Earth Science Mission Operations Project

428-10-08 Revision 1

Afternoon Constellation Operations Coordination Plan

February 2011
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National Aeronautics and Space Administration

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Greenbelt, Maryland

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Afternoon Constellation

Operations Coordination Plan

February 2011

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Preface

This plan is a cooperative effort of the representatives of the member missions of the Afternoon Constellation. It is maintained by the Earth Science Mission Operations (ESMO) Project at the Goddard Space Flight Center (GSFC). The ESMO Constellation Team Manager has the responsibility for maintenance and configuration control of this document. If a member of the Afternoon Constellation mission teams finds it necessary to change this document, he/she shall document the proposed change following the process delineated in Appendix D.

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Section 1. Purpose

The purpose of this document is to describe the concept, jointly developed by the member missions, for coordinating the operations of the satellites in the Afternoon Constellation and to describe the agreed-to procedures and processes for constellation operations, including coping with anomalous situations.

A number of Earth Science space missions have elected to operate in the same, or in nearly the same orbit for the purpose of making coordinated, co-registered, and near simultaneous science measurements. This is accomplished by matching the orbital parameters and by aligning the orbital positions of these satellites, one relative to another, in such a way that the fields of view of their instruments can overlap while maintaining adequate spacing between spacecraft to insure mission safety for all constellation members. This allows two or more satellites to measure phenomena at the same geographic or atmospheric location within a few seconds or a few minutes of one another. One such manifestation of this concept is the Afternoon Constellation (also known as the A-Train). The Afternoon Constellation comprises the Aqua, CloudSat, Cloud Aerosol Light Detection And Ranging (Lidar) and Infrared Pathfinder Satellite Observations (CALIPSO), Polarization and Anisotropy of Reflectances for Atmospheric Science Coupled with Observations from a Lidar (PARASOL), Aura, Glory, the Global Change Observation Mission 1st - Water (GCOM-W1), and the Orbiting Carbon Observatory-2 (OCO-2) missions. The PARASOL mission began the end-of-mission-life process and left the A-Train orbit on December 2, 2009. Each member mission is independently funded and independently responsible for its mission operations.

In order to perform these independent and coordinated measurements and thereby derive greater science value than the individual missions alone, each satellite in the Afternoon Constellation needs to know the trajectory and mission operations plans for the other missions. Each mission has a vested interest in the well being of the other satellites and of the Afternoon Constellation as a whole by not allowing the orbital configuration of the constellation to be disrupted or broken. Each mission also has an interest in not allowing the safety and/or integrity of another member satellite to be compromised or threatened by collision or close approach. For example, a satellite in a "safe-hold" mode and unable to perform the orbital maneuvers necessary to maintain its location within a pre-defined "control box" could become an unwitting threat to other Afternoon Constellation members. Under a worst-case scenario, a prolonged anomaly on one or more satellites at the same time could create the need for other satellites to exercise "defensive" maneuvers to avoid a collision. To ensure the integrity of the scientific measurement coordination and to ensure safety of all members of the Afternoon Constellation, the National Aeronautics and Space Administration (NASA) has created this Operations Coordination Plan to provide high-level agreements among the Afternoon Constellation members that outline the means for dealing with these member-related anomalies.

To accomplish the Plan's purpose, the ESMO Project at NASA's GSFC provides a focal point for facilitating the exchange of information between missions, independently assessing anomalous situations that may arise, and providing recommendations for remedial actions in the event of anomalies. With ESMO support and the processes outlined in this document, it is possible for the Afternoon Constellation members to proceed in conducting their nominal operations and, at the same time, have confidence that there are processes and procedures in place for handling anomalies within the Afternoon Constellation.

1.1. Scope

This document describes the coordination plan for the Afternoon Constellation developed to ensure the health and safety of the constellation as a whole and to enable the coincident observations required for science. The coordination plan for the Morning Constellation (Earth Observing System [EOS] Terra, Landsat-7, Earth Observing 1 [EO-1], and Satelite de Aplicaciones Cientificas-C [SAC-C]) is contained in a separate document (Ref. RD4). Afternoon Constellation operations coordination does not extend into the detailed operations of each of the missions. Each mission has an operations plan to follow which is based on each mission's science plan and requirements. Interface Control Documents (ICDs) between each Afternoon Constellation member and ESMO will detail items such as product definitions and formats.

The integrity of the Afternoon Constellation depends on the conformance of the member missions to this Plan. This Plan documents the agreements and concurrence from all of the missions that they will conform to the Plan. It is the responsibility of each individual mission to ensure that its mission operations conform to this established and agreed upon baseline.

This document provides a description of the following:

a. the configuration of satellites within the Afternoon Constellation, i.e., the relative placement of one satellite with respect to the others, as well as the allowable variations in their relative locations,
b. the operational methodology for controlling the satellite's relative motion and maintaining these satellites in their agreed to positions in the Afternoon Constellation configuration,
c. a summary of science requirements for Coincident Observations (CO), i.e., congruency and simultaneity of coordinated measurements,
d. a summary of the means by which navigational data, to facilitate science data co-registration, are exchanged between missions (and any actions to be taken by ESMO to enable these exchanges),
e. the process by which anomalous conditions on a satellite or satellites within the Afternoon Constellation are identified and communicated to the other members,
f. the definition of what constitutes an "anomalous situation" that may or does represent a threat to the well-being of one or more members of the Afternoon Constellation, and
g. the process by which anomalous situations are addressed.

1.2. Science Goals and Requirements for Coincident Observations

(Derived from "Formation Flying: The Afternoon (A-Train) Satellite Constellation", NASA Facts, FS-2003-1-053-GSFC, February 2003, and from the Afternoon Constellation MOWG Presentations, March 2003)

The Afternoon Constellation enables near-coincident, co-located observations for some instruments on different constellation spacecraft. By combining the information from several sources the scientists derive more complete answers to many questions than would be possible from any single satellite. Some of the most important science questions are listed here followed by examples of how the data from the Afternoon Constellation are used by scientists to answer these questions. See Figure 1-1.

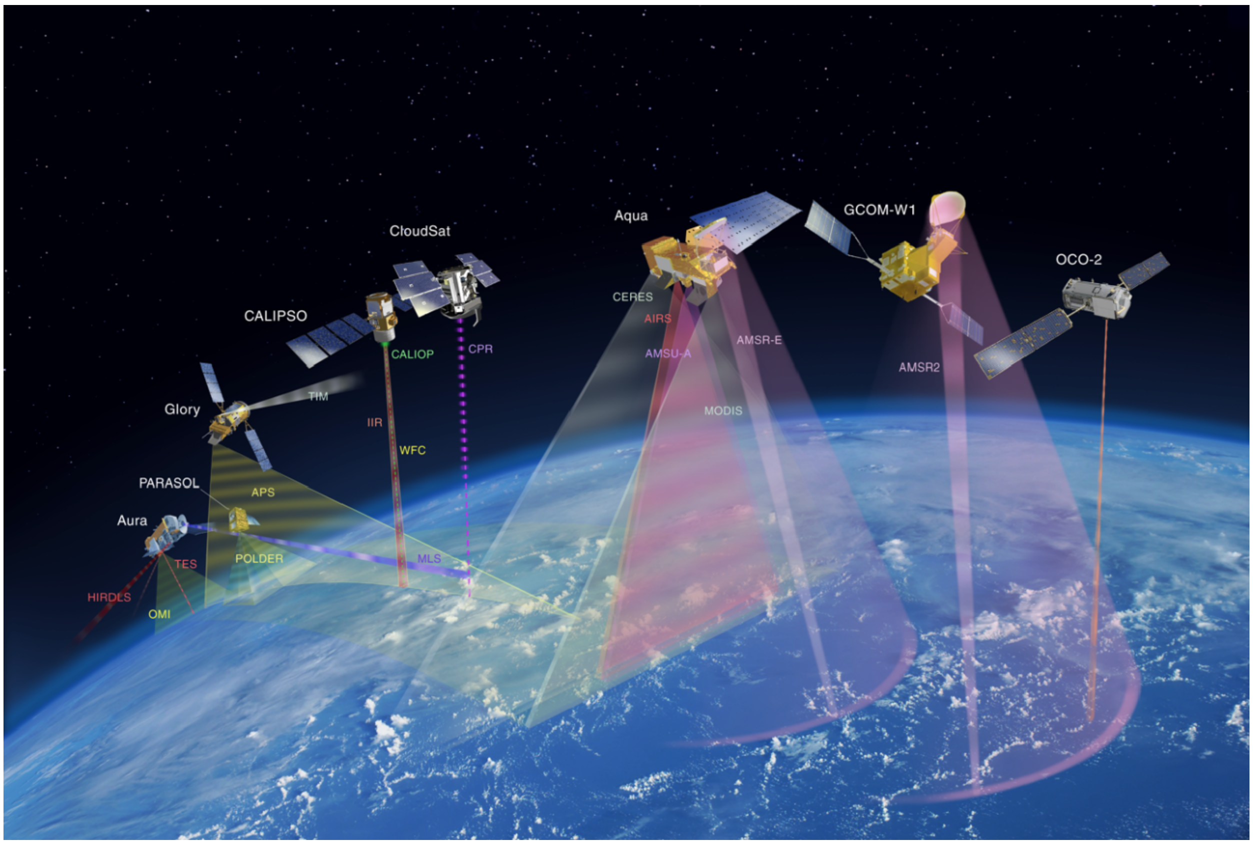

Figure 1-1 Afternoon Constellation Showing Instrument Swaths

- **What are the major aerosol types and how do observations match global emission and transport models?**

Aerosol height information obtained by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument (on CALIPSO) is combined with data on aerosol size distribution and composition obtained by the Polarization and Directionality of the Earth's Reflectances (POLDER) instrument on PARASOL, the Moderate Resolution Imaging Spectrometer (MODIS) (on Aqua), and the Aerosol Polarimetry Sensor (APS) (on Glory). CALIOP also provides additional information on aerosol shape and a qualitative classification of aerosol size; scientists use profile data from CALIPSO to improve information from the Ozone Monitoring Instrument (OMI) (on Aura) on the global distribution of absorbing aerosols. The combination of APS and

MODIS views of ocean glint allows the determination of absorption by aerosols to be extended from the ultraviolet (UV) (from OMI) into the visible and near infrared. APS estimates of aerosol mixed layer depth also allow for improved estimates of aerosol absorption by OMI.

- **How do aerosols contribute to the Earth Radiation Budget (ERB)/climate forcing?**

Data from CALIOP, POLDER, APS, MODIS and OMI all help answer this question. Data from the Clouds and the Earth's Radiant Energy System (CERES) instrument (on Aqua) is crucial for providing information on the ERB. Data from Atmospheric Infrared Sounder (AIRS), Humidity Sounder-Brazil (HSB), Advanced Microwave Scanning Radiometer-EOS (AMSR-E) (on Aqua) and AMSR-2 (on GCOM-W1) instruments provide information on how aerosol climate is forcing changes with atmospheric humidity. In conjunction with data from CloudSat's Cloud Profiling Radar (CPR), these sensors offer an unprecedented opportunity to understand what role aerosols play in changing cloud properties and thus changing the ERB.

- **How does cloud layering affect the Earth Radiation Budget?**

Data obtained by CloudSat's CPR, augmented by data from both CALIPSO's CALIOP and Aqua's MODIS, provide the first global survey of vertical cloud structure. Scientists use data from CALIOP and MODIS to help augment the cloud detection capabilities of the CPR.

- **What is the vertical distribution of cloud water/ice in cloud systems?**

Information from CALIOP, CPR, HSB, AMSR-E, and Microwave Limb Sounder (MLS) are combined to produce vertical profiles of cloud systems. Combining information from CPR, CALIOP, POLDER and APS will shed light on the nature of mixed phase clouds (clouds composed of both water and ice) and improve parameterizations of these processes in atmospheric models. The combination of APS and MODIS and/or AIRS allows for a more detailed examination of the conditions under which super-cooled water clouds exist and facilitate physically based parameterizations of this phenomenon in atmospheric models.

- **What is the role of Polar Stratospheric Clouds in ozone loss and denitrification of the Arctic vortex?**

CALIOP data provides direct information on polar stratospheric cloud height and, in some instances, on cloud type. High Resolution Dynamic Limb Sounder (HIRDLS) on Aura provides some cloud height information. Combined with temperature readings, nitric acid, and chlorine oxide concentrations obtained by MLS and column ozone amounts from OMI, information is being obtained on the role of polar stratospheric clouds in Arctic chemical processes.

1.3. Definition of Terms

Term	Definition
Afternoon Constellation	The group of Earth orbiting satellites with synergistic science objectives in similar sun-synchronous orbits all with their ascending node equator crossings near 13:30 hours Mean Local Time (MLT). This Constellation is also known as the "A-Train".
Afternoon Constellation Member Mission	One of the Earth Science Missions participating in the Afternoon Constellation.
Along-Track Separation	The distance between two satellites measured along the satellite's orbit. To be precise, it is actually the distance along the orbit of the reference satellite to the

Term	Definition
	projection of the other satellite's orbital position into the reference orbit plane. Despite the orbit parameters for Constellation members being very nearly equal, they in fact are not exactly equal and the difference in parameters requires that the along-track separation between two satellites be measured in one orbit plane or the other.
Anomaly	An unplanned deviation in a satellite's operations caused by off-nominal performance or by off-nominal operations of the ground system supporting the satellite.
Braking Maneuver	A maneuver performed by a member of the constellation to decrease its semi-major axis such as to not violate the back of its control box. This occurs when the atmospheric drag unexpectedly drops or when the applied Drag Make-Up (DMU) maneuver is higher than planned.
Circulation Orbit	The path followed by a satellite in its motion relative to other constellation satellites inside of its control box, i.e., the back and forth motion along the orbit caused by drag.
Constellation	A group of satellites utilizing an orbit with essentially the same parameters (i.e., orbital elements) and with the satellites distributed along the orbit in close proximity, such that they over-fly the same geographic region within seconds to minutes of each other. These satellites maintain their relative positions and control boxes by actively, but independently, maneuvering. (See definitions for Control Box, Drag Make-Up Maneuver, and Inclination Adjust Maneuver)
Constellation Coordination System (CCS)	A collection of web-based tools for data and information sharing and constellation orbit analysis.
Control Box	A theoretical construct centered at some reference position on a satellite's drag-free orbit with dimensions defined by an allowable along-track movement relative to the box's center (the reference position). In practice, this along-track movement is coupled with an East-West movement of the satellite's ground-track relative to the idealized ground-track of the drag-free orbit. It is this limitation in both the along-track and cross-track movements that creates the notion of a "box".
Cross-Track Direction	The direction perpendicular to the direction of motion and the radius vector; the direction perpendicular to the orbit plane.
Drag Make-Up Maneuver	A satellite propulsive maneuver intended to increase the orbital semi-major axis to counteract the effects of atmospheric drag, which decreases semi-major axis. This maneuver re-initializes the circulation orbit for a satellite.
Fleet Envelope	The region between the perigee and apogee limits of the Afternoon Constellation, defined as 694 km and 711 km, respectively, above a spherical Earth equatorial radius of 6378.137 km.
Formation	A special orbital configuration within the constellation where the location of the control box for one satellite is slaved to the position of another satellite, and not to the basic orbit. For the Afternoon Constellation, only two missions have a formation relationship: CloudSat is slaved to CALIPSO.
Formation Flying Maneuver	A maneuver used to maintain the relative position of two satellites flying in formation. Because of the close proximity of the satellites and the requirements for tight control, Formation Flying requires the exchange of orbital ephemeris data between members of the formation.
Formation Maintenance Maneuver	A satellite propulsive maneuver to re-initialize the circulation orbit in order to maintain a slave satellite within its control box and, at the same time, the control box properly positioned with respect to the master satellite.
Frozen Orbit	An elliptical orbit with the eccentricity (e) and argument of perigee (ω) carefully selected such that e and ω will vary in a coupled oscillation, thereby limiting the extent of their variation. Thus, by carefully selecting the orbit parameters to balance the perturbations on the orbit, the values of e and ω can be maintained

