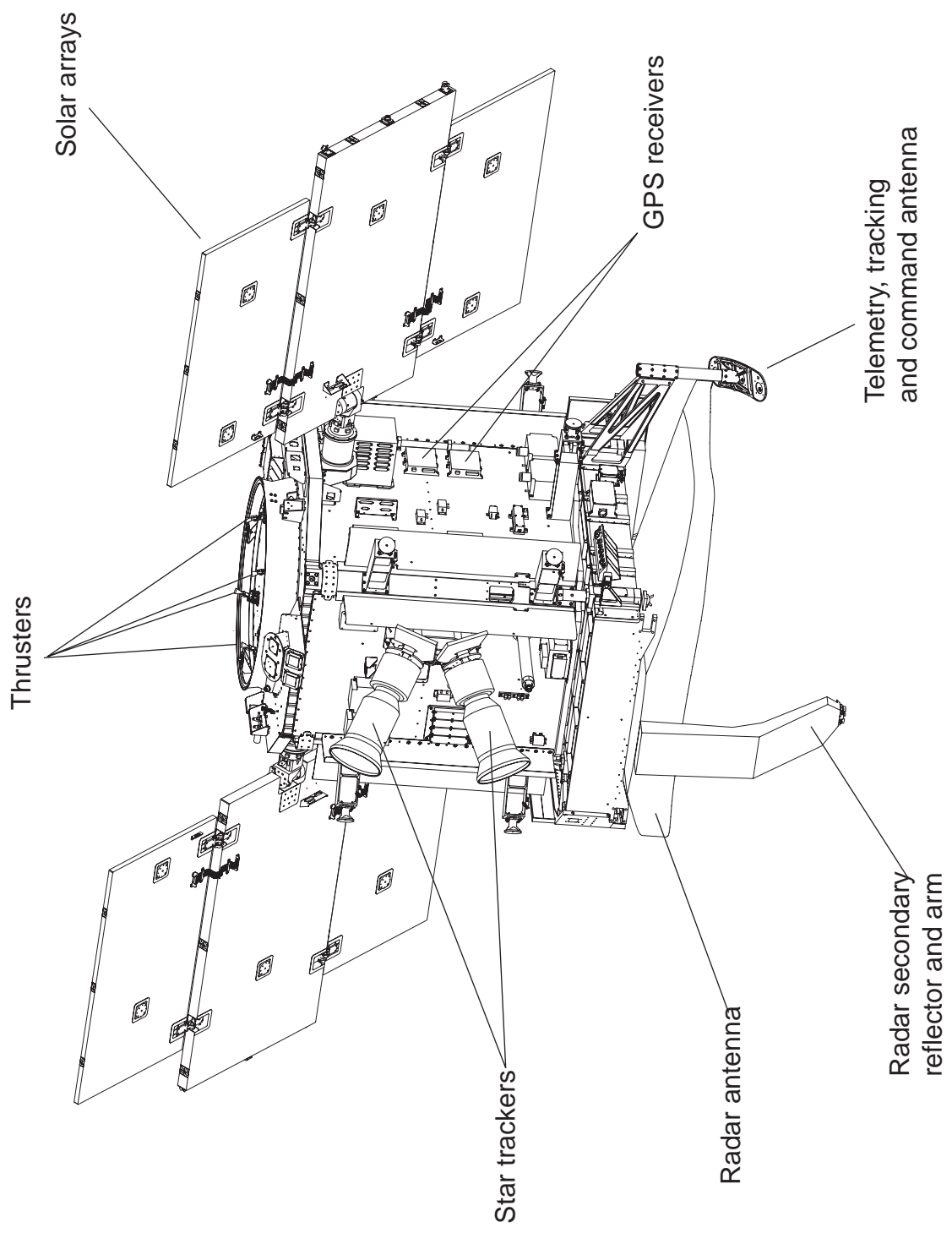
The CloudSat payload consists of a 94-gigahertz cloud-profiling radar, which will obtain the mission's cloud profile information, working in conjunction with measurements from instruments on NASA's Aqua spacecraft and the CALIPSO lidar.

Developed jointly by NASA's Jet Propulsion Laboratory and the Canadian Space Agency, the radar's design has a strong heritage derived from many existing ground-based and airborne cloud radars, which aided the radar's instrument design and technology, data processing and retrieval algorithms.

Use of millimeter-wave radar systems over the past decade has flourished, leading to a broader understanding of the radar reflection properties of various types of clouds than was available at the time that the CloudSat mission was first being formulated. Cloud radars now operate routinely at a number of surface sites around the world, operating at frequencies of 94 or 35 gigahertz, and are also deployed on a number of research aircraft. In fact, most of the design parameters and subsystem configurations for CloudSat are nearly identical to those for the JPL/University of Massachusetts Airborne Cloud Radar, a facility that has already been deployed in a number of field campaigns.

As CloudSat orbits Earth, it transmits radar pulses (waves) straight down into Earth's atmosphere to penetrate through clouds and create vertical profiles of clouds. It measures the power backscattered by clouds (cloud reflectivity) as a function of their distance from the radar (altitude). As the pulse hits condensed water particles in the cloud, the pulse gets rebounded back, and is received by the satellite. Each pulse transmitted by CloudSat will pass through the clouds and continue until it reaches Earth's surface, where it will rebound and return to CloudSat. The time delay in the return signal allows us to make a map of the location of the clouds, and the strength of the return is an indication of the size of the particles and the amount of water and ice that they contain. These data sets are then transmitted to a receiving station, where the data are used to create graphs of the information.

The design of the radar is driven by the science objectives. Because clouds are weak scatterers of microwave radiation, the overriding requirement on the radar is to achieve the maximum possible sensitivity and hence maximize cloud detection. Sensitivity is primarily determined by radar-received power and noise level and optimizing this sensitivity involves a careful tradeoff among competing and conflicting factors, including the cloud backscattering properties, the vertical resolution, atmospheric weakening as the radar pulse is absorbed by gases such as water vapor, liquid water droplets and



*CloudSat satellite*

raindrop-sized particles, available power delivered to the system, the orbit altitude and radar technology.

The received power can be increased by increasing the antenna size and increasing transmitter output power. The chosen antenna diameter of 1.85 meters (73 inches) is limited by launch vehicle constraints. The transmitter power is also limited by both the transmitter technology and the power supply capability of the spacecraft. The amount of power received is also strongly influenced by the cloud reflectivity and atmospheric weakening effects. Cloud reflectivity increases with increasing radar frequency but atmospheric weakening becomes prohibitive at higher frequencies. To achieve sufficient cloud sensitivity, a relatively low frequency radar would require an enormous antenna and high peak power. At frequencies much greater than 100 gigahertz, a large antenna and high peak power are also needed due to rapid weakening of the signals as they are absorbed by the clouds. In addition, technologies at such high frequencies are less well developed.

The 94-gigahertz frequency was chosen to meet performance within the spacecraft resources. It allows an increase of 33 decibels in sensitivity over the 14-gigahertz Tropical Rainfall Measuring Mission radar. The choice of frequency means that when very thick clouds or heavy rain are present, the radar will be able to penetrate to the cloud base most of the time.

If CloudSat were flying in isolation, it would probably reside at a lower altitude, similar to that of the Tropical Rainfall Measuring Mission, giving its radar even greater sensitivity and improved ability to detect clouds. However, because CloudSat is part of the A-Train formation, the science team has chosen to have it fly in a higher altitude. This compromise gives the radar excellent cloud-detection capabilities to achieve CloudSat's mission objectives but also enables maximum synergism with the other A-Train missions. To detect low-reflectivity clouds, the instrument will average many independent samples of the radar backscatter power and subtract from it the estimated system noise level.

The power measured by the receiver subsystem of the radar system is converted into a quantity referred to as radar reflectivity. The CloudSat radar detects the majority of clouds that significantly affect the radiation budget and the critical elements of the water budget of the atmosphere. The radar should be able to detect more than 90 percent of all ice clouds and 80 percent of all water clouds.

## **Instrument Subsystems**

The radar is composed of the following subsystems: the radio frequency electronics subsystem, the high power amplifier, the collimating antenna subsystem, power distribution unit and the digital subsystem.

The radio frequency electronics subsystem is divided into the upconverter, which acts as the signal generator producing the desired waveforms/pulses, and the receiver, which receives, amplifies and downconverts backscatter power.

