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esa

The Legacy and Future of the International Earth Science Constellation (ESC)

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Agenda

A Brief History of the Earth Science Constellation (ESC)

- Overview, Orbit Characteristics and Constellation Evolution
- Historical views of sensor footprints and coordinated science

What's been done to ensure safe and efficient ESC operations?

- How can a mission benefit yet remain independent?
- What are control boxes?
- How do missions coordinate and communicate?
- What resources are available to ensure safe operations?

What does the future of the ESC look like?

- New missions, constellation exits, satellite servicing

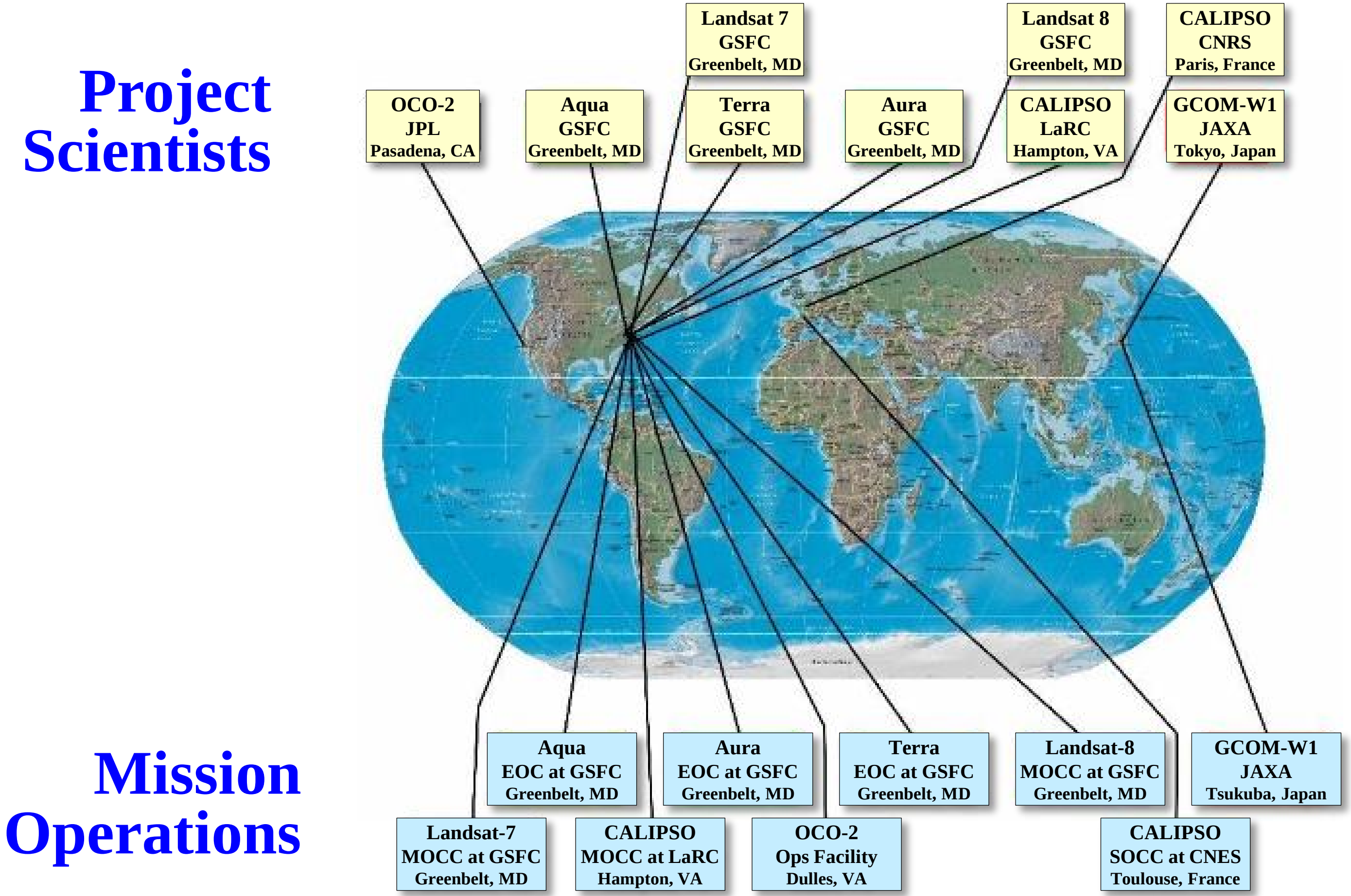
Overview

The ESC has proven to be an effective and efficient way to acquire earth science data.

By flying together:

- **Sensors on ESC satellites in the constellation take measurements of the same air, water, or land mass at essentially the same time.**
- **The sensors form a single "virtual satellite".**

ESC Globally Distributed Science and Mission Operations



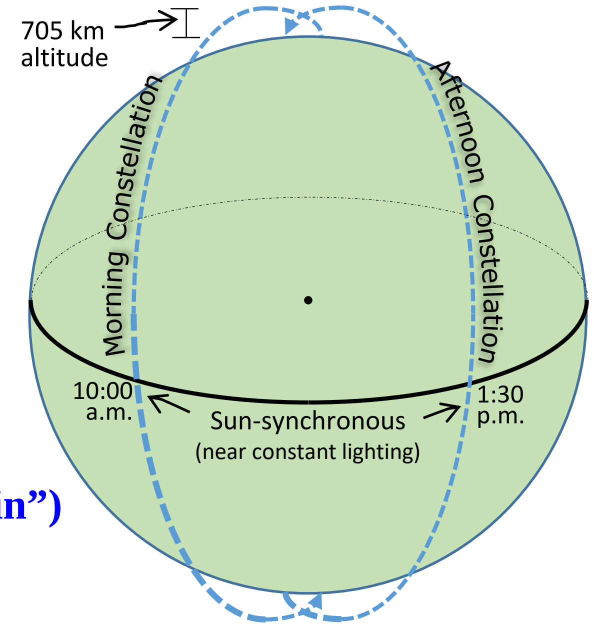
ESC Orbits

- **705 km nominal equatorial altitude**
- **Polar at 98 deg. Inclination**
  - **Benefit: Provides near global coverage**
- **Repeating** (233 orbits/16 days)
  - **Benefit: Easier to see changes**
- **Sun-synchronous**
  - **Benefit: Consistent lighting**

