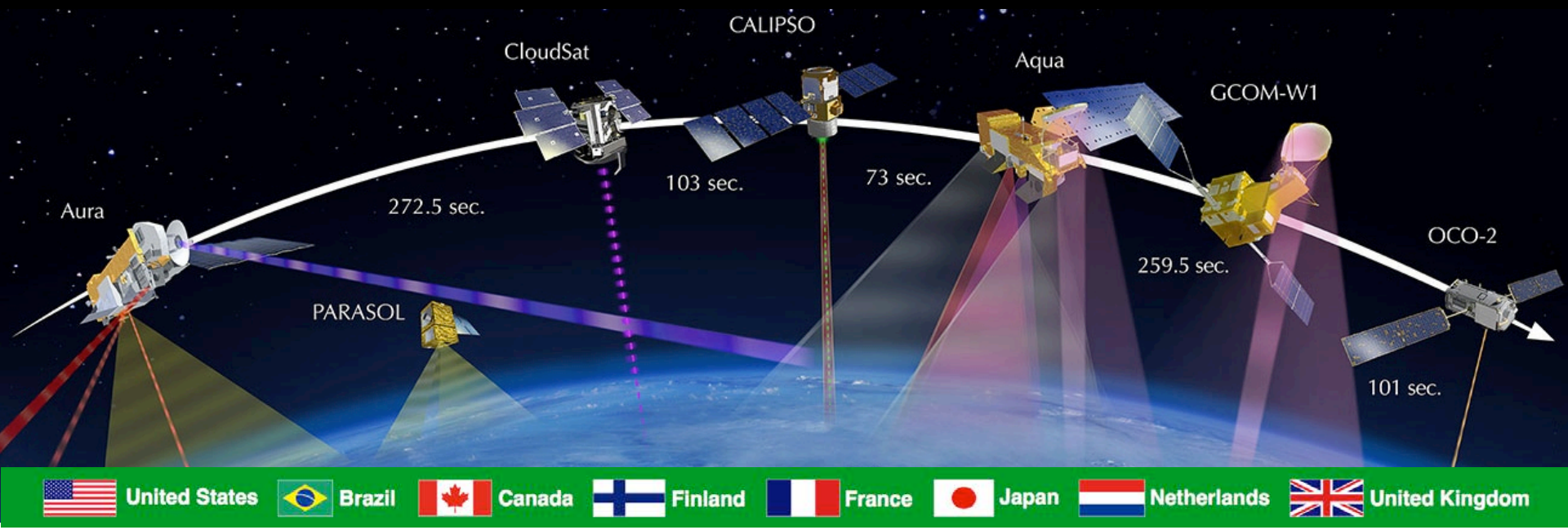


A-Train Science Mini-Workshop, March 8, 2013

A-Train Operations and Coordination

Angelita C. Kelly
Mission Operations Manager (MOM)
Earth Observing Constellations
NASA Goddard Space Flight Center

Overview

Introduction to the technical and operations aspects of the current Earth observing constellations at the 705 km orbit

- **Afternoon Constellation (e.g., the A-Train)**
- **Morning Constellation**

TOPICS

- **Constellation Overview**
- **Mission Operations Working Group (MOWG) Coordination**
- **Challenges**
- **Coordination Agreements & Procedures**
- **Constellation Coordination Benefits**

Why Fly Constellations?

Science is key!

Constellations form single "virtual" platforms which enable near-coincident observations, thus providing enhanced science

International Earth Observing Constellations

- NASA and other space agencies have satellites flying in two Earth observing constellations.
  - The two constellations include instruments from North America, South America, Asia, and Europe.

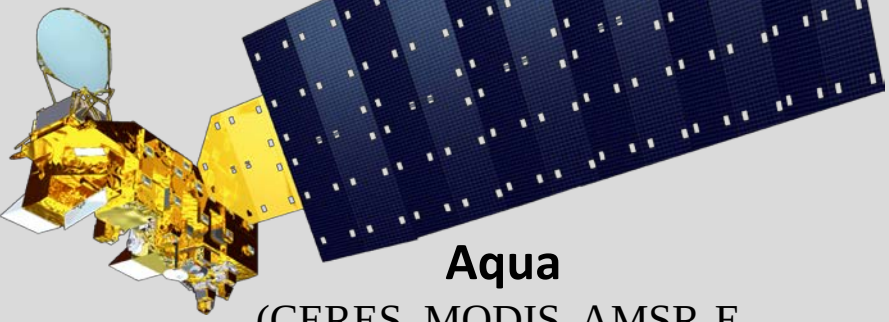
Morning Constellation (Around 10:30 MLT‡)		Afternoon Constellation (Around 13:30 MLT‡)	
Landsat-5	March 1, 1984	**EOS Aqua**	**May 4, 2002**
Landsat-7	April 15, 1999	EOS Aura	July 15, 2004
Terra	**December 18, 1999**	PARASOL	December 18, 2004
EO-1	November 21, 2000	CloudSat	April 28, 2006
SAC-C	November 21, 2000	CALIPSO	April 28, 2006
Landsat-8 (LDCM)	**February 11, 2013**	OCO	February 2009*
		Glory	March 2011*
		GCOM-W1	**May 18, 2012**
		OCO-2	February 2014

** Failed to reach orbit*

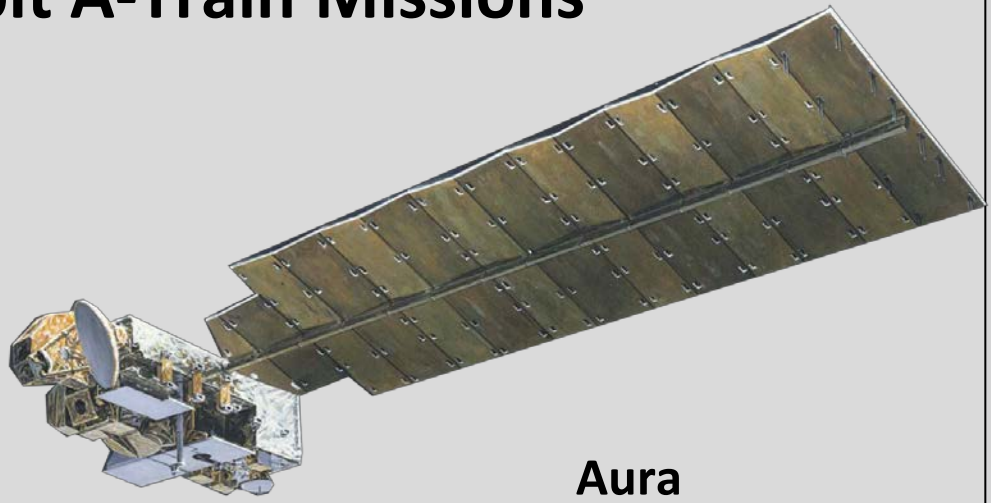
- **All satellites are at 705 km altitude in sun-synchronous orbits with a 16-day / 233 orbit repeat cycle**

United States Brazil Canada Finland France Japan Netherlands United Kingdom

Current On-Orbit A-Train Missions

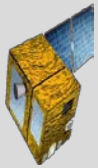


Aqua
(CERES, MODIS, AMSR-E, AMSU-A, AIRS, HSB)
Launch: May 2002



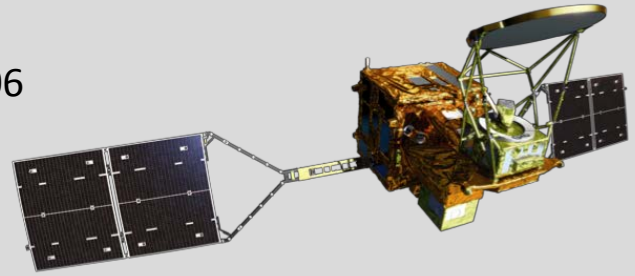
Aura
(HIRDLS, MLS, OMI, TES)
Launch: July 2004