The high-power amplifier is divided into the high-voltage power supply and a specialized vacuum electron device called an extended interaction klystron. The high-power amplifier is the only physically redundant radar instrument assembly. Similar to the magnetrons used in microwave ovens, klystrons generate radio waves such as those transmitted by CloudSat's radar. A critical part of the klystron is the cathode, which could be considered the heart of the radar. A commercial extended interaction klystron unit was redesigned in Canada to be qualified to operate in space. It is required to amplify the transmitted pulse to 1.7 kilowatts. The flight model exceeds this requirement, amplifying to 2 kilowatts.

The collimating antenna subsystem consists of the antenna, and quasi-optical transmission line built on an optical bench. The antenna couples electromagnetic radiation between a transmitter and receiver and free space. It is constructed of composite graphite material and meets the challenge of low surface roughness and delivers a highly directional beam with a half-width less than 0.12 degrees. The quasi-optical transmission line assembly serves as a free-space beam waveguide that allows for transmission and reception with significantly reduced losses. It minimizes loss through the system. This will be the first time this technology has flown in space on a radar of this wavelength.

The power distribution unit is the power supply that provides conditioned electrical power for the instrument.

The digital subsystem assembly provides for overall command and telemetry control.

## **Spacecraft Bus**

The CloudSat spacecraft bus, developed by Ball Aerospace & Technologies Corp., provides the necessary resources for the Cloud Profiling Radar instrument to operate in space. It is an RS2000 spacecraft bus, used previously for both NASA's Quikscat and ICESat missions, that incorporates a number of CloudSat-specific modifications. The spacecraft structure consists of the primary structure and secondary structural assemblies or components of both the spacecraft bus and the radar instrument.

The spacecraft measures approximately 254 centimeters (100 inches) by 203 centimeters (80 inches) by 229 centimeters (90 inches). The solar array wingspan, when fully deployed, measures approximately 508 centimeters (200 inches) from tip to tip.

The satellite has a launch mass of approximately 848 kilograms (1,870 pounds) and an in-orbit power generation capability of more than 800 watts.

The satellite is fully redundant and is designed to survive for 22 months, with consumable resources such as fuel designed for a minimum of three years operating time.

### **Telecommunications**

This subsystem includes a standard Air Force Satellite Control Network Space-Ground Link System transponder and associated transmit and receive antennas. Other subsystem assemblies include the solid state recorder to be used for storing science data and the wide-band transmitter to be used to downlink these data. All assemblies are redundant.

### **Flight Software**

The flight software is comprised of six modules: central processing memory, command, telemetry, payload, attitude determination, and control, utilities and command and telemetry unit.

### **Propulsion**

The required on-orbit thrust is 107 meters (351 feet) per second, while the actual performance capability is 170 meters (558 feet) per second, resulting in a fuel margin of 84 percent. The spacecraft uses an all-welded, chemical, blow-down monopropellant system for attitude control and translational maneuvers. The propellant is hydrazine and the pressurant is gaseous nitrogen. Passing the hydrazine over a heated catalyst results in a chemical reaction. There are four thruster assemblies, each rated at 4.45 newtons (1 pound) and possessing a specific impulse of 220 seconds. Other propulsion system components include the fill/drain valve, fill/vent valve, pressure transducer and two latching isolation valves.

### **Attitude Determination and Control Subsystem**

The attitude determination and control subsystem provides for three-axis control of the spacecraft. Two star trackers provide high-accuracy attitude determination. Low-accuracy attitude determination is provided by 14 coarse sun sensors, which also provide sun direction for solar array control, and three two-axis magnetometers. Three dual-winding torque rods, along with the magnetometers, are used for managing momentum. Momentum storage and spacecraft maneuverability is provided by four reaction



wheels. Two global positioning system receivers provide GPS time and position and velocity to the onboard location determination process.

### **Command and Data Handling Subsystem**

The command and data handling subsystem controls the overall operation of the radar and provides most electrical interfaces between the instrument and the CloudSat spacecraft bus. The subsystem receives and formats the processed radar echo from the radar electronics and engineering telemetry from all subsystems and supplies radar data to the spacecraft, which then transmits the data to ground stations. The subsystem includes fault protection to place the instrument into a "safe" state if engineering telemetry exceeds expected ranges. The subsystem also receives and processes commands.

The subsystem has a redundant and cross-strapped configuration providing reliable and long-life operation. The radar interfaces to the command and data handling subsystem includes serial-digital command and telemetry paths, and bi-levels. Command processing is done by the command decoder unit. The telemetry processing is done by the digital telemetry units, which collect spacecraft health and status data. Housekeeping or state-of-health data are stored in the digital storage unit. It has a storage capability of 256 megabytes. The spacecraft control computer performs attitude control, payload control function and can receive real-time command from either command decoder unit. The radar outputs mission data directly to the 2-gigabyte solid-state recorder.

### **Electrical Power and Distribution Subsystem**

The electrical power and distribution subsystem uses a robust direct energy architecture with two solar array wings providing the power source. The total solar cell area is 5.2 square meters (56 square feet) with a total array area of 6.4 square meters (69 square feet). The solar arrays produce 1,228 watts end-of-life at their closest point to the sun, 23.25 degree off-pointing angle during nominal operations. During solar eclipse the 40 amp-hour battery supplies the operational loads and any necessary impulse energy to clear any load faults.

The power control unit is the primary controller, providing power charge control, distributing power to the essential bus and the five switched buses, performing command processing and telemetry, providing fault detection and control for the buses and battery, and providing the spacecraft with a single point ground. Distribution of power from the power control unit main buses to various buses is provided by the power dis-

tribution assembly, which is also the controller for the solar array release system and the 26 spacecraft bus heaters.

The support electronics package is a group of electronic modules that perform miscellaneous support functions for the power and other spacecraft subsystems.

### **Thermal Control**

The spacecraft's thermal design is passive except for 24 (plus two spares) active heater controllers, and employs multi-layer insulation with selected surface finishes.

# CloudSat Science Objectives

CloudSat and CALIPSO will provide the first space-based global survey of cloud and aerosol profiles and physical properties, across seasonal and geographic variations. Together these observations will help scientists evaluate the way clouds and aerosols are measured and interact in global models, ultimately contributing to improved predictions of weather, climate, and the cloud-climate feedback problem.

CloudSat seeks to overcome shortcomings in our understanding of how cloud processes influence climate and will provide the observations needed to accurately characterize these processes and validate climate model predictions. These observations are a significant advance over present cloud observing capabilities.

The objective of the CloudSat mission is to provide, from space, the first global survey of cloud profiles and properties with seasonal and geographic variations, needed to evaluate the way clouds are parameterized in global models, thereby contributing to predictions of weather, climate and the cloud-climate feedback problem. Derived from this mission objective are three broad science objectives and one goal.

## Science Objectives

- Quantitatively evaluate the representation of clouds and cloud processes in global atmospheric circulation models
- Quantitatively evaluate the relationship between the vertical profiles of cloud liquid water and ice content and the radiative heating of the atmosphere and surface by the various cloud systems
- Evaluate cloud properties retrieved from other satellite systems, in particular those of Aqua

## Goal

- Investigate the way aerosols affect clouds and precipitation.