  Morning Constellation ~10:00 a.m. at equator crossing

  Afternoon Constellation ~1:30 p.m. at equator crossing

  (The Afternoon Constellation is also known as the "A-Train")



- **Satellites in close proximity**
  - **Benefit: Near-simultaneous observations**
- **Follows the Worldwide Reference System-2 (WRS-2) developed by USGS for Landsat**
  - **Benefit: Observations overfly the same ground tracks**


ESC Evolution
Morning Constellation
Afternoon Constellation
Landsat 8
Terra
SAC-C
EO-1
Landsat 7
OCO
Glory
OCO-2
GCOM-W1
Aqua
CALIPSO
CloudSat
PARASOL
Aura
Mission no longer operational

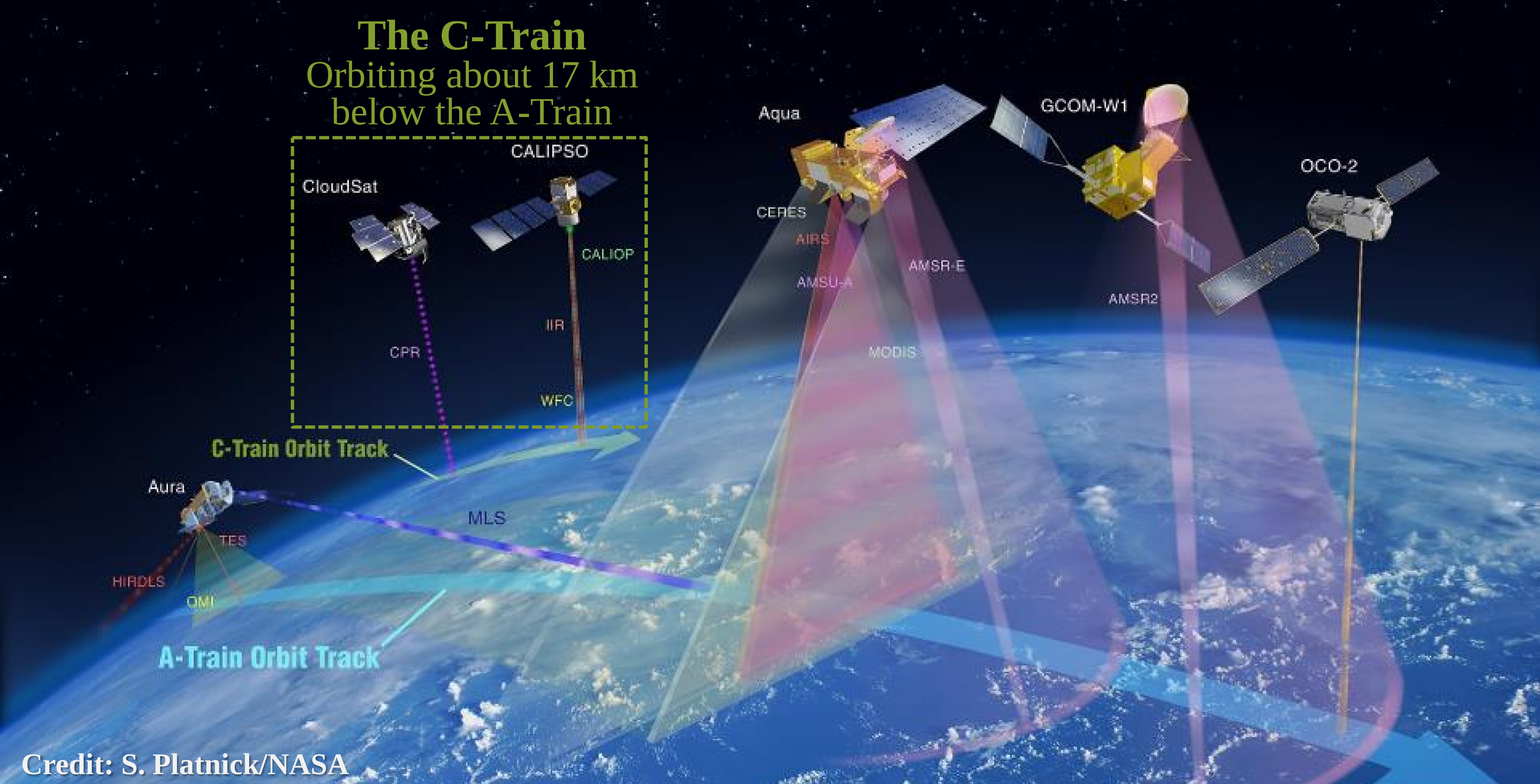
The ESC (2018)

November 2018:
The 2 missions co-located to a new orbit forming the ‘C-Train’