CloudSat
(CPR)
Launch: April 2006



PARASOL
(POLDER)
Launch: December 2004

CALIPSO
(CALIOP, WFC, IIR)
Launch: April 2006



GCOM-W1
(AMSR-2)
Launch: May 2012

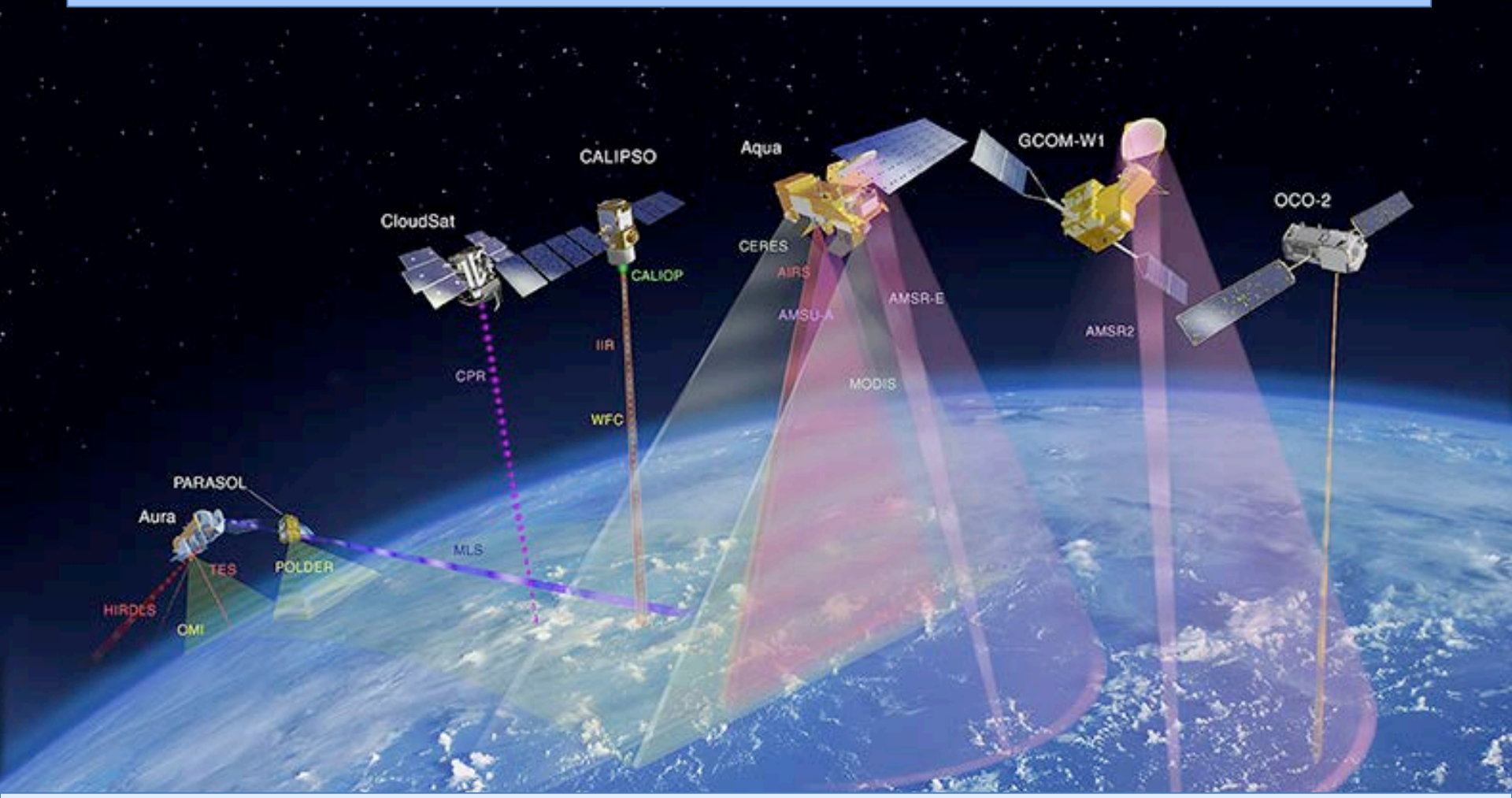
Science Principles of Constellations

- **Science requirements** drive constellation flying requirements
- **Combined science** exceeds the sum of all individual science
- **For maximum benefit, scientists/Science working groups collaborate** to enable cross-mission or joint products
- **Constellation/A-Train science results are shared** via presentations at conferences such as the AGU, IGARSS, etc.
  - ➢ Two International A-Train symposia have been held:
    - October 2007 in Lille, France
    - October 2010 in New Orleans, Louisiana
  - ➢ **Next International Conference—2014**

Afternoon Constellation (A-Train)

The A-Train satellites fly within *seconds* to *minutes* of each other to enable near-coincident observations of the land, atmosphere, oceans, and clouds.

- **Passive and active sensors**
- **Horizontal and vertical views of the atmosphere**



"The whole is greater than the sum of its parts"

Mission Operations Working Group (MOWG)

The Afternoon Constellation MOWG was officially formed in 2003 to coordinate safe flying of constellation satellites, primarily for the A-Train

- **Members include Operations** and **Science teams**
- Face-to-face Meetings are held twice a year; extensive use of e-mail and telecons

MOWG Objective

To enable nearly simultaneous science observations by keeping the constellation satellites safe.

The MOWG members work together in a spirit of mutual respect, trust, and cooperation.

Mission Operations Working Group (MOWG)

MOWG Meeting
NASA Goddard Space Center
October 15-17, 2012

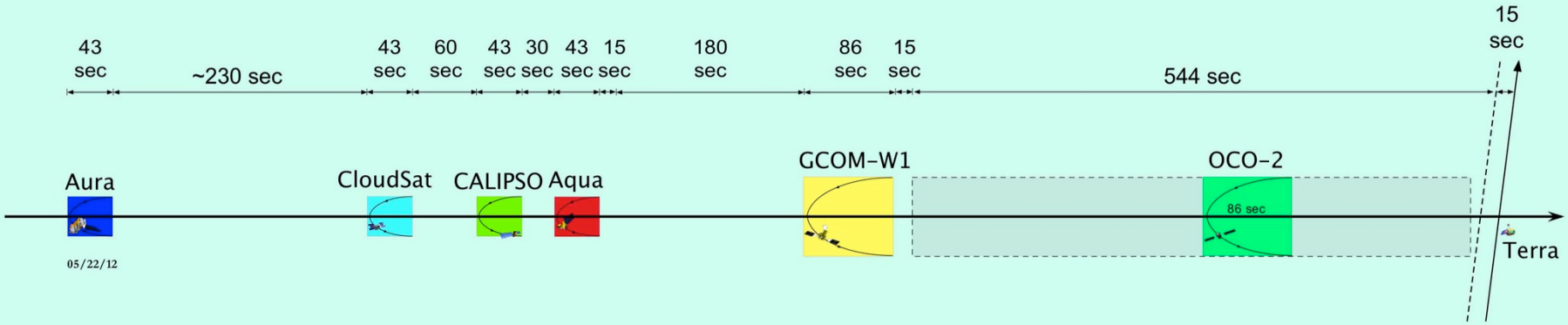
United States Brazil Canada Finland France Japan Netherlands United Kingdom

Constellation Flying Challenges

- **SAFETY**
  - Satellites fly within seconds to minutes of each other
  - Satellites fly near many other satellites around the 705-km orbit
  - Constellation configuration must be monitored and communicated to Mission Teams to ensure SAFETY
  - Advanced warnings of potentially unsafe situations must be provided
  - Orbital Debris Monitoring (*see next slide*) must be included
- **Multiple organizations** (U.S. and International Partners) — different cultures, different concepts, varied approaches
- **Widely separated locations** (multiple control centers, time zones)
- **Data Sharing, i.e., Open Data Policy**