## CloudSat Science Team

Graeme Stephens, Colorado State University, *Principal Investigator*  
Thomas Ackerman, University of Wisconsin  
Howard Barker, Meteorological Service of Canada  
Jean-Pierre Blanchet, University of Quebec at Montreal, Canada  
Dave Donovan, Royal Netherlands Meteorological Institute  
Frank Evans, University of Colorado  
Jurgen Fischer, University of Berlin, Germany  
David Hudak, Meteorological Service of Canada  
Anthony Illingworth, University of Reading, United Kingdom  
Hiroshi Kumagai, Communications Research Laboratory, Japan  
Fuk Li, NASA's Jet Propulsion Laboratory  
Zhanqing Li, University of Maryland  
Gerald Mace, University of Utah  
Sergey Matrosov, National Oceanic and Atmospheric Administration  
Environmental Technology Laboratory  
Teruyuki Nakajima, University of Tokyo, Japan  
Steve Platnick, NASA's Goddard Space Flight Center  
Markus Quante, GKSS Research Centre, Germany  
David Randall, Colorado State University  
William Rossow, NASA's Goddard Institute for Space Studies  
Kenneth Sassen, University of Alaska  
James Spinhirne, NASA's Goddard Space Flight Center  
Ron Stewart, McGill University, Canada  
Steve Sekelsky, University of Massachusetts  
Jacques Testud, Université de Versailles St-Quentin, France  
Alexander Trishchenko, Canadian Climate and Remote Sensing Center  
Thomas Vonder Haar, Colorado State University  
Steven Walter, Northrop Grumman Space Systems  
Bruce Wielicki, NASA's Langley Research Center  
David Winker, NASA's Langley Research Center

### *CloudSat Applications Advisory Group*

Gerald Schmidt, Naval Research Laboratory  
Lt. Col. Randy LeFevre, U.S. Air Force Airborne Laser System Program Office  
Christian Jakob, Bureau of Meteorology Research Centre, Australia  
John Zapotocny, U.S. Air Force Weather Agency  
Martin Miller, European Centre for Medium-range Weather Forecasting, United Kingdom  
Mitch Moncrieff, National Center for Atmospheric Research  
Arthur Hou, NASA's Goddard Space Flight Center  
Fuzhong Weng, Joint Center for Satellite Data Assimilation  
Warren Wiscombe, U.S. Department of Energy Atmospheric Radiation Measurements  
Program

# CALIPSO Satellite

CALIPSO's payload includes three co-aligned nadir-viewing instruments: the lidar instrument; an imaging infrared radiometer with three channels in the infrared window region optimized for retrievals of cirrus cloud particle size; and a wide-field camera, a moderate spatial resolution camera with one visible channel that provides a meteorological perspective and a way to accurately register or compare CALIPSO observations to those from the moderate resolution imaging spectroradiometer instrument on the Aqua satellite.

These instruments are designed to operate autonomously and continuously, although the wide-field camera acquires data only under daylight conditions.

The payload also includes several support systems: a payload controller and an X-band transmitter subsystem. The payload controller performs control and data handling functions for all three instruments as well as for the X-band transmitter, which is used to downlink instrument science and other data. The CALIPSO payload was built by Ball Aerospace & Technologies Corp., in Boulder, Colo.; the radiometer is provided by France's space agency, Centre National d'Etudes Spatiales.

## Lidar

CALIPSO's primary instrument is a three-channel polarization lidar (light detection and ranging instrument) that will provide unique information on clouds and aerosols. The instrument provides high-resolution vertical -- top to bottom -- profiles of aerosols and clouds. It consists of a laser transmitter subsystem and a receiver subsystem. While most satellite instruments are passive, observing scattered sunlight or emitted heat and try to infer the altitude and properties of aerosols and clouds, CALIPSO will use a laser to actively sense where they are located, similar to the way radar works.

The lidar uses three receiver channels: one measuring the 1064 nm backscatter intensity and two channels measuring orthogonally polarized components of the 532 nm backscattered signal. Dual 14-bit digitizers on each channel provide an effective 22-bit dynamic range. The receiver telescope is 1 meter in diameter. A redundant laser transmitter is included in the payload.

An active boresight system is employed to maintain co-alignment between the transmitter and the receiver.

Each laser is housed in its own sealed canister filled with dry air at approximately stan-

standard atmospheric pressure. The basin resonator design is relatively simple and has been proven in flight-hardened military systems.

A common mirror is used for both lasers, with two beams striking the mirror at different locations. The laser electronics are fully redundant, and cross strapping allows either electronics system to drive either optical head.

There are no threats to a ground observer or aircraft pilot or passenger from the CALIPSO lasers. The laser divergence was chosen to expose a ground observer to far below the maximum permissible exposure.

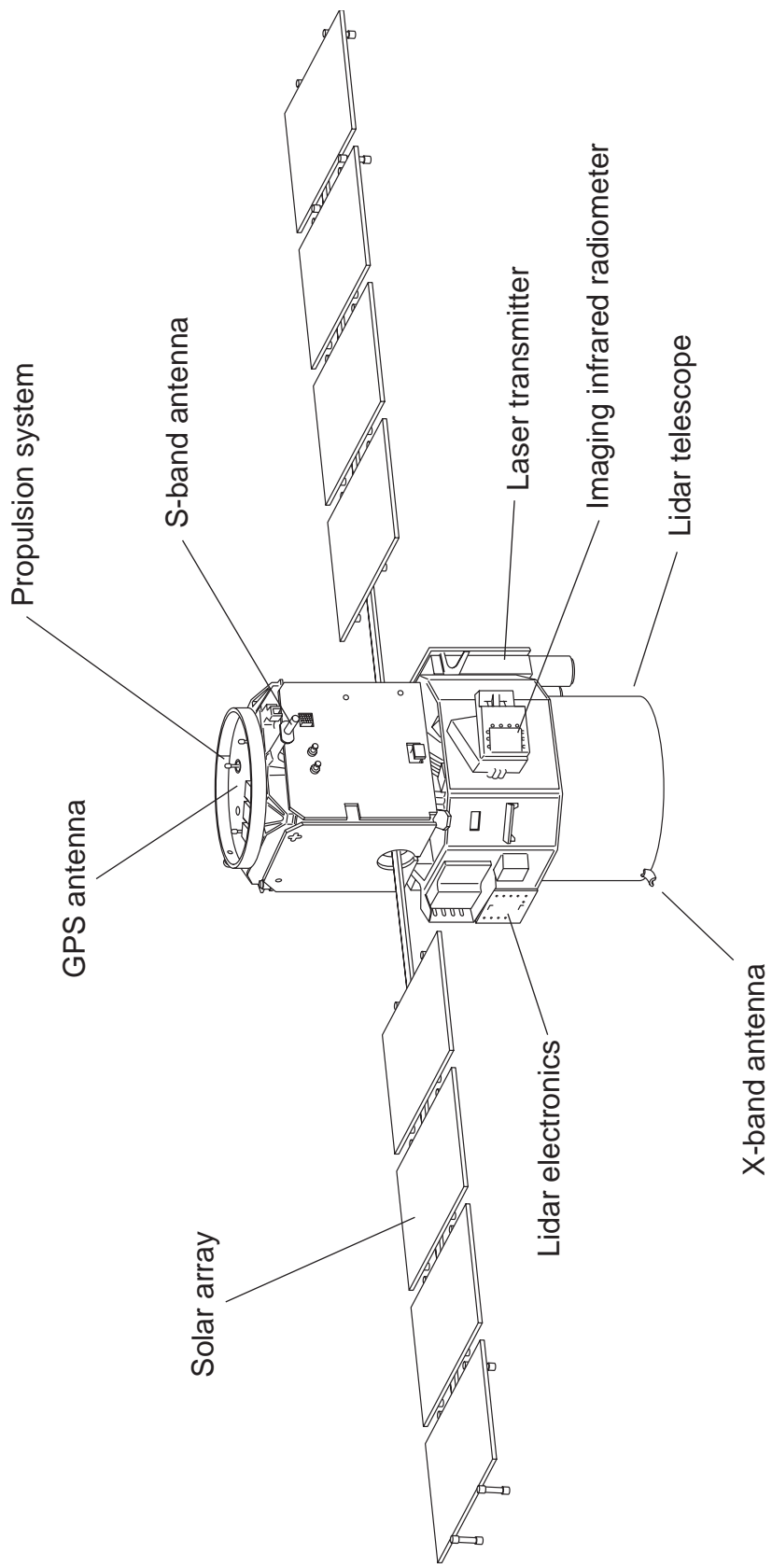
### **Imaging Infrared Radiometer**

Operating continuously, day or night, the radiometer will provide information on cirrus cloud particle size and infrared emissions activity -- looking at the top surface of a broad sweep of cloud area. The three-channel radiometer is provided by France's space agency with algorithm development performed by the Institute Pierre Simon Laplace in Paris. It has a nadir-viewing, non-scanning imager having a 64 km by 64 km "view" with a pixel size of 1 km. The lidar beam is nominally aligned with the center of the radiometer image.

The instrument uses a single microbolometer array or thermal detector, with a rotating filter wheel providing measurements at three channels in the thermal infrared window region at 8.7 microns, 10.5 microns, and 12.0 microns. These wavelengths were selected to optimize joint lidar-radiometer retrievals of cirrus cloud emission and particle size.