September 2018:
CALIPSO lowered its orbit

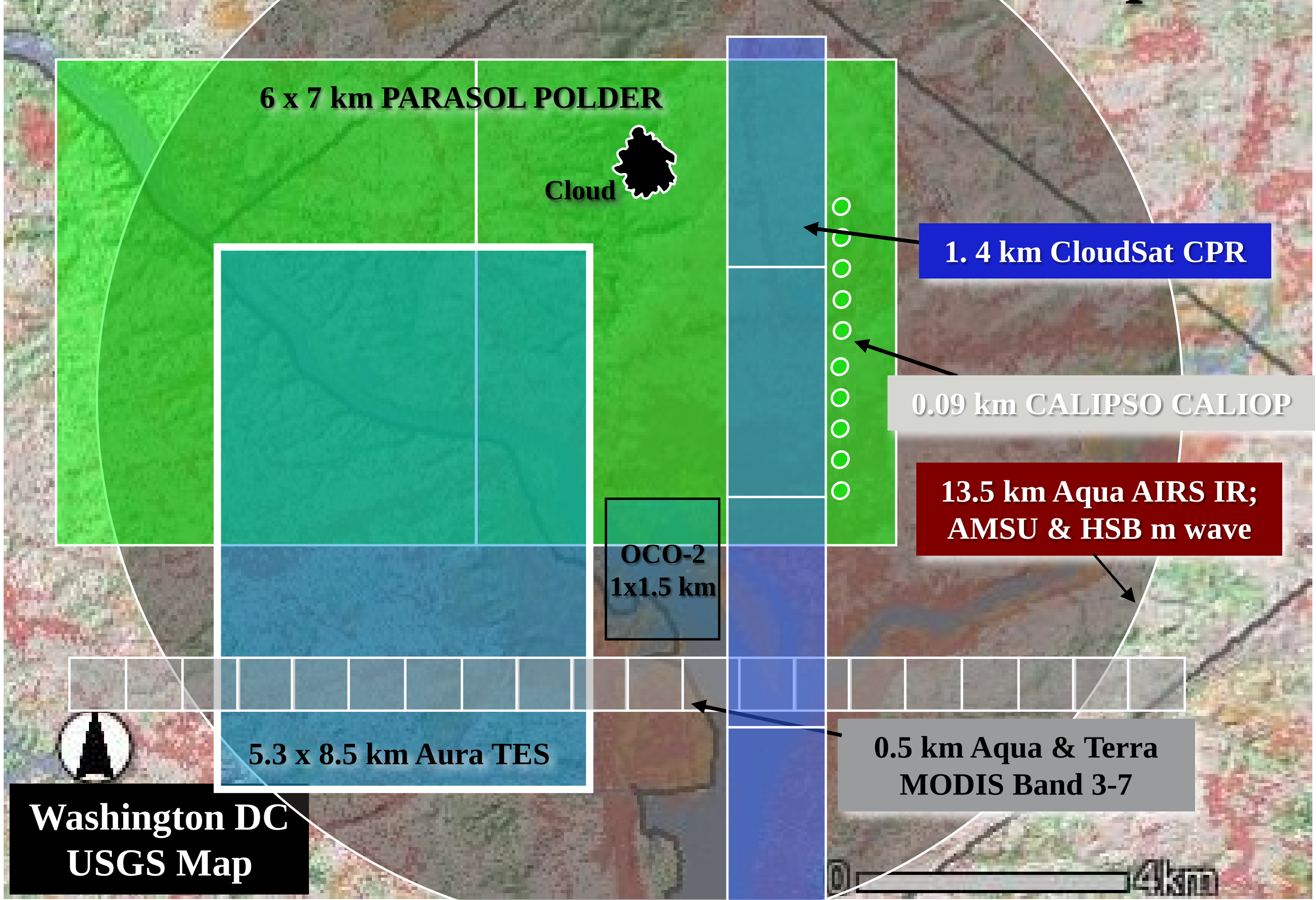
February 2018:
CloudSat lowered its orbit