Term	Definition
	relatively fixed, or "frozen", with generally small oscillations with respect to the selected stable point. Since the value for eccentricity that enables this oscillation is small, e.g., on the order of 0.001 or less depending on the other orbit parameters, a frozen orbit closely approximates the characteristics of a real circular orbit. The result is an orbit of essentially constant shape and orientation relative to the Earth so that altitude variations over any spot on the Earth are minimal, which improves the repeatability of science observations.
Inclination Adjust Maneuver	A satellite propulsive maneuver to adjust to a value that maintains the MLT in a pre-specified range.
Maneuver	The use of the satellite's propulsion subsystem to fire thrusters and bring about an intentional change in the orbital elements. A maneuver may involve one or more burns.
Maneuver Anomaly	An anomaly that disrupts a satellite's performance of a maneuver, i.e., a case where the commanded maneuver was not achieved as expected.
Mean Local Time	The angular distance measured along the equator from the mean solar meridian to the satellite's node, usually measured in units of time.
Orbit Raising Maneuver	A satellite propulsive maneuver intended to increase the orbital semi-major axis and to raise the satellite from the injection orbit into its operational orbit.
Relative Phasing	The time difference between equatorial crossings of two satellites. This is equivalent to the along-track separation, when expressed in units of time.
Safe Hold	A satellite anomaly whereby a satellite cannot perform a propulsive maneuver.
Zone of Exclusion	A rectangular region in a satellite radial, in-track, cross-track (RIC) coordinate system.

Section 2. Documentation

The most current version for each document below applies. The publications dates and version numbers listed are for reference only.

2.1. Applicable Documents (AD)

Interface Control Documents (ICDs) between each mission in the Afternoon Constellation and the ESMO Project at NASA GSFC define the information (type, format, frequency, etc.) to be exchanged.

AD1. PC-GND-902, Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)/Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar (PARASOL)/Earth Science Mission Operations (ESMO) Project ICD for the Operations Coordination of the Afternoon Constellation, June 4, 2004 Version 2

AD2. JPL Document No. D-20209, CloudSat/ESMO ICD, April 4, 2006

AD3. GSFC/Glory Project Document No. 426-4.0-01, ESMO Afternoon Constellation Coordination to Glory Project ICD, Revision B, November 2009

AD4. GCOM-W1/ESMO ICD, JAXA Document – to be published

AD5. OCO-2/ESMO ICD – to be published

2.2. Reference Documents (RD)

RD1. JPL-D23047, CALIPSO/CloudSat ICD, July 12, 2003, Version 1.0

RD2. PIC-P0-0-SP-220-CNES, CALIPSO Satellite Operations Ground System (SOGS)/Mission Operations Ground System (MOGS) ICD, April 10, 2002, Issue 2

RD3. CloudSat Satellite Operations Center (SOC) ICD, CloudSat Operations Product Exchange, May 2003, Version 1.6

RD4. NASA/GSFC, 428-10-02, Morning Train (AM) Coincident Observation Implementation and Operations Plan, September 2002

RD5. NASA/CNES, CAL-OP-0-IF-2502-CNES, Operational Interface Agreement (OIA) Between CNES And NASA For The Aqua Train Constellation, November 1, 2003, Issue 1.

RD6. CCS System Design Review Presentations, September 2003

RD7. NASA Earth Science Enterprise (ESE) Strategy, NP_2003-10-318-HQ

RD8. EOS Program Plan, GSFC 420-01-01

RD9. Afternoon Constellation Contingency Procedures, Revision 1 428-10-09

RD10 "United States Strategic Command Joint Functional Component Command For Space and National Aeronautics And Space Administration Goddard Space Flight Center Interagency Operating Instruction for Robotic Missions Support", 25 Sep 2009.

2.3. Document Tree

Figure 2-1 illustrates the relationship between this Afternoon Constellation Operations Coordination Plan and other Afternoon Constellation documentation.

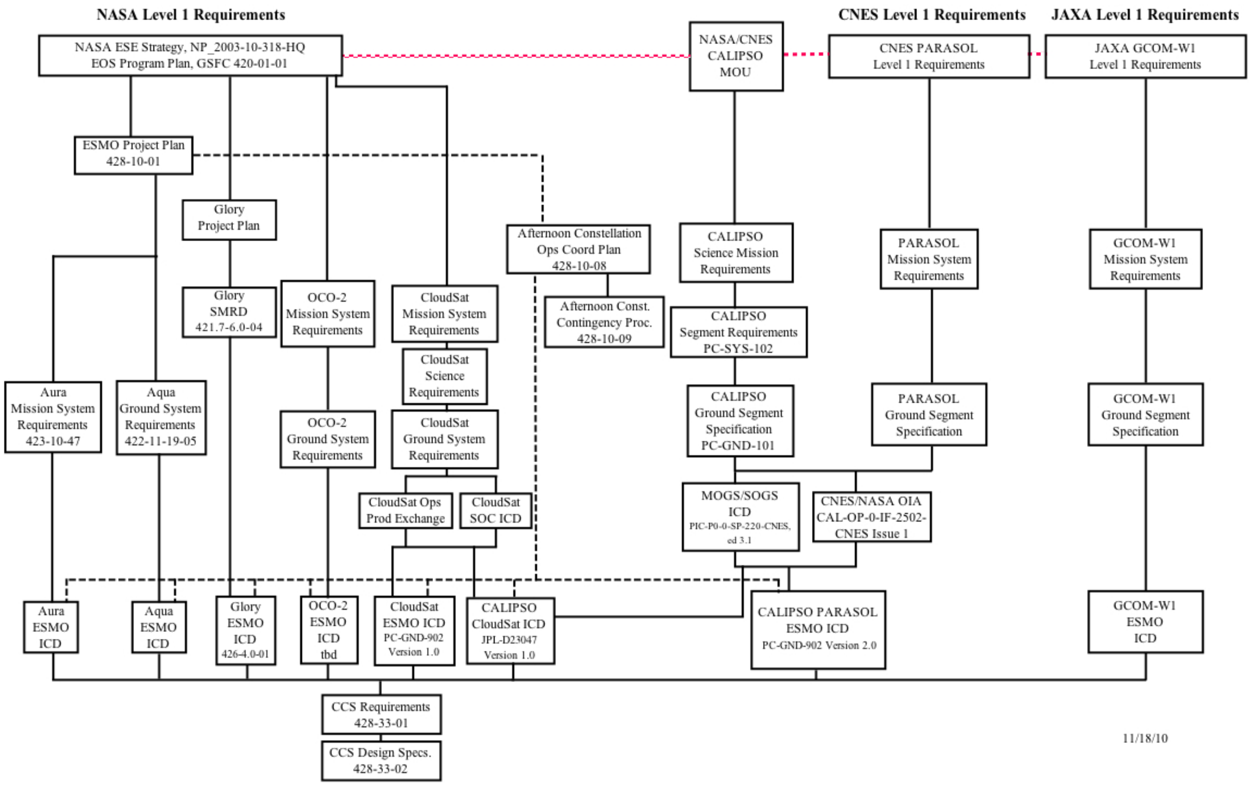

Figure 2-1. Document Tree

Section 3. Constellation Coordination

3.1. Responsible Organization

The requirement to ensure the safety of the Afternoon Constellation is derived from NASA's Science Mission Directorate document, "Earth Science Enterprise (ESE) Strategy" (ref. RD7), and the "EOS Program plan" (ref. RD8).

In accordance with its responsibility for the on-orbit operation of NASA's EOS missions, the GSFC ESMO Project is coordinating constellation operations with the other member missions.

3.2. Why Coordinate?

The primary reason for coordination is to ensure the integrity and safety of the constellation. When satellites in the constellation are performing nominally, minimal coordination is required. This is because each satellite has its assigned position on the orbit with respect to the others and each satellite has a control box, which defines the acceptable limits in the variation of that assigned position. However, when a satellite anomaly occurs leading to a safe hold state, member satellites potentially affected by this safe hold must coordinate their efforts to avoid the threat of one satellite drifting dangerously close to another, possibly creating a risk of collision. In some cases, defensive maneuvers may be necessary to avoid collision.

An equally important reason for coordination is to enhance the overall science return. Most satellite instruments within the A-Train operate continuously and produce a steady stream of science data. Some of these data will be made available and shared with other member missions for correlation with their science data. This is the scientific benefit of being together in the constellation. However, maneuvers can temporarily interrupt the continuity of the data stream. If a maneuver occurs at a particularly critical observation time for another satellite, the opportunity for coincident science observations and data correlation will be temporarily lost.

3.3. Afternoon Constellation Mission Operations Working Group

Coordination among the missions is accomplished through participation in the Afternoon Constellation Mission Operations Working Group (MOWG) and adherence to this Plan. The charter for the Afternoon Constellation MOWG is to:

- Ensure the integrity and safety of the constellation through cooperative agreements and through cooperative actions
- Define and agree to the baseline constellation orbital configuration, i.e., the placement of satellites and their control boxes with respect to each other within the constellation
- Provide the forum for defining changes to the baseline constellation configuration, when necessary
- Define the information/data to be exchanged between member missions and the means of making the exchanges
- Provide the means for the coordination of cooperative science campaigns
- Review specific mission plans that might impact the other constellation missions (e.g., the insertion of new missions into and/or the removal of an old mission from the constellation)

- Provide the forum for discussing and resolving on-orbit issues and contingency situations between member satellites within the constellation.

3.3.1. MOWG Meetings

MOWG meetings/telecons are scheduled two or three times a year, as needed, to provide a forum to identify and work any issues that arise and need to be addressed by the Afternoon Constellation community. Any changes to planned operations are communicated by the Ground System/Operations Lead Personnel identified in Table 3-1 to the Afternoon Constellation MOWG and to the affected Mission Flight Operations Teams (FOTs) for review and execution. The ESMO Constellation Team Manager is responsible for scheduling the meetings/telecons, monitoring the progress of Afternoon Constellation action items, and providing the required coordination between members and others as required. Afternoon Constellation coordination details are addressed in the Afternoon Constellation Operations Coordination section of this Plan (see Section 6.0).

3.3.2. MOWG Science and Operations Leads

The mission scientists and ground system/operations lead personnel for each mission are shown in Table 3-1.

3.3.3. Afternoon Constellation MOWG Executive Board

The Afternoon Constellation MOWG Executive Board shall be the arbiter of conflicts that cannot be resolved by the MOWG. The Board consists of the following:

- ESMO Project Manager (Chair) — Wynn Watson
- Afternoon Constellation Project Scientist (Co-Chair) — Steve Platnick
- ESMO Constellation Team Manager — Angie Kelly
- Mission Director or Mission Operations Manager (one from each mission).
    - Aqua/Aura — William Guit
    - CloudSat — Mark Rokey
    - CALIPSO — David MacDonnell
    - PARASOL — Thérèse Barroso
    - Glory — Eric Moyer
    - GCOM-W1 — Keizo Nakagawa
    - OCO-2 — Peter Kahn

The Board will make recommendations for resolving conflicts that cannot be settled at the working levels and if needed, bring them to the attention of NASA, Centre National D'Etudes Spatiales (CNES) and Japan Aerospace Exploration Agency (JAXA) Headquarters levels for final resolution.

Table 3-1. Afternoon Constellation Science and Operations Leads

Mission	Ground System/Ops Lead	Science Responsibility
Aqua	Bill Guit / GSFC william.j.guit@nasa.gov	Claire Parkinson, Project Scientist (PS)/ GSFC Claire.L.Parkinson@nasa.gov Lazaros Oraiopoulos, Deputy PS/ GSFC lazaros.oraiopoulos-1@nasa.gov
Aura	Bill Guit / GSFC william.j.guit@nasa.gov	Anne Douglass, PS / GSFC Anne.R.Douglass@nasa.gov
CloudSat	Mark Rokey / Jet Propulsion Laboratory (JPL) mark.j.rokey@nasa.gov	Graeme Stephens, Principal Investigator (PI)/ CSU stephens@atmos.colostate.edu Deborah Vane, Deputy PI/ JPL dvane@jpl.nasa.gov
CALIPSO	David MacDonnell / Langley Research Center (LaRC) david.g.macdonnell@nasa.gov	Dave Winker, PI / LaRC David.M.Winker@nasa.gov Jacques Pelon, Co-PI / Centre National de la Recherche Scientifique (CNRS) jacques.pelon@aero.jussieu.fr
PARASOL	Christophe Maréchal/ CNES christophe.marechal@cnes.fr	Didier Tanre, PI / Lille University didier.tanre@univ-lille1.fr Anne Lifermann, PS / CNES anne.lifermann@cnes.fr
Glory	Eric Moyer / GSFC eric.m.moyer@nasa.gov	Brian Cairns, APS Instrument Scientist / Goddard Institute for Space Studies (GISS) bcairns@giss.nasa.gov Greg Kopp, TIM Instrument Scientist / Laboratory for Atmospheric and Space Physics (LASP) Gregory.kopp@lasp.colorado.edu
GCOM-W1	Norimasa Ito / JAXA Ito.norimasa@jaxa.jp	Keizo Nakagawa / JAXA nakagawa.keizo@jaxa.jp
OCO-2	Peter Kahn/JPL peter.b.kahn@nasa.gov	Dr. Michael Gunson /PS mgunson@jpl.nasa.gov
Constellation Mission Coordination	Angie Kelly / GSFC (Constellation Team Manager) angelita.c.kelly@nasa.gov	Steve Platnick, PS/ GSFC Steven.E.Platnick@nasa.gov

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Section 4. Afternoon Constellation Overview

The Afternoon Constellation currently consists of five on-orbit missions (see Figure 4-1). Two are NASA EOS missions. One is a multi-national mission with NASA jointly cooperating with CNES. Another is a joint mission with the Canadian Space Agency and the United States Air Force. The PARASOL mission, operated by CNES, is still considered part of the A-Train but has dropped out of the A-Train orbit. There are currently three additional missions in various stages of planning and readiness that are scheduled to join the A-Train between 2011 and 2013 (see Table 4-1.) This grouping of satellites provides scientists with the opportunity to perform coincident observations using data from two or more instruments on various satellites with measurements taken at approximately the same time.

