The CloudSat Experience and Lessons-Learned Applicable to Future Constellations

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ABSTRACT

Lessons learned from my personal observations and experiences during the Proposal, Development, and Operational Phases of the CloudSat mission.

1. BACKGROUND ON THE SCIENCE SYNERGY OF CLOUDSAT, CALIPSO AND THE A-TRAIN

In 1994-1995, a team of Langley Research Center (LaRC) and Jet Propulsion Laboratory engineers, led by scientists at LaRC and Colorado State University (CSU) , developed a mission concept for a combined cloud radar/cloud lidar payload. Motivation was provided by the anticipation of the very first Earth System Science Pathfinder (ESSP) Announcement of Opportunity (AO). Unfortunately, the AO, when released in 1996, had a very low cost cap ($90M) that could not support the combined radar/lidar payload. The teams split into two competing proposals (PICASSO, later CALIPSO, and CloudSat). Neither was selected during that round.

In 1998, the second ESSP AO was released with a higher cost cap ($120M), but still not high enough to support a combined radar/lidar payload. Again, the teams competed, but this time both were selected. PICASSO had proposed to fly in formation with Aqua, and CloudSat had proposed to fly in formation with ICESat. The selecting official at NASA realized the potential of CloudSat joining PICASSO in formation with Aqua, and the rest is history.

So, CloudSat and CALIPSO began as one mission idea, then split into two competing missions during the ESSP AO process, and they were re-united as a virtual platform by formation-flying in the A-Train. This is an example of how science drives the need for, and benefits from, on-orbit constellations (LESSON 1). It also provides a example of how science vision at the implementing agency level is critical (LESSON 2).

2. FORMATION FLYING

Happening in parallel with the proposal activities was the development of the idea of tight formation flying to achieve single-footprint-overlap between the radar and the lidar. This idea kick-started when a system engineer (Ron Boain/JPL) suggested the POSSIBIITY to a scientist (Graeme Stephens/CSU), and Graeme'e imagination and excitement exploded with possibilities. After that, Ron was on the hot-seat to figure out how to make the possibility a reality. But as everyone knows, all great engineers covet great challenges. Eventually, Don Keenan from Aerospace Corporation joined the team and developed the detailed and mathematically elegant method that the CloudSat team has used since launch to maintain footprint overlap with CALIPSO.

And, take note, there is a big difference between coordinated flying in a constellation and tight formation flying. Flying so that the swath (or nadir track) of an instrument on one satellite lies within the swath of an instrument on another satellite (my definition of coordinated flying) is far simpler than overlapping a single footprint of one instrument on a single footprint of another instrument (my definition of tight formation flying) which is what CloudSat does to achieve overlap of the CloudSat radar with the CALIPSO lidar. This tight formation-flying, if needed in a future constellation, is now a proven technique but it requires a deeper commitment of people, time and resources (LESSON 3)

3. CHOICE OF ORBIT

Active instruments like those flown on CloudSat and CALIPSO benefit from low Earth orbits (lower than 700km), but being in the A-Train at 705km with the other platforms from NASA, CNES and JAXA provides a wealth of additional observations. The benefit of these complementary observations outweighs the performance-sensitivity loss of the active instruments due to the higher altitude. Also, CloudSat accepted changes in the mission architecture to accommodate the CALIPSO sunglint constraints. When a new, future constellation is created, the participants must be willing to accept compromise (LESSON 4).

The choice of orbit is critical to attracting additional satellite participation (LESSON 5). PARASOL, GCOM-W and OCO have joined or will join the A-Train not only because the other satellites are already there but also because it is an attractive orbit for Earth observations. Orbit altitude, inclination, nodal crossing time/direction can make-or-break the attractiveness of a constellation. If the components of the constellation are known in advance, these choices can be negotiated. But equally likely is the scenario that a mission is shopping around for other already-approved or already in-flight missions. In the latter case, the orbit architecture is already determined.

4. DATA PRODUCTS AND SUPPORTING SYNERGISTIC SCIENCE

As the A-Train began to take shape, Graeme developed many ideas for ways in which the observations of the A-Train could be folded into algorithms for CloudSat data products. As his ideas grew, so did our concern that this growing number of products would overwhelm the small, CloudSat data processing center, but at that time we were on our own because our project was cost-capped to include the end-to-end mission as proposed to NASA. Fortunately, the young, creative talent at the CloudSat data processing center managed to keep their heads above the rapidly rising tide of new data products without asking for more funds. Following launch, NASA provided opportunities through the Sr. Review process for funding for new data products, which allowed CloudSat to add some new products to the inventory. Additionally, NASA ROSES research calls encouraged investigations using multi-satellite A-Train data. For future constellation, thought must be given to supporting the creation/distribution of multi-satellite datasets and supporting research that uses these datasets (LESSON 6). Multi-satellite datasets require resources that may be beyond a single satellite project. And there needs to be thought given to how to fund researchers to use data from all constellation satellites.

5. ALL GOOD THINGS COME TO AN END

Each satellite should understand how long they can stay in the constellation and what it will take to exit the constellation. It is also helpful to identify situations that would trigger urgent exit from the constellation (LESSON 7). This is a hard lesson learned during the CloudSat recovery from the battery anomaly of 2011 and re-entry to the A-Train in 2012. Ron Boain's paper in this conference is a good reference.

6. COORDINATION

The A-Train Constellation Working Group has proved its value again and again. The concept of on-orbit control boxes and contingency procedures is a simple, ingenious method of keeping the constellation safe. Every constellation needs such a overarching set of agreements (LESSON 8).

7. SUMMARY

Constellations don't just happen. They need vision, leadership and enabling resources. Sometimes they require compromise, and if the working relationships are strong between platforms – as they are between CloudSat and CALIPSO – then challenges can be overcome (such as the CloudSat/CALIPSO post-anomaly formation architecture). Constellations are far more than the sum of the parts: they are a valuable scientific resource for the Earth-science community and are worth the extra investment.