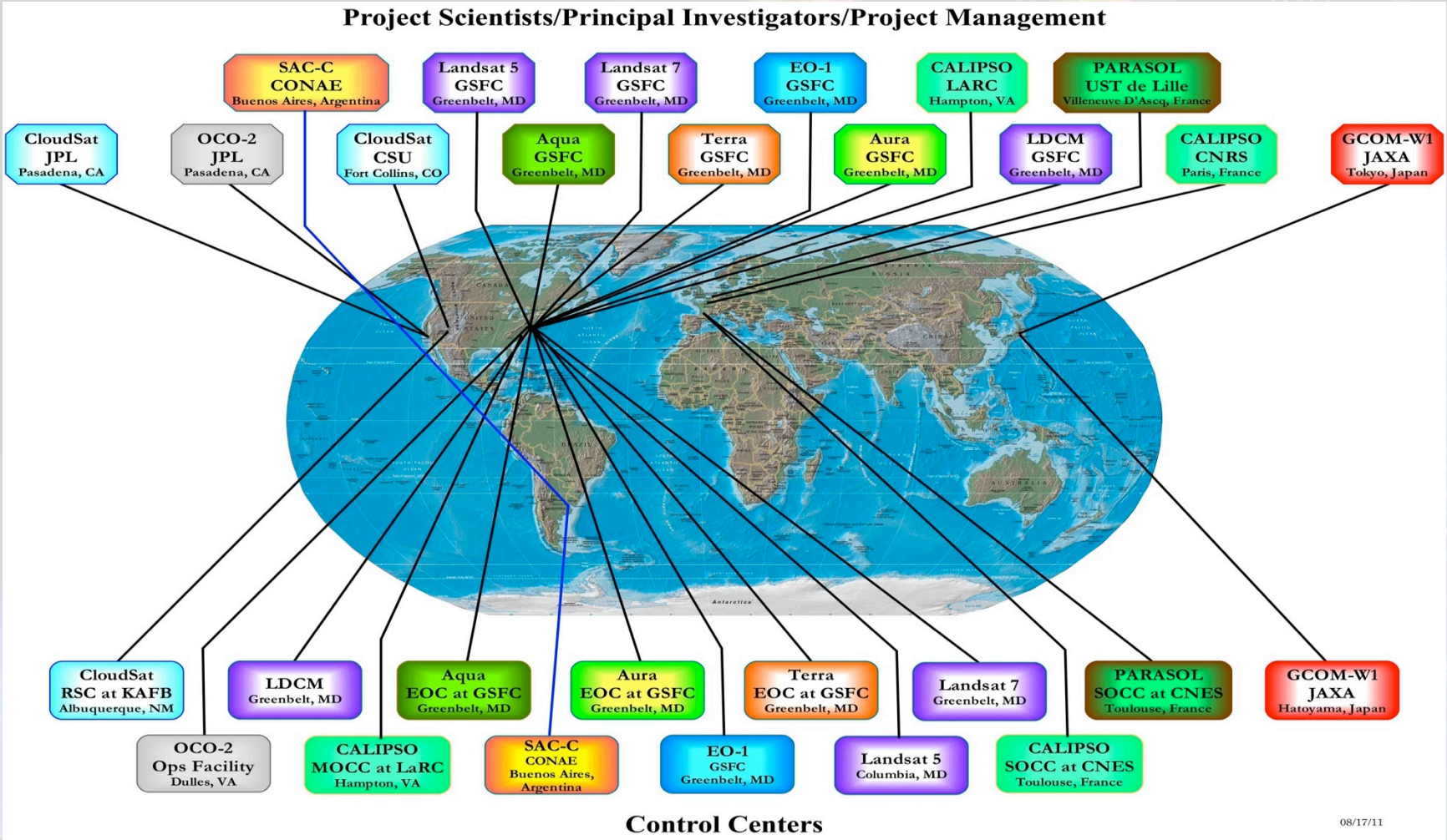
Constellation Flying Challenges

- **Concern: SAFETY**
  - Satellites fly within seconds to minutes of each other
- **Approach:** Teams must agree on an orbital configuration that ensures safety.
  - Close approaches/collisions must be avoided.
- **Solution:** To simplify operations, A-Train teams implemented a **"control box"** concept that meets science requirements
  - Each satellite can move anywhere within its designated control box, but shall not drift outside without a valid reason.



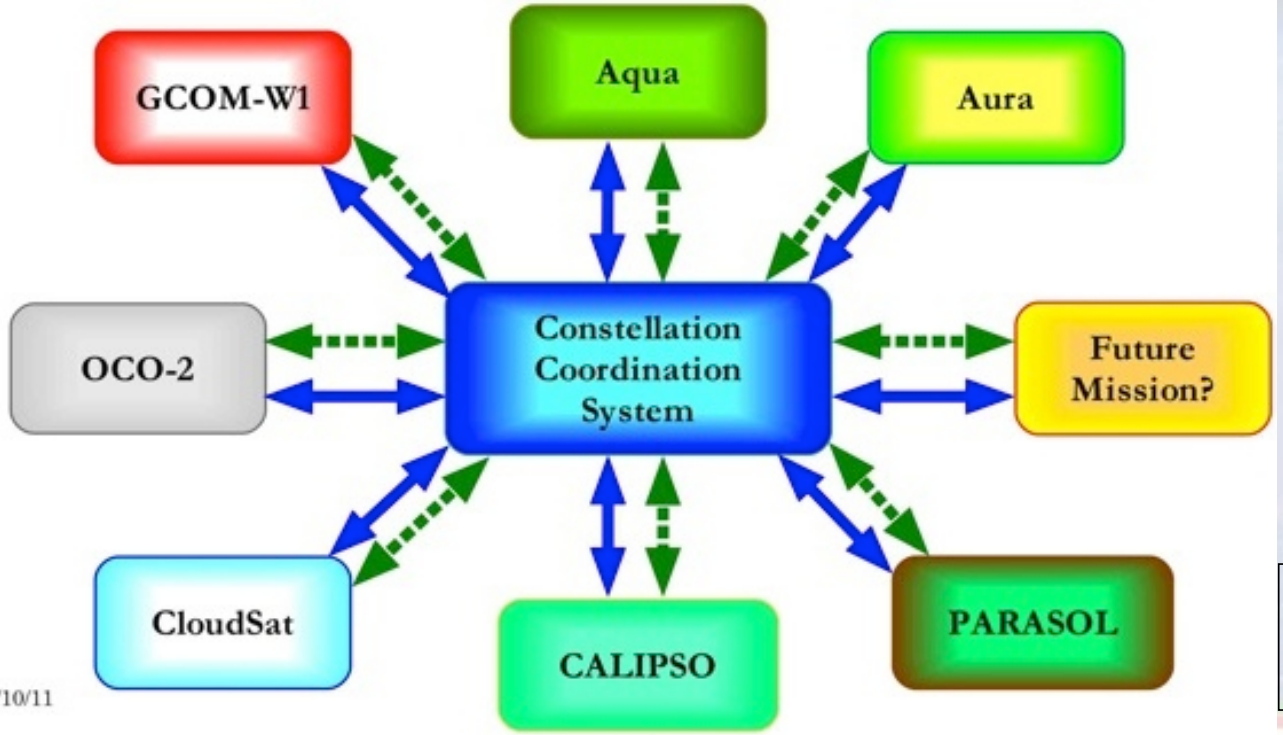
Constellation Flying Challenges

- **Multiple organizations** (U.S. and International Partners) — different cultures, different concepts, varied approaches
- **Widely separated locations** (multiple control centers, time zones)



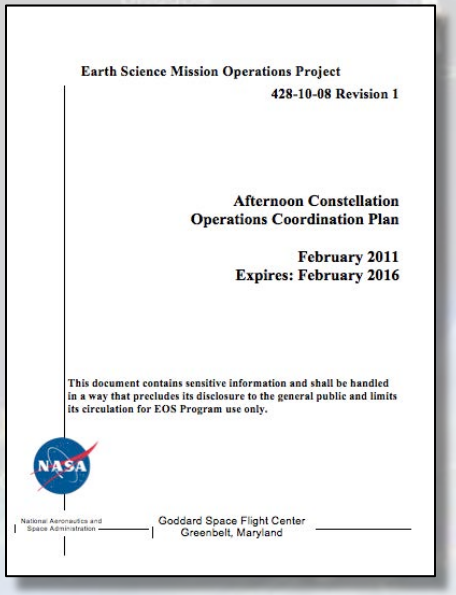
MOWG Operations Coordination

- **The MOWG established guidelines for safe constellation flying**
- **Constellation coordination system**
  - Monitors the constellation configuration and status (based on daily orbit data from the missions)
  - Provides advance warning of predicted control box violations
  - Enables teams to exchange orbital data products



Constellation Agreements

The Constellation mission teams abide by the agreements that they negotiated, documented, and signed.