NASA launched the EOS Aqua satellite on May 4, 2002. On July 15, 2004, the EOS Aura satellite was launched and phased with EOS Aqua such that one of the Aura instruments, the MLS, is able to view the same air mass that Aqua observed eight minutes earlier. In 2008, Aura was moved forward to eliminate this eight-minute delay. The joint NASA/CNES mission CALIPSO, and the NASA/United States Air Force (USAF) mission CloudSat were launched on April 28, 2006 using the same expendable launch vehicle. CALIPSO flies from 30 to 120 seconds behind Aqua. CloudSat leads CALIPSO by 17.5±2.5 seconds. This tight formation enables synergistic measurements with Aqua, which is a key science requirement for the Afternoon Constellation. The CNES mission, PARASOL, was launched on December 18, 2004 and flew between 15 and 58 seconds behind the CALIPSO control box until it left the constellation in December 2009. The NASA mission, Glory will be launched in 2011 and will maintain its control box 30 seconds behind the CALIPSO satellite control box. The JAXA mission, GCOM-W1 will be launched between November 2011 and March 2012 and will maintain its MLT of the ascending node between 79.5 and 259.5 seconds earlier than the Aqua's MLT. The OCO-2 mission will be launched in 2013 and will maintain it MLT of the ascending node to be at least 101 seconds earlier than the MLT of GCOM-W1.

All A-Train satellites will cross the equator within a few minutes of one another at approximately 13:35 MLT. Since these missions are all at the same mean equatorial altitude, 705 kilometers (km), they are referred to as a constellation (note that the term "formation" has also been used although it applies only to CloudSat with respect to CALIPSO). The set of missions is referred to as the Afternoon Constellation due to the early afternoon equator crossing of each mission. Each individual mission has its own science objectives; all will improve our understanding of aspects of the Earth's climate. The synergism that is expected to be gained by flying in close proximity to each other should enable the overall science results of the Afternoon Constellation to be greater than the sum of the science of each individual mission.

For additional descriptions of the missions and instruments, visit the following websites:

- Aqua – http://aqua.nasa.gov/
- Aura – http://aura.gsfc.nasa.gov/
- CloudSat – http://cloudsat.atmos.colostate.edu/
- CALIPSO – http://smsc.cnes.fr/CALIPSO/ and http://www-calipso.larc.nasa.gov

- PARASOL – http://smsc.cnes.fr/PARASOL/
- Glory – http://glory.gsfc.nasa.gov/
- GCOM-W1 - http://www.jaxa.jp/projects/sat/gcom_w/index_e.html
- OCO-2 - http://oco.jpl.nasa.gov/

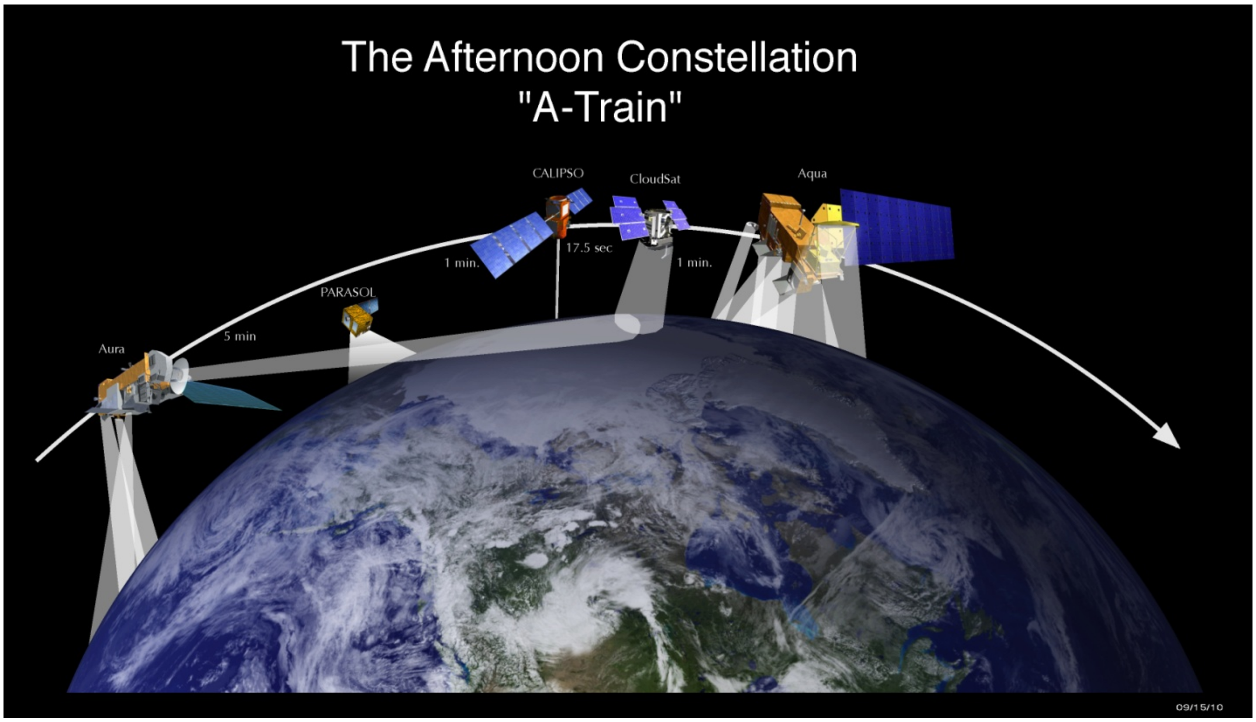

Figure 4-1. Afternoon Constellation (current configuration)

Notes:

- Drawing not to scale
- Times shown are nominal separation times between satellites (in terms of equator crossing times)

Table 4-1 Afternoon Constellation Mission Summary

Satellite	Summary Of Mission	Instruments	Launch Date	Responsible Organization
Aqua	Aqua, Latin for water, named for the large amount of information that the mission is collecting about the Earth's water cycle, including evaporation from the oceans, water vapor in the atmosphere, clouds, precipitation, soil moisture, sea ice, land ice, and snow cover on the land and ice.	AIRS/AMSU-A/HSB AMSR-E CERES MODIS	May 4, 2002	NASA/GSFC
Aura	Aura (Latin for air) studies the Earth's ozone, air quality, and climate. It is designed exclusively to conduct research on the composition, chemistry, and dynamics of the Earth's atmosphere. Limb sounding and nadir imaging observations allow studies of the horizontal and vertical distribution of key atmospheric pollutants and greenhouse gases and how these distributions evolve and change with time.	HIRDLS MLS OMI TES	July 15, 2004	NASA/GSFC
PARASOL	Polarized light measurements allow better characterization of clouds and aerosols in the Earth's atmosphere. (Left the A-Train in December 2009).	POLDER	December 18, 2004	CNES
CALIPSO	Observations from space-borne lidar, combined with passive imagery, lead to improved understanding of the role aerosols and clouds play in regulating the Earth's climate.	CALIOP IIR WFC	April 28, 2006	NASA/GSFC NASA/LaRC CNES
CloudSat	Cloud Profiling Radar allows for the most detailed study of clouds to date and should better characterize the role clouds play in regulating the Earth's climate.	CPR	April 28, 2006	NASA/GSFC NASA/JPL
Glory	Increase understanding of aerosols as agents of climate change and continue the total solar irradiance monitoring mission	APS TIM	Anticipated February 2011	NASA/GSFC
GCOM-W1	The GCOM-W1 observes integrated water vapor, integrated cloud liquid water, precipitation, sea surface wind speed, sea surface temperature, sea ice concentration, snow water equivalent, and soil moisture.	AMSR-2	Anticipated November 2011	JAXA
OCO-2	Three grating spectrometers will make global, space-based observations of the column-integrated concentration of CO_2, a critical greenhouse gas.	Three grating Spectrometers	Early 2013	NASA/JPL
				10/21/10

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Section 5. Derived and Operational Requirements

All missions in the Afternoon Constellation are in sun-synchronous, frozen orbits with a mean equatorial altitude of 705 km, and an inclination of 98.2 degrees and an MLT of approximately 13:30. The Afternoon Constellation satellites are spread out along-track in the orbit in order to provide room for each satellite's control box and safe spacing between them so that they don't overlap. This placement of A-Train satellites and their control boxes along the orbit also defines the relative position of one satellite with respect to the next constellation member (see Figure 5-1). Refer to Table 5.1 for a summary of the important orbital characteristics. This relative placement is intended to remain fixed over the lifetime of the constellation, but can be modified with the approval of the MOWG. And with the placement and spacing fixed, each satellite can conduct its operations independently (to first order) of the other satellites (CloudSat and CALIPSO are slight exceptions to this in that CALIPSO's operations are independent of the other constellation members but CloudSat's operations are more strongly tied to CALIPSO's because the two are formation flying together).

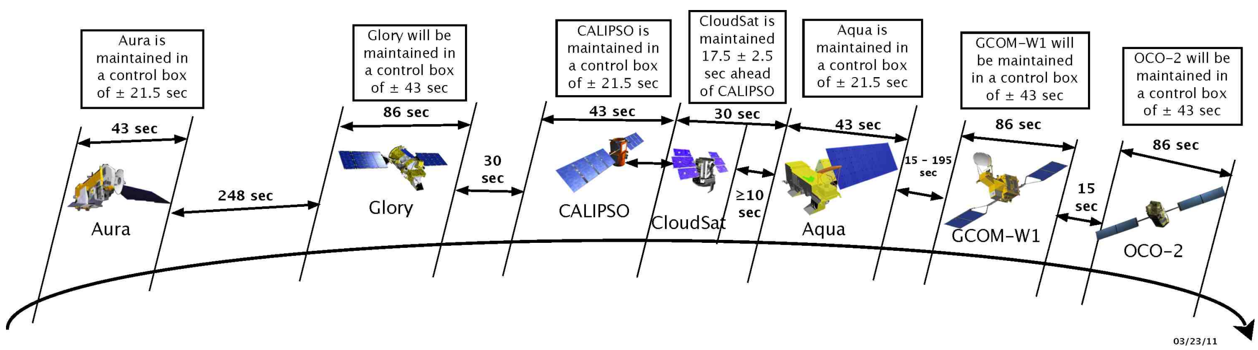

Figure 5-1 Afternoon Constellation Orbit/Formation Configuration

Notes:

- Aqua, CALIPSO, OCO-2, Glory, GCOM-W1 and Aura all have independent control boxes.
- CloudSat is slaved to CALIPSO.
- All time differences refer to equator crossing times.

The separation between two spacecraft measured as the time between equator crossings is not the same as the along-track separation between the satellites. In particular, given the orbit inclination and planned difference in the Right Ascension of Ascending Nodes (RAANs), when CALIPSO crosses the equator 73 seconds behind Aqua it is 77.7 seconds behind Aqua along track (Figure 5-2). So CALIPSO would need to move 77.7 seconds ahead in its orbit (not 73 seconds) to potentially collide with Aqua at the point their orbits intersect. In other words, a collision is possible when the along track separation goes to zero, not when the equator crossing time difference goes to zero.

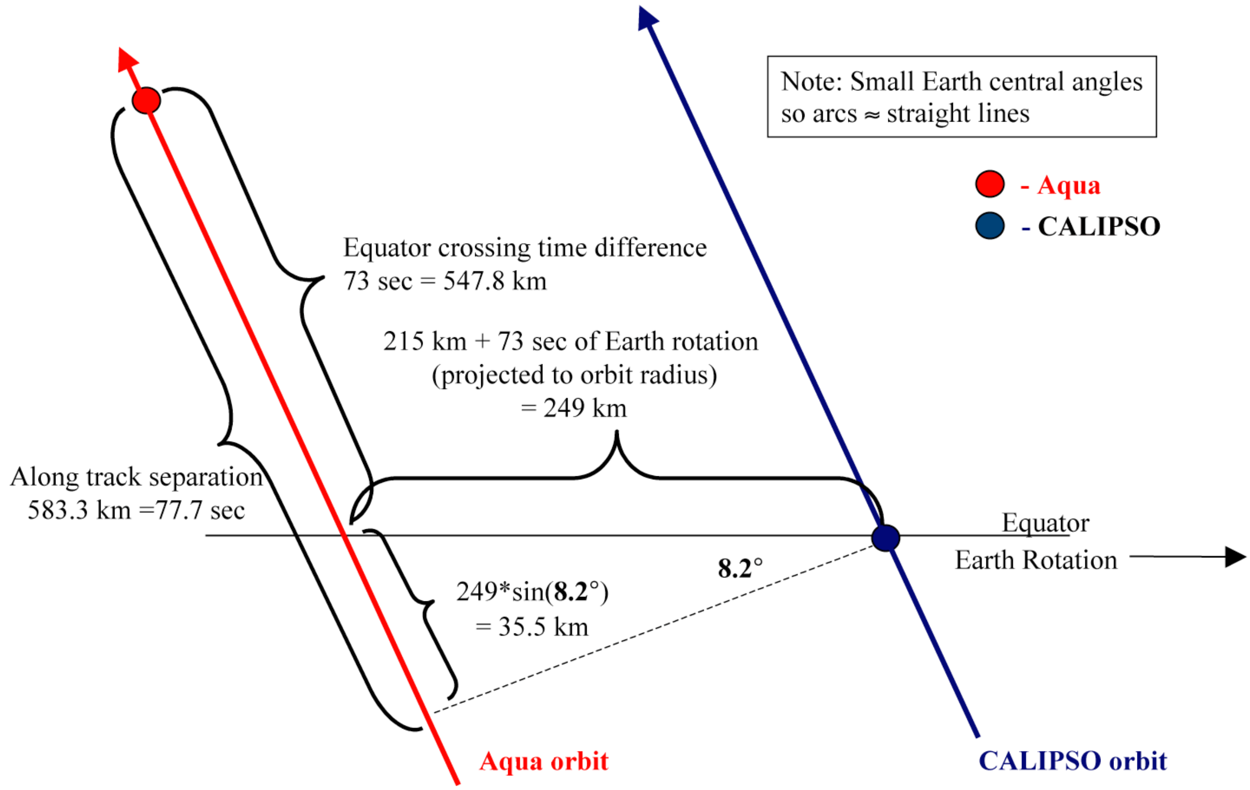

Figure 5-2 Equator Crossing Time Difference vs. Along Track Separation

The MOWG objective is to ensure the overall health and safety of the Afternoon Constellation by avoiding close approaches between satellites.

