Leverage your science data return by flying with the International Earth Science Constellation (ESC)

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Agenda

- **What is the Earth Science Constellation (ESC)?**
  - Overview and ESC Orbit Characteristics
  - Morning and Afternoon Constellation Evolution
- **What are the benefits of flying in the ESC?**
- **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?**

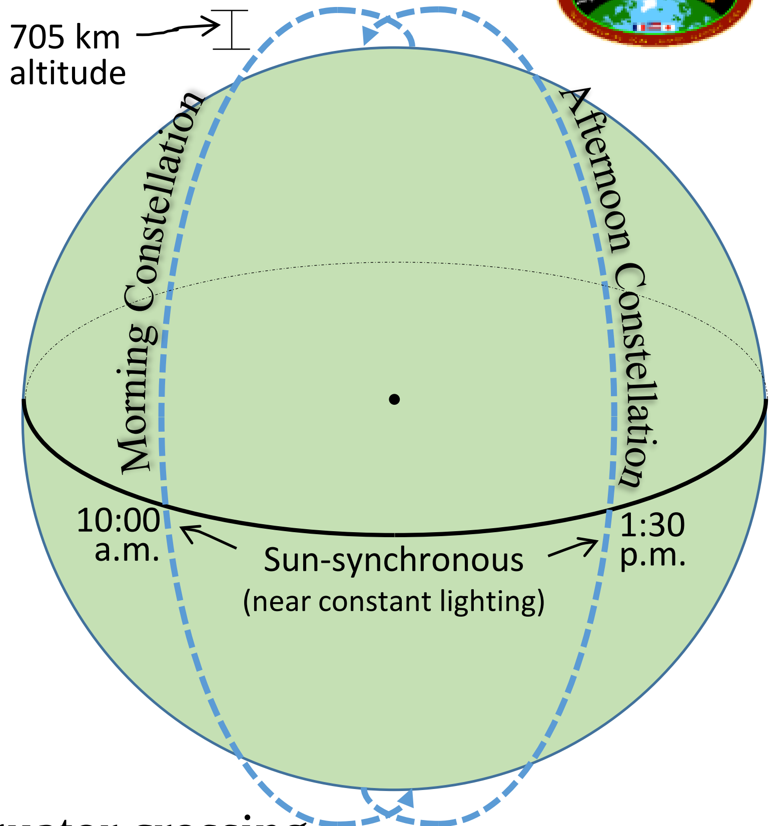
Overview