Earth Science Mission Operations Project
428-10-08 Revision 1

Afternoon Constellation
Operations Coordination Plan

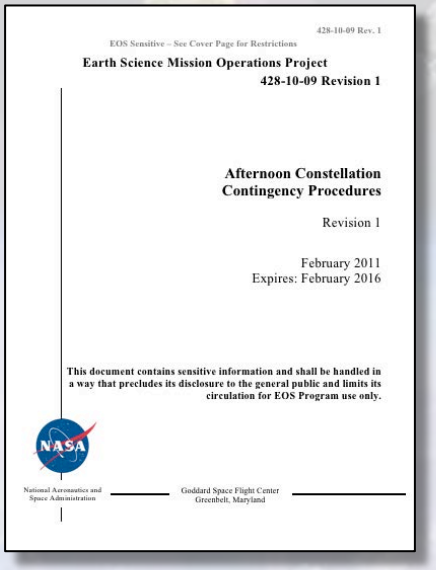
February 2011
Expires: February 2016

This document contains sensitive information and shall be handled in a way that precludes its disclosure to the general public and limits its circulation for EOS Program use only.

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

Operations Coordination Plan

"The A-Train Bible"


428-10-09 Rev. 1
EOS Sensitive – See Cover Page for Restrictions

Earth Science Mission Operations Project
428-10-09 Revision 1

Afternoon Constellation
Contingency Procedures

Revision 1

February 2011
Expires: February 2016

This document contains sensitive information and shall be handled in a way that precludes its disclosure to the general public and limits its circulation for EOS Program use only.

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

Contingency Procedures

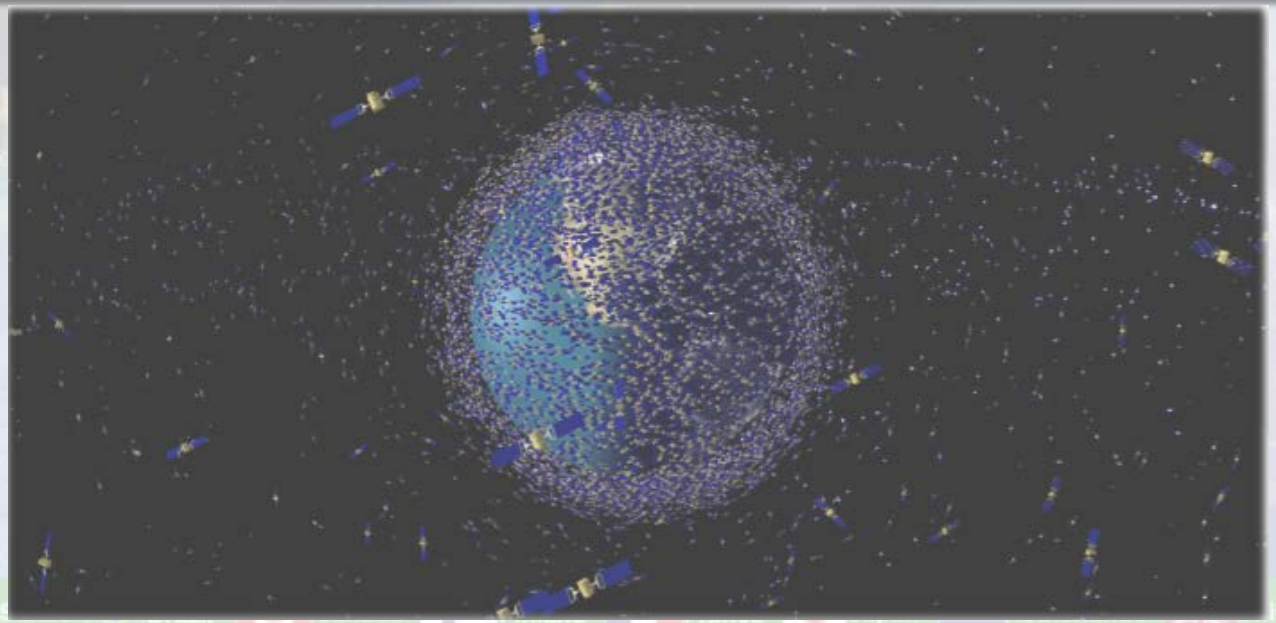
These are "living" documents and are the primary source for information about the Afternoon Constellation configuration, agreements, and procedures.

Operational Benefits of Constellation Coordination

- **SAFE operations – The mission teams are committed to maintaining a SAFE Constellation configuration**
- **Constellation configuration is monitored and communicated to Mission Teams**
  - Mission teams have 24x7 access to the constellation status
  - Advanced warnings of potentially unsafe situations are provided
  - Orbital Debris Monitoring (see next slide)
- **Data Sharing, i.e., Open Data Policy**
- **Responsiveness to changing science requirements**
  - All teams are aware of proposed changes and have a chance to provide comments/impacts before a change is implemented
- **Sharing of "Best practices" and "lessons learned"**
  - Assistance is provided to new and existing missions, for example to ensure safe insertion into (and exit from) the Constellation

Constellation Benefit
Orbital Debris Monitoring

- Orbital debris is a cause for concern by all space missions.
- NASA has an agreement with the US Air Force to provide notification of predicted conjunctions between Constellation satellites and other maneuverable and non-maneuverable space objects (e.g., orbital debris).
- This is implemented by the *Robotic Systems Protection Program* at Goddard.



Questions/Discussion Items

1. **Are there NASA and JAXA satellites that would be good candidates for constellation flying?**
   a) **Current missions**
   b) **Future missions**
2. **Are there scientists in Japan who are using or are interested in using A-Train or constellation data?**
3. **A-Train Constellation Science Contacts — *see next slide***

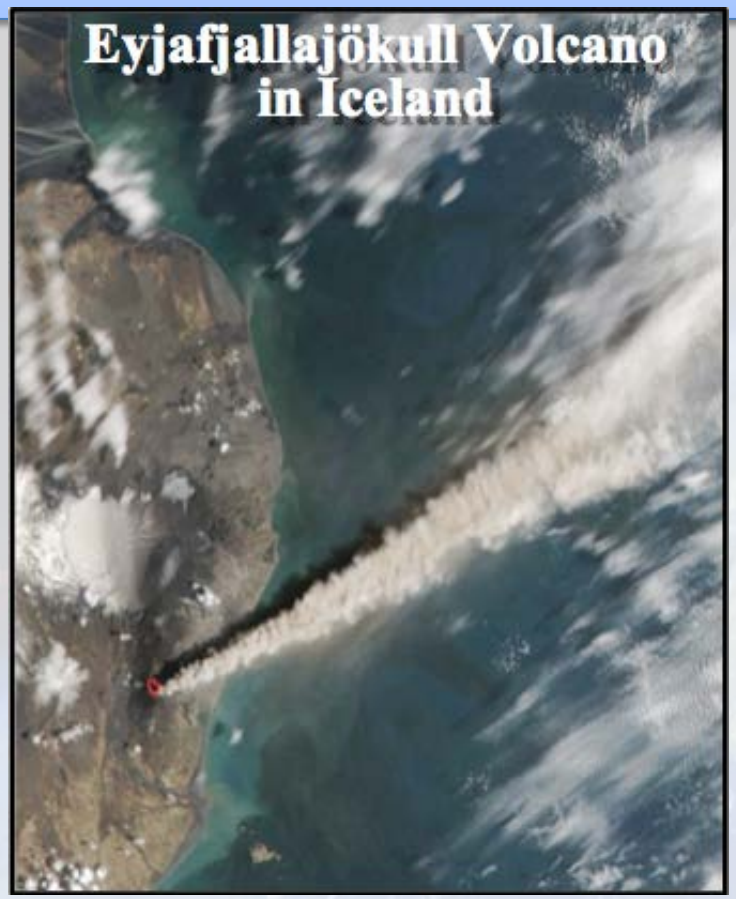
The MOWG teams will provide consultation and analysis support for any mission wishing to join the Morning or Afternoon Constellation or wishing to form another Earth observing constellation.