The general approach to managing the constellation's dynamics and maintaining sufficient separation between satellites is based on the concept of the "control box" (see Definition of Terms). As long as each satellite stays in its control box and the control boxes remain appropriately separated, there is no risk of satellites making a close approach with each other. Only when a satellite goes outside its control box (an unplanned departure) does it become necessary to place affected constellation members on alert. Under these conditions there is the need for a timely assessment as to how close and how soon it will approach another satellite's Zone of Exclusion and eventually the satellite itself (see Section 6.2.2: Zone of Exclusion).

It is also important to monitor satellites when entering or leaving the constellation, because during that mission phase a satellite will be outside its control box but maneuvering in close proximity to other constellation satellites.

5.1. Afternoon Constellation Placement Requirements

5.1.1. Aqua

The Aqua satellite, launched on May 4, 2002, leads the Afternoon Constellation, and should continue to do so until the launch of GCOM-W1 and OCO-2 and their placement at the head of the constellation. The Aqua orbit was phased with the Morning Constellation (EOS Terra, Landsat-7, EO-1, and SAC-C) to reduce resource contention at the polar ground stations. Aqua is flying the Worldwide Reference System-2 (WRS-2) track to facilitate comparison of Aqua data with the data from Terra and Landsat and originally operated within a pre-defined ground-track control box of ± 20 km as measured at the descending node. See Appendix C for information on the WRS. In response to a request from CALIPSO and CloudSat, the Aqua control box was reduced to ± 10 km before the CALIPSO/CloudSat launch. As the first mission in the Afternoon Constellation, Aqua establishes the orbital profile baseline for the other constellation missions.

For Aqua, coincident observations are a secondary mission goal and should be carried out in a way that reduces any impact to the primary science objectives of the Aqua mission.

In order to meet data delivery requirements, Aqua requires at least one Solid State Recorder (SSR) dump opportunity every orbit at the EOS polar ground stations in Alaska and Norway. The capacity of the SSR is approximately two orbits of collected data.

Aqua is controlled by the EOS FOT at the EOS Operations Center (EOC) at NASA GSFC in Greenbelt, Maryland.

5.1.2. Aura

The Aura satellite brings up the rear of the Afternoon Constellation. It is phased with the Aqua satellite such that Aura flies approximately 8 minutes behind Aqua in along-track position. This allows Aura to observe the same air mass as CloudSat and Aqua. This results in Aura's ground-track being 18 kilometers east of Aqua on the same WRS path. Aura operates within its pre-defined ground-track control box of ± 10 km measured at the descending node around this reference point. Note that Aura was originally phased to be approximately 15 minutes behind Aqua, but was moved forward in 2008 to enhance the coincidental science return.

Like Aqua, Aura requires at least one SSR recorder dump opportunity every orbit at the EOS polar ground stations in Alaska and Norway in order to meet data delivery requirements (including a three-hour data latency requirement). The capacity of the SSR is approximately three orbits of collected data.

Aura is controlled by the EOS FOT at the EOC at NASA GSFC in Greenbelt, Maryland.

5.1.3. CALIPSO

CALIPSO maintains its lidar footprint 215 km +/- 25 km to the east of the Aqua sub-satellite point at its ascending node. CALIPSO maintains a pre-defined ground-track control box (±10 km). The leading edge of the CALIPSO control box (which is 43 seconds long) lags behind the trailing edge of the Aqua control box by 30 seconds (in equator crossing time). The CALIPSO team will provide notification to the A-Train community at least 6 months prior any constellation location change, assuming no rapid and unexpected changes in spacecraft health or performance which may require a more immediate response by the CALIPSO team.

CALIPSO retains the option to someday adjust its inclination so that it slowly precesses to the western edge of the Aqua MODIS swath.

The satellite is controlled from the Satellite Operations Control Center (SOCC) at CNES, Toulouse, France working with the NASA Langley Research Center (LaRC) Mission Operations Control Center (MOCC) in Hampton, Virginia (see RD1 and RD2).

5.1.4. CloudSat

CloudSat flies in tight formation with CALIPSO, positioned along-track 17.5 ± 2.5 seconds in front of CALIPSO. Measurements of a specific cloud field obtained from CloudSat's CPR instrument are correlated with measurements taken by the MODIS instrument on Aqua and the lidar measurements taken on CALIPSO. For all points along the CALIPSO lidar ground-track, the edge of the nearest CloudSat CPR footprint shall fall within 2 km of the edge of the nearest CALIPSO-lidar footprint on the same orbit with a two-sided 3-sigma probability (99.73%). Note that the CALIPSO lidar is pointed 3 degrees forward from geodetic nadir (0.3 degrees prior to 28 Nov. 2007) and the CloudSat CPR is pointed 0.16 degrees forward from geodetic nadir. So the CALIPSO lidar ground-track is 2.543 kilometers east of the satellite sub-point ground-track at the equator and the CloudSat CPR ground-track is 0.135 kilometers east of the satellite sub-point ground-track at the equator. There is a goal to have the instrument footprints overlapping at least 50% of the time. The CloudSat CPR ground-track must be maintained to within ±1 km of the CALIPSO lidar ground-track in the cross-track direction to ensure that the edges of their footprints remain within 2 km of each other with a 3-sigma probability.

The CloudSat mission is operated and controlled by the United States Air Force at their Research, Development, Test, and Evaluation (RDT&E) Support Complex (RSC) at Kirtland Air Force Base (KAFB) in Albuquerque, New Mexico. (See AD2, RD1 and RD3)

5.1.5. PARASOL

While it was in the constellation orbit, the leading edge of the PARASOL control box lagged 15 seconds (in equator crossing time) behind the trailing edge of the CALIPSO control box to get the sub-satellite point within the POLDER images. PARASOL operated within its pre-defined ground-track control box of ± 10 km (relative to WRS-2 reference) and any maneuvering was relative to CALIPSO maneuvers.

PARASOL is currently in its extended mission since it did not have sufficient fuel to follow the rest of the Afternoon Constellation when they performed coordinated inclination adjust maneuvers (IAMs) in Spring 2009. PARASOL does not follow the inclination campaigns and lowered its orbit on December 2nd, 2009 by approximately 4 kilometers. Therefore, it does not continue to maintain its along-track separation either with the rest of the Afternoon Constellation. Since then PARASOL does not perform any Drag Make-Up maneuvers and is slowly drifting away from the A-Train. As its apogee is higher than the A-Train perigee, it is not considered out of the A-train. Despite this, common measurements with the A-train are still possible approximately every 80 days.

The satellite is controlled from the SOCC at CNES, Toulouse, France.

5.1.6. Glory

The Glory satellite is phased with the Aqua satellite such that Glory flies between 124.5 and 210.5 seconds behind Aqua with regard to equator crossing time. In addition, Glory will maintain a 30-second minimum separation between its control box and that of CALIPSO. Glory will fly 215 km east of Aqua on the WRS-2 grid allowing the nominal ground track of the Glory spacecraft to over-fly the ground track of the CALIOP instrument on CALIPSO. Glory will operate within its pre-defined ground-track control box of ± 20 km measured at the descending node around this reference point.

Glory requires at least one successful SSR recorder dump within each 24-hour period at one of the Universal Space Network (USN) ground stations located in Alaska, Hawaii, or Australia in order to prevent the potential loss of science data on the spacecraft. The capacity of the SSR is approximately two days of collected science and housekeeping data.

Glory will be controlled by the Glory Mission Operations Center (MOC) at the Orbital Sciences Corporation facilities in Dulles, Virginia.

5.1.7. GCOM-W1

GCOM-W1 will be phased with the Aqua satellite such that GCOM-W1 flies over the Aqua's ground track on the WRS-2. GCOM-W1 will maintain the MLT of ascending node between 79.5 and 259.5 seconds earlier than the Aqua's MLT, depending on when GCOM-W1 launches within its 3-minute launch window. GCOM-W1 will operate within a pre-defined ground-track control box of ± 20 km measured at the descending node around the reference point. The trailing edge of its control box will be at least 15 seconds ahead of the Aqua control box.

GCOM-W1 will be controlled from the Tsukuba Space Center at JAXA, Japan. (See AD3)

5.1.8. OCO-2

OCO-2 plans to maintain its MLT at the ascending node (MLTAN) to be greater than 13:21:21 and at least 101 seconds earlier (less) than the MLTAN of GCOM W1. Note that the 101 seconds comes from 43 + 43 + 15 = 101 seconds. The operational orbit has been defined in relation to both the Morning and Afternoon Constellations to reduce the possibility of close approaches and reduce interference during data dumps over the Alaska ground stations.

OCO-2 will be controlled by the OCO-2 MOC at the Orbital Sciences Corporation facilities in Dulles, Virginia. (See AD4)

Table 5-1. Afternoon Constellation Orbital Characteristics

	Aqua	Aura	CALIPSO	CloudSat	Glory	GCOM-W1	OCO-2	PARASOL
Launch	05/04/02	07/15/04	04/28/2006	04/28/2006	2011	2011	2013	12/18/2004
Design Lifetime	6 years	6 years	3 years	2 years	3 years	5 years	2 years	2 years
Altitude	705 km							701 km
Inclination	98.2 degrees							98.2 deg.
Orbit Type	Sun-synchronous frozen							-
Nominal Equator Crossing Time wrt Nominal Aqua	0.0	~8 minutes	73 seconds	55.5 seconds (17.5 ± 2.5s earlier than CALIPSO)	167.5 seconds	79.5 – 259.5 seconds (Note 4)	180.5 – 360.5 seconds (in front) (Note 4)	Note 2
Required MLT at the ascending node	13:30 – 13:45	13:30-14:00	9 minutes later than Aqua	12.2s ± 2.5s earlier than CALIPSO	11 min 14 sec. later than Aqua	13:15 – 13:45	13:21:21	Note 2
Operational MLT at the ascending node	13:30 – 13:45 Beta angle limited	8 minutes later than Aqua	9 minutes later than Aqua	12.2s ± 0.4s earlier than CALIPSO	11 min 14 sec. later than Aqua	79.5-259.5 seconds earlier than Aqua (Note 4)	180.5 – 360.5 seconds earlier than Aqua (Note 4)	Note 2
Ground-track Reference	WRS-2	-18.0 (East) of Aqua	215 km East of Aqua WRS-2	CALIPSO lidar	215 km East of Aqua WRS-2	WRS-2	WRS-2	Note 2
Ground-track Control	± 10 km as measured at the descending node.	± 10 km as measured at the descending node	± 10 km as measured at the ascending node.	CPR ground-track +/- 1 km wrt to CALIPSO lidar ground-track (cross-track)	± 20 km as measured at the descending node	± 20 km as measured at the descending node	± 20 km as measured at the descending node	Note 2
Coincident Observation	N/A	MLS sees air mass viewed by Aqua and CloudSat	Aqua MODIS based on ground-track reference	Maintain position in front of CALIPSO for lidar and Aqua MODIS	Glory nadir pixel over-flies CALIOP ground track within 3 minutes	~10 minutes in front of Aqua	TBS	Note 2
Buffer to closest Control Box	30 seconds to front of CALIPSO box (Note 3)	3 min 15.5 sec to back of GLORY box	15 seconds to front of Glory box	Note 3	30 seconds to back of CALIPSO box	Between 15 – 195 seconds to front of Aqua box	Minimum 15 seconds to front of GCOM-W1 box	Note 2
								02/10/11

Notes:

1. The CALIPSO and PARASOL orbit definition and maintenance information is contained in their system documents. These documents have precedence over this Operations Coordination Plan. Refer to Section 2.3 for a document list and tree.
2. PARASOL stopped maintaining the sun synchronous inclination after the planned Spring 2007 inclination maneuver series. On December 2, 2009, PARASOL lowered its orbit by 4 km and broke with the standard Afternoon Constellation orbital configuration.
3. CloudSat moves in a control box (±2.5 seconds along-track) which is centered at a fixed distance of 17.5 seconds in front of CALIPSO. Thus, potentially, the front of CloudSat's control box could be as close as 10 seconds from the back of Aqua's control box.
4. The OCO-2 and GCOM-W1 locations will be determined after launch. The complete range of values is listed.

5.2. Afternoon Constellation On-Orbit Maneuver Strategies

The satellites within the Afternoon Constellation maintain their respective positions relative to each other with operations that are, for practical purposes, independent. Member satellites exchange orbital position information and maneuver plans more for coordinating and co-registering scientific measurements than for maintaining positional control.

Satellites are required to control their along-track motion to remain within their respective "control boxes". Buffer zones between control boxes provide space that allows each satellite to fully use the dimensions of its control box without encroaching on the space occupied by another satellite, i.e., its control box.

The primary cause of a satellite's movement within the control box is decay in the SMA owing to drag. All of the constellation satellites operate relative to a drag-free reference orbit, which also defines its reference ground-track. The drag-free orbit is an unperturbed orbit for a satellite against which along-track motion is measured relative to a defined reference point, the center of its control box, which is situated exactly over the reference ground-track. A real satellite affected by drag but with its SMA greater than that of the drag-free orbit will move backwards along-track relative to the reference point. When the SMA has decayed to be equal to the SMA of the drag-free orbit, the along-track motion stops and reverses direction. As the SMA continues to decay, the satellite's motion is forward along-track. At the same time as the satellite moves back and forth relative to the drag-free orbit, its ground-track moves from east to west relative to the reference ground-track in a coupled motion. The path followed by the satellite through this cycle, back and forth, east and west, and up and down is referred to as the "circulation orbit" within the control box.

As the satellite's movement approaches a control box boundary, it becomes necessary to perform a drag make-up maneuver to restore the SMA and to re-initialize the circulation orbit.

Regardless of the type of maneuver (e.g., DMU, inclination adjust, braking, etc.), each member mission notifies the other Afternoon Constellation teams of the upcoming maneuver, providing the date/time of the maneuver and its expected result (e.g., the total SMA change, inclination change, etc.). Subsequent to the maneuver, the member mission then provides the actual results.

5.2.1. Aqua Drag Make-up Maneuvers

The burn date and start time are fixed approximately two weeks prior to a maneuver. The target opportunities are mid-week (either Tuesday, Wednesday, or Thursday) during prime shift for the FOT (U.S. Eastern Time Zone 8 a.m.-5 p.m.). The planned burn time is close to the ideal burn time within the orbit to improve frozen orbit status while still meeting all contact requirements. Instrument science campaigns are avoided, to the extent possible. All burns are completed in one maneuver and during real-time contact with the satellite.

