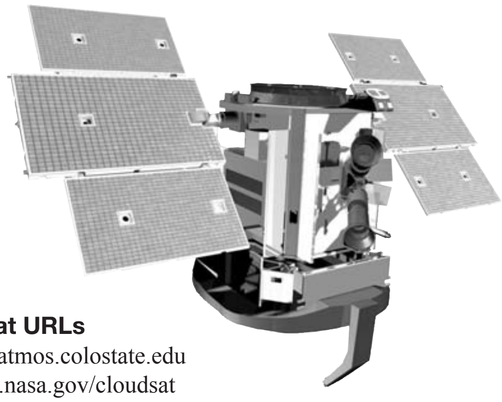
CloudSat



CloudSat URLs
cloudsat.atmos.colostate.edu
essp.gsfc.nasa.gov/cloudsat
cloudsat.cira.colostate.edu

Key CloudSat Facts

Joint with Canada

Orbit:
Type: Sun-synchronous
Altitude: 705 km
Inclination: 98.2°
Period: 99 minutes
Repeat Cycle: 16 days

Dimensions: 2.3 m × 2.3 m × 2.8 m

Mass: 999 kg

Power: 700 W

Downlink: S-band to U.S. Air Force antenna network

Mission Life: 22 months

Design Life: 3 years

Contributors

Canadian Space Agency (CSA), U.S. Air Force (USAF), U.S. Department of Energy (DOE)

Summary

CloudSat will study clouds in detail to better characterize the role they play in regulating Earth's climate. CloudSat will provide the first direct, global survey of the vertical structure and overlap of cloud systems and their liquid- and ice-water contents. Data returned should lead to improved cloud representations in atmospheric models, which should help improve the accuracy of weather forecasts and climate predictions made using these models.

Instrument

Cloud Profiling Radar (CPR)

Points of Contact

- *CloudSat Principal Investigator:* Graeme Stephens, Colorado State University
- *CloudSat Deputy Principal Investigator:* Deborah Vane, NASA Jet Propulsion Laboratory/California Institute of Technology

Other Key Personnel

- *CloudSat Program Scientist:* Donald Anderson, NASA Headquarters
- *CloudSat Program Executive:* Steve Volz, NASA Headquarters
- *CloudSat Project Manager:* Thomas Livermore, NASA Jet Propulsion Laboratory/California Institute of Technology

Mission Type

Earth Observing System (EOS) Exploratory Mission (Earth System Science Pathfinder)

Launch

Date and Location: April 28, 2006 (shared launch with CALIPSO), from Vandenberg Air Force Base, California

Vehicle: Delta II rocket

Relevant Science Focus Areas

(see NASA's Earth Science Program section)

- Climate Variability and Change
- Weather

Related Applications

(see Applied Sciences Program section)

- Aviation

Also valuable for weather prediction

CloudSat Science Goals

Profile the vertical structure of clouds: Understanding the vertical structure of clouds is fundamentally important to improving our understanding of how clouds affect both the local and large-scale environment.

Measure the profiles of cloud liquid water and ice water content: These two quantities—predicted by cloud process and global scale models alike—determine practically all other cloud properties, including precipitation and cloud optical properties.

Measure profiles of cloud optical properties: These measurements, when combined with water and ice content information, provide critical tests of key cloud process parameterizations and enable the estimation of flux profiles and radiative heating rates through the atmospheric column.

CloudSat Mission Background

Clouds and their properties are inadequately represented in climate models, leading to continued uncertainty in the prediction of global warming with increasing carbon dioxide (CO_2). Even small changes in abundance or distribution of clouds can profoundly alter the climate response to changes in greenhouse gases. Clouds also influence climate by affecting the efficiency at which the hydrological cycle operates.

One of the main reasons model predictions of climate warming vary from model to model is the different ways models specify vertical cloud distributions and overlap. The vertical distribution and overlap of cloud layers directly determine both the magnitude and vertical profile of heating in the atmosphere. The heating by high cloud layers in the tropical atmosphere exerts a dominant influence on the large-scale, 'Hadley' 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.

CloudSat will provide the observations necessary to advance our understanding of these issues. It will provide the first direct measurements of cloud vertical structure on a global basis. CloudSat will also measure the profiles of cloud liquid-water and ice-water content (microphysical properties) and will match these microphysical properties to cloud optical properties. This matching is a critical test of key parameterizations in models that enable calculation of flux profiles and radiative heating rates throughout the atmosphere.

CloudSat data will provide a rich source of information for evaluating cloud properties derived from other satellite data. CloudSat will fly as part of the A-Train of satellites including four other NASA missions—Aqua, Aura, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), and eventually the Orbiting Carbon Observatory (OCO)—as well as a French Centre National d'Etudes Spatiales (CNES) mission called Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL). This combination of observations offers an unprecedented resource for exploring aerosol-chemistry-cloud interactions.

CPR

Cloud Profiling Radar

CPR is a 94-GHz radar with 500-m vertical resolution. The radar sends out a pulse and receives a return signal. Because the 94-GHz signal is not strongly attenuated by most clouds, the radar should be able to detect more than 90% of all ice clouds and 80% of all water clouds.

CloudSat will utilize a 94-GHz Cloud Profiling Radar to obtain measurements of cloud properties. Cloud radars now operate routinely or quasi-routinely at a number of surface sites worldwide and are also deployed on a number of research aircraft. Measurements collected by these instruments provide a rich heritage for the CloudSat radar.