The A-Train and C-Train today

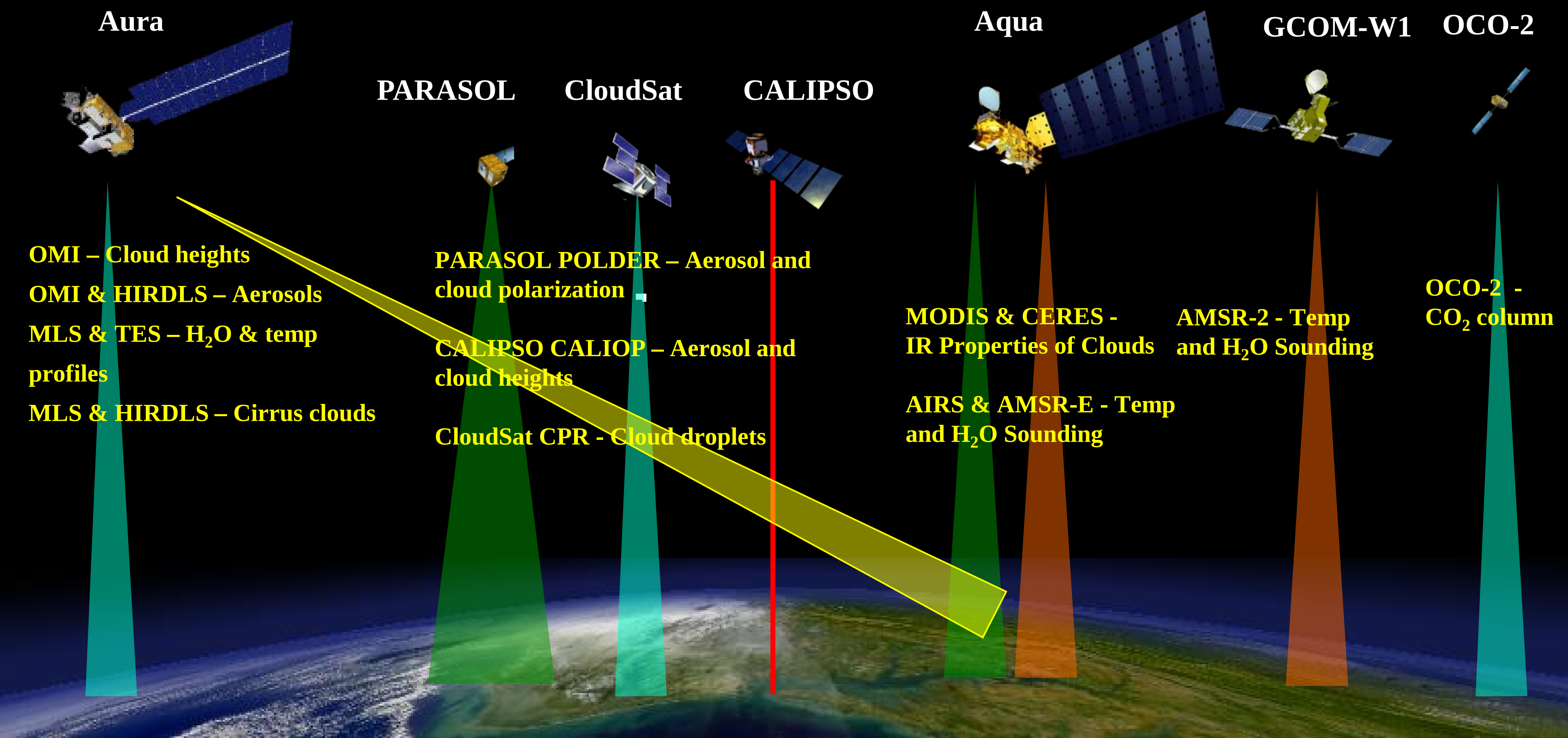


Credit: S. Platnick/NASA

Historical view of "A-Train" Nadir Footprints

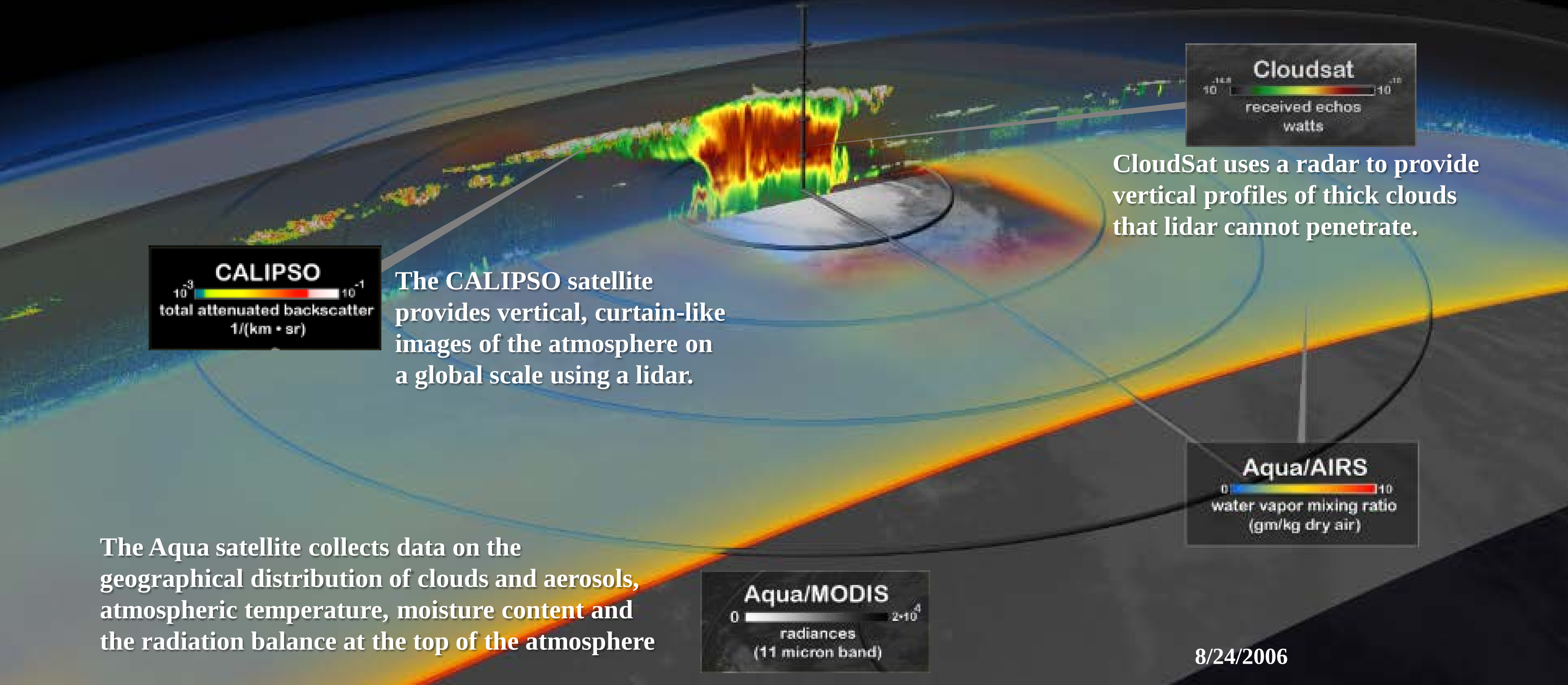


Historical View of Afternoon Constellation Coincidental Science



Constellation Benefit – Enhanced Science

Aqua, CALIPSO, and CloudSat Observe Hurricane Debby



CloudSat uses a radar to provide vertical profiles of thick clouds that lidar cannot penetrate.

The CALIPSO satellite provides vertical, curtain-like images of the atmosphere on a global scale using a lidar.