The target burn size is the smallest of three separate plans:

1. Variable WRS turnaround target. The selection is based on starting position, solar activity, and operational concerns.
2. Limit post burn negative WRS rate.
3. Limit maximum negative WRS error at requirement boundary if solar activity drops to reasonably low levels.

Note that Aqua does not have a retrograde maneuver capability.

Prior to a burn, the satellite’s yaw is increased 14.35 degrees to align the effective thrust vector with the satellite center of mass.

5.2.2. Aura Drag Make-up Maneuvers

The burn date and time are fixed approximately two weeks prior to a DMU maneuver. The target opportunities are mid-week (either Tuesday, Wednesday, or Thursday) during FOT prime shift (US Eastern Time Zone 8 am-5 pm). The planned burn time is close to the ideal burn time within the orbit to improve frozen orbit status. Instrument science campaigns are avoided, to the extent possible. All burns are completed in one maneuver and during real-time contact with satellite.

The target burn size is the smallest of three separate plans:

1. Variable WRS turnaround target. The selection is based on starting position, solar activity, and operational concerns.
2. Limit post burn negative WRS rate
3. Limit maximum negative WRS error at requirement if solar activity drops to reasonably low levels.

Note that Aura does not have a retrograde maneuver capability.

Prior to a burn, the satellite's yaw is increased 13.493 degrees to align the effective thrust vector with the satellite center of mass.

5.2.3. CALIPSO Drag Make-up Maneuvers

DMU maneuvers are planned when the satellite orbit has a ground-track error of +10 km with a margin of 1 km from the customized WRS-2 path, which is defined as 215 km east of Aqua's WRS-2 path. The burn is sized to achieve a ground-track error turnaround at –10 km with a margin of 1 km. Retrograde maneuvers can be made to prevent exceeding the negative side of the requirements box. Each maneuver contains two burns separated by 1.5 orbits. Maneuvers can be done on any day of the week and in the blind if necessary.

5.2.4. CloudSat Maneuvers

CloudSat maintains its equator crossing time 17.5 ± 2.5 seconds ahead of CALIPSO's and its groundtrack within 1 km of the CALIPSO's lidar groundtrack. CloudSat typically conducts retrograde (orbit lowering) maneuvers when its groundtrack at the equator is approximately 0.625 km to the west of CALIPSO's lidar groundtrack. These maneuvers cause CloudSat's groundtrack to move to the east relative to CALIPSO's and will be sized so that, due to atmospheric drag, this motion stops and reverses direction at approximately 0.125 km to the east of CALIPSO's lidar groundtrack. This timing and sizing is often adjusted somewhat so as not to conflict with A-train meetings, holiday weekends, and satellite operational activities or to position CloudSat within its control box prior the DMU or inclination maneuvers. The frequency of these maneuvers depends upon the atmospheric density, which is significantly affected by solar flux. They are anticipated to occur about once every two or three weeks on average. In the event that such a maneuver overshoots this desired turnaround point and CloudSat's groundtrack is approaching the eastern boundary, a posigrade (orbit raising) maneuver will be conducted when CloudSat's groundtrack is 0.625 km east of CALIPSO's lidar ground track to stop the eastward motion. About twice a year, CloudSat will execute small inclination changing maneuvers in order to control the relative RAAN drift between CloudSat and CALIPSO and thus maintain the 17.5 ± 2.5 seconds of separation in their equator crossings. All these maneuvers are calculated 30 to 54 hours prior to their execution upon the daily receipt of the CALIPSO ephemeris.

CloudSat also conducts coordinated DMU maneuvers with CALIPSO. Each time CALIPSO performs a DMU maneuver, CloudSat needs to do a corresponding maneuver to maintain the formation. This maneuver is sized to match CALIPSO's predicted results with a possible adjustment to place CloudSat on a new circulation orbit relative to CALIPSO. CloudSat DMU maneuvers are typically completed in one burn even though CALIPSO is using a two-part burn. CloudSat will use a two-part burn if a single burn would result in CloudSat violating its frozen orbit requirements relative to CALIPSO.

CloudSat's corresponding maneuver is usually conducted about a day after CALIPSO's providing enough time for the CloudSat operators to wait for confirmation of the CALIPSO maneuver before uploading CloudSat's maneuver to the spacecraft. If timing does not allow CloudSat to wait for the CALIPSO confirmation before the upload, CloudSat may plan a second maneuver to counteract its DMU maneuver, in order to protect against the possibility that CALIPSO is unable to perform its DMU maneuver as planned. This second maneuver would be uploaded to CloudSat at the same time as the first maneuver. If CloudSat does not receive confirmation in time to cancel its execution this second maneuver is executed 6 to 24 hours after the first, well before CloudSat would enter CALIPSO's zone of exclusion.

5.2.5. PARASOL Drag Make-up Maneuvers (Prior to Lowering Orbit)

Prior to PARASOL's orbit lowering in December 2009, PARASOL DMU maneuvers were planned when the satellite orbit had a ground-track error of +10 km with a margin of 1 km from the customized WRS-2 path (see Section 5.2.3). The burn was sized to achieve a ground-track error turnaround at –10 km with a margin of 1 km. Retrograde maneuvers could be made to prevent exceeding the negative side of the requirements box. Each maneuver contained two burns separated by 1.5 orbits. Maneuvers could have been done on any day of the week and in the blind if necessary.

5.2.6. Glory Maneuvers

Glory station keeping activities will consist of DMU maneuvers performed in order to maintain the satellite within its control box. The frequency of the maneuvers will depend on the intensity of solar activity and, assuming mean solar flux values, are projected to occur on a cycle of every 36 days to 94 days throughout the mission lifetime. Glory orbit maintenance plans also include participation in the delta inclination maneuvers performed by the other missions in the Afternoon Constellation.

5.2.7. GCOM-W1 Drag Make-up Maneuvers

GCOM-W1 DMU maneuvers will be performed in order to maintain the satellite within its control box and to keep a frozen orbit. The frequency will be depending on the atmospheric density and solar activity. The maneuver will be planned every TBD week if necessary and performed on the specified day of week. The burn of magnitudes and time will be fixed TBD days prior to the maneuver.

Note that GCOM-W1 does not perform a retrograde maneuver except in an emergency.

5.2.8. OCO-2 Maneuvers

OCO-2 orbit maintenance will consist of DMU maneuvers, the frequency of which will depend on solar activity. At the solar maximum, maneuvers will be planned at approximately one per month. At 90% of solar maximum, maneuvers will be planned at approximately 45-day intervals. At the solar mean, maneuvers will be planned at the rate of one every three months. OCO-2 orbit maintenance plans also include participation in the delta inclination maneuvers performed by the other missions in the Afternoon Constellation.

5.3. Inclination Maneuvers

Aqua must occasionally perform IAMs to prevent violation of its 13:45 ascending node MLT requirement.

Where possible, Aqua and Aura inclination maneuvers should not be scheduled within 60 days of Afternoon Constellation satellite launches. Inclination maneuvers must be coordinated between all on-orbit missions.

A summary of all Afternoon Constellation IAM campaigns is shown in Table 5-2. In August 2009, a Configuration Change Request (CCR) was opened to request that IAMs be performed on an annual basis beginning in the spring of 2010. This was approved by the MOWG members in late 2009 and the annual IAM process started in the spring of 2010.

Table 5-2 – Coordinated Afternoon Constellation IAM campaigns

DATES	TOTAL MANEUVERS
October 7, 2003	1
September – October 2004	9
August 22 – September 12, 2006	22
March 6 – May 18, 2007	17
March 2 – May 6, 2009	31
March 9 – April 1, 2010	13

Section 6. Afternoon Constellation Operations Coordination

6.1. Coordination Concept

Afternoon Constellation coordination refers to the cooperative interaction between and among member missions of the constellation. The job of monitoring and declaring the constellation status is the collective responsibility of the members, as is the making of timely decisions in the event of a satellite safe hold, which could lead to a contingency situation.

It is through the Afternoon Constellation MOWG that member missions develop and agree on processes, procedures, and solutions that effectively monitor the constellation for nominal operations, notify appropriate constellation members when conditions are not nominal, and take action to facilitate the resolution of contingency situations in a timely manner.

To help make this coordination as routine as possible, the CCS tool is utilized. The CCS was built and is being maintained under ESMO funding to meet MOWG requirements. More detailed descriptions of CCS functions and usage are found in Appendix B.

6.2. Coordination Guidelines

Afternoon Constellation member missions will conform to the following guidelines.

6.2.1. Orbit and Maneuver Information

- Each member mission shall make its own assessment of its satellite's status and notify the affected missions accordingly.
- Member missions will keep the MOWG apprised of any changes in their status.
- The member missions will provide orbital and maneuver information to the CCS as detailed in each of the ICDs between each satellite project and the ESMO Project (see Figure 6-1).

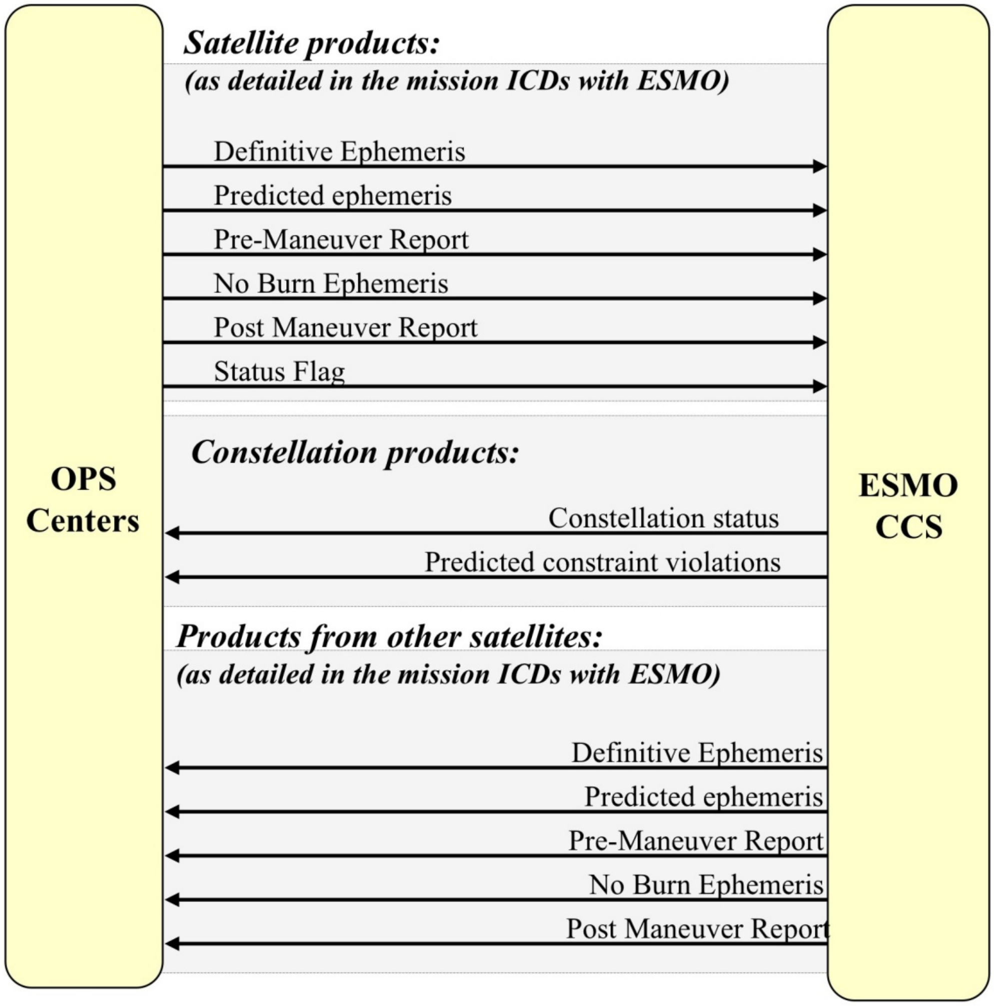

Figure 6-1. Information Exchange Between Member Mission Operations Centers and the ESMO CCS

6.2.2. Zone of Exclusion

- In order to quantify what is considered by the MOWG to be an unacceptable separation distance between two satellites, the MOWG has arbitrarily defined the concept of a Zone of Exclusion (ZOE). The ZOE (Figure 6-2) is rectangular box, a volume in space, centered on each of the constellation's satellites specifying a "keep-out" or "no-go" zone for other satellites (note that some organizations use the equivalent coordinates of “UVW” in place of “RIC”, i.e., “radial”, “in-track”, and “cross-track”).

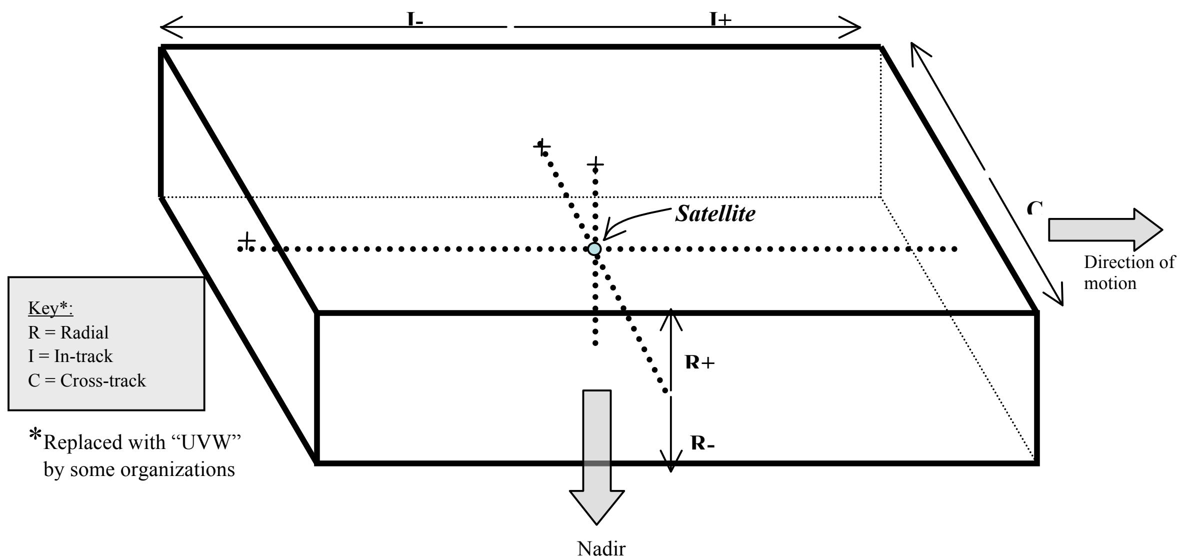

Figure 6-2. Zone of Exclusion

- By mutual agreement among the constellation members, a trajectory of one satellite relative to another passing through a satellite's ZOE is deemed unsafe and represents an unacceptable level of risk of collision between the two satellites. A violation of a ZOE is, therefore, considered cause for high alert and action in that there may be the potential of a collision between two satellites. As a result, an evasive maneuver may have to be planned and may be required by the functioning, in-place satellite in order to prevent a collision. The "Afternoon Constellation Contingency Procedures" (ref. RD9) document provides additional details.
- There are two ZOEs (Figure 6-3) with the dimensions defined in Table 6.1:

  – *Alert ZOE*
  – *Action ZOE*

  Note that these dimensions have been set empirically, not through any study of possible values.