Sodern built the radiometer for CALIPSO and detection systems for many other missions including the Advanced Earth Observing Satellite and military missions. It is a two-channel uncooled thermal infrared radiometer that provides median-resolution digital images of the nadir regions sounded by the lidar. The radiometer consists of two single-channel infrared sensor modules integrated together with a black body source for calibration. Each infrared sensor module consists of a single box that includes optics, a detection module associated with front-end electronics, an electronics module performing the detector command and temperature control functions, a data processing chain, and the power supply

The instrument captures one frame every 4.8 seconds per channel to provide 100 percent coverage of the nadir track with 15 percent overlap between frames, giving a data rate of 20.5 kilobytes per second or the total of both channels.



CALIPSO satellite

## **Wide-Field Camera**

Camera data will be used to determine cloud uniformity and provide an overall meteorological view of the scanned area. The camera is a modified version of the commercial off-the-shelf Ball Aerospace & Technologies Corp.'s CT-633 star tracker digital camera—a rugged charged coupled device camera reducing the risk and cost. Its design has the benefit of a broad heritage of camera designs that have been built for space applications, including the Hubble Space Telescope advanced camera. It is a fixed, nadir-viewing imager with a single spectral channel covering the 620-670 nm region, selected to match band 1 of the moderate resolution imaging spectroradiometer instrument on Aqua for comparative purposes of a similar viewing field. The camera cuts a 61-km wide swath with a pixel resolution of 125 meters (410 feet). Pixels outside the central five-kilometer (3.1 mile) cross-track swath are averaged to produce low-resolution one-kilometer (0.6 mile) image samples. The camera only collects images during the daytime portion of the orbit.

## **Proteus Multi-Mission Platform**

After the science instruments completed a successful series of ground tests at Ball in late 2003, CALIPSO was shipped to the Alcatel Space facility in Cannes, France, where the U.S. and French payload was integrated into a Proteus spacecraft platform.

Proteus is designed to accommodate 500-kilogram (1,100-pound) satellites. The bus structure is the basic platform for the mission instruments and others required for the satellite to function. Proteus was developed by the French space agency to adapt to different, smaller instrument platforms and reduce mission design costs.

The Proteus spacecraft is cube-shaped -- nearly 1 meter (1.093 yards) per side -- with all the equipment units on four lateral panels and the lower plate. The interface with the launcher is through a specific adapter bolted to the bottom of the structure. The mechanical interface with the payload is provided through four corners of the platform. The Proteus is a highly redundant, low-risk spacecraft based on a mature technology with proven flight history. A previous NASA-CNES collaboration produced the JASON Earth-observing mission, which also employed the Proteus spacecraft JASON was launched in December 2001 and is operational today.

## **Proteus Subsystems**

The thermal control subsystem is sized to withstand the maximum thermal loads defined by the mission. Proteus uses passive second surface mirror radiators and active regulation with heaters being monitored by the central computer. To ensure the



safety and health of the payload, Proteus provides thermal control and heater power to the payload in all modes.

Electrical power is generated by two symmetrical solar wing arrays covered with silicon cells that provide 599 watts to 611 watts orbital average. The power is distributed through a single non-regulated primary electrical (23/36 volts) using a recurrent SPOT4 nickel-cadmium battery.

The Proteus flight software, designed using centralized architectures, has been designed with emphasis on producing a modular, adaptable and maintainable system that can be scaled according to spacecraft and payload requirements.

The primary functions of the data-handling unit are:

- Satellite modes management; automatic mode transitions and routines.
- Failure detection and recovery; monitors spacecraft health and switches to safe hold mode if necessary.
- On-board observability; generation, maintenance, and downlink of housekeeping telemetry data.
- Satellite command ability; consisting of management of "telecommands" sent by ground either to hardware or software.

The on-board command and data handling relies on a fully centralized system. It performs most of the tasks through the central processor running the satellite software. It also supports the management of the communication links.

It generates a clock reference, manages spacecraft data storage, and insures telemetry frame decoding. A maximum of 1,000 time-executable commands may be uplinked and stored in any given orbit pass, although many more may be uplinked.

# CALIPSO Science Objectives

The CALIPSO satellite mission objective is 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 create models to answer significant questions about climate processes and create a better understanding of global climate change.

Specific mission objectives:

- ❑ Atmospheric aerosols directly affect Earth's energy balance by absorbing, scattering and emitting solar and infrared radiation. Estimates of aerosol properties and activity can be made using models or, increasingly, directly from observations. CALIPSO will provide a global suite of measurements from which the first operationally based estimates of direct aerosol properties and uncertainties can be made. CALIPSO profiles will provide vertical information on aerosol distribution, extinction rate, hydration state, and discrimination of large and small particles. CALIPSO also offers an improved understanding of clouds ability to mask aerosols. These observations will allow improved assessments of the representation of aerosol distribution and properties in models. Use of CALIPSO observations, alone and together with other A-train observations, will allow improved aerosol activity and model-based assessments.
- ❑ Aerosols have an indirect radiative effect on clouds by modifying their reflective properties and life span. CALIPSO will dramatically improve the global and regional observations of these processes. Changes in aerosols can potentially affect cloud reflectance and lifetime, but there are many uncertainties in how effective these mechanisms are in the real world. Regional assessments based on global datasets are needed. CALIPSO profiles will provide information on the vertical location of aerosols and whether or not they are in contact with, and therefore able to influence, clouds. CALIPSO also offers improved data on cloud masking of aerosols and provide an opportunity to assess the possible aerosol variables; these introduce uncertainties in current assessments of indirect aerosol effects.
- ❑ The largest uncertainty in determining the balance of solar and thermal energy at Earth's surface is the effect of multi-layer clouds. Current global data of surface and atmospheric radiative changes contain significant uncertainties, largely due to the effects of clouds on radiation and in particular -- the effects of cloud multilayering. CALIPSO with the A-Train satellites will provide a systematic collection of multilayered cloud observations and significantly improve our knowledge of the radiation budget at the Earth's

surface. CALIPSO and CloudSat will provide comprehensive observations of cloud height, thickness and layering. Concurrent cloud observations from CALIPSO, CloudSat and other satellites will provide an opportunity to create a greatly improved dataset of surface and atmospheric radiative changes, particularly in the polar regions.

- Provide a new ability to assess the role of clouds in the climate system including the effects of thin cirrus, polar clouds, and multilayered clouds with information on their altitude, thickness, and optical and microphysical properties. The combined measurements of clouds, atmospheric properties and solar and infrared radiation will be a fundamental scientific advance in the ability to improve our understanding of global cloud-climate feedback mechanisms. The fundamental problem in modeling cloud-radiation feedbacks involves the prediction of cloud properties based on atmospheric conditions and then using these properties to compute radiative changes. Testing the models requires nearly simultaneous observations of clouds, radiation, and atmospheric state. Cloud profiles from CALIPSO and CloudSat will be combined with data from instruments on NASA's Aqua satellite on cloud properties, radiative changes and atmospheric state to provide the most complete closure of the cloud-radiation-atmospheric state feedback loop in the foreseeable future.

## **CALIPSO Science Team**

David Winker, NASA's Langley Research Center, *Principal Investigator*  
Steven Ackerman, University of Wisconsin-Madison  
Tad Anderson, University of Washington  
François-Marie Bréon, Laboratoire des Sciences du Climat et de l'Environnement, France  
Thomas Charlock, NASA's Langley Research Center  
Robert Charlson, University of Washington  
James Coakley, Oregon State University  
Pierre Flamant, Institut Pierre Simon Laplace, France  
Raymond Hoff, University of Maryland  
Chris Hostetler, NASA's Langley Research Center  
Yoram Kaufman, NASA's Goddard Space Flight Center  
Herve LeTreut, Institut Pierre Simon Laplace, France  
Norman Loeb, Hampton University  
Patrick McCormick, Hampton University  
Ali Omar, NASA's Langley Research Center  
Jacques Pelon, Institut Pierre Simon Laplace, France  
Mike Pitts, NASA's Langley Research Center  
Martin Platt, Colorado State University  
Lamont Poole, Science Applications International Corp.  
John Reagan, University of Arizona  
Ken Sassen, University of Alaska  
Graeme Stephens, Colorado State University  
Didier Tanre, Laboratoire d'Optique Atmospherique, France  
Chip Trepte, NASA's Langley Research Center  
Bruce Wielicki, NASA's Langley Research Center

# Why Study Clouds and Aerosols?

They are the scenery of dreams. At times serene, at other times violent, they have inspired, captivated and mystified us since the dawn of humanity. They can envelop us, blanket us in warmth, cool us down, deluge us, obscure our sight, or paint our landscape a snowy white. An ever-changing kaleidoscope of water made visible, they ride chariots of wind on a never-ending crusade, delivering the 2.5 percent of all water on Earth that is fresh to Earth's parched masses.