Constellation Science Contacts

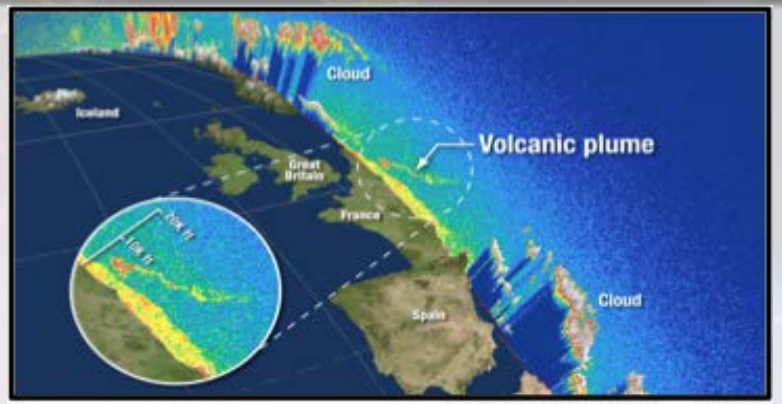
- **Morning Constellation:**
  - Terra: Dr. Kurt Thome
  - Landsat Scientists at GSFC: Dr. Jeremy Irons, Dr. Jeff Masek
  - EO-1: Dr. Elizabeth (Betsy) Middleton
  - SAC-C: Dr. Sandra Torrusio
- **Afternoon Constellation:**
  - A-Train Program Scientist: Dr. Hal Maring/NASA HQ
  - A-Train Project Scientist: Dr. Steve Platnick
  - Aqua: Dr. Claire Parkinson
  - Aura: Dr. Anne Douglass; Dr. Bryan Duncan
  - CALIPSO: Dr. Dave Winker, Dr. Jacques Pelon/
  - CloudSat: Dr. Graeme Stephens, Dr. Deborah Vane
  - GCOM-W1: Dr. Taikan Oki; Dr. Haruhisa Shimoda
  - OCO-2: Dr. David Crisp
  - PARASOL: Dr. Didier Tanre

Summary

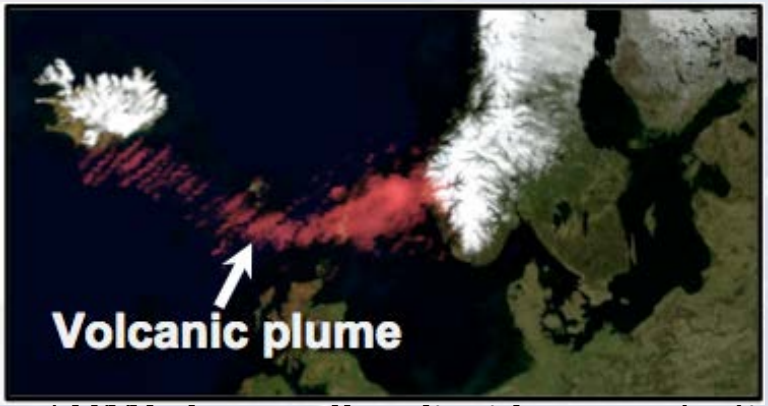
- ***Coordination has been the key to the success of the A-Train***
- ***There is some effort required to develop and operate a constellation, but the opportunity for enhanced science makes it all worthwhile.***



Aqua/MODIS provides a natural color view
Credit: NASA Goddard / MODIS Rapid Response Team



CALIPSO shows ash cloud at 1,500m~7,000m altitude
Credit: NASA/Kurt Severance & Tim Marvel



Aura/ OMI shows sulfur dioxide concentrations
Credit: OMI Science Team

Additional Information

→ 1st INTERNATIONAL EARTH OBSERVATION CONVOY AND CONSTELLATION CONCEPTS WORKSHOP

Science and Application Opportunities from Novel Multi-Satellite Approaches

eo convoy

support to science element

9–11 October 2013 | ESA-ESTEC | The Netherlands

The Preliminary Workshop Objectives

- To identify and discuss **science and application opportunities** from Earth observation constellations across all Earth science domains including the interactions between these domains.
  - The key science accomplishments of existing constellations.
  - Identification of observational gaps, novel observations, enhanced Earth Observation products and science questions across all Earth science domains, which can be effectively addressed by satellite convoys and constellations.
- To present **existing experience** of Earth Observation convoys and constellations e.g. international considerations, orbital aspects and data management
- To present the **results of the ESA Convoy studies**.
  - Ocean and Ice Convoy Study: science and derived concepts.
  - Land Convoy Study: science and derived concepts.
  - Atmosphere Convoy Study: science and derived concepts.

The Preliminary Workshop Objectives

4. To discuss the **challenges of convoys and constellations** e.g. international cooperation, sensor and measurement considerations, orbital aspects and data management.
5. To discuss **future Earth observation convoy and constellation concepts** and satellite coordination options in relation to identified science questions and observational gaps.
6. To collect **recommendations for a future constellation studies and activities development roadmap**.

Workshop Information

- ESA is co-organizing the workshop with NASA
- Dates: 9 – 11 October 2013
- Location: ESA-ESTEC in the Netherlands
- Abstract deadline: Extended until Monday, April 29
- Registration is free. Space will be limited:

http://congrexprojects.com/13M12

A-Train website (http://atrain.gsfc.nasa.gov/)

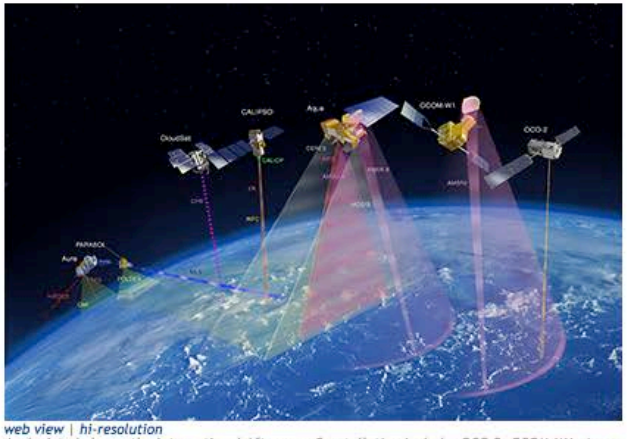
National Aeronautics and Space Administration

The Afternoon Constellation

- Home
- Mission Operations
- Science
- Data
- Newsroom
- Publications
- Multimedia
- A-Train Links

A-Train Fact

Both CALIPSO and CloudSat use their instruments to make vertical profiles or cross-sections of the Earth's atmosphere. CALIPSO uses a laser to observe Earth's aerosols, while CloudSat uses its radar to penetrate clouds to see what's inside.



web view | hi-resolution

As depicted above, the international Afternoon Constellation includes OCO-2, GCOM-W1, Aqua, CALIPSO, CloudSat, PARASOL, and Aura. GCOM-W1, Aqua, CALIPSO, CloudSat, PARASOL, and Aura are currently on orbit. OCO-2 is scheduled to join the configuration in 2013. On November 16, 2011, PARASOL was lowered to 9.5 km under the A-Train and continues its nominal mission observing clouds and aerosols. PARASOL will exit the A-Train fully in the fall of 2013. The instruments on these precisely engineered satellites make almost simultaneous measurements of clouds, aerosols, atmospheric chemistry, and other elements critical to understanding Earth's changing climate. The footprint of each of the A-Train's instruments is shown: active instruments aboard CALIPSO/CALIOP and CloudSat/CPR are indicated with dashed lines. This illustration color-codes instrument swaths—the area of Earth's surface, or the surface of its atmosphere, over which data is collected—based on observed wavelength ranges. Microwaves (observed by both AMSRs, AMSU-A, CPR, MLS) are represented by red-purple to deep purple colors; solar wavelengths (POLDER, OMI, OCO-2), yellow; solar and infrared wavelengths (MODIS, CERES), gray; other infrared wavelengths (IIR, AIRS, TES, HIRDLS) are represented by reds.

What is the A-Train?

NASA and its international partners operate several Earth-observing satellites that closely follow one after another along the same orbital "track." This coordinated group of satellites, constituting a significant subset of NASA's current operating major satellite missions, is called the Afternoon Constellation, or the A-Train, for short. The satellites are in a polar orbit, crossing the equator northbound at about 1:30 p.m. local time, within seconds to minutes of each other. This allows

Announcements

GCOM-W1 Successfully Enters the A-Train
The Afternoon Constellation or "A-Train" welcomed a new member on June 29, 2012 -- the Global Change Observation Mission-Water (GCOM-W1) "SHIZUKU" satellite -- which was launched by the Japan Aerospace Exploration Agency (JAXA) on May 18. SHIZUKU successfully executed a series of orbit control maneuvers required to position itself in its control box. It is now positioned in front of Aqua, making it the lead satellite in the constellation. On July 3, 2012, the antenna rotation on the Advanced Microwave Scanning Radiometer 2 (AMSR2), on SHIZUKU, was increased from a rate of 11 rpm to 40 rpm and it is not acquiring observation data.