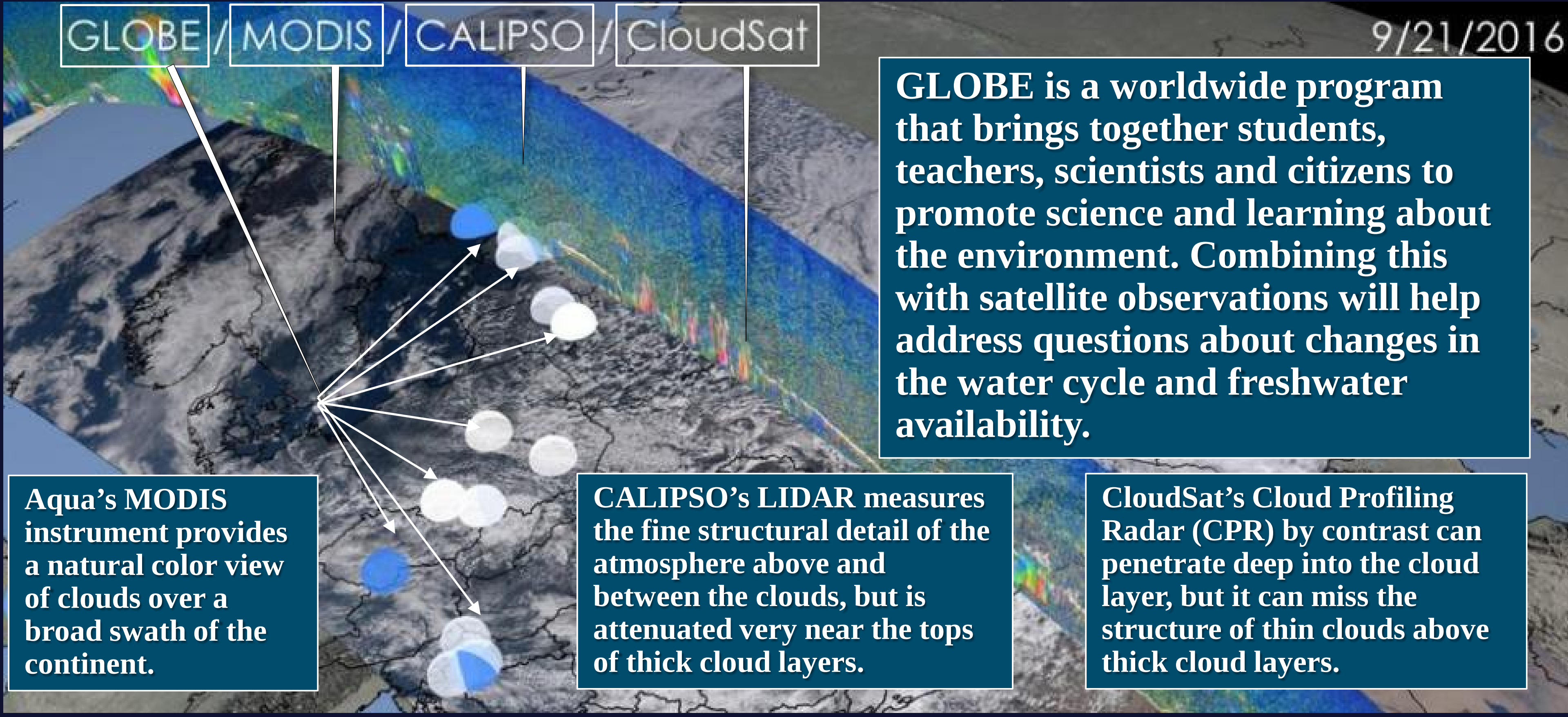
The Aqua satellite collects data on the geographical distribution of clouds and aerosols, atmospheric temperature, moisture content and the radiation balance at the top of the atmosphere

8/24/2006

Credit: NASA Earth Observatory (https://earthobservatory.nasa.gov/Features/CALIPSO) and NASA/Goddard Space Flight Center Scientific Visualization Studio (https://svs.gsfc.nasa.gov/3437)

Constellation Benefit – Enhanced Science

Aqua, CALIPSO, and CloudSat data used for the Global Learning and Observations to benefit the Environment (GLOBE) Program



GLOBE is a worldwide program that brings together students, teachers, scientists and citizens to promote science and learning about the environment. Combining this with satellite observations will help address questions about changes in the water cycle and freshwater availability.

Aqua's MODIS instrument provides a natural color view of clouds over a broad swath of the continent.

CALIPSO's LIDAR measures the fine structural detail of the atmosphere above and between the clouds, but is attenuated very near the tops of thick cloud layers.

CloudSat's Cloud Profiling Radar (CPR) by contrast can penetrate deep into the cloud layer, but it can miss the structure of thin clouds above thick cloud layers.

Safe Efficient Effective Operations

Key Goal

Keep the operations as independent and safe as possible in order to minimize the operational burden and costs

Institutional Advantages

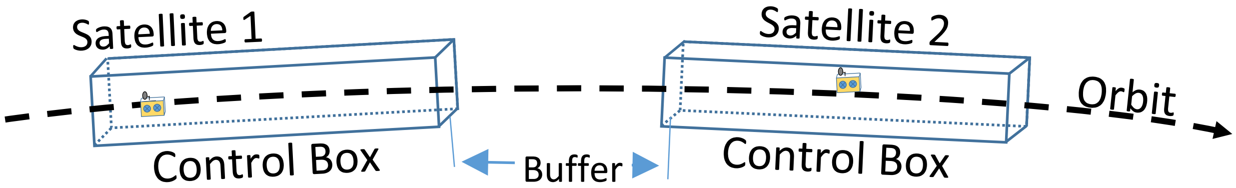
Coordination systems, agreements and procedures are in place

Experienced teams are ready to lend a hand to new members

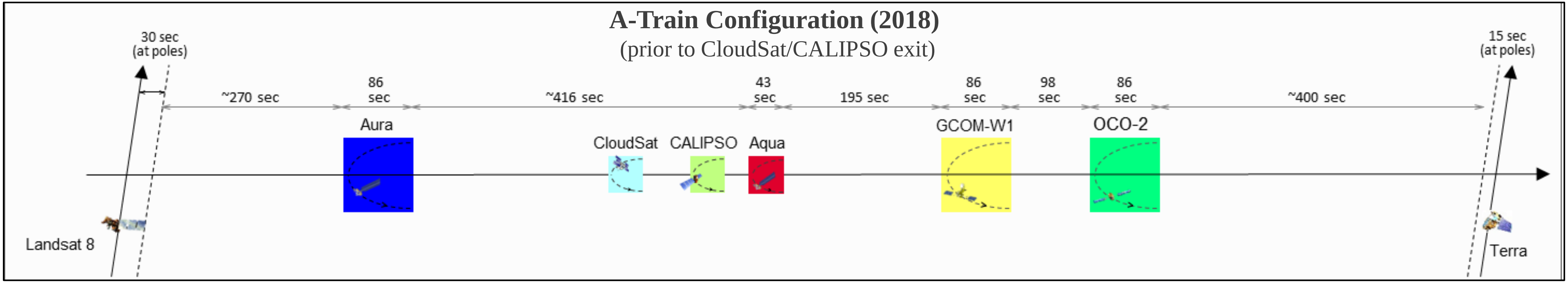
- Flight dynamics expertise
- Orbital debris collision avoidance interface