They are clouds, our seemingly familiar neighbors in the sky. We take them for granted much of the time, yet they play a vital role in shaping Earth's weather and climate. They are a key element of Earth's water cycle, providing our planet's only method of recycling the life-sustaining liquid that is rapidly becoming Earth's most critical natural resource and delivering it from the air to the ground. They also dominate Earth's energy budget through their influence on how much energy the planet absorbs from the sun and how much it reflects back into space.

Scientists have long studied these floating phantoms, yet despite tremendous advances in technology, much about clouds remains a mystery. Our current global perspective on clouds is based largely on measurements from satellites. Spacecraft already in orbit can tell us, for example, how much rain falls in the tropical atmosphere -- yet we still cannot estimate within a factor of two the mass of water and ice in these clouds, let alone how much of the water in clouds falls as rain or snow outside the tropics.

It would seem that when it comes to clouds, we have more questions than answers. What fraction of clouds worldwide cause precipitation that falls to the ground? How might clouds change as our climate changes? The list of questions is lengthy. Scientists believe that the main uncertainties in climate model simulations are due to the difficulties in adequately representing clouds and their radiative properties.

NASA's CloudSat mission aims to shed light on questions like these. The data gathered will improve both near-term weather forecasts and long-term climate forecasts, potentially saving lives and money. CloudSat will also help scientists determine if and why our climate is warming and what the long-term impacts of such change might be on both regional and global scales. And it will help us better manage our precious water resources by shedding new insights on where it's going to be raining in the future and where it will be dry.

A lead role in the mystery of clouds is played by aerosols -- small particles suspended in the atmosphere. Aerosols are the nuclei around which cloud droplets form; without them, cloud formation would be next to impossible in Earth's atmosphere. In the case of clouds made up of liquid water, if more aerosols are present, the cloud droplets that form are smaller and more numerous. As a result raindrops take longer to form, so the

clouds tend to last longer. Also, the smaller droplets tend to reflect more sunlight back to space and contribute to cooling of the underlying surface.

The impact of aerosols on society extends well beyond the realm of clouds. Aerosols also affect global climate in a direct way by reflecting or absorbing incoming solar radiation. They can also pose threats to public health. For example, the air quality on hot, stagnant summer days often reaches unhealthy levels, and the tiny aerosols present in such situations can aggravate or cause breathing problems. Aerosols can also threaten the safety of aviation by reducing visibility in heavily polluted areas.

The list of unanswered questions on aerosols is just as lengthy as that on clouds. How are human activities contributing to the amount and types of aerosols in the atmosphere? What types of aerosols are the best nuclei for forming clouds? How long do aerosols of different types persist in the atmosphere? CALIPSO, CloudSat's sister mission, will take direct aim on questions such as these.

### **CloudSat and CALIPSO: Revealing the Secrets of Clouds and Aerosols**

Together and separately, clouds and aerosols affect our climate in ways that are not completely understood. Clouds are a fundamental stage of Earth's water cycle, condensing water vapor and forming rain. They affect the amount of solar energy that reaches Earth, and the amount of energy that leaves Earth. They tend to cool Earth by reflecting sunlight back to space, while simultaneously warming the planet by absorbing and reemitting thermal radiation emitted by the surface and lower atmosphere. By modulating the distribution of heating within the atmosphere and at the surface, clouds fundamentally influence the circulations of the atmosphere and oceans. Shifts in this balance influence our climate. Aerosols affect where and how clouds form, and how much rain falls. Because we do not know enough about clouds and aerosols, there are uncertainties introduced into our predictions of climate change.

CloudSat and 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. Employing revolutionary measurement technologies, they will probe Earth's atmosphere as never before, fueling discoveries that will improve our weather and climate forecasts, while helping public policy makers and business leaders make more informed, long-term environmental decisions about public health and the economy.

The two missions will achieve a number of important scientific firsts:

- ❑ CloudSat and CALIPSO will provide the first statistics on the vertical structure of clouds. For the first time, we will see clouds from their tops to their bottoms -- like getting a CT scan of clouds from space.

- ❑ CloudSat and CALIPSO will provide the first indirect but validated estimate of how much clouds and aerosols contribute to the vertical distribution of atmospheric warming.
- ❑ CloudSat will provide the first global estimates of the percentage of Earth's clouds that produce rain.
- ❑ CloudSat will provide the first vertically sliced picture of how much water and ice are in Earth's clouds.
- ❑ CloudSat will provide the first ability to detect snowfall from space.
- ❑ CloudSat will provide the first estimates of how efficiently the atmosphere produces rain from condensates.
- ❑ CALIPSO will provide the first statistics on the global vertical distribution of aerosols and aerosol types.
- ❑ CALIPSO will reveal for the first time how often "subvisible" cirrus clouds -- very thin clouds invisible to the naked eye -- occur, and whether they change with the seasons.

### **Taking the A-Train**

Developed under NASA's Earth System Science Pathfinder program, the CloudSat and CALIPSO satellites will fly in orbit as part of what is known as the "A-Train" --a constellation of three other Earth Observing satellites, including NASA's Aqua and Aura and France's PARASOL satellite. CloudSat and CALIPSO will fly as even closer partners in formation, with CloudSat closely tracking CALIPSO. Adjustments to CloudSat's orbit are expected to happen around once per week to maintain its relative position with CALIPSO.

The usefulness of data from CloudSat, CALIPSO and the other satellites of the A-train will be much greater when combined. Joint observations will allow scientists to better understand the impact of aerosols on climate, and how sources of local pollution affect air quality. The combined set of measurements will also provide new insight into the distribution and evolution of clouds over the globe that will lead to improvements in weather forecasting and climate prediction. The data will be used to study interactions between aerosols and clouds that may change the amount of sunlight they reflect and absorb, or enhance or suppress rainfall: subjects of current scientific debate.

### **Anatomy of a Cloud**

Clouds consist of billions of tiny, visible liquid water droplets and/or ice crystals suspended in the atmosphere. As long as these water droplets and ice crystals are small,

they remain suspended in the cloud. For clouds to form, moisture is needed in the form of water vapor, which enters the atmosphere via either evaporation of water from Earth's surface or from tiny openings on the leaves of plants as they "breathe" -- a process known as evapotranspiration. Indeed, if little moisture is available, it is unlikely that clouds will form.

But the presence of water vapor by itself, in the atmosphere is not enough to form a cloud. Also needed are very small particles for the water vapor to condense around - "seeds," so to speak. When water vapor condenses on the particles as a liquid, these tiny solid or liquid particles are called cloud condensation nuclei. If water vapor directly attaches to them in the form of ice, the particles are called ice nuclei. This usually happens when the temperature is well below 0 degrees Celsius (32 degrees Fahrenheit).

The nuclei that form the seeds for both condensation and ice consist of small particles called aerosols. Indeed, if there were no aerosols in the atmosphere, there would be no clouds. A typical size for an aerosol particle is on the order of 1/1,000,000th of a centimeter in diameter. Although aerosols that act as cloud condensation nuclei are abundant, ice nuclei are much rarer.

Some aerosols occur naturally, originating from volcanoes, dust storms, forest and grassland fires, biological activity and sea spray. In addition to these sources, human activities, such as the burning of fossil fuels or human-set fires, can generate concentrations of aerosols far in excess of natural sources.

As aerosol concentration increases inside a cloud, the water in the cloud gets spread over many more particles, which become progressively smaller. Smaller particles fall more slowly in the atmosphere and decrease the amount of rainfall. Clouds with smaller drops also reflect more sunlight and last longer, because it takes more time for small drops to fatten into drops that are large enough to fall to the ground. For these reasons, changes in the aerosols in the atmosphere can change the frequency of cloud occurrence, cloud thickness and rainfall amounts.

Clouds usually form when a portion of air, called a "parcel," becomes saturated, or full of water. This can happen when the wind moves enough moisture into a parcel of air through a process called moisture transport. But it can also happen if a parcel of air that initially is unsaturated is lifted to a higher altitude.