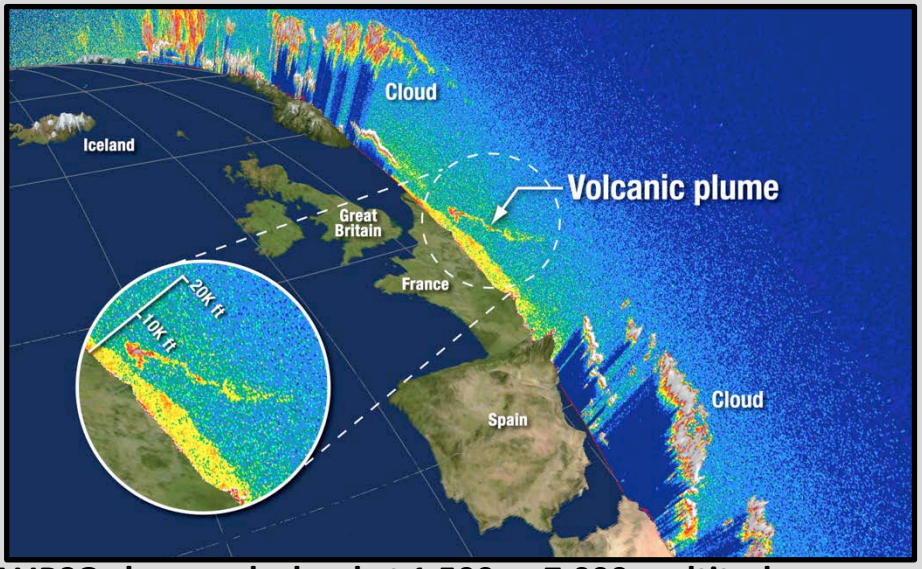
Welcome Back CloudSat
CloudSat was successfully placed back in the A-Train on May 15, 2012 after the completion of a second orbit-raise maneuver. The spacecraft returns after being lowered from the A-Train in June 2011 following a bus undervoltage caused by the emergence of one or more weak battery cells. The only item remaining is an inclination maneuver set to occur in mid-July that will lock CloudSat's orbital node with respect to the CALIPSO spacecraft. CloudSat is now about 103 seconds behind CALIPSO; formerly, it had been 17.5 seconds ahead of CALIPSO. This location allows for concurrent observations with other A-Train instruments while ensuring safe constellation operations. Click here for more details on the status of CloudSat.

Thank you.

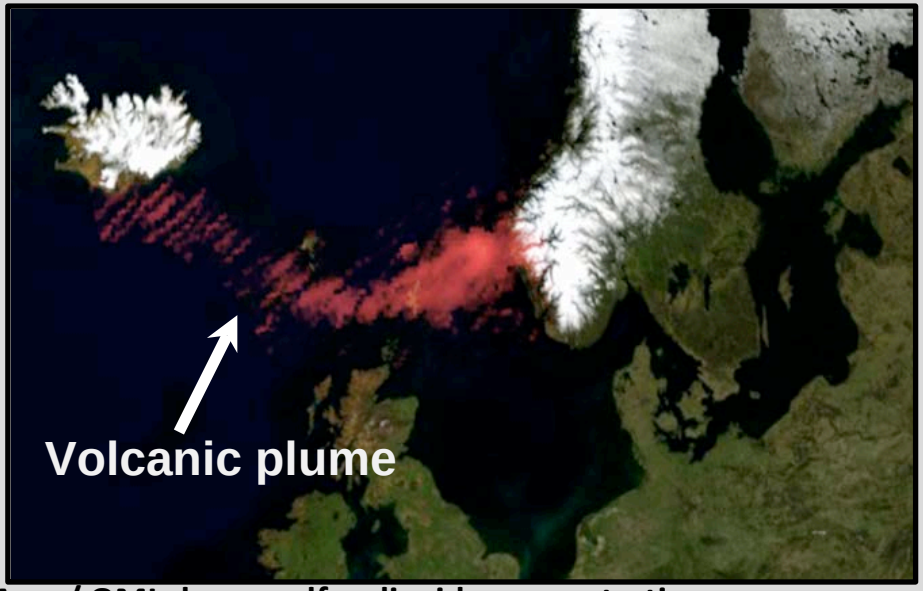
Dōmo arigatōgozaimashita

Questions?

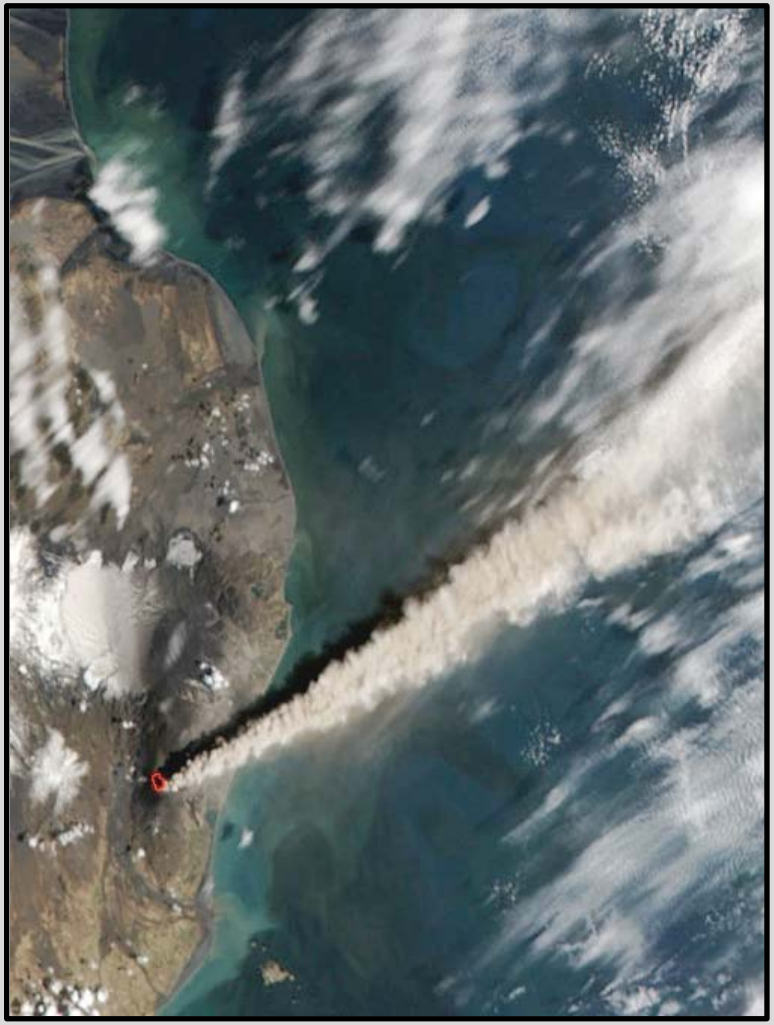
A-Train Science Results – Eyjafjallajökull in Iceland (2010)



CALIPSO shows ash cloud at 1,500m~7,000m altitude
Credit: NASA/Kurt Severance & Tim Marvel



Aura/ OMI shows sulfur dioxide concentrations
Credit: OMI Science Team



Aqua/MODIS provides a natural color view
Credit: NASA Goddard / MODIS Rapid Response Team

A-Train Data Policy

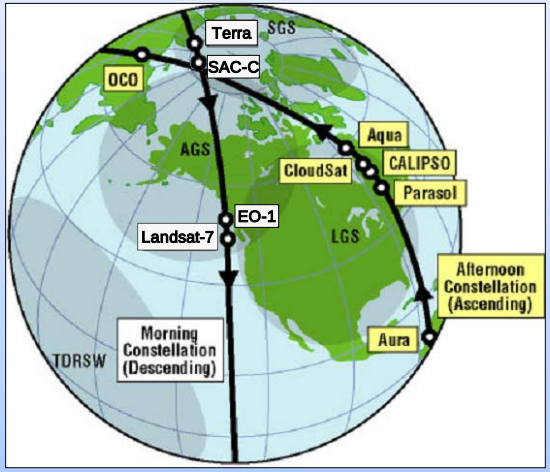
- A-Train mission members agree to abide by a **common set of data exchange and access principles** to maximize the use of A-Train data for public benefit.
- To enable data verification, inter-instrument data comparisons and algorithm synergy, A-Train member agencies make available the **algorithms for calibration and higher level data products.**
- A-Train member agencies establish **appropriate mechanisms for providing data and documents.**
- **Data will be made available as soon as the initial calibration and validation has been completed**; the goal will be to release data in a preliminary form within six months of acquisition after the start of routine data acquisition.
- A-Train member agencies may **require registration of data users.**
- **Redistribution of A-Train data** by users may be limited by member agencies; redistribution of "value-added" data sets (i.e., from which original data cannot be extracted) is permitted.