Control Boxes

Control Boxes minimize the amount of coordination required

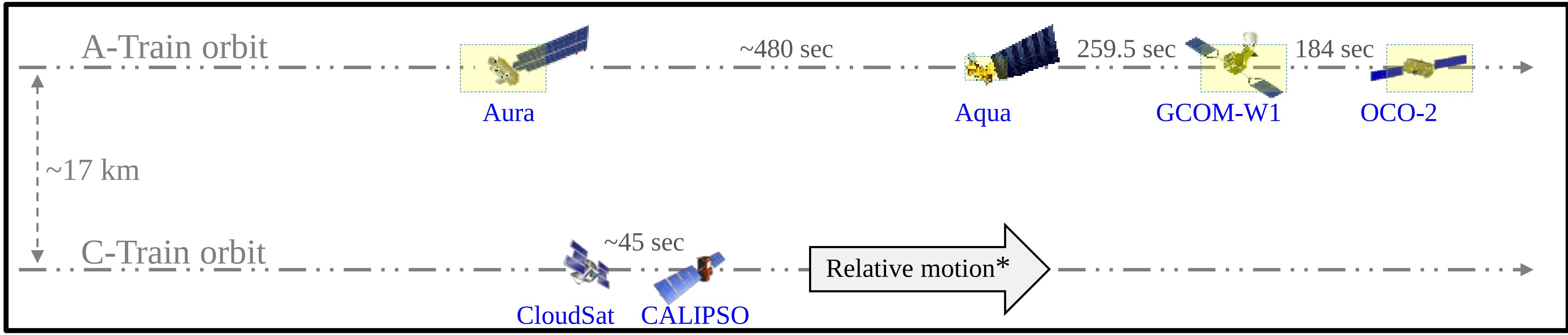


As long as the spacecraft stays inside its control box, little or no daily coordination or complex interfaces are required.



A-Train Control Box Configuration

Latest A-Train control box configurations shown (as of Spring 2019)



*** After lowering their orbits in 2018, CALIPSO and CloudSat perform formation flying approximately ~17 km below the A-Train orbit in what is called the C-Train. They pass the A-Train every ~20 days allowing for more coincidental observations**

Agreements

The agreement between Landsat-7 and Terra for coincident observations after their 1999 launches formed the basis for the Morning Constellation coordination

The A-Train Mission Operations Working Group (MOWG) was established in 2003 comprising science and mission operations representatives

The Morning and Afternoon constellation working groups were formally combined into a single ESC MOWG in 2015

MOWG Policies and Procedures

The MOWG developed policies and procedures that

- **Handle contingencies**
- **Manage changes to the constellation configuration**
- **Define a conflict resolution process**
- **Setup communications guidelines**

The MOWG meets twice per year to review policies, procedures, status, and plans

Tools

NASA's Earth Science Mission Operations (ESMO) Project at Goddard Space Flight Center developed the Constellation Coordination System (CCS) to facilitate coordination between the teams:

Exchanges ephemeris data

Monitors constellation configuration

Sends out alerts as required

Generates plots and reports to analyze orbital safety and develop "what-if analysis"

Performs ephemeris conversions and comparisons

<u>CCS Analyses</u>

- Ad Hoc Analysis
- Argument of Latitude
- Close Approach Analysis
- Control Box and Phasing Analysis
- Mean Local Time at the Nodes
- Phase Margin Analysis
- Phasing at the Poles
- Satellite Situational Awareness
- Single Orbit Altitude Versus Latitude

Michael Machado Logout

Constellation Coordination System (CCS)

19:57:51 UTC

- Home
- Products
- Missions
- Tools
- Utilities
- My Account
- About Us
- Help
- Logout

Home

Status Flags

EOS Afternoon Constellation

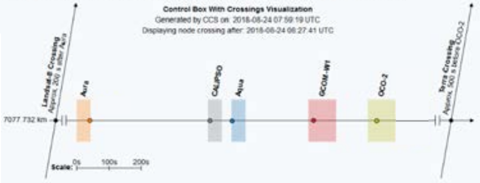
Categories	Aura	CALIPSO	Aqua	GCOM-W1	OCO-2
Satellite	Green	Green	Green	Green	Green
Instrument	Green	Green	Green	Green	Green
Constellation	Green	Green	Green	Green	Green

EOS Morning Constellation

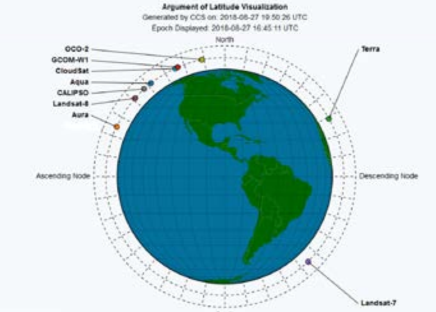
Categories	Landsat-8	Landsat-7	Terra
Satellite	Green	Green	Green
Instrument	Green	Green	Green
Constellation	Green	Green	Green

Automated Analyses

Control Box With Crossings Automated Analysis (Afternoon Constellation)

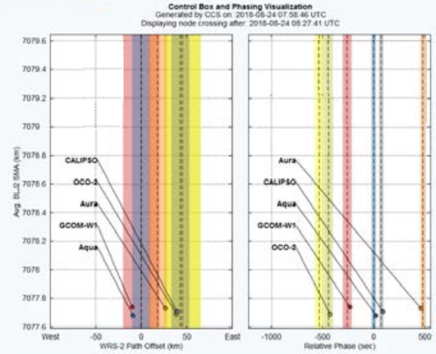


Argument Of Latitude Visualization



Predicted Current Control Box Visualization (Afternoon Constellation)

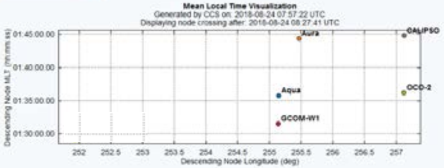
Predicted Current | Future

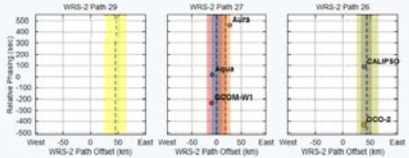


› Data for the Control Box Visualization (Afternoon Constellation):

Predicted Current Mean Local Time Visualization (Afternoon Constellation)

Predicted Current | Future





› Data for the Mean Local Time Visualization (Afternoon Constellation):

Future ESC Changes

New Missions

The ESC has a process in place to accept new missions.