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 Orbits



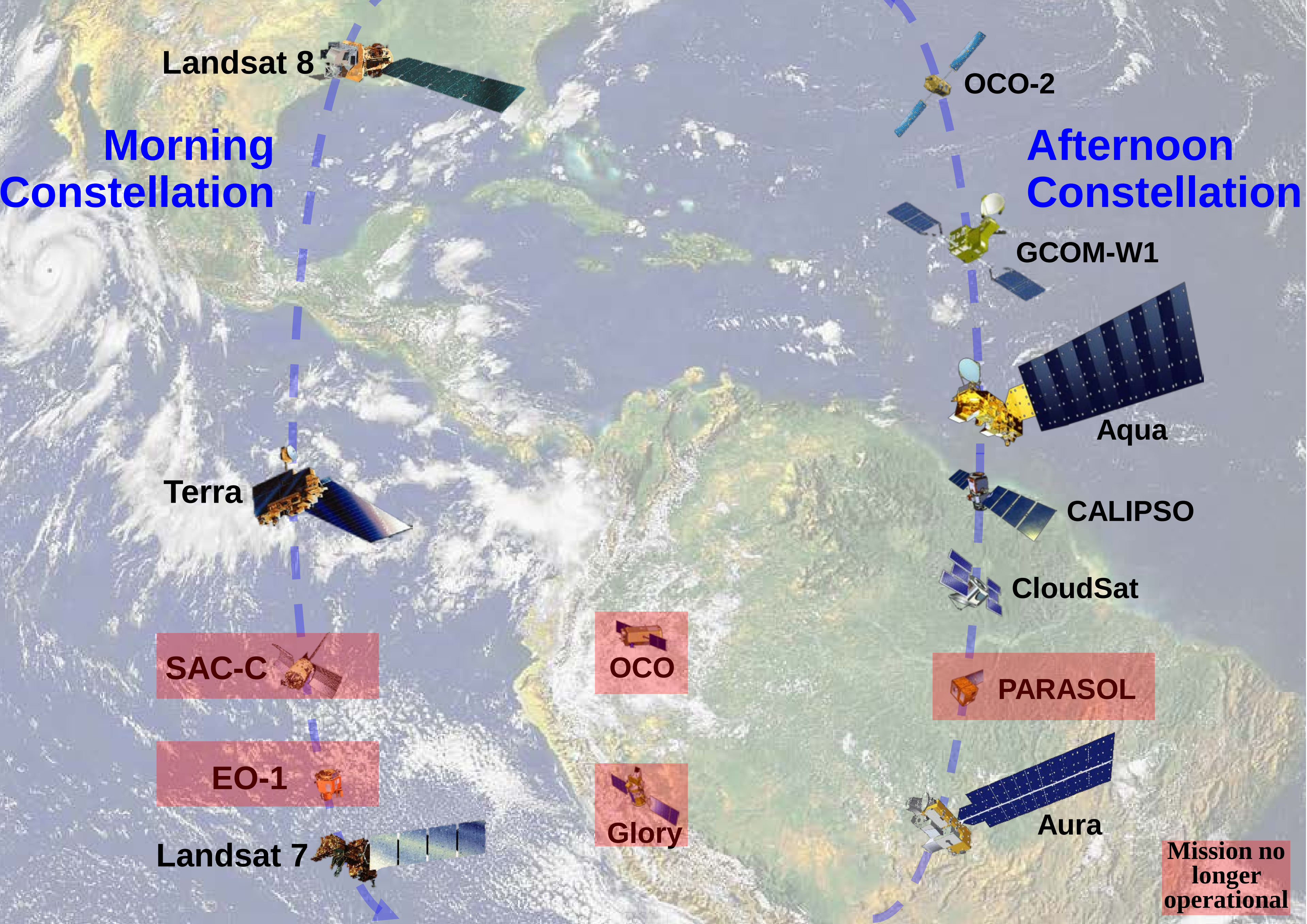
- **705 km nominal equatorial altitude**
- **Polar at 98 deg. Inclination**
  - ➢ Benefit: Provides near global coverage
- **Repeating** (233 orbits/16 days)
  - ➢ Benefit: Easier to see changes
- **Sun-synchronous**
  - ➢ Benefit: Consistent lighting

    Morning Constellation ~10:30 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)**
  - ➢ Benefit: Observations overfly the same ground tracks