Table 6-1. Zone of Exclusion (ZOE) Dimensions

ZOE	Radial (km)	In-track (km)	Cross-track (km)
Alert ZOE	± 2	± 25	± 25
Action ZOE	± 0.5	± 5	± 5

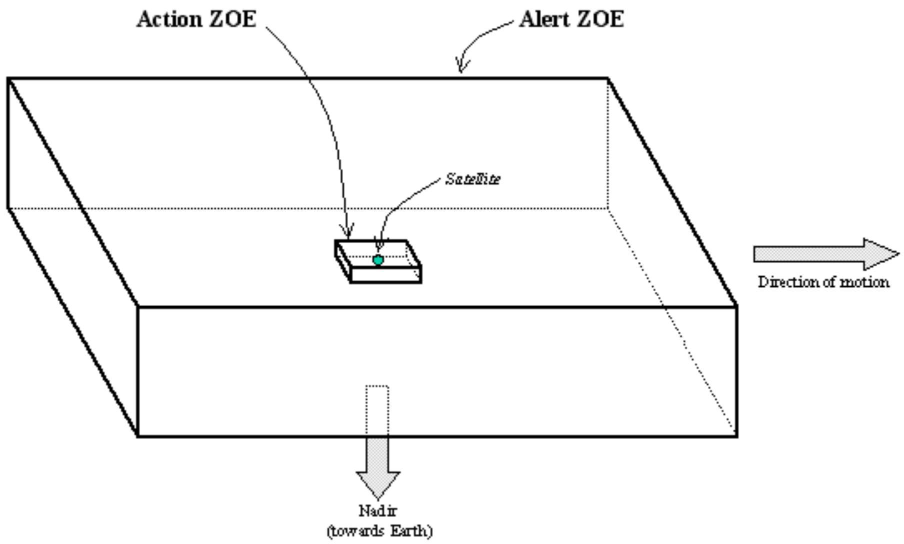

Figure 6-3. ZOE Relationships

This 2-tier structure reflects the difference in concern in the two volumes. For example, a satellite that is just inside the Alert ZOE does not present an immediate danger, whereas a satellite that enters an Action ZOE is cause for action.

- The Alert ZOE is used to provide notifications to affected missions of a potential close approach. Predicted entry into this region is cause for concern, but not necessarily immediate reaction. The Alert ZOE defines a "keep-out" or "no-go" zone for other satellites. A close approach between two constellation satellites that is inside of the ZOE may be considered unsafe by representing an unacceptable level of risk of collision. Orbit prediction tools are accurate enough, even including uncertainties, that if the Alert ZOEs are honored during maneuver design there is no chance of collision with another satellite.

  An Alert ZOE violation by any satellite is the basis for setting the Red Constellation Status flag in the CCS, as the violation creates an elevated risk to satellites.

- An Action ZOE violation signifies a higher risk of a collision than an Alert ZOE violation and is to be avoided, if possible, by use of an evasive maneuver. If an Action

ZOE violation is predicted to occur, the functioning satellite team may decide to maneuver its satellite out of the way of the approaching object. The decision will be based on a number of factors, including probably of collision (Pc) and orbit geometry. Please refer to RD10 for more specific discussion of close approach handling procedures. Not that when a functioning satellite maneuvers in order to pass above (or below) another satellite in the constellation it shall do so in a manner such that neither satellite's Action ZOE is violated (taking into account 3 sigma errors in orbit determination and maneuver execution).

6.2.3. Constellation-Related Flags

- Mission teams agree to set three status flags for their mission based on the following definitions:
  - The Constellation Status flag represents the status of the satellite relative to its configuration within the constellation (Table 6-2).
  - The Satellite Status flag represents the status of the individual satellite (see Table 6-3).
  - The Instrument Status flag represents the status of the instruments on an individual satellite (see Table 6-4).

Note: The CCS will not autonomously set these flags for any mission. This responsibility rests with the authorized CCS Mission Operator (CMO) designated for each mission.

Table 6-2. Constellation Status Flag Definitions

FLAG	TYPE	ACTION	DEFINITION
RED	ZOE violations	Action is required immediately	An Alert ZOE violation has occurred.
YELLOW	Control Box violations	Action may be required, but not immediately	Does not qualify as RED, but a Control Box violation has occurred *OR* an Alert ZOE violation is predicted to occur during the next 5 days.
GREEN	Nominal operations	No action is required	Does not qualify as RED or YELLOW. That is, the satellite is in its control box and no Alert ZOE violations have occurred or are predicted to occur during the next 5 days.

Table 6-3. Satellite Status Flag Definitions

FLAG	TYPE	DEFINITION
RED	Safe Hold	The satellite has entered a state or a mode whereby it has lost its ability to perform a propulsive maneuver.
YELLOW	Subsystem Interruption	One or more of the instruments is in non-nominal state and therefore not generating science data, or a satellite bus subsystem, such as the command and data handling system, is not operational, thus science data are not being downlinked.
GREEN	Nominal operations	The satellite is able to maneuver as required and is collecting science data.

Table 6-4. Instrument Status Flag Definitions

FLAG	TYPE	DEFINITION
RED	Inoperative	An instrument is not capable of collecting science data.
YELLOW	Degraded operations	An instrument's performance is degraded.
GREEN	Nominal operations	All instrument performance is nominal.

6.2.3.1 CCS Status Display

- CCS will provide a status display showing the latest constellation status as reported by the mission teams (example shown in Figure 6-4).

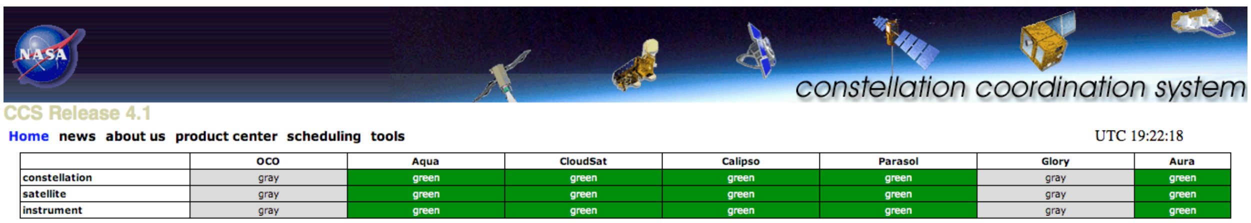

Figure 6-4. CCS Constellation & Satellite Status Flags Display Example

- Member missions shall update the CCS status flags within two hours of learning that their satellite cannot maneuver or that it experiences unexpected thruster activities (e.g., Safe Hold Mode) that could endanger other satellites.
- The time period for notification may be up to 16 hours for any non-nominal situation that is not a threat to the other satellites.

6.2.4. CCS E-Mail Notifications

6.2.4.1 CCS E-Mail Notifications from Predictive Ephemeris Data

- If the predictive ephemeris data, including planned maneuvers, indicate that a satellite will violate its Control Box during the span of the ephemeris that is validated, CCS will send an e-mail message to the CMOs of that mission and to the ESMO Constellation Management team. No other mission teams will be notified.
- If the predictive ephemeris data, including planned maneuvers, indicate that a satellite will violate the ZOE of another satellite during the overlapping span of the two missions' ephemerides, CCS will send an e-mail message to the CMOs of the affected missions and to the ESMO Constellation Management team.

6.2.4.2 CCS E-Mail Notifications from Status Flag Changes

- When a CMO changes the *Constellation Status* flag, CCS will automatically send an e-mail message to all Afternoon Constellation CMOs and to the ESMO Constellation Management team notifying them of the change.
- When a CMO changes the *Satellite Status* flag, CCS will send an e-mail message to the ESMO Constellation Management team notifying them of the change. Any additional email notifications will be at the discretion of the mission CMO.
- When a CMO changes the *Instrument Status* flag, CCS will send an e-mail message to the ESMO Constellation Management team notifying them of the change. Any additional email notifications will be at the discretion of the mission CMO.
- In general, Afternoon Constellation teams may be expected to respond to changes in a mission's *Constellation Status* flag, while the *Satellite Status* flag and the *Instrument Status* flag are informative in nature.

6.2.5. Intentional Control Box Violations

- Member missions intentionally planning to exceed their control box shall notify the other Afternoon Constellation members of their plans detailing their rationale for the excursion, their maneuver plans, and their plans for the future restoration of their satellite into their original box. Additionally, the member missions planning to exceed their box shall provide precision trajectory predictions of any anticipated close approaches with other constellation satellites. This box excursion rule also applies to member missions planning to vacate the constellation with de-orbit activities at the end of their nominal mission. Notification of plans for exceeding box limits shall be provided to the Afternoon Constellation MOWG members in accordance with the Afternoon Constellation Contingency Procedures document (ref. RD9).

6.2.6. Conflicts and Anomalies

- Member missions will coordinate conflict and anomaly resolution in accordance with this Plan (refer to Section 6.3).

6.2.7. CNES Coordination

- Coordination with CNES missions will be as defined in the *OIA between CNES and CALIPSO for the Aqua Train Constellation* (ref. RD5) and the *CALIPSO/PARASOL/ESMO ICD* (ref. AD1).

6.2.8. JAXA Coordination

- Coordination with JAXA missions will be as defined in the standard operations interface agreements between NASA and JAXA *(document tbs)* and the *GCOM-W1/ESMO ICD* (ref. AD3).

6.3. Anomaly and Conflict Resolution

The following procedure is established to resolve conflicts (see Figure 6-5). The term "conflict" is used in this document to denote either an "anomalous" situation (e.g., a satellite has lost its ability to maneuver or a satellite is predicted to violate a ZOE) or a real scheduling conflict (e.g., between one satellite's inclination maneuver and another's launch and early orbit activities).

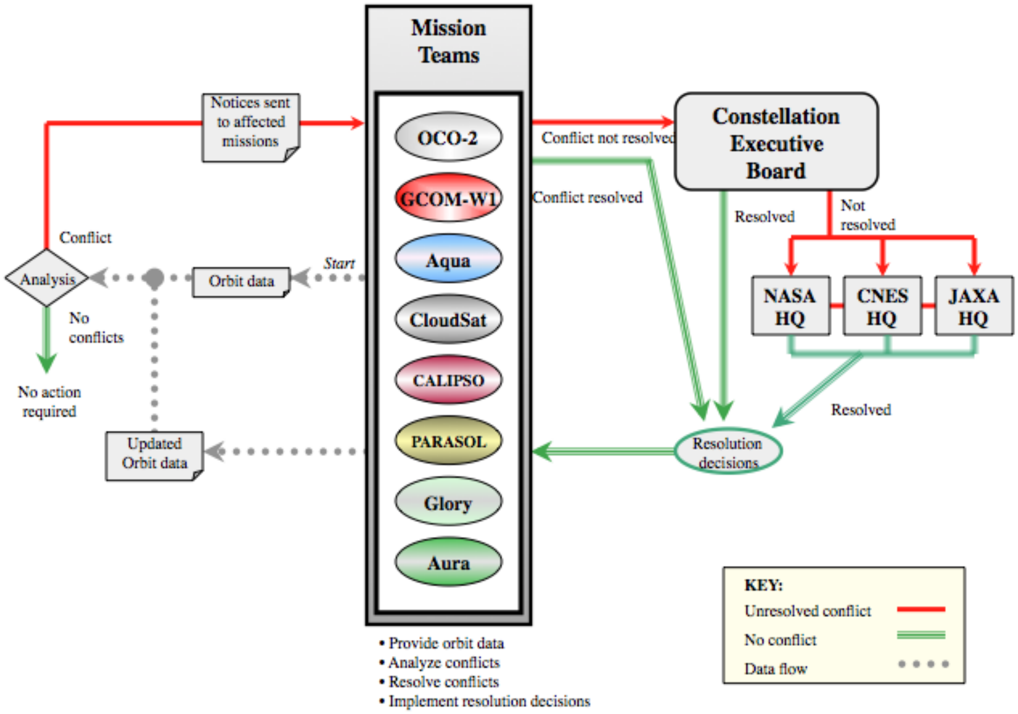

Figure 6-5. Afternoon Constellation Coordination

1. The affected mission operations teams will work together to resolve conflicts. The key players at this point are the Mission Directors (MDs)/Mission Operations Managers (MOMs) of the affected teams. Once a set of actions has been agreed-upon, the affected operations teams will implement them. Updated orbit information or maneuver plans, as appropriate, will be provided to the ESMO CCS. The relevant CMOs will update their mission status in CCS after verifying that the anomalous situation/conflict no longer exists. A few example scenarios are listed:
   a. It may be that the predicted orbital anomaly is an artifact and can be eliminated using the improved ephemeris data. Teams may only need to submit predictive orbital information to CCS to resolve the apparent conflict.
   b. If the predicted orbital conflict is "real", then one team may decide to perform (or re-schedule, as the case may be) a maneuver, eliminating the conflict.
   c. It may be that a satellite anomaly has occurred and one satellite is drifting towards another. If unable to maneuver, the other satellite(s) may have to perform evasive maneuvers to avoid the approaching satellite.
   d. If coincident measurements are at risk due to a planned maneuver, perhaps the maneuver can be postponed. If this is not feasible, the respective Project Scientist will have to be informed by the MD/MOM.

2. At times there may be competing interests preventing the affected teams from reaching a consensus on the optimal way to resolve the conflict. As an example, one team may think it essential to perform a maneuver at a certain time, but this particular time occurs during a science campaign of another mission. Neither mission may feel that its event can be rescheduled, but the science campaign may suffer due to the unavailability of some science data.