- Need to enhance the overall science
- Requires approval from the existing MOWG teams and their space agencies
- Direct Ascent into the ESC is not advisable

Constellation Exit

All teams have to determine when to leave the ESC based on their fuel reserves or spacecraft health

Upcoming changes:

2021: Landsat-7 exits ESC orbit
Landsat-9 launches then joins the ESC
2022: Restore-L technology demonstration spacecraft plans to refuel Landsat-7
Later: Landsat-7 de-orbits; Aqua, Aura, Terra exit ESC orbit
New missions proposed in response to decadal survey (some to fly in ESC)

Summary

The ESC has been successful for nearly 2 decades providing a record of coincidental earth science observations

The ESC serves as a model for future constellation designs

The ESC continues to evolve and welcome new missions as older missions depart

If you have questions or requests . . .

Contact Michael.J.Machado@nasa.gov

Questions?

Acronyms and Abbreviations

AIRS	Atmospheric Infrared Sounder
AMSR-E	Advanced Microwave Scanning Radiometer-EOS
AMSU	Advanced Microwave Sounding Unit
AUX	auxiliary
ASTER	Advanced Spaceborne Thermal Emission and Reflection and Radiometer
CA	California
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations
CCS	Constellation Coordination System
CERES	Clouds and the Earth’s Radiant Energy System
CIRA	Cooperative Institute for Research in the Atmosphere
CNES	Centre National D’Etudes Spatiales
CNRS	Centre national de la recherche scientifique
CO	carbon monoxide
CO_2	carbon dioxide
CPR	Cloud Profiling Radar
CVT	Constellation Visualization Tool
dBZ	decibel relative to Z (the equivalent reflectivity factor)
deg	degree
DPC	Data Processing Center
E	east
EO-1	Earth Observing 1
EOC	EOS Operations Center
EOS	Earth Observing System
ESC	Earth Science Constellation
ESMO	Earth Science Mission Operations
ETM	Enhanced Thematic Mapper
GCOM-W1	Global Change Observation Mission – Water 1
GEOPROF	geometrical profile
gm	gram
GSFC	Goddard Space Flight Center
H_2O	water
HIRDLS	High Resolution Dynamics Limb Sounder
HSB	Humidity Sounder for Brazil
IIR	Imaging Infrared Radiometer
IR	infrared
IWC	ice water content
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
kg	kilogram
km	kilometer
LaRC	Langley Research Center
Lat	latitude
LIDAR	Light Detection And Ranging
Log	logarithm
Lon	longitude
MD	Maryland
MISR	Multi-angle Imaging. Spectroradiometer
MLS	Microwave Limb Sounder
MOCC	mission operations control center
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurement of Pollution in the Troposphere
MOWG	Mission Operations Working Group
NASA	National Aeronautics and Space Administration
Nov	November
nm	nanometer
OCO	Orbiting Carbon Observatory
OLI	Operational Land Imager
OMI	Ozone Monitoring Instrument
Ops	Operations
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar
POLDER	Polarization and Directionality of the Earth's Reflectances
SAC-C	Satelite de Aplicaciones Cientificas-C
sec	second
SOCC	Satellite Operations Control Center
TES	Tropospheric Emission Spectrometer
TIRS	Thermal Infrared Sensor
Tot	total
USA	United States of America
USGS	United States Geological Survey
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercato
VA	Virginia
W	west
WFC	Wide Field Camera
WRS	Worldwide Reference System

Afternoon Constellation (A-Train) (1 of 2)

Satellite	Summary Of Mission	Instruments	Launch	Responsible Organization
Aqua	Aqua is 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
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

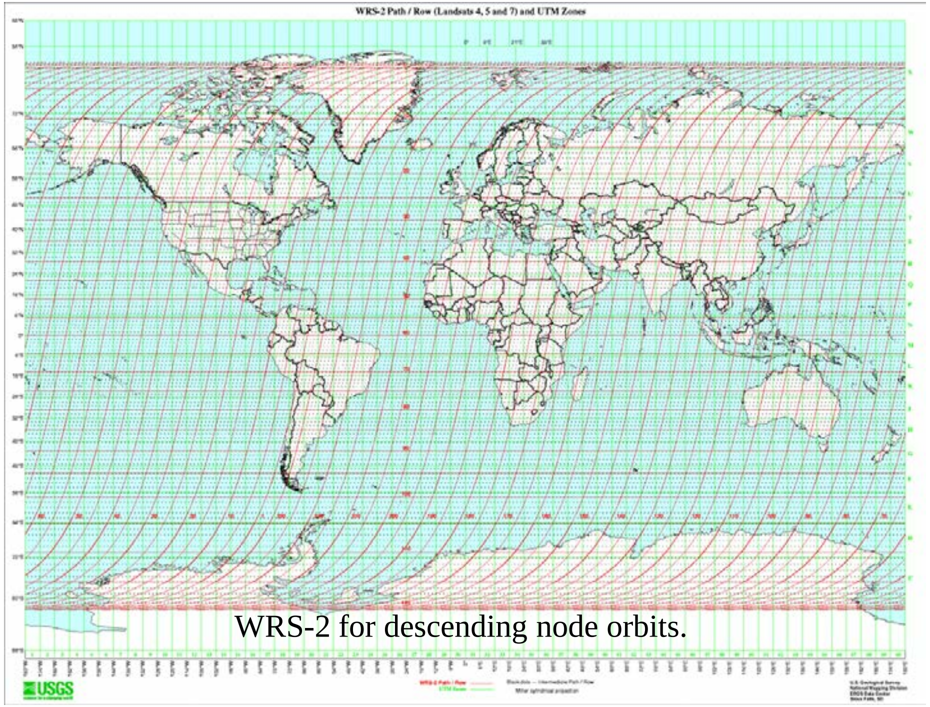
Afternoon Constellation (A-Train) (2 of 2)

