# THE A-TRAIN: NASA'S EARTH OBSERVING SYSTEM (EOS) SATELLITES AND OTHER EARTH OBSERVATION SATELLITES

**Angelita C. Kelly**
Science Interface Manger
Code 428/Earth Science Mission Operations (ESMO) Project
NASA Goddard Space Flight Center
Greenbelt, Maryland U.S.A. 20771
Email: Angie.Kelly@gsfc.nasa.gov
Tel. 1-301-6145317; fax #: 1-301-614-5270

**Edward J. Macie**
Operations Director
Code 428/Earth Science Mission Operations (ESMO) Project,
NASA Goddard Space Flight Center
Greenbelt, Maryland U.S.A. 20771
Email: Edward.J.Macie@nasa.gov
Tel. 1-301-614-5416; fax: # 1-301-614-5267

ABSTRACT

This paper describes the Earth Observing System (EOS) "A-Train" and its impact on mission operations. The A-Train refers to the constellation of United States satellites and international Earth Science satellites that plan to fly together with EOS Aqua to enable coordinated science observations. These satellites have an afternoon crossing time close to the mean local time (MLT) of the "lead" satellite, Aqua which is 1:30 p.m.; thus, the name, "A (short for afternoon) train". The A-Train consists of: EOS Aqua, CloudSat, CALIPSO, PARASOL, EOS Aura, and OCO. The "A-Train" concept was originally articulated by Dr. Mark Schoeberl, EOS Aura Project Scientist [Reference 1].

The A-Train presents an interesting challenge for mission operations. The satellites are managed by different organizations and controlled at different locations. The objective of this paper is to discuss the planning for the operations of the A-Train. The Earth Science Mission Operations (ESMO) Project at Goddard has formed a constellation mission operations working group (MOWG) to address the long-term operations coordination for the A-train. This paper discusses the work that has been done to date in evaluating constellation operations.

## 1. INTRODUCTION

Coordinating the operations of the A-Train is imperative to ensure the health and safety of the constellation while ensuring the missions meet science requirements, including those for coincidental observations. An MOWG composed of representatives from the various satellite missions has been formed to develop the constellation operations plan, guidelines, and procedures.

## 2. OVERVIEW

The A-Train can be thought of as a virtual science platform of Earth Science missions. It consists of four NASA missions, one French Centre National d'Etudes Spatiales (CNES) mission, and one joint NASA/CNES mission (see Table 1). All six satellites orbit at a mean equatorial altitude of 705 km and cross the equator within a few minutes of one another at around 1:30 p.m. local time. Collectively, they are referred to as the Afternoon Constellation since the ascending equator crossings occur in the early afternoon. Each mission has specific science objectives; all will improve our understanding of the Earth's climate. As a constellation, the synergistic measurements will improve the quality and accuracy of the results. Scientists plan to perform coincidental observations, i.e., use data taken at approximately the same time from two or more instruments on the various satellites to investigate a specific area of interest, such as a particular region of the atmosphere.

**Table 1 – A-Train Missions**

| Observatory | Primary Mission | Launch Date | Responsibility |
|---|---|---|---|
| Aqua | Water/energy cycle | May 2002 | NASA/GSFC |
| Aura | Atmosphere chemistry | January 2004 | NASA/GSFC |
| Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) | Aerosols & clouds | October 2004 | NASA/GSFC<br>NASA/LaRC<br>CNES |
| CloudSat | Clouds | October 2004 | NASA/GSFC<br>NASA/JPL |
| Polarization and Anisotropy of Réflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) | Aerosols & clouds | 2005 or later | CNES |
| Orbiting Carbon Observatory (OCO) | Carbon cycle | 2006-2007 | NASA/GSFC<br>NASA/JPL |

The EOS Aqua satellite was launched in May 2002 and it is currently performing nominally. In January 2004, NASA will launch the EOS Aura satellite and phase it with EOS Aqua such that it will follow Aqua by 15 minutes. Aura will be placed on a different orbital track to cross the equator 8 minutes after Aqua, which results in specific synergy between the Aura and Aqua instruments. In October 2004, CALIPSO and CloudSat will share a single launch vehicle. Once in orbit, CALIPSO will fly in formation with CloudSat reacting to any changes in CALIPSO's orbit. CALIPSO will, in turn, react to changes in Aqua's orbit. This tight formation between CALIPSO and CloudSat enables synergistic measurements between the two, and with Aqua, which is a key science requirement. A year or two later, CNES plans to launch PARASOL and fly it one minute behind CALIPSO. Lastly, in the early planning stage today is the OCO mission, which is being designed to fly 15 minutes in front of Aqua. Figure 1 illustrates the constellation spacing.