Types of Constellations

Most constellations are spaced around the Earth to provide instantaneous, global coverage (e.g., GPS, communications, satellite radio, weather).

GPS Constellation

In contrast, the 705 Constellations' satellites orbit in *close proximity* so that **observations occur at about the same time over approximately the same region.**



Morning and Afternoon Constellations

Constellation Coordination

In practice, there is a range of constellation types in existence with varying coordination requirements.

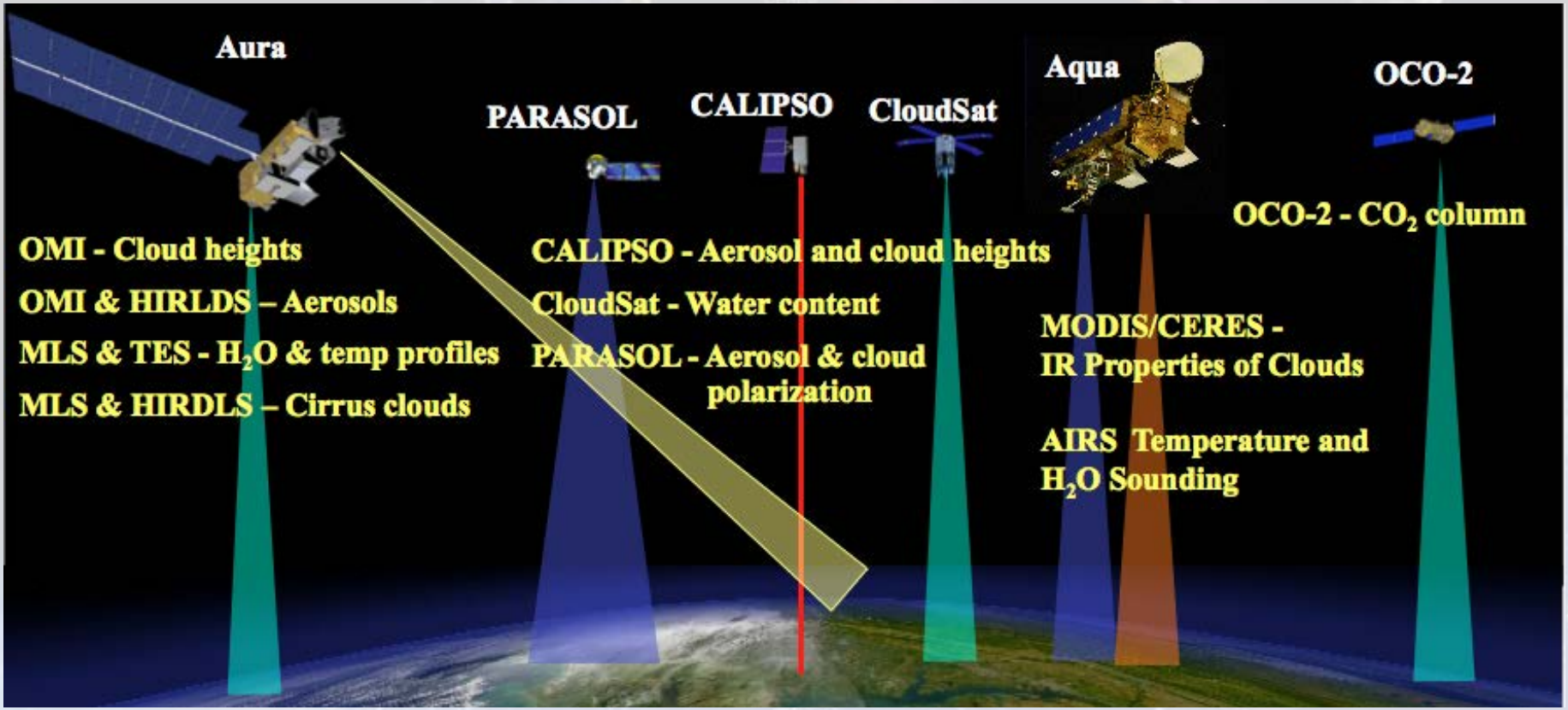
Increasing coordination

Operations Coordination	Typical Characteristics	Coordination	Examples
Minimal	• Heterogeneous satellites • Some orbit parameters may be similar) • Multiple owners • Multiple organizations	• Operations are not coordinated • Coincidental science results can be correlated • Little negotiation	GPM constellation (including ISRO's Megha-Tropiques)
Moderate	• Heterogeneous satellites • Satellites often in close proximity (but not required) • Multiple agencies • Operations handled by separate organizations	• Some maneuver coordination • Science data sharing • Moderate negotiation	Earth Observing Constellations • A-Train (Afternoon Constellation) • Morning Constellations
Central (single organization)	• Homogeneous satellites • Single agency • Easy Coordination	• Tightly coupled objectives and data sharing • Little negotiation	GPS GRACE Iridium

The coordination sometimes evolves over time as the science community identifies innovative ways to leverage available data from one satellite with data from another.

Earth Science Afternoon Constellation

The Earth Observing Constellations are *not* a homogenous mix of identical satellites. They comprise *several* satellites with diverse instruments that provide complementary observations.



Afternoon Constellation Challenges

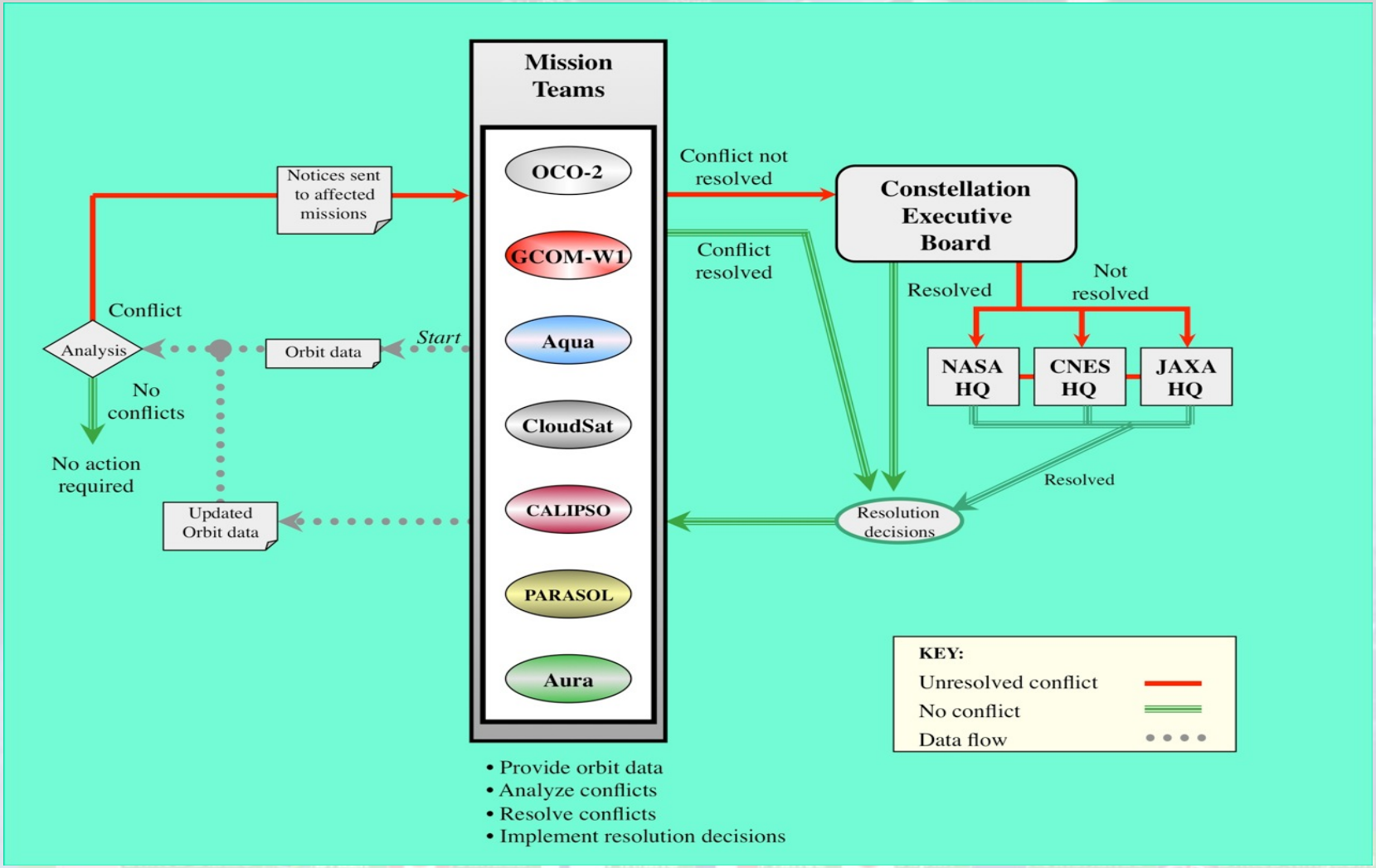
Numerous organizations are involved in this international undertaking

