# CloudSat and the EOS Constellation

Graeme L. Stephens
Colorado State University
Department of Atmospheric Science
Fort Collins, CO 80523-1371

## I. INTRODUCTION

The CloudSat mission was selected under the NASA Earth System Science Pathfinder Program and has now been confirmed to move into its implementation phase leading to a launch in 2003. Although the original CloudSat concept included the combination of lidar and radar and even precipitation measurements (GEWEX, 1993), the estimated cost of this original concept exceeded the maximum allowable under the ESSP program. The cost constraint imposed by ESSP led to two significant architectural decisions: the use of partners to provide funding for specific portions of the mission reducing the net cost of the mission to NASA, and the use of formation flying with other spacecraft as a way of making near-simultaneous measurements from a combination of sensors. CloudSat will fly in tight formation with the EOS–PM (Aqua) spacecraft seconds behind it and, together, these are to be followed by EOS-Chem (Aura) some 15 minutes later. This constellation will be augmented sometime after the CloudSat launch by the lidar mission of PICASSO-CENA and the polarimeter mission of PARASOL thus providing a unique observing system for studying clouds, aerosol and interactions between the two.

The formation flying establishes CloudSat is a multi-satellite, multi-sensor experiment designed specifically to measure cloud and precipitation properties that are either unavailable or poorly resolved by current satellite measurement systems but yet are deemed to be critical for understanding the role of clouds in weather and climate. The baseline CloudSat payload consists of a millimeter-wave radar (hereafter the 94 GHz cloud radar) and launch of the spacecraft is planned for 2003.

## II. CLOUDSAT OVERVIEW

The two key ingredients of the multi-satellite CloudSat experiment is the millimeter-wave cloud profiling radar carried on the CloudSat spacecraft and the formation flying capability of the CloudSat spacecraft that facilitates the combining radar data with other sensor data of Aqua, possibly P-C and PARASOL as well as Aura. CloudSat will formation fly with Aqua with such precision as to overlap the radar with the footprints of the Aqua sensors. The precision of this formation flying capability, as noted previously, is unique to CloudSat and has been designed originally to accommodate the overlap fields of view of the radar observations (slightly larger than 1 km) with lidar measurements of PICASSO-CENA being approximately 100m. At this time, however, the launch date of PICASSO-CENA is uncertain and has slipped significantly from that the proposed launch of CloudSat to the point that it is unclear whether any significant overlap between the radar and lidar can be expected.

### *A. Mission Science Goals*

The science goals of the mission are:

1.) Quantitatively evaluate the representation of clouds and cloud processes in global atmospheric circulation models, leading to improvements in both weather forecasting and climate prediction

2.) Quantitatively evaluate the relationship between the vertical profiles of cloud liquid water and ice content and cloud radiative properties, including the radiative heating by clouds.

3.) Evaluate cloud information derived from other research and operational meteorological spacecraft;

4.) Improve our understanding of the indirect effect of aerosols on clouds by investigating the effect of aerosols on cloud formation.

### *B. Payload*

The CloudSat payload consists of a 94-GHz Cloud Profiling Radar (CPR). Radar reflectivity measurements will be augmented by the dual wavelength lidar system of PICASSO-CENA and the various sensors of EOS Aqua notably CERES, AIRS, AMSR and MODIS. The CloudSat Cloud Profiling Radar (CPR) provides calibrated radar reflectivity, (*e.g.*, radar backscatter power), as a function of distance from the spacecraft. The CPR will provide a nominal minimum detectable reflectivity factor (hereafter MDS) of approximately -29 dBZ, a 70 dB dynamic range, and a calibration accuracy of 1.5 dB. The radar footprint is 1.4 km, and will be averaged over 0.3 seconds to produce an effective footprint of 4 km (along-track) by 1.4 km (cross-track). The normal mode of operation will yield 500-m vertical resolution between the surface and 25 km with a resolution of cloud boundaries at 250m.