   In such a case where the conflict cannot be resolved at the MD/MOM levels, the unresolved conflict will be brought to the attention of the MOWG Executive Board (see Section 3.3.3). The Board will convene and discuss the problem/issue via a teleconference.

   a. The affected MDs/MOMs, in consultation with their respective Project Scientists/Principal Investigators, will provide the impact to their missions.
   b. The ESMO Project Manager will evaluate the overall impact on safety and mission operations. The Project Scientist/Principal Investigators will evaluate science impacts, as needed.
   c. The ESMO Project Manager and the relevant mission Project Managers/Principal Investigators will evaluate options and select a course of action to resolve the conflict. Overall mission safety will take priority over any temporary loss of science.
   d. The mission teams will carry out the MOWG Board directions and send updated orbit data to the CCS. The teams will evaluate their individual status and update the flag information on CCS after verifying that the conflict has been resolved.

3. There may be situations when the mission teams in conflict will not agree with the recommendation of the MOWG Executive Board. In this case, the conflict will have to be elevated expeditiously to the NASA/CNES/JAXA Headquarters levels, as appropriate. **Under no circumstance will a decision be postponed if it involves safety of any of the constellation missions.**

   a. If the missions are all U.S.-based, the Board will forward the results of their deliberations to NASA Headquarters. If at least one affected mission is based in France or Japan, the Board will forward the results of their deliberations to CNES or JAXA Headquarters as well as NASA Headquarters.
   b. The Headquarters organization(s) will assess the impacts and come to some consensus and provide direction to the MOWG Executive Board and the affected missions.
   c. The mission teams will carry out these directions and send updated orbit data to the CCS. The teams will evaluate their individual status and update the flag information on CCS after verifying that the conflict has been resolved.

6.4. Pre-launch Afternoon Constellation Coordination

To ensure the safety of each member of the Afternoon Constellation and for the constellation to provide the coordinated observations required by the scientists, the operations of the Afternoon Constellation missions must be planned and coordinated carefully prior to the launch of each mission. The member missions agree to provide the following analyses.

6.4.1. 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 use the same polar ground stations in Norway and Alaska, so the ground station resources were enhanced prior to the Aura launch to ensure that the uplink and downlink requirements could be met. In addition, Aura was initially phased with Aqua to ensure a minimum 15-minute separation at the ground stations due to these resource limitations. The resources were subsequently augmented. As a result, Aura was moved about 7 minutes closer to Aqua in 2008. This improved the coincidental science by reducing the latency between Aura instrument observations and other Afternoon Constellation member instrument observations. CALIPSO and CloudSat use other ground services, thus avoiding conflicts with Aqua and Aura. PARASOL uses the same command and control services as CALIPSO. Potential conflicts on the CNES Telemetry and TeleCommand Earth Terminal (TTCET) have been analyzed and are under control at CNES.

6.4.2. Link Analyses

The extent of radio frequency interference (RFI) among the Afternoon Constellation missions and from external sources must be understood. RFI may also exist between ground stations in close proximity and must be examined, e.g., the various polar ground stations in Alaska. This analysis may point to design changes and/or operational constraints. RFI caused by simultaneous Direct Broadcast (Direct Readouts) from multiple satellites must also be understood early in the planning and design phase so that changes can be made to reduce or eliminate it. Conflicts may have to be resolved using agreed-upon science priorities.

6.4.3. Launch and Early Orbit (L&EO) Analysis

The launch and ascent plans for the member missions shall be evaluated in relation to the Afternoon Constellation. Each mission's plan for orbit insertion must be understood and agreed to by the affected Afternoon Constellation missions. Missions being added to the Afternoon Constellation shall not adversely impact those already in the constellation.

Specifically, the new satellite shall not target an initial injection orbit higher than 2 km below the Afternoon Constellation fleet envelope, to ensure that it will avoid the Alert ZOE of all other satellites.

Close coordination among all parties is required.

6.4.4. Close Approach Analysis

The MOWG will review agency directives/guidelines and define the Afternoon Constellation close approach constraints after coordination with all parties. On-orbit, member missions will be notified of the risk of an Alert ZOE or Action ZOE violations and an impending predicted close approach impending close approach by the CCS or Goddard's Conjunction Assessment (CA) team. See Appendix B for more information.

6.4.5. Orbital Debris

Member missions shall operate in such a way as to preclude adding debris to or leaving debris in the Afternoon Constellation orbit. The MOWG will adhere to agency directives/guidelines and define and document the Afternoon Constellation debris generation constraints.

6.4.6. Constellation Exit Planning

Each mission shall plan to leave the constellation at some point, usually at end of life (i.e., decommissioning) and is required to have an Afternoon Constellation Exit Plan. The Exit Plan shall state that their satellite will leave in a way that does not threaten other Afternoon Constellation satellites.

Specifically, the exiting satellite shall lower its maximum apogee to be at least 2 km below the Afternoon Constellation fleet envelope, to ensure that it will avoid the Alert ZOE of all other satellites.

Missions shall provide a copy of their Exit Plan to the MOWG prior to expected exit. The Exit Plan shall be reviewed in the context of that mission's position in the Afternoon Constellation. Issues regarding the Exit Plan shall be coordinated and worked through the MOWG.

Note that this requirement can be satisfied by providing Exit Plans in an End Of Mission (EOM) Plan. An EOM Plan is more comprehensive and will include, among other things, the triggers that identify the end of mission

6.4.7. Other Pre-Launch Activities

Member missions will participate and provide input, to the extent that they are able, in an independent simulation to be done before launch, for each mission's constellation/formation control scheme. The object of the simulation is to verify that the satellites can be maintained within their respective control boxes as designed without problems. In addition, member missions will participate, to the extent that they are able, in inter-project pre-launch rehearsals for missions joining the Afternoon Constellation and for routinely flying in the constellation.

6.5. New Missions

Member missions agree to support the evaluation of new/proposed missions that plan to join the Afternoon Constellation. A new/proposed mission planning to join the Afternoon Constellation needs to inform the MOWG regarding its plan and provide all available information pertaining to the required pre-mission analyses through the use of the Afternoon Constellation Checklist (Appendix E). The requirements for each new mission must be analyzed in the context of the Afternoon Constellation to ensure that the attendant mission design is consistent with the constellation environment. For example, the science requirements of CALIPSO and CloudSat made 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 of these missions designed their control systems and procedures to meet their requirements and did extensive analyses with regard to their formation flying. Analyses such as these must be evaluated in relation to the rest of the Afternoon Constellation. This should be done as soon as possible, early in its conceptual stage, even prior to its final approval as a mission. This will benefit the new mission as it proceeds with formulating its operations concept and mission design. Although this early coordination does not guarantee the new mission final approval by the responsible agency/organization, it should reduce conflicts with the current Afternoon Constellation once the new mission is finally approved.

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Section 7. Agreements

By their signatures on this document, the members of the Afternoon Constellation concur that the guidelines, concepts, and plan in this document are accurate and satisfactory. Further, they and their operations teams agree to abide by the operations coordination processes and guidelines described within and to the interfaces described in the applicable ICDs. These agreements are effective upon the signing of this document and will be in force until the end of each Afternoon Constellation mission.

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Appendix A. Acronym List

AD	applicable document
AIRS	Atmospheric Infrared Sounder
AMS	American Meteorological Society
AMSR-E	Advanced Microwave Scanning Radiometer-EOS
AMSU	Advanced Microwave Sounding Unit
APS	Aerosol Polarimetry Sensor
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CCB	configuration control board
CCS	Constellation Coordination System
CERES	Clouds and the Earth's Radiant Energy System
CMA	CCS Mission Administrator
CMO	CCS Mission Operator
CNES	Centre National D'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique
CO	coincident observations
CPR	Cloud Profiling Radar
CSU	Colorado State University
DMU	Drag Make Up
EO-1	Earth Observing 1
EOC	EOS Operations Center
EOM	end of mission
EOS	Earth Observing System
ERB	Earth radiation budget
ES	Earth Science
ESE	Earth Science Enterprise
ESMO	Earth Science Mission Operations
ESSP	Earth System Science Pathfinder
FOT	flight operations team
FTP	file transfer protocol
GISS	Goddard Institute for Space Studies
GCOM-W1	Global Change Observation Mission 1st - Water
GSFC	Goddard Space Flight Center

GSRD	Ground System Requirements Document
HIRDLS	High Resolution Dynamics Limb Sounder
HSB	Humidity Sounder for Brazil
IAM	inclination adjust maneuver
ICD	interface control document
IEEE	Institute of Electrical And Electronics Engineers
IGARSS	International Geoscience and Remote Sensing Symposium
IIR	Imaging Infrared Radiometer
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
KAFB	Kirtland Air Force Base
km	kilometer
L&EO	launch and early orbit
LaRC	Langley Research Center
LASP	Laboratory for Atmospheric and Space Physics (at University of Colorado)
LIDAR	light detection and ranging
LOA	Laboratoire d'Optique Atmosphérique
MD	Mission Director
MD	Maryland
MIGS	Micro-satellite Ground Segment
MLS	Microwave Limb Sounder
MLT	mean local time
MOC	mission operations center
MOCC	mission operations control center
MODIS	Moderate Resolution Imaging Spectroradiometer
MOGS	Mission Operations Ground System
MOM	Mission Operations Manager
MOWG	Mission Operations Working Group
MSRD	Mission System Requirements Document
NASA	National Aeronautics and Space Administration
OCO-2	Orbiting Carbon Observatory-2
OIA	operations interface agreement
OMI	Ozone Monitoring Instrument
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar
PI	principal investigator
PS	Project Scientist

POC	Point of Contact
POLDER	Polarization and Directionality of the Earth's Reflectances
RAAN	Right Ascension Of Ascending Node
RD	reference document
RFI	radio frequency interference
RIC	radial, in-track, cross-track
RDT&E	Research, Development, Test, and Evaluation
RSC	RDT&E Support Complex
SAC-C	Satelite de Aplicaciones Cientificas-C
SMA	semi-major axis
SMC	Space and Missile Systems Center (at KAFB)
SOGS	Satellite Operations Ground System
SRD	Segment Requirements Document
SSR	Solid State Recorder
TBD	to be determined
TBS	to be supplied
TES	Tropospheric Emission Spectrometer
TGARS	Transactions on Geoscience and Remote Sensing
TIM	Total Irradiance Monitor
TOMS	Total Ozone Mapping Spectrometer
TTCET	Telemetry and TeleCommand Earth Terminal
UARS	Upper Atmosphere Research Satellite
USN	Universal Space Network
UV	ultraviolet
WFC	Wide Field Camera
WRS	Worldwide Reference System
wrt	with respect to
ZOE	zone of exclusion

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Appendix B. Constellation Coordination System (CCS) Operations Concept and Plan

B.1 Introduction

This section describes the purpose of the CCS, identifying at a high level how the CCS was implemented to assist with monitoring the health and safety of the Afternoon Constellation.

B.1.1 Purpose

The ESMO Project at NASA GSFC is tasked to coordinate the Earth Science constellation operations. The CCS was built to achieve the goal of making Afternoon Constellation coordination as routine and automated as possible. The CCS is used by members of the Afternoon Constellation to provide constellation status, to facilitate data exchange, and to allocate shared resources. Additionally, CCS is used by members of the Morning Constellation to exchange data. This section describes the components of the CCS and how the system operates. Tasks performed by the CCS to ensure Afternoon Constellation safety include monitoring the current orbital status of the constellation, coordination of maneuver planning activities, prediction of potential collision situations and facilitation of satellite movement into and out of the constellation. The CCS includes tasks to allow data sharing both among Afternoon Constellation member missions and with non-member missions. The CCS also facilitates the optimal sharing of operational resources (ground stations, etc.)

B.2 System Description

B.2.1 System Objectives

The CCS was developed to meet the following objectives:

- Make Afternoon Constellation management as routine as possible.
- Provide a mechanism for monitoring the current status of Afternoon Constellation member missions with respect to their placement in the Afternoon Constellation.
- Provide a mechanism for alerting Afternoon Constellation member missions of constellation control box and close approach constraint violations.
- Provide a solution for constellation status updates and necessary mission data exchange that applies to the ascent of missions into the Afternoon Constellation, nominal operations of the constellation, inclination maneuvers by member missions, and the removal of missions from the constellation.

B.2.2 Functional Description

The CCS is a system that performs analyses based on inputs from the member missions. The output from these analyses is returned to the missions via a notification process and can be used as part of the conflict resolution process. Figure B-1 is a diagram representing the high level functional elements and interfaces that support the CCS. Inputs from the member missions will drive the type and quality of analyses performed by the CCS. As defined in the mission–specific ICDs with ESMO, the following are needed for CCS analysis:

- A predicted ephemeris, including upcoming maneuvers, for constellation monitoring,
- Mission modeling parameters.

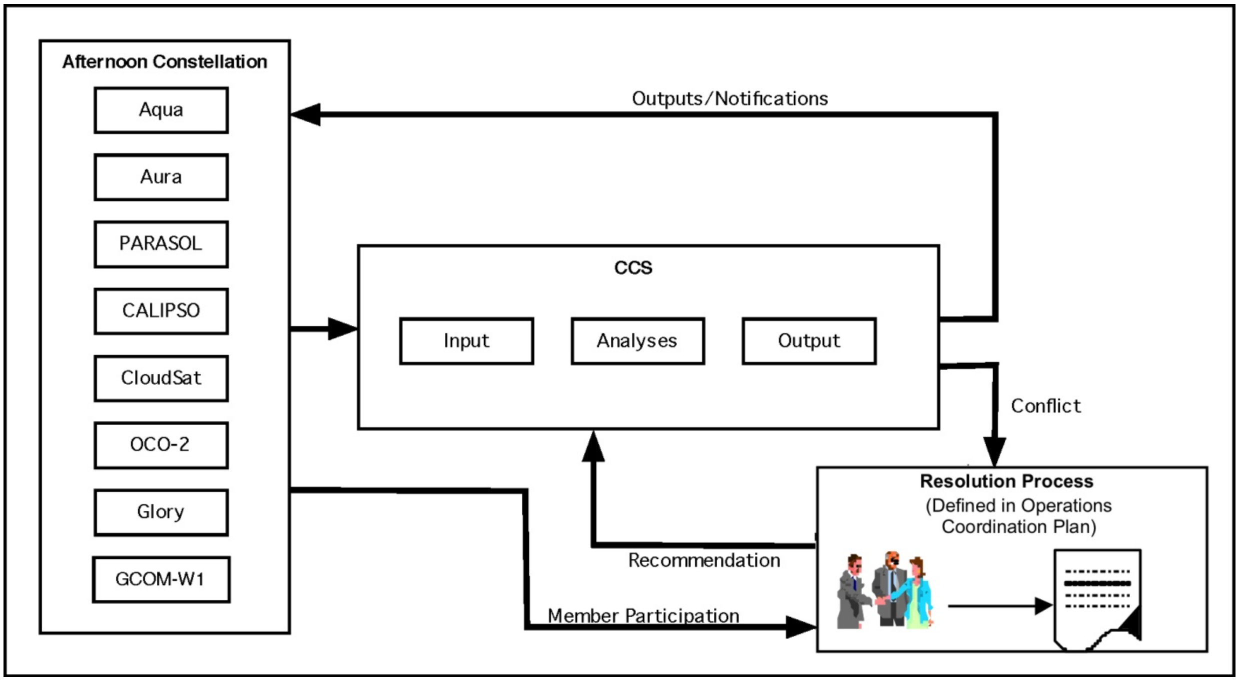

Figure B- 1. CCS High Level Functional Elements and Interfaces.