As the parcel rises through the atmosphere, it expands and it gets colder. Cooler air cannot hold as much moisture as warmer air and so, eventually, the humidity of the parcel reaches 100 percent. The temperature at which this occurs is called the dew point. When an air parcel cools to its dew point, excess water vapor condenses on aerosol particles, causing cloud droplets to form. As the parcel keeps rising, more water condenses and the cloud droplets grow in size. If they get large enough, they fall out of the cloud as rain.



Knowing the water content of cloudy air is fundamental to predicting cloud evolution and other key properties of clouds. For example, cloud particles grow at a rate proportional to the water content. Also, the ways that clouds radiate heat energy are directly related to the clouds' water content.

The character and movement of clouds are primarily governed by the large-scale circulation of the atmosphere and are one of the main features of weather systems. Motions of cloud masses trace the circulation patterns of the atmosphere. By tracking movements of individual cloud elements, we can also determine fields of winds.

### **Clouds and the Water Cycle**

Fresh water is a truly precious resource, and clouds play a key role in the cycling of water over the planet. Of the small amount of fresh water on Earth, two-thirds is locked away in ice caps at the poles. The remaining fresh water is found in lakes, rivers and in underground reservoirs. If our world had no clouds, there would be no way to replenish these reservoirs of fresh water.

Driven by the sun's energy, water cycles continuously throughout the Earth system, rising from oceans, lakes and the land surface as water vapor into the atmosphere, cooling and forming into clouds -- which are transported by air currents around the globe, and eventually falling from clouds back to Earth's surface as rain or snow. Snow can accumulate as ice caps and glaciers, which can store frozen water for thousands of years. Snow packs in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt. Most precipitation falls back into the oceans or onto land where, due to gravity, the precipitation flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with stream flow moving water toward the oceans. Runoff and ground-water seepage accumulate and are stored as freshwater in lakes.

Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration. Some of this water stays close to the land surface and can seep back into surface-water bodies and the ocean as ground-water discharge. Some ground water finds openings in the land surface and emerges as freshwater springs. Shallow ground water is taken up by the roots of plants and is transpired from the surfaces of leaves back into the atmosphere. Some water infiltrating into the ground goes deeper and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time. Over time, though, this water keeps moving, some to reenter the ocean, where the water cycle ends and begins anew.

### **Cloud Formation Processes**

As air rises in the atmosphere, it cools at an average rate of 10 degrees Celsius (18 degrees Fahrenheit) per 1,000 meters (3,281 feet). There are several different mecha-

nisms that could cause air to rise. These include: convective lifting, orographic lifting, low-level convergence and overrunning.

□ **Convective Lifting.** When a parcel of air is heated by the surface, becoming warmer than the surrounding atmosphere and starting to rise, this is called "convection." When the sun heats Earth, the air parcel begins to rise up from the warm surface, cooling and expanding as it rises. The parcel becomes diluted as it mixes with the surrounding air, losing some of its buoyancy. However, each successive parcel following the same path rises a little further than the previous one, and if a parcel is able to rise high enough so that it cools to its dew point, the moisture within condenses and becomes visible as a cloud. If the process continues long enough, the clouds can grow and produce rain.

Convection is more likely to occur under certain atmospheric conditions. Sometimes the atmosphere is marked by a relative slow decrease in temperature (or even a temperature increase) with height, and we say the atmosphere is stable. A stable atmosphere is resistant to change. If an air parcel is given an initial upward "push" in a stable air mass, it will tend to return to its original position -- growth of large convective clouds cannot easily occur in this environment.

On the other hand, sometimes temperature in the atmosphere decreases relatively quickly with height and we say the atmosphere is unstable. If a parcel of air is given an initial upward thrust in this environment, it will tend to continue to rise. An unstable atmosphere allows for the development of large convective clouds like those we see during thunderstorms.

Clouds that form in this manner are cumulus-type clouds, sometimes called clouds of vertical extent. They include the fair weather cumulus humilis, as well as the thundercloud, cumulonimbus.

□ **Orographic Lifting.** When air encounters a mountain, it cannot simply go through it. The air is forced up the mountain -- a process called "orographic lifting." The air cools as it travels up the mountain, and if it cools to its dew point, the water vapor condenses and a cloud forms. If the air is unstable, these clouds can be of the cumulus type; if the air is stable, clouds can be stratiform. 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 cumuliform clouds.

Often, rain will fall on the side of the mountain that faces toward the wind (the windward side) and it will be very dry on the other side of the mountain (the leeward side).

- ❑ **Low-Level Convergence.** When moisture moves horizontally into a region -- a process called advection -- the horizontal flow of air bunches up along Earth's surface. That air must go somewhere and since it's not able to go into the ground, it can only go up. Large-scale convergence lifts an entire layer of air -- sometimes hundreds of kilometers across. The air cools as it rises, and if the rising air cools to its saturation point, the water vapor will condense out to form cloud droplets. Convergence often occurs as the leading edge of air masses of different temperature and moisture content interact with each other -- what we represent as warm fronts and cold fronts on weather maps.

Like orographic clouds, the type of clouds that form depend on the stability of the atmosphere. As a cold front progresses, the advancing cold air lifts the warm moist air ahead of it. The rising air is cooled and the water vapor condenses to form clouds, typically ahead of and along the cold front. Strong lifting often occurs along a cold front, resulting in more vertically developed (convective) clouds.

In contrast, lifting along a warm front is different than what takes place along a cold front. As the warm air nudges against the colder, denser air mass ahead of it, warmer air behind the front is forced up and over the frontal surface and over the colder air ahead of it. The lifted air cools, and the water vapor condenses to form clouds in advance of the front. The lifting along a warm front is gentler than the lifting that occurs along a cold front. Consequently, warm frontal clouds are more widespread and less vertically developed. These clouds are sometimes observed up to a thousand kilometers in advance of an approach warm front.

- ❑ **Overrunning.** Sometimes a dome of cold air exists near Earth's surface. Because this air is so dense, warm air trying to replace it is forced over the top. This is called "overrunning."

## Cloud Types

Clouds are classified into a system that uses Latin words to describe the appearance of clouds as seen by an observer on the ground. The four basic types or families are cirrus (wispy), stratus (layered), cumulus (heap) and nimbus (rain). Clouds are further classified by the height of their bases.

- ❑ High cloud types include cirrus, cirrocumulus and cirrostratus. The name **cirrus** is Latin for a curl of hair. These are ice clouds and are found at altitudes ranging from 6,096 to 12,192 meters (20,000 to 40,000 feet). Cirrus is the wispy tail-type cloud usually associated with nice weather, but which sometimes indicate the approach of a front. Contrails (condensation trails) are a type of cirrus caused by aircraft. It is thought they may have an effect on climate change. Cirrocumulus are a type of cumulus cloud based high in the

atmosphere. They indicate great instability at that level. Cirrostratus are thin, sheet-like clouds of ice crystals. They are the first clouds to precede a warm front in an overrunning situation and are indicative of eventual rain or snow.

- ❑ The word **stratus** comes from the Latin word meaning "to spread out." These low clouds range from Earth's surface to an altitude of 2,591 meters (8,500 feet). These are horizontal, layered clouds that cover the sky like a blanket. Stratus clouds often form at the boundary where layers of warm, moist air pass over layers of cool air, warming the cool air, causing the excess water vapor to condense to form a layer of stratus clouds. Low clouds include stratus, stratocumulus and nimbostratus.
- ❑ Clouds that extend mostly vertically (with a small horizontal diameter) have the word **cumulus**, which comes from the Latin word for a heap or pile. These puffy, cotton-ball-like clouds are generated through either thermal convection or frontal lifting, they can grow to heights in excess of 12,000 meters (39,000 feet). They are capable of releasing tremendous amounts of energy through condensation of water vapor within the clouds themselves. Cumulonimbus clouds are those commonly associated with thunderstorm activity.
- ❑ Nimbus comes from the Latin word meaning "rain." Nimbus clouds are rain clouds.

## Clouds and Climate

The role of clouds in climate is significant and complex. Even small changes in the abundance or distribution of clouds could alter the climate more than the anticipated changes caused by greenhouse gases or aerosols.

