THE AFTERNOON CONSTELLATION: A FORMATION OF EARTH OBSERVING SYSTEMS FOR THE ATMOSPHERE AND HYDROSPHERE

Mark R. Schoeberl
NASA/ Goddard Space Flight Center
Greenbelt, Md. 20771

ABSTRACT

Two of the large EOS observatories, Aqua (formerly EOS-PM) and Aura (formerly EOS-CHEM) will fly is nearly the same inclination with 1:30 PM ±15 min ascending node equatorial crossing times. Between Aura and Aqua a series of smaller satellites will be stationed: Cloudsat, CALIPSO (formerly PICASSO / CENA), and PARASOL. This constellation of low earth orbit satellites will provide an unprecedented opportunity to make atmospheric cloud observations. This paper will provide details of the science opportunity and describe the sensor types for the afternoon constellation.

INTRODUCTION

NASA's shift from large observatories of the EOS Terra class to smaller spacecraft and from large institutional investigations to principal investigator (PI) mode studies has lead to a proliferation of smaller and simpler single sensor missions. On the other hand, the scientific need for ancillary data required to make the most scientific use of the sensor has pushed the science community to begin thinking of flying these simple missions in loose formation with other platforms providing the ancillary data. The afternoon constellation provides a good example of a constellation formed by the accretion of small missions around two large observatories. In many ways, this type of constellation will act as a giant virtual observatory and points the way toward the development of a "sensor web", part of the Earth Science Vision.[1]

THE AFTERNOON CONSTELLATION

The afternoon constellation is bracketed by two of the large EOS Observatories, Aqua and Aura. These spacecraft are in polar sun synchronous ascending node orbits with ~98^{o} inclinations. The equatorial crossing time for Aqua is nominally 1:30 PM and for Aura is 1:38 PM. Aqua will be in an orbit with a 16 day repeat cycle corresponding to the WRS-2 grid. The ground track is not identical for reasons described below, and this means that even though the crossing times are 8 minutes apart, the two spacecraft follow each other by about 15 minutes.

Sandwiched between Aura and Aqua are three additional small satellites: CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) (formerly PICASSO/CENA), Cloudsat, and PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a LIDAR). Each of these small missions augments the observing capabilities of the afternoon constellation. Because of the fact that each will make observations of the same air mass within few minutes, we can, to first order, assume that the atmosphere is nearly "frozen" so that we are, in effect, making all of the observations from a single virtual platform. As an abbreviation, the afternoon constellation is sometimes referred to as the "A-Train" or "PM Constellation"

Aqua leads he train with an ascending node, 1:30 PM crossing time. PARASOL will follow Aqua by 4 minutes. Both are on the WRS-2 grid. CALIPSO and Cloudsat will fly in close formation with each other. CALIPSO will be 2 minutes behind Aqua and Cloudsat 105 seconds behind Aqua. Cloudsat and CALIPSO are offset 13.9 and 20.85 km from the WRS-2 grid, respectively. Aura follows the train 15 minutes behind Aqua but is offset from the WRS2 Aqua track to the west by about 197 km. This offset allows the forward limb sounding of Aura to be aligned with the Aqua WRS-2 path.

MANEUVERS
No inter-satellite communication is planned nor is there any on-board software management of the formation (as with EO-1). Furthermore, most of the spacecraft will be managed by different operations centers. Aura and Aqua will be managed by NASA/Goddard. The other satellites will be managed by foreign centers and the Air Force. Maneuvers are required to make up drag alterations in the orbit. Both Aqua and Parasol plan to maneuver independently to maintain a ±10 km error in the WRS-2 position. This is equivalent to a ±22 second control box relative to the reference orbit. CALIPSO will maintain the same ±22 second control box along its offset WRS-2 path.

The plan is for Cloudsat to perform two maneuvers for every CALIPSO maneuver. When CALIPSO raises its orbit, Cloudsat will do the same, but halfway between the CALIPSO maneuvers, Cloudsat will perform an orbit lowering maneuver to maintain the 75-120 km position from CALIPSO. This corresponds to a 15±2.5 second control box.

Extensive analysis of failure modes has been done to determine the evolution of the train given that one or some of the satellites fail to make orbit adjustments. In all cases, orbit decay will cause the satellite to move ahead of the train. Close proximity (possibly collision) could occur as soon as one day after failure to make the maneuver. CALIPSO and Cloudsat need to be especially careful to coordinate their operations (Peter Demarest, private communication).