Satellite	Summary Of Mission	Instruments	Launch	Responsible Organization
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	May 18, 2012	JAXA
OCO-2	Three grating spectrometers will make global, space-based observations of the column-integrated concentration of carbon dioxide, a critical greenhouse gas.	Three grating spectrometers	July 2, 2014	NASA/JPL

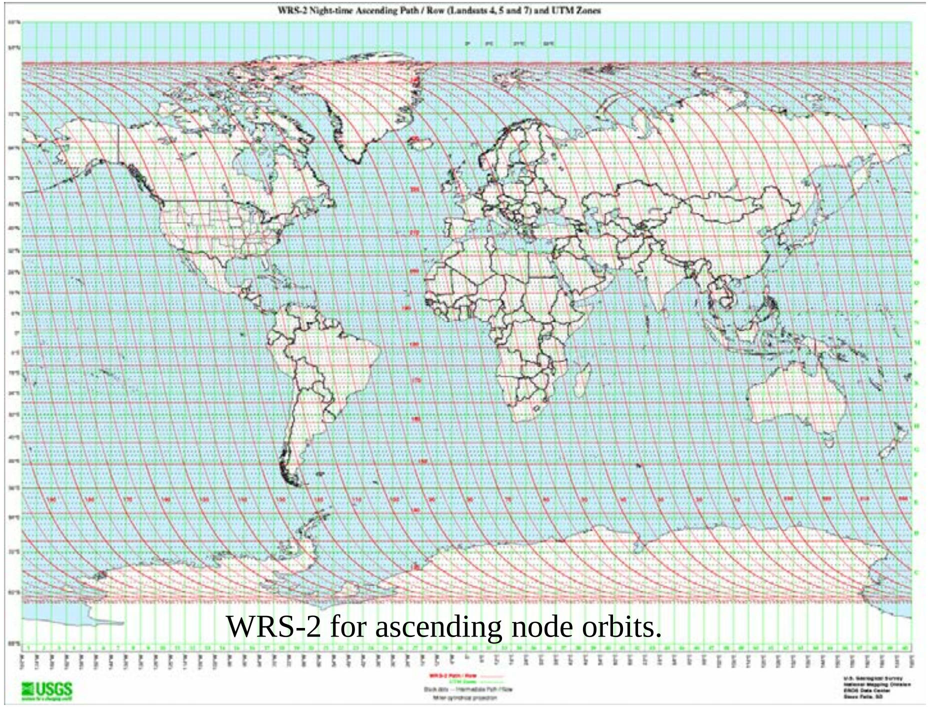
Morning Constellation

Satellite	Summary Of Mission	Instruments	Launch	Responsible Organization
Landsat-7	Provides global coverage, and spectral characteristics to allow comparisons for global and regional change detection and image data to various international users throughout the world during times of sudden global changes (e.g., earthquakes or floods).	ETM+	April 15, 1999	US Geological Survey (USGS)
Terra	Terra is a multi-national, multi-disciplinary mission that will help us to understand how the complex coupled Earth system of air, land, water and life is linked.	MISR CERES MOPITT ASTER MODIS	December 18, 1999	NASA/ GSFC
Landsat 8	Provides moderate-resolution measurements of the Earth's terrestrial and polar regions in the visible, near-infrared, short wave infrared, and thermal infrared. Landsat 8 provides continuity with the 45+ year Landsat land imaging data set.	OLI TIRS	February 11, 2013	USGS

Worldwide Reference System-2
(Established for the Landsat Missions)



WRS-2 for descending node orbits.



WRS-2 for ascending node orbits.

Source: https://landsat.usgs.gov/

Constellation Coordination System (CCS) Detailed Analyses Descriptions

Ad Hoc Analysis	Enables the user to create, save, and view custom plots and/or text reports of a variety of selectable orbit parameters for a mission for the span of a selected ephemeris. Users can select daily products, or can choose trending products by selecting the "view only trending products" check box.
Argument of Latitude	Enables the user to visualize the missions' latitude at the end of its ephemeris (or the end of the ephemeris overlap for multiple missions). This is a 2-D visualization that only gives a basic representation, projecting all missions onto the same orbit plane.
Close Approach Analysis	Enables the user to screen several missions and determine whether a close approach situation is encountered. The radial, in-track, and cross-track separations are analyzed in order to determine if any specified Zone of Exclusion is violated.
Control Box and Phasing Analysis	Enables the user to visualize where an afternoon constellation mission is within its designated control box over a specific time period and determine if any violations will occur. Each missions control box and all associated data is referenced to the descending node of its orbit.
Mean Local Time at the Nodes	Enables user to conduct a trending analysis utilizing archived data and a predictive analysis utilizing predictive future data of the Mean Local Time of the Ascending and Descending Nodes of CCS defined Morning and Afternoon Constellation missions.
Phase Margin Analysis	Enables the user to save and view text reports detailing the difference in the descending node crossing times of two selected missions.
Phasing at the Poles	Enables the user to conduct a phasing analysis of any two CCS defined Morning and Afternoon Constellation missions at the North and the South orbit plane intersection of the two satellites.
Satellite Situational Awareness	Provides a user customizable three dimensional and two dimensional visualization of the location of chosen satellites and their ground tracks with user controlled play speed. The three dimensional visualization also supports variable view angles.
Single Orbit Altitude Versus Latitude	Enables the user to have the ability to analyze the altitude versus the latitude relationship for a single orbit of any two CCS defined Morning and Afternoon Constellation missions.