Earth is constantly bombarded by energy from the sun. Earth's climate system constantly tries to maintain a balance between the energy that reaches Earth from the sun and the energy that goes from Earth back out to space. Scientists refer to this process as Earth's "radiation budget." The components of the Earth system that are important to the radiation budget are the planet's surface, atmosphere and clouds.

Cloud systems regulate variations in incoming solar radiation over Earth's surface and play an important role in distributing solar energy evenly across the surface. As storms move across the planet, excess energy that builds up in the tropics is spread toward the poles.

The energy coming from the sun to Earth's surface is called solar or "shortwave" energy, because most of it is in the form of the shorter wavelengths of electromagnetic radiation -- those responsible for the visible light detected by our eyes. Both the amount of energy and the wavelengths at which energy is emitted by any body depend on the

average temperature of the body's radiating surfaces. The sun's energy is emitted in all directions, with only a small fraction directed toward Earth.

Energy goes back to space from the Earth system in two ways: reflection and emission. Part of the solar energy that comes to Earth is reflected back out to space at the same, short wavelengths in which it came to Earth. The fraction of solar energy reflected back to space is called the "albedo."

Different parts of Earth have different albedos. For example, ocean surfaces and rain forests have low albedos, which means that they reflect only a small portion of the sun's energy -- informally, we think of them as "dark." Deserts and clouds, however, have high albedos, and they reflect a large portion of the sun's energy; we think of them as "light." Over the whole surface of Earth, about 30 percent of incoming solar energy is reflected back to space.

Clouds in the atmosphere help to moderate Earth's temperature. Some clouds cool Earth by reflecting solar energy back to space. Other clouds warm Earth by acting like a blanket and trapping radiation emitted by Earth's surface and lower atmosphere; this energy is called thermal energy, infrared energy or longwave radiation. The balance between how much energy a cloud reflects back into space, and how much energy it traps, will dictate whether any given cloud type will add to the air's natural warming of Earth's surface or produce a cooling effect. The effect of clouds on climate depends on the competition between the reflection of incoming solar radiation and the absorption of Earth's outgoing infrared radiation.

High-altitude clouds such as cirrus clouds are significantly colder than Earth's surface beneath them, and are typically composed of ice crystals that come in a variety of shapes and sizes. They tend to have what scientists call "low optical depth values," meaning that they don't block much of the sun's incoming radiation. However, high clouds absorb some of Earth's outgoing radiation (from the warmer atmosphere and surface below) and then re-radiate the energy at a lower rate than the surface or underlying atmosphere (because the high clouds have a much lower temperature). Therefore, the overall impact of high-altitude clouds is to warm the planet.

Most low-altitude clouds such as stratus clouds have temperatures close to the temperature of the surface beneath them, and are typically composed of water droplets. They tend to have what scientists call high optical depth values -- meaning that they block a significant portion of the sun's incoming radiation. But because they are relatively warm, they absorb and re-radiate at about the same temperature as the surface below the cloud. Therefore, they don't significantly impact the radiation given off by Earth's surface. The overall impact of low-altitude clouds is to cool the planet, based on their high optical-depth values.

Deep convective clouds are neutral. Typical of these are cumulonimbus clouds, which can be many kilometers thick, with a base near Earth's surface and a top frequently

reaching an altitude of 10 kilometers (33,000 feet), and sometimes much higher. Because the tops of cumulonimbus clouds are high and cold, the energy radiated to outer space is lower than it would be without the cloud. But because they are also very thick, they reflect much of the solar energy back to space. Thus, with a reduced amount of solar energy to be absorbed, there is essentially no excess radiation to be trapped. As a result, the cloud's tendencies to reflect or trap heat almost balance, and the overall effect of cumulonimbus clouds is neutral -- neither warming nor cooling. Nonetheless, the presence of the cloud vertically redistributes energy in the atmosphere; that is, the energy distribution due to the presence of the cloud is different than a clear sky.

In a global sense, then, determining the net effect of clouds on Earth's energy balance is difficult because so many factors have to be considered: the height distribution of the clouds, the optical depth of the cloud, the size and shape of the condensed particles within the cloud, the amount of water and/or ice the cloud contains, and how much of Earth's surface the cloud covers. Research to date suggests that, globally averaged, the overall cooling caused by clouds is more powerful than the warming they cause, but there is still much we don't understand about how clouds behave and how this balance might shift in the future.

Another reason modeling clouds is difficult is that clouds change almost instantaneously compared to the rest of the climate system. For example, cumulus clouds can form in a matter of minutes, even seconds, and the entire life cycle of a massive thunderstorm plays out within a few hours. Not only that, but the impact of a cloud system can extend across a much smaller region than other climate effects. A thunderstorm might only impact tens of miles of the Earth's surface during its life cycle. Most models that scientists use aren't well equipped to represent phenomena that change so rapidly or impact such a small portion of Earth at any given time.

Cloudiness -- which is to say, the proportion of the sky covered by any form of cloud -- is one of the elements of climate. The cloudiness of the United States averages somewhat less than 50 percent. The Great Lakes region and the coast of Washington and Oregon have the greatest cloudiness (60 to 70 percent), while the Southwestern United States is the least cloudy region (10 to 30 percent).

### **Clouds and Climate Models: Finding the Silver Lining**

Weather and climate models -- the prediction tools scientists use to study the Earth system -- are complicated, and the information scientists use to build models of clouds and their properties is incomplete. Models represent clouds as fields of liquid and frozen water with equations that describe their essential processes. These equations contain significant approximations that cannot be tested on a global scale. It is for these reasons that scientists believe that the main uncertainties in current climate model simulations are due to the difficulties we have in adequately representing clouds and their radiative properties.

One of the main reasons predictions of climate warming vary from model to model is the different ways the models specify how clouds are vertically distributed and overlap. The vertical distribution and overlap of cloud layers influence both the magnitude and vertical profile of heating in the atmosphere. Heating by high cloud layers in the tropical atmosphere exerts a dominant influence on the large-scale circulation of the atmosphere. The vertical distribution of clouds assumed in models also influences the predicted precipitation.

Direct measurements of the vertical structure of clouds have, until now, been limited to a few ground-based sites. More indirect efforts to obtain a global-scale view of vertical cloud structure rely on water vapor variations observed in global weather balloon data and on limited surface-based cloud radar data. Studies have shown that overlapping cloud layers occur about 40 percent of the time but vary from less than 10 percent over deserts and mountains to more than 80 percent in tropical convective regions.

### **What Will CloudSat Do?**

CloudSat will provide the first global survey of cloud properties that are critical for understanding their effects on both weather and climate. These cloud properties are not obtainable from current satellite measurement systems. The mission's primary science goal is to furnish data needed to evaluate and improve the way clouds are shown in global models -- thus contributing to improved predictions of weather, climate and a poorly understood problem of feedback between clouds and climate. CloudSat will provide new ways of examining relationships between clouds and other properties of the atmosphere that are important for understanding Earth's hydrological cycle. The key observations are vertical profiles of cloud liquid water and ice water contents, and related properties of clouds.

CloudSat flies the first satellite-based radar functioning at a wavelength of about a millimeter- an instrument that is more than 1,000 times more sensitive than existing weather radars. Unlike ground-based weather radars that use longer wavelengths to detect raindrop-size particles, the CloudSat radar will allow us to detect much smaller particles of liquid water and ice that make up the large cloud masses that shape our weather. We will be able to see processes that convert the tiny condensed cloud particles to precipitation. From the observations of clouds we hope to learn how to improve on our ability to predict where and why clouds form and how much water condenses in them. This is essential for understanding how the water cycle works, how much fresh water is supplied to our reservoirs and why this supply might change in the future. CloudSat observations will also allow us to predict the effects of clouds on our climate and their effects on possible climate change.

CloudSat's cloud profiling radar will "see" into clouds, like a physician using sophisticated diagnostic tools to examine the human body, providing a vertical, cross-sectional view of clouds and furnishing new meteorological data types including cloud-layer

thickness, cloud top and base altitudes, cloud optical properties and cloud water and ice content.

Another important benefit of CloudSat is its potential use by the U.S. military. There are many areas of study within the U.S. Air Force and other branches of the Department of Defense for which CloudSat data could prove to be beneficial. The U.S. Air Force Weather Agency plays an active role in advising the CloudSat science team on the use of data products for operational user applications. Some examples of data of interest to the Defense Department that CloudSat can supply are cloud cover and layering, slant range visibility and severe weather. Other potential uses of CloudSat's cloud-profiling radar data include detection of light rainfall over land and better accounting for the effects of soil moisture in numerical weather prediction models. CloudSat measurements used together with other A-Train satellite data can be used to improve our understanding of aircraft icing. In addition, the vertical profiles of cloud optical properties can be analyzed, helping to improve the performance of optical systems onboard crewed and robotic aircraft and missiles.