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 attenuation, available power delivered to the system, the orbit altitude, and radar technology. Increasing the antenna size and increasing transmitter output power are both ways to increase the power received. The antenna diameter of 1.85 m is limited by launch 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 attenuation. Cloud reflectivity increases with increasing radar frequency but atmospheric attenuation becomes prohibitive at higher frequencies. From these considerations, the operating frequency of 94 GHz is an optimum compromise and provides an increase of more than 30 dB over the 14-GHz Tropical Rainfall Measuring Mission (TRMM) radar. An international frequency allocation of 94 GHz has been established for spaceborne radar use.

Sensitivity is also related to the pulse length. The radar uses 3.3-µs pulses providing cloud and precipitation information with a 500-m vertical range resolution between the surface and 25 km. The radar measurements along-track are averaged by the on-board data processor over 0.16 s intervals, producing an oblong effective footprint of 1.4 km × 1.8 km. The radar data can be further averaged in ground processing to 0.48 s, increasing the effective footprint in the along-track dimension to 3.8 km. This provides the averaging needed to achieve the required sensitivity.

CPR will be sensitive enough to detect the majority of clouds that significantly affect the radiation budget and critical elements of the water budget of the atmosphere. CPR is expected to detect 90% of all ice clouds and 80%

of all water clouds. Other sensors that are flying or will fly as part of the A-Train formation, particularly the Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO, are expected to augment the cloud-detection capabilities of CPR. Likewise, CPR will improve the cloud-detection capabilities of MODIS. This is but one of many examples of the value of the synergistic measurements enabled by the A-Train formation.

If CloudSat were flying in isolation, it would probably reside at a lower altitude, similar to that of TRMM. This would give CPR even greater sensitivity and improved ability to detect clouds. However, because CloudSat has chosen to be part of the A-Train formation, it flies at a higher altitude. This compromise still gives CPR excellent cloud-detection capabilities to achieve CloudSat's mission objectives, while also enabling maximum synergism with the other A-Train missions.

The antenna subsystem consists of the collimating antenna and the Quasi-Optical Transmission Line (QOTL). The antenna, constructed of composite graphite material, meets the challenge of low surface roughness (less than an RMS of 0.05 mm over the entire surface) and delivers a highly directional beam of half-width less than 12°. The antenna also has the far-side lobe levels 50 dB below that of the main lobe, as required to remove aliasing of these side lobes into the profiles of following pulses. The QOTL minimizes loss through the system. This will be the first time QOTL technology has flown in space at the wavelength of this radar. Another important challenge in the radar design is the High Power Amplifier (HPA) subsystem. The HPA has complete redundancy and consists of two Extended Interaction Klystrons (EIKs) and two high-voltage power supplies. One key development was the redesign of the commercial EIK unit to become qualified to operate in space.

CPR URL

cloudsat.atmos.colostate.edu

CloudSat References

Stephens, G. L., D. G. Vane, R. J. Boain, G. G. Mace, K. Sassen, Z. Wang, A. J. Illingworth, E. J. O'Connor, W. B. Rossow, S. L. Durden, S. D. Miller, R. T Austin, A. Benedetti, C. Mitrescu, and the CloudSat Science Team, 2002: The CloudSat Mission and the A-Train: A new dimension of space based observations of clouds and precipitation. *Bull. Amer. Meteor. Soc.*, **83**, 1771–1790.

Key CPR Facts

Heritage: Aircraft and ground-based 94-GHz radars

Nadir-pointing 94-GHz radar measures cloud reflectivity vs. altitude along nadir track

Single science operation mode
- Vertical resolution: ~500 m from 0 to 25 km altitude
- Transmits 3.3-μs monochromatic pulses
- Horizontal resolution: ~1.4 km
- Duty cycle: 100%

Technical Resource Allocations:
- Mass: 260 kg
- Power: 270 W

Data Rate: 25 kbps

Antenna: 1.85-m diameter

Performance:
- Minimum detectable reflectivity: -26 dBZ, nominally –28 dBZ
- W-band frequency: 94 GHz
- High radiated power: > 1.5 kW
- High-gain antenna: 62 dBi
- Low sidelobes: -50 dB
- Quasi-optical (free space) front end to minimize RF loss
- Noise subtraction to measure signals that are ~15 dB below noise floor

Calibration: 1.5 dB

Dynamic Range: 80 dB to capture low-reflectivity clouds and surface return

Platform Pointing Requirements (platform + instrument, 3σ):
- Control: < 0.1°
- Knowledge: < 0.1°

Spacecraft Design: Ball Aerospace

Instrument Design: NASA JPL, Canadian Space Agency

Data Processing: Cooperative Institute for Research in the Atmosphere (CIRA) (Colorado State University)

Ground Operations: U.S. Air Force

Validation: DOE, Atmospheric Radiation Measurements (ARM) Program and the contributions of many Co-I institutions and facilities around the world.

CloudSat Data Products

Product Name or Grouping	Processing Level	Coverage	Spatial/Temporal Characteristics
CPR			
Raw CPR Data	0	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Auxiliary Data	1A	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Calibrated Radar Reflectivities	1B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Cloud Geometric Profile—expressed in terms of occurrence and reflectivity (significant echoes); includes (gas) attenuation corrections	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Classification of Cloud Type, Including Precipitation Identification and Likelihood of Mixed-Phase Conditions	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Cloud Optical Depth (by layer)	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Cloud Liquid-Water Content	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Cloud Ice-Water Content	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]
Atmospheric Radiative Fluxes and Heating Rates	2B	Global, along nadir track	500 m vertical resolution/ twice daily [day, night]

CloudSat Data Products