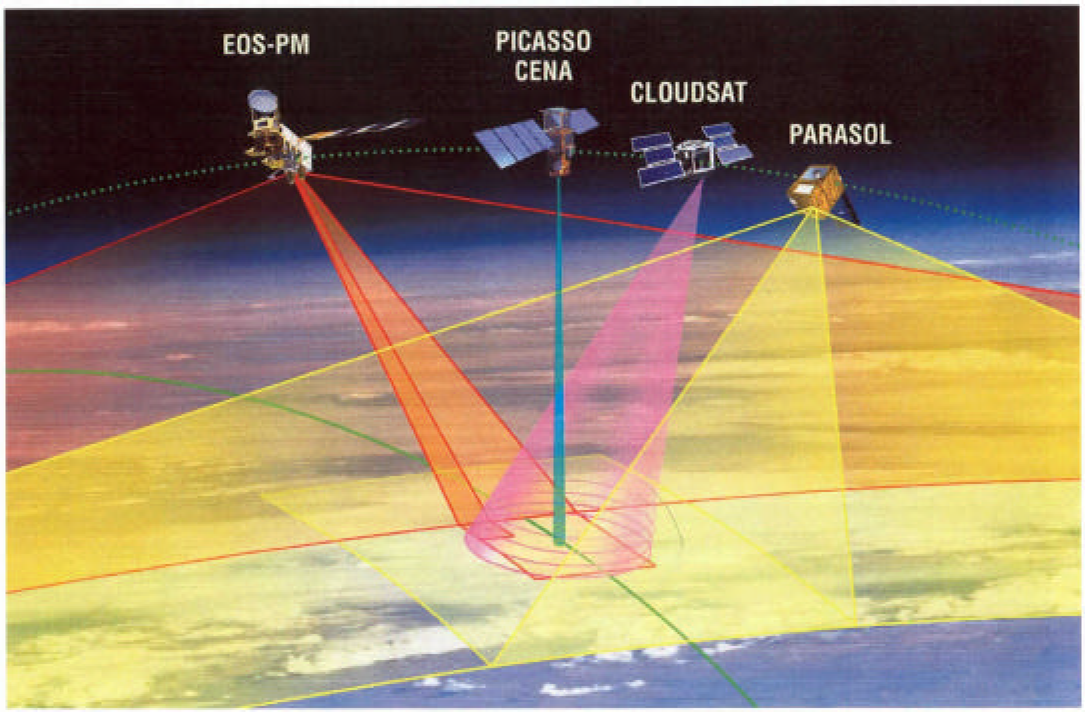


Fig. 1 The concept of the EOS-PM constellation (A-train) with CloudSat flying in formation with EOS Aqua. Aura (not shown) follows some 15 minutes behind this constellation.

*C. Mission Characteristics*

The mission characteristics may be summarized as follows:

*1.) Management:* The mission PI is the principle author of this abstract and he is responsible for all aspects of the mission. The mission is managed for the PI by NASA's Jet Propulsion Laboratory.

*2.) Launch:* Proposed launch date is March 2003. Both CloudSat and PICASSO-CENA are to be dual manifested on the Delta 7240-10 launch vehicle.

*3.) Spacecraft:* The spacecraft is designed around the Ball Aerospace RS2000 spacecraft bus used for both QuikScat and ICESat. Communications is accomplished via an S-band transceiver using a nearly omni-directional patch antenna.

*4.) Formation flying:* Formation flying enables CloudSat to track the orbit of PICASSO-CENA and EOS-PM in a very precise way. The radar and lidar footprints on the ground are estimated to directly overlap each other for a substantial fraction of all the orbits. In this way, the overlapped footprints of PICASSO-CENA create a coordinated and essentially simultaneous set of measurements with the CloudSat radar.

*5.) Orbit and duration:* The CloudSat orbit is dictated by the desire to formation fly with the EOS Aqua which is a sun-synchronous, 705 km altitude orbit with an equator crossing time of 1:30pm offering a full daylight (an nighttime) view of the Earth. The CloudSat mission was also designed with a two-year lifetime requirement to enable more than one seasonal cycle to be observed, although there is no technical reason that prohibits the mission lifetime extending beyond two years.

*6.) Ground sector and data processing:* The U. S. Air Force Space Test Program is to provide ground operations and manage communications with the space-craft. It is expected that the data will be downlinked up to about 10 times per day providing a data latency of about 2-4 hours. The Cooperative Institute for Research in the Atmosphere (CIRA) at the Colorado State University (CSU) will handle data processing and archiving of the data for the duration of the mission. Some portion of the data will be processed and distributed to operational centers for use in near-real-time assimilation and cloud forecast evaluations. The archive of all data will be transferred to the NASA Langley DAAC at mission completion.

## III. CONSTELLATION SYNERGY

The EOS constellation constitutes a unique multi-satellite observing system for studying the atmospheric processes of the hydrological cycle and the effect of aerosol on these processes. There are a number of ways the synergy of the measurements of the constellation can be expected to advance our understanding of these processes:

*1.) Through the comparison of like products*: In this case cloud and precipitation information derived independently using algorithms applied to specific measurement type related to a specific sensor. This comparison provides some way of evaluating internal assumptions of the individual algorithms.

*2.) Producing enhanced information by combining the measurements of different sensors from different satellites:* There are a number of examples of this type of synergy and further multi-sensor-based retrieval methods will continue to be developed in the coming years. A key example of this type of synergy lies in the retrieval of precipitation using the combination of the microwave radiances from AMSR and the radar reflectivities provided by the CloudSat radar. Precipitation information derived from both sensors individually has particular limitations that can be substantially overcome when the data are combined into a single retrieval system.

*3.) The combination of sensor information:* Offers the possibility of deriving new information not possible from individual sensors alone.

*4.) The combination of observations and resulting information opens the way to addressing new science problems not possible from existing satellite observations:* For example the potential of aerosol for changing cloud properties and the subsequent influence of these changes on the radiative and water budgets of clouds is a topic of much discussion and continuing research. The aerosol context provided other constellation measurements (such as by MODIS on Aqua and the lidar of PICASSO-CENA), the cloud water, ice and precipitation information of CloudSat, optical property information and the CERES radiative fluxes all combine to produce an unprecedented resource for advancing our understanding of this very complex problem.

## IV. Summary

CloudSat is a multi-satellite satellite experiment designed to utilize the opportunity provided by the EOS constellation to deliver, as directly as possible, information relevant for assessing the way cloud processes are parameterized in global weather prediction and climate models. In this way, CloudSat will provide a means for the critical evaluation of model prediction of clouds. The prime source of this information is to be extracted from vertical profiles of radar reflectivity obtained with the CloudSat 94 GHz nadir pointing radar. When this information is augmented by other measurements of the constellation, a rich data source for studying clouds, precipitation and the interaction of cloud processes with aerosol can be expected.

There remain a number of key challenges for optimally extracting the important information from the suite of constellation measurements. Included in these challenges is the need both to understand the disparate nature of the information content contained in multi-sensor data and develop a retrieval framework that optimizes this information content.

## V. Acknowledgments

The research reported in this paper has been supported by NASA research grants NAS5-99237 and NAS5-6637.