### **Aerosol Sources and Types**

"Aerosol" is a word scientists use to describe a myriad of small liquid or solid particles suspended in the atmosphere. Aerosols typically range in size from around 10 nanometers (10 billionths of a meter) to around 100 micrometers (100 millionths of a meter). Aerosols in the lower part of the atmosphere normally last for only several days before being washed out by rain or by falling out of the atmosphere due to gravity. In the upper parts of the atmosphere, aerosols can persist much longer.

There are many examples of aerosols created as a result of natural processes. Pollen from trees and other plants, mold spores, and airborne bacteria and viruses are examples of biogenic aerosols -- ones that result from activities of living things. Volcanic eruptions release tons of aerosols into the atmosphere. Particularly violent eruptions can propel these particles into the stratosphere, where they can persist for several years. Wind blowing across the open ocean creates a constant blanket of salty sea spray aerosols over the ocean surface. In a similar vein, sand and dust particles are swept up by winds from the surface of Earth's deserts and are often carried to distant parts of the globe.

Today, we are especially concerned with aerosols that are produced by human activities. Major cities produce large amounts of pollution aerosols as a result of industrial activity and automobile emissions. The burning of fossil fuels (primarily oil and coal) to produce energy emits large quantities of aerosols into the atmosphere. It should come as no surprise that the concentration of pollution aerosols is highest near industrial regions in the northern hemisphere. Fires set by humans around the world for agricultural purposes, such as clearing cropland, are also major sources of what are called biomass burning aerosols.



## **Aerosols and Climate**

Aerosols have a direct effect on Earth's climate because they scatter incoming solar radiation, which as a result cools the surface immediately below. The amount of cooling depends on the size, shape and chemical composition of the aerosols, as well as the type of underlying surface. Some aerosols, such as black-carbon aerosols and some mineral-based aerosols, can also absorb incoming sunlight and warm the surrounding atmosphere, especially over bright surfaces such as snow or desert.

Aerosols also indirectly influence climate through their influence on the properties of clouds. Cloud droplets in Earth's atmosphere form on pre-existing aerosol nuclei. The droplets grow, collide and coagulate until they grow large enough to fall as raindrops. If the amount of aerosols in the cloud is relatively low, the cloud will consist of relatively fewer but larger droplets. If the amount of aerosols is increased, the cloud droplets that form tend to be smaller and more numerous; it takes longer for raindrops to form, and the clouds last longer. Clouds consisting of smaller droplets also reflect more sunlight back to space and contribute to increased cooling of the underlying surface. More recently it has been discovered that aerosols that absorb sunlight can actually suppress the formation of clouds by elevating the atmospheric temperature and, thus, preventing the condensation of water vapor.

Predicting the climate effects of aerosols using mathematical models is difficult for many reasons. Scientists need to know their size and shape as well as their chemical composition. To further complicate matters, all of these properties can and do change with time, such as when mineral-based desert dust moves over an urban area and black-carbon based aerosols attach to the mineral core. Scientists also need to know the altitude of aerosol layers to better understand aerosol lifetimes, their source, and their radiative interaction with nearby cloud layers. Unlike greenhouse gases, the effects of aerosols tend to be localized and larger near their source regions, which makes it difficult to estimate the net global impact of aerosols on climate.

## **Aerosols and Human Health and Safety**

Aerosols can have serious impacts on society, such as threatening public health. On hot, stagnant summer days, the air quality over urban areas often deteriorates to unhealthy levels, and aerosols are a primary component of the dangerous mix. Tiny aerosols with diameters less than 2.5 micrometers (2.5 millionths of a meter) can penetrate deep into human lungs and aggravate or cause breathing problems. The risk is especially high for the elderly and the very young.

Aerosols can also threaten the safety of aviation. Visibility is often greatly reduced in polluted areas. In the event of volcanic eruptions, airplanes are re-routed around the aerosol plumes to avoid the possibility of damaging particles being ingested into jet engines.

More recently, it has been shown that viruses can be moved over thousands of miles as passengers on wind-driven desert dust aerosols.

### **What Will CALIPSO Do?**

CALIPSO will help determine the altitudes and composition of clouds, and estimate the abundance and sources of aerosols creating a global set of measurements. With its main lidar (light detection and ranging) instrument, CALIPSO will send short pulses of laser light toward Earth. The laser transmitter and mirror telescope-like receiver will actively observe scattered sunlight or emitted heat and determine the altitude and unique properties of aerosols and clouds. Scientists will then be able to create more advanced models to answer important questions about climate processes and create a better understanding of global climate change.

Other benefits from studying aerosols could be a potential gain to aviation safety. Improvements to wind and clear-air turbulence forecasts and the identification of potential aircraft icing zones could help provide more accurate real-time cockpit weather information.

There is a considerable amount of documentation of the growth of greenhouse gases over the last two centuries and practically none for aerosols. With increases in greenhouse gases and changes in the stratosphere's ozone layer, a continuing rise in the average global temperature, and as human activity continues to influence the Earth and its atmosphere, long-term measurements and studies are needed to create a better understanding of aerosols, their influence on clouds and the atmosphere, and its part in global climate change.

Before CALIPSO, the first time this type of lidar laser system flew in space was in the cargo bay of the space shuttle Discovery in September 1994. The Lidar In-space Technology Experiment, or LITE, was developed as part of a NASA initiative to explore applications of space-based lidar and to develop active sensing techniques for Earth science studies. NASA's Ice, Cloud and Land Elevation Satellite, or ICESat, launched in 2003 and currently operationing, also takes intermittent lidar measurements. While it provides some information on clouds and aerosols, its primary focus is on measuring the height of the polar ice sheets.

CALIPSO builds on the LITE and ICESat missions by flying a more advanced space-based lidar system on a satellite in low Earth orbit that provides ongoing, daily coverage of global cloud characteristics and aerosols created by dust storms, biomass burning and urban pollution. A permanent instrument in space allows scientists to measure how many aerosols, both natural and human-made, are in the global atmosphere on a daily basis.

CALIPSO's innovative lidar and imaging system also provides valuable information on the vertical layering of clouds and the ability to identify clouds composed of ice and

water droplets. CALIPSO's lidar will further allow it to detect thin clouds that are invisible to radar, and sometimes to the human eye. This information, together with observations from the other A-Train satellites, will help scientists to better understand how clouds form and how they affect the climate.

# Program/Project Management

The CloudSat mission is managed for NASA's Science Mission Directorate, Washington, by the NASA's Jet Propulsion Laboratory (JPL), Pasadena, Calif. The CALIPSO mission is managed for NASA's Science Mission Directorate jointly by NASA's Langley Research Center (LaRC), Hampton, Va. and Goddard Space Flight Center (GSFC), Greenbelt, Md.

At NASA Headquarters, Dr. Mary Cleave is associate administrator for the Science Mission Directorate. Dr. Colleen Hartman is deputy associate administrator for the Science Mission Directorate. Dr. Jack Kaye is director of the Research and Analysis Program, Earth-Sun System, Science Mission Directorate. Dr. Stephen Volz is the CloudSat-CALIPSO program executive. Dr. Donald Anderson is the CloudSat-CALIPSO program scientist.

At the JPL, Thomas Livermore is the CloudSat project manager. Dr. Deborah Vane is the CloudSat deputy principal investigator. The California Institute of Technology, Pasadena, Calif., manages JPL for NASA.

At Colorado State University, Fort Collins, Colo., Dr. Graeme Stephens is the CloudSat principal investigator.

At the Canadian Space Agency, Montreal, Canada, Dr. Rejean Michaud is the CloudSat Canadian science program manager.

At GSFC, Dale Schulz is CALIPSO project manager. At LaRC, Dr. David Winker is the CALIPSO principal investigator.

At Hampton University, Hampton, Va., Dr. M. Patrick McCormick is a CALIPSO co-principal investigator.

At the Institut Pierre Simon Laplace, Paris, France, Dr. Jacques Pelon is a CALIPSO co-principal investigator.