Analyses performed by the CCS:

- Display the current Afternoon Constellation status,
- Detecting control box violations,
- Detect close approach violations, and
- Detect phase margin violations,

Outputs generated by the CCS are a combination of visual displays and reports provided to the member missions via email, file distribution, and/or directly from the CCS web site. These outputs include:

- Visual indication of Afternoon Constellation status in the CCS,
- Notification of Afternoon Constellation violations and their nature,

B.3 External System Interfaces

This section describes the external interfaces to the CCS and how the clients will interact with the system. Interfaces into and out of the system are defined. Interfaces into the CCS include file transfer via File Transfer Protocol (FTP) or secure FTP (sFTP) for product and status report delivery and inputs via the web interface for ad-hoc analysis requests. One interface out of the system is the visual display of analysis items on the web interface. Output reports and warning notifications are also sent via sFTP and email to subscribed clients. Products can be downloaded via the web interface or auto-delivered via sFTP.

B.3.1 Client Interaction

The CCS is used by clients on a variety of levels and for a variety of purposes. A client from the ESMO management team would use the system to periodically assess and monitor the overall health and safety of the Afternoon Constellation. A client from a member mission flight operations team could regularly use the system for product exchange, to receive warnings of control box violations, and to facilitate anomaly resolution. A mission scientist would use the system to coordinate activities with the flight operations team. A mission analyst would use the system to obtain data and perform analyses relating to one or more member missions. Other missions would use the system to obtain data and aid analysis of non-routine operations that may impact the Afternoon Constellation.

B.4 Implementation

This section describes the major analysis components of the CCS. These components make up the autonomous operation portion of the CCS. The components described in this section represent the initial functionality of the system implemented prior to the launch of Aura. Details on the operational scenario of the CCS (required inputs and expected outputs as well as description of a day in the life for each component) are described in the CCS Operations Concept Plan (Ref # RD6).

B.4.1 Provide Current Afternoon Constellation Status

This component produces the Visualizations and Status Bar. A visual display is generated that presents the current position of each Afternoon Constellation satellite within its control box and the relative position of the control boxes. A status bar displays the status (red, yellow, or green) of each satellite. A text summary report can be emailed to subscribed clients.

B.4.2 Detect Control Box Violation

This component of the CCS provides a capability to scan provided ephemerides for control box violations on a scheduled or ad-hoc basis, providing autonomous notification as appropriate. Ephemerides provided are checked for both excursions from the mission's own control box and entrances into other mission's control boxes.

B.4.3 Detect Close Approach Violation

This component of the CCS provides a capability to scan provided ephemerides for close approaches with other Afternoon Constellation member missions on a scheduled or ad-hoc basis, providing autonomous notification as appropriate.

B.4.4 Detect Phase Margin Violation

This component of the CCS provides a capability to scan provided ephemerides for phase margin violations with other member missions on an automated basis.

B.5 Security

The CCS conforms to the requirements and procedures of NASA NPG-2810.1, Security of Information Technology for Mission Information. In addition, security for the CCS:

- Provides a secure environment for CCS components including product files, database, and web site,
- Allows authorized public access,
- Allows CCS to provide external notification via email, FTP, and secure FTP
- Provides sufficient resources to support the entire Afternoon Constellation.

The specifics of the hardware and software configuration include:

- Placing all components behind a primary firewall,
- Allowing access to secure CCS components via a Microsoft Internet Security and Acceleration (ISA) Server,
- Placing secure CCS components behind a secondary firewall, and
- Placing the FTP server, used as a collection and pass-through mechanism for mission product files, behind the primary firewall with the ISA server.

Appendix C. Worldwide Reference System

The Worldwide Reference System is a global grid developed for use as a scheduling tool by the Landsat missions. Landsat 1, 2 and 3 used the WRS-1. The WRS-2 is used by Landsat 4, 5, 6, and 7 as well as many other missions. The WRS-2 divides the globe into 233 paths and 246 rows as shown in Figure C-1. The intersection of a row and a path designates the nominal center of a Landsat imaging scene.

The WRS-2 paths provide a reference to which Earth observing missions can maintain their ground tracks. The WRS-2 paths cross the equator at 233 descending passes and 233 ascending passes. Historically, missions using the WRS have had their descending nodes in the daylight portion of the orbit. Consequently these missions have used the descending nodes, referenced to Path 1 at 295.4° East Longitude to control their orbit. Aqua was the first mission using the WRS-2 to have its descending node in the nighttime portion of its orbit; still, its orbit is controlled at the descending node. Orbit maintenance is achieved by controlling the WRS Error within fixed bounds, where the WRS Error is defined as the distance along the equator between the descending node of the satellite and the nearest WRS-2 path.

While it is conceivable to maintain an orbit relative to the ascending paths of the WRS-2, it is not recommended. The reference longitude for the Ascending Path-1 is documented to be 103.0395° East Longitude, but this longitude does not account for the eccentricity of the orbit. Since the time to travel from the descending node to the ascending node is approximately 9 seconds longer than the time to travel from the ascending node to the descending node, this reference longitude results in a 2-km offset in the WRS Error measured at the ascending node compared to the WRS Error measured at the descending node. Other documentation from the 1980's gives the Path 1 ascending longitude as 103.0333° East Longitude. Due to these inconsistencies and the resulting offset in WRS Error, this document refers to values of WRS Error and control strategies measured at the descending node exclusively.

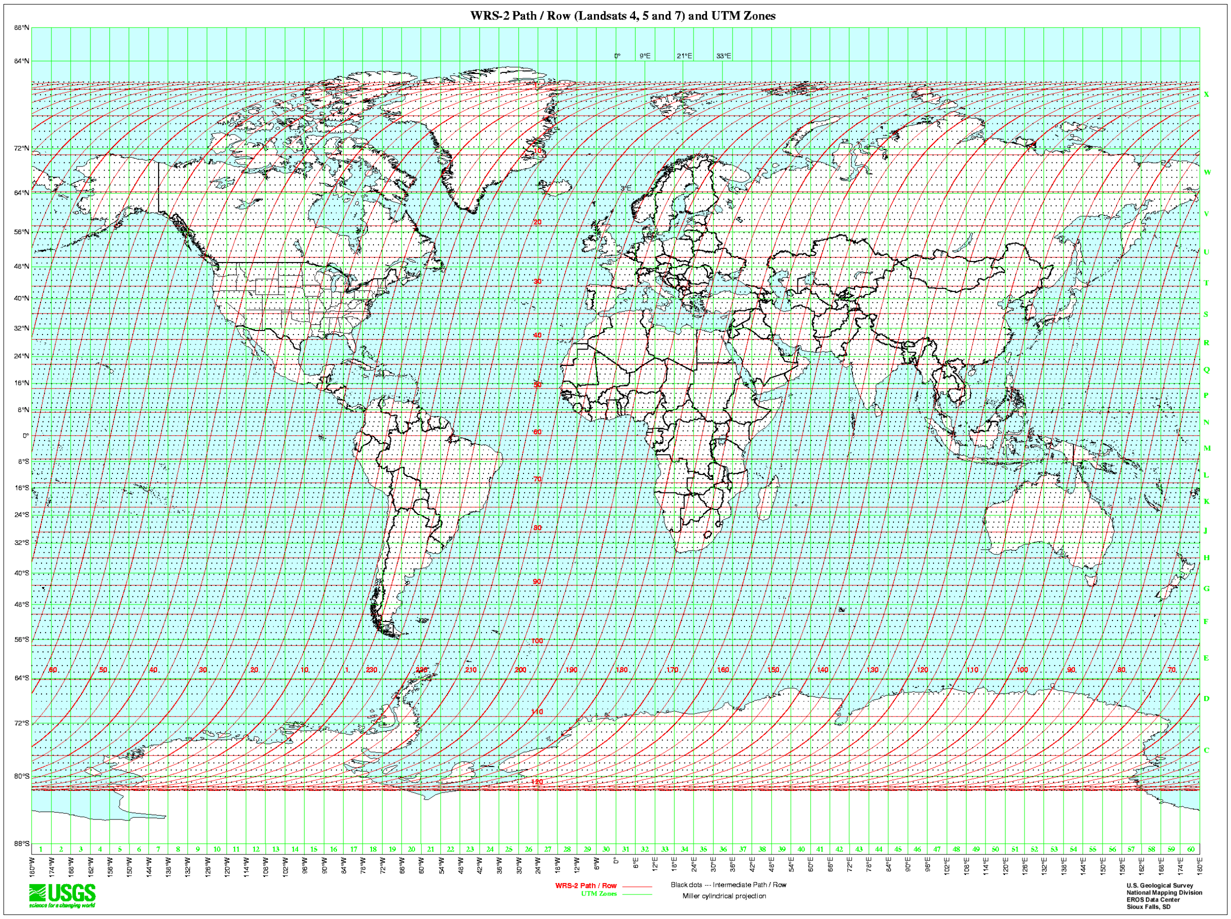

Figure C- 1. WRS-2 Global Path and Row

Appendix D. Afternoon Constellation Change Approval Process

The following steps are to be followed to modify Afternoon Constellation documentation. This documentation includes the Afternoon Constellation Operations Coordination Plan (this document), the Afternoon Constellation Contingency Procedures document, and Constellation ICDs.

1) The Member Mission requesting a change shall complete an “Afternoon Constellation Baseline Configuration Change” form (Figure D-1) and provide it to Constellation Team Manager who will distribute it to the mission teams.
2) The mission teams shall review the request and if found to be agreeable, sign the form to indicate their approval of the proposed change. Typically, proposed changes will be discussed at a MOWG meeting, but a telecon or e-mail exchange may be sufficient.
3) Each mission team lead is responsible for obtaining the necessary signatures from their respective Project Managers and Project Scientist/Principal Investigators.
4) Once all approvals have been received, the Constellation Team Manager shall forward the completed form with the signatures to all Afternoon Constellation team leads. The Constellation Team Manager shall also ensure that the Afternoon Constellation Operations Coordination Plan and the Afternoon Constellation Contingency Procedures documents are updated to reflect the change.
5) The owners of affected ICDs shall ensure that the affected ICDs are updated to reflect the change.
6) The requested change shall be implemented.

AFTERNOON CONSTELLATION
BASELINE CONFIGURATION CHANGE

TITLE:			**CCR #**
REQUESTOR:	**DATE:**	**Comments Due:**	

CHANGE DESCRIPTION:
1.

JUSTIFICATION:

IMPACTS (cost, schedule, technical):
Documentation:
Technical:
Schedule:
Cost:

APPROVALS:

William Guit/GSFC Aqua Mission Director	Date	Dr. Claire L. Parkinson/GSFC Aqua Project Scientist	Date
William Guit/GSFC Aura Mission Director	Date	Dr. Anne R. Douglass/GSFC Acting Aura Project Scientist	Date
David MacDonnell/LaRC CALIPSO Operations Manager	Date	Dr. Charles Trepte/LaRC CALIPSO Project Scientist	Date
Adam Loverro/JPL CloudSat System Engineer	Date	Dr. Deborah Vane/JPL CloudSat Deputy Principal Investigator	Date
Thérèse Barroso/CNES CALIPSO/PARASOL Mission Coordinator	Date	Dr. Didier Tanre/LOA PARASOL Principal Investigator	Date
Bryan A. Fafaul/GSFC Glory Project Manager	Date	Dr. Michael Mishchenko/GISS Glory Project Scientist	Date
Keizo Nakagawa/JAXA GCOM Project Manager	Date	Norimasa Ito /JAXA GCOM Ground System Manager	Date
Peter Kahn/JPL OCO-2 Project Engineer	Date	Dr. Michael Gunson OCO-2 Project Scientist	Date
Angelita C. Kelly/GSFC ESMO Constellation Team Manager	Date	Wynn Watson/GSFC Earth Science Mission Operations Project Manager	Date
Cheryl Yuhas/NASA Headquarters Program Executive for Operations	Date	Dr. Hal Maring/NASA Headquarters A-Train Program Scientist	Date

SAMPLE

Figure D-1. Afternoon Constellation Baseline Configuration Change Form Sample

Appendix E. Afternoon Constellation Checklist

Submitter: ______________________________ Date: ________________________

1. OVERVIEW

ITEM	DESCRIPTION
Mission	
Instruments	
Launch date	
Mission lifetime	
Proposed location relative to Aqua	
Control box size	

2. ORGANIZATION

ORG NAME	NAMES / LOCATION	POINT(S) OF CONTACT
Project		
PI(s)		
Prime spacecraft contractor		
Instrument contractors		

3. SPACECRAFT / INSTRUMENT OVERVIEW

ITEM	SUB-ITEM	DESCRIPTION
Instrument objectives (list for each instrument)		
Maneuver capability / limitations (e.g., “no retrograde maneuvers”)		
Maneuver strategy	Ascent/entry to Constellation:	
	Drag makeup maneuvers:	
	Inclination change	

	maneuvers:	
Transmit bands/frequencies/data rates	S-Band:	
	X-Band:	
Onboard data storage capacity (e.g., orbits, minutes, or GBytes)		
Dumps per day		
GN&C parameters	Method (e.g., GPS)	
	Positional accuracy	
Conjunction assessment service provider for orbital debris – who performs? For example, “A-Train”, “JAXA”, “None”, or “Other”		

4. GROUND SYSTEM RESOURCES

FACILITY	NAME / LOCATION	POINT(S) OF CONTACT
Control Center		
Ground stations		
Data processing facilities		

5. MAJOR REVIEWS

REVIEW	LOCATION	DATE

6. CONTROLLING DOCUMENTS

DOCUMENT NAME	PUBLICATION DATE

7. CONSTELLATION DOCUMENTATION UPDATES

DOCUMENT	EXPECTED DATE
Proposed updates to the Afternoon Constellation Operations Coordination Plan	
Proposed updates to the Afternoon Constellation Contingency Procedures document	
Interface Control Documents (ICDs)	
Ascent Plan	
Constellation Exit Plan	

8. PRE-MISSION ANALYSES

ANALYSIS	SUPPORT REQUESTED	DATE
Space and ground system resources for uplink and downlink		
Link analyses		
Launch and early orbit (L&EO)		
Constellation exit / End-of-life plan		
Contamination		