Mission	Affiliation	Locations	
		Project Scientist/ Principal Investigator/Project Management	Control Center
Aqua	NASA	GSFC, Greenbelt, MD	GSFC, Greenbelt, MD
Aura	NASA	GSFC, Greenbelt, MD	GSFC, Greenbelt, MD
CloudSat	NASA	CSU, Ft. Collins, CO CloudSat Project, JPL, CA.	Air Force Facility, New Mexico
CALIPSO	NASA/CNES	LaRC, Hampton, VA CNRS, Paris, France	LaRC, Hampton, VA CNES, Toulouse, France
PARASOL	CNES	UST de Lille Villeneuve D'Ascq, France	CNES, Toulouse, France
GCOM-W1	JAXA	Tokyo, Japan	EOC, Hatoyama, Japan
OCO-2	NASA	JPL, Pasadena, CA	Dulles, VA

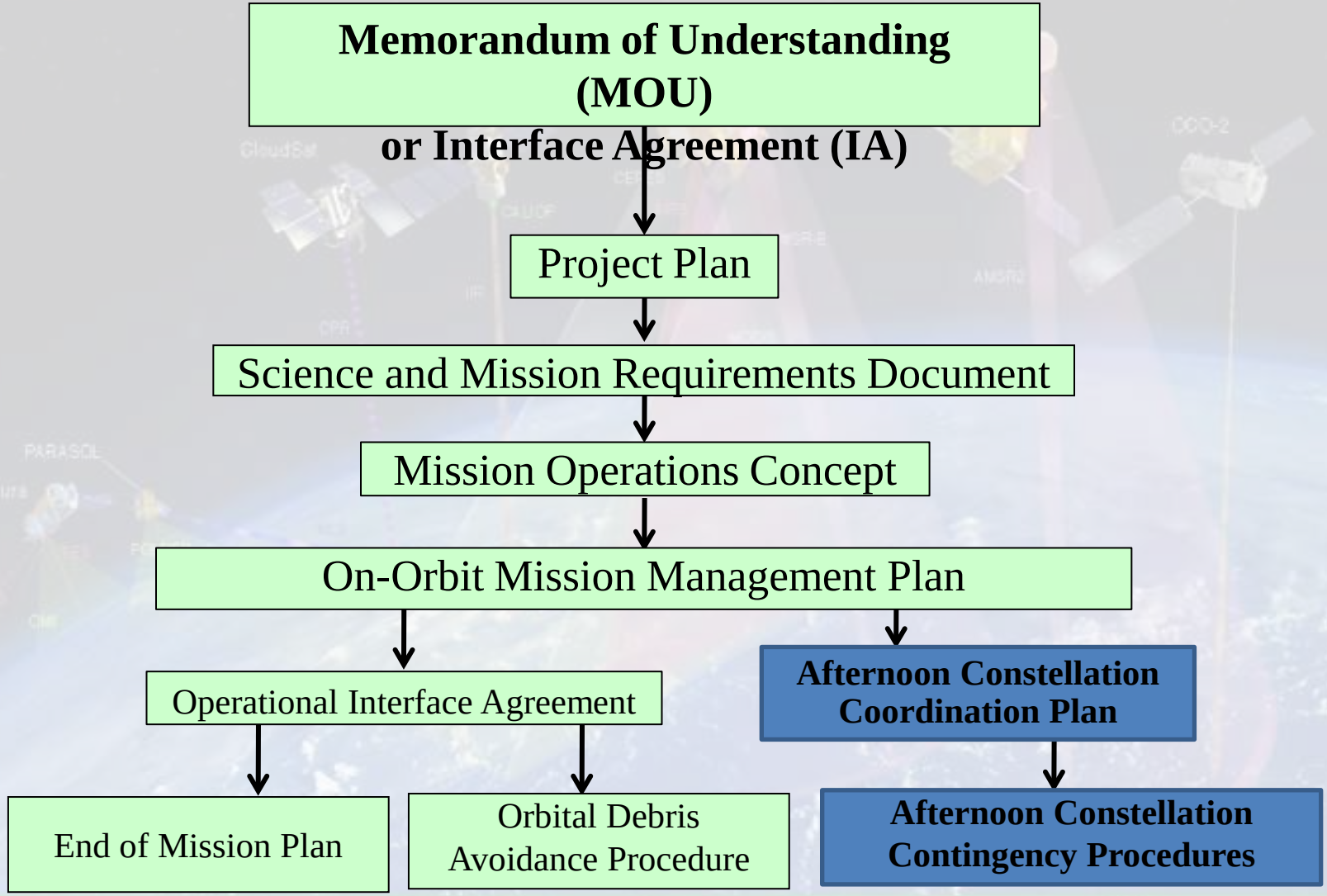
United States Brazil Canada Finland France Japan Netherlands United Kingdom

Constellation Agreements: Conflict Resolution Process

A process exists to resolve conflicts.

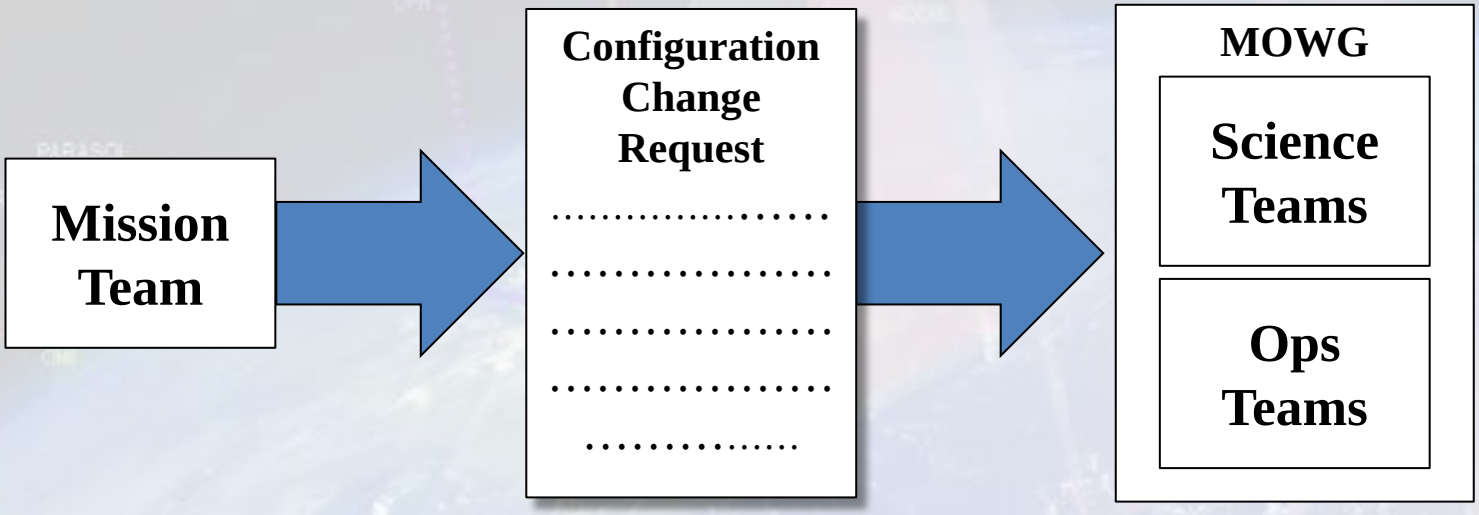


Example
Afternoon Constellation Documentation



Constellation Agreements: Change Process

The A-Train has a process for making changes to the constellation to accommodate new science requirements. This process has been exercised several times.



A Mission Team submits a change request to be considered by the MOWG.