AQUA

Aqua carries 6 instruments, MODIS, AIRS, AMSU, HSB, AMSR/E and CERES. These instruments and their acronyms are described in detail at http://aqua.gsfc.nasa.gov/. MODIS is a high spatial resolution, multi-spectral imager with 36 channels from the visible to the near-IR (0.4 to 14 µm). AIRS is an advanced infrared spectrometer for temperature and moisture sounding is has channels in the range of 0.4 to 1.7 µm and 3.4 to 15.4 µm range. Augmenting AIRS measurement of temperature and moisture are the microwave instruments AMSU (temperature -50 to 89 GHz) and HSB (moisture -150 to183MHz). Thus temperature and moisture soundings can be made through thick clouds (but at lower vertical resolution). CERES is an earth radiation budget instrument measuring short wave and longwave radiation as well as total. AMSR/E which measures total column water, precipitation, etc (6.9 to 89 GHz). (Launch mid 2002)

CLOUDSAT

Cloudsat is an ESSP3 mission designed to measure cloud properties using a 94 GHz nadir viewing radar (http://essp.gsfc.nasa.gov/cloudsat/index.html). Using the radar returns, Cloudsat can estimate precipitation rate and particle size within the clouds. From this information cloud heating rates and water content can be derived. [Launch 2004]

CALIPSO

CALIPSO will fly a 2 wavelength lidar (532 and 1064 nm) and a three channel infrared imaging radiometer (8.7, 10.5, 12 µm) (http://www-calipso.larc.nasa.gov/picasso.html). The main advantage of CALIPSO over Aqua and Cloudsat is that it provides very precise height information for clouds and aerosols. For example, subvisible cirrus is easily detected by CALIPSO lidars but will be difficult to detect using the Cloudsat radar and some of the other Aqua instruments. CALIPSO and Cloudsat are co-manifested for a Delta launch. [Launch 2004]

PARASOL

PARASOL is a proposed CNES microsat mission with a single polarimeter, POLDER (http://www-projet.cst.cnes.fr:/PARASOL/index.html). POLDER was flown on the Japanese ADEOS satellite. POLDER is a 9 channel camera, of which three channels (443, 670, 865 nm) have three polarization filters which are moved sequentially in front of the aperture. Aerosols, cloud particles and certain land surface types strongly polarize reflected light thus POLDER is able to get additional information on aerosol types an cloud particle size distributions by from the polarization information. [Launch 2005].

AURA

Aura is the third large EOS observatory, and is designed to study the chemistry of the atmosphere (http://aura.gsfc.nasa.gov). The payload is comprised of four instruments: MLS, a microwave limb sounder staring out of the front of the spacecraft; HIRDLS, and infrared limb sounder which scans the trailing field of view; TES a Fourier transform spectrometer (3.2 to 15.4 µm) with about 50 times the spectral resolution of AIRS (but smaller swath) which has both nadir and limb sounding capabilities; and OMI, a nadir sounding UV-Visible spectrometer. MLS has the capability of high vertical resolution measurements of water vapor in clouds. Because MLS observes forward from the spacecraft velocity, these limb measurements are made 7-8 minutes in front of Aura or 7-8 minutes behind Aqua. In addition to the aerosol measurement being made by CALIPSO, MODIS (Aqua), and PARASOL, the OMI instrument will make column aerosol measurements. [Launch early 2004]

COMBINED SCIENCE

One of the outstanding science questions that have emerged in the last score of years is: what is the role of clouds and aerosols in heating and cooling of the global climate? The afternoon constellation will make a superb series of measurements that will directly address this question. For example, the radiation budget measurements by CERES can be uses to address the role of subvisible cirrus in the radiation budget. Identification regions of subvisible cirrus can be made by the MODIS IR measurement, but the key parameter, the height of the cirrus cloud and optical thickness will be made by CALIPSO's lidar. The particle size distribution in aerosols and clouds is help determine the role such clouds have in dehydration of the upper troposphere. Particle sizes and types can be estimated by the polarimeter and MODIS data. Large particles or dense cirrus clouds may also be seen by MLS and the Cloudsat radar. More importantly, MLS measurements of the vertical profile of water vapor can be used to answer the question on the dehydration capability of these types of clouds.

Thicker clouds can also be studied using the same approach. Cloud top temperature can be estimated by AIRS which can be related to moist adiabatic processes through the measurement of cloud height using the CALIPSO lidar. Cloudsat's radar can measure precipitation rate and AMSR/E can estimate total available water in the column. The distribution of water vapor down to the freezing level can be determined by MLS in the upper tropospheric cloud region as well as by HSB in the lower troposphere. The challenge for the scientists working with these measurements is the relative footprint of the observations. For example, the AIRS footprint is 13,500m in nadir, CloudSat is 1,400 m and the CALIPSO lidar has an 88 m footprint. AIRS will aggregate information across the clouds while the radar and lidar will probe individual structures. The role of aerosols and clouds in climate can be addressed by combining CERES radiation data with aerosol information (type and size distribution) from OMI, PARASOL and MODIS.

The above are just a few sample science issues that can be addressed by the combination of sensors flying in the "A-Train."

SUMMARY

The PM constellation will provide an unprecedented opportunity to make observations of clouds and aerosols. This constellation is, which will be completely formed up in the 2004-2006 time frame, consists of up to six satellites flying within 15 minutes of each other over roughly the same ground track. This constellation is not managed – it is a constellation of accretion. Nonetheless, it probably represents the first component of a future "sensor web."

REFERENCES

[1]Schoeberl et al., The Earth Science Vision, IEEE, IGARSS, Presented in Honolulu Hawaii, 2000.