## 3. OPERATIONS PLANNING

The MOWG is developing the *Afternoon Constellation (A-Train) Coincidental Observation Implementation and Operations Plan* that deals with the process for coordinating the operations of the A-Train to (a) ensure the health and safety of the individual missions and the constellation as a whole and (b) maximize the science return. Constellation operations coordination does not extend into the detailed operations for each of the missions. Each mission

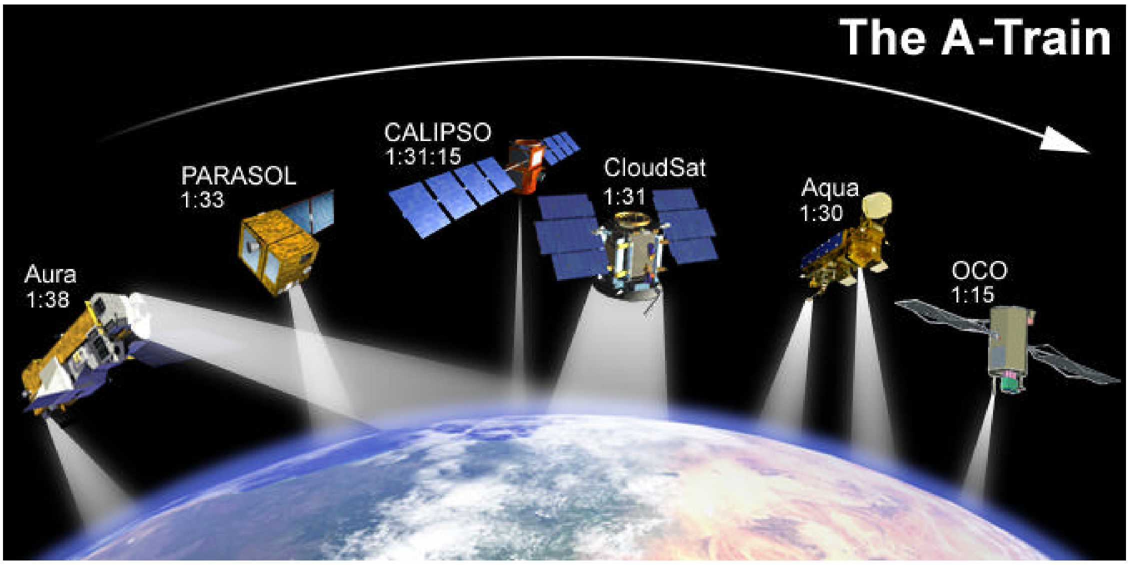

**Figure 1 - A-Train Mission Spacing**

is controlled independently, but the success of the constellation can only be achieved through cooperation and teamwork. Prior to launch, the following analyses must be performed:

a) Analysis of Science and Operational Requirements

The requirements for each mission must be analyzed in the context of the constellation to ensure that the attendant mission design is consistent with the constellation environment. For example, the science requirements of CALIPSO and CloudSat make it imperative for these two missions to be in tight formation with each other and at specific locations in relation to the Aqua satellite for the life of the missions. Both these missions are designing their control systems and procedures to meet their requirements. These requirements must be evaluated in relation to the rest of the constellation.

b) Analysis of Space and Ground System Resources for Uplink and Downlink

A realistic loading analysis must be done to ensure there are sufficient resources to support all missions. For example, Aqua and Aura operate on the same radio frequencies and use the same polar ground stations in Norway and Alaska, so the ground station resources were enhanced prior to the Aqua launch to ensure that the mission requirements could be met. In addition, Aura will be phased with Aqua to ensure a minimum 15-minute separation at the ground stations. CALIPSO and CloudSat will use other services, thus avoiding conflicts with Aqua and Aura. Likewise, PARASOL will use the same command and control services as CALIPSO. The OCO mission will be supported by commercial facilities; this needs to be analyzed further.

c) Link Analyses

The extent of radio frequency interference (RFI) among the constellation missions and from external sources must be understood. This analysis may point to design changes and/or operational constraints. RFI caused by simultaneous Direct Broadcasts from multiple satellites must also be understood early in the planning and design phase so that changes can be made to minimize or eliminate it. Conflicts may have to be resolved using agreed-upon science priorities.

d) Launch and Early Orbit Analysis

The launch and ascent plans for the member missions shall be evaluated in relation to the constellation. Missions being added to the constellation shall not adversely impact those already in the constellation. Close coordination among all parties is required.

e) Close Approach Analysis

Guidelines and policies shall be reviewed to quantify the close approach constraints. This activity requires close coordination with all parties and knowledge of orbital debris positions.

f) End-of-Mission Analysis

Each mission is required to have an end-of-life plan that includes triggers to identify the end of mission. Each mission plan shall be reviewed in the context of their position in the constellation. End of life disposal requirements shall be coordinated with the constellation teams.

## 4. CONSTELLATION OPS COORDINATION CONCEPT AND PLAN

Based on input from the member missions, NASA is designing a system to provide all the missions a mechanism to coordinate constellation-related operations. The initial phase is to accomplish the orbital coordination in a relatively autonomous manner to ensure the safety of each mission. Each mission will provide current orbital characteristics and maneuver plans. The orbits will be propagated several weeks into the future searching for possible conflicts (e.g., if a mission is expected to exceed its “control box”, possibly endangering the safety of itself and another satellite). The system will provide notifications and warnings to allow for a timely response.

In a later phase, mission teams will be involved to enhance the system to maximize the science return from coincidental observations. The mission teams and science teams will review the current status and processes periodically to ensure that the requirements for coincidental observations are being met.

## 5. SUMMARY

Planning for the success of the A-Train is progressing. The system to enable the member missions to share information and coordinate their operations in an efficient and effective manner is being developed to be in place prior to the launch of each of the member missions. Effective coordination is expected to provide safe constellation operations and the maximum amount of coincidental science observations.

## 6. REFERENCES

1. Dr. M. Schoeberl, *The Afternoon Constellation, Aqua, CALIPSO, Cloudsat, PARASOL, Aura, The “A” Train* presentation, NASA/GSFC (2002)