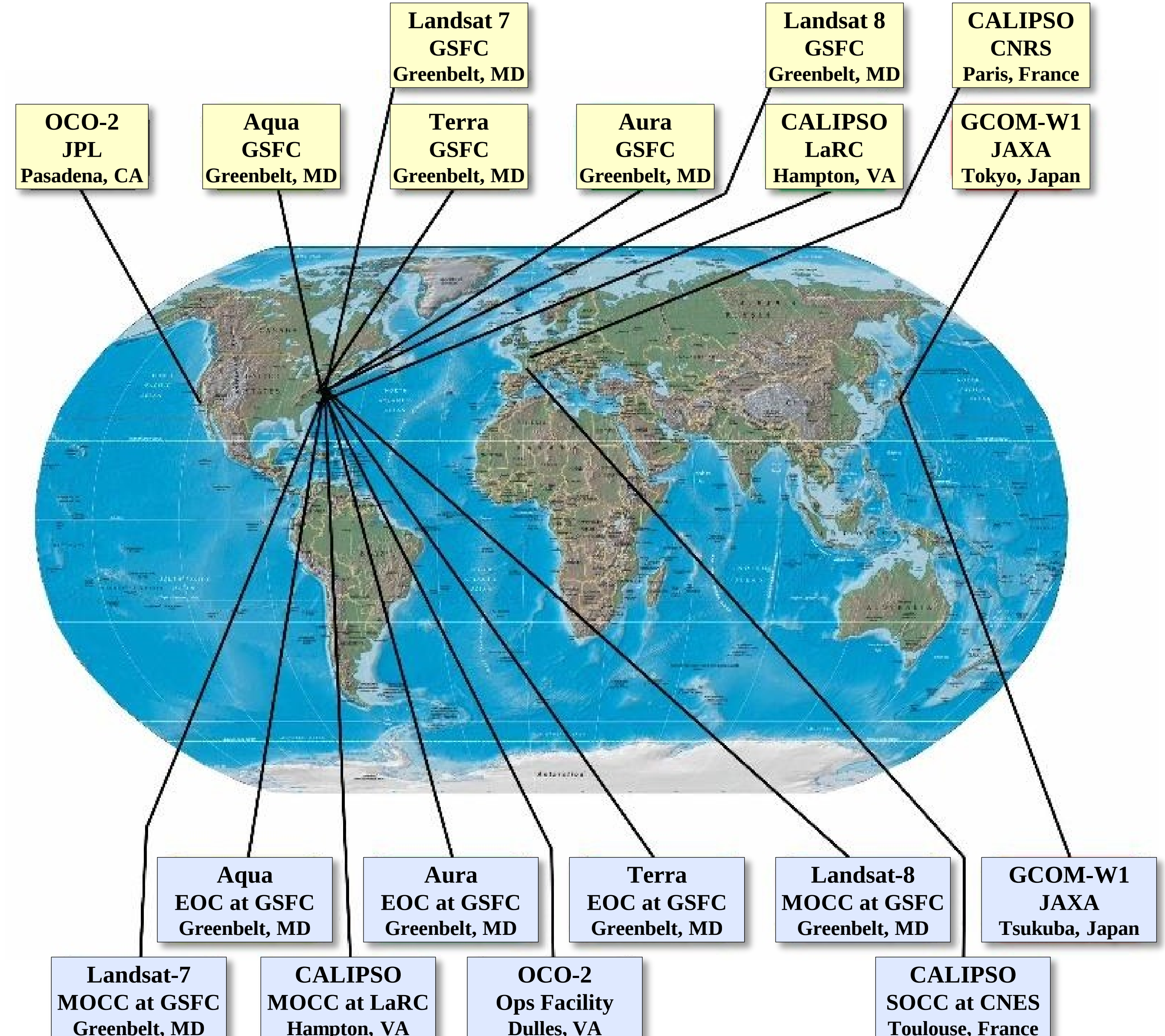
ESC's Evolution



The ESC Today

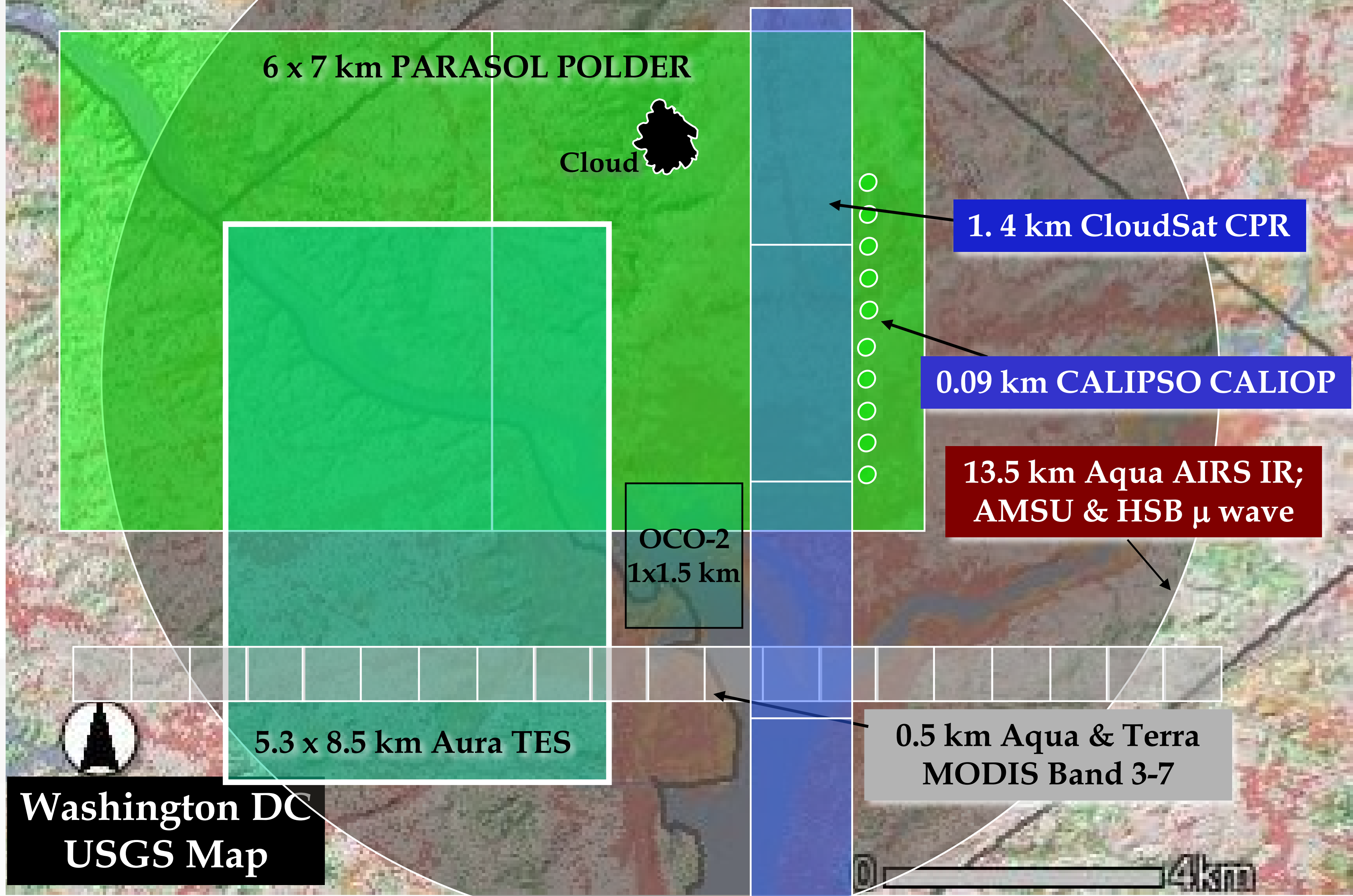
Globally Distributed Science and Mission Operations

Project Scientists



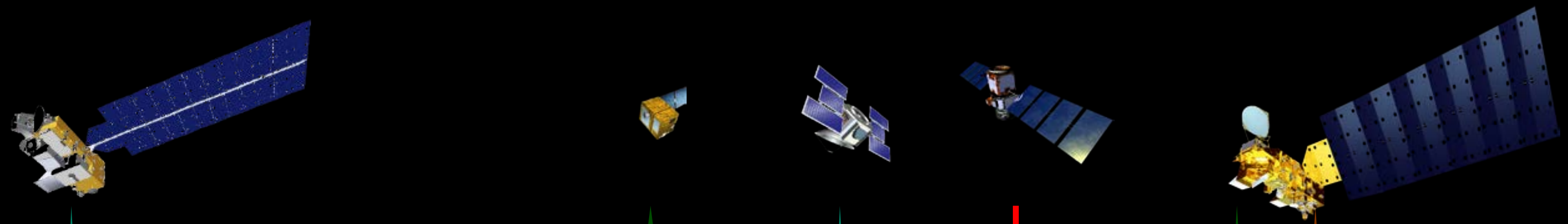
Mission Operations

"A-Train" Nadir Footprints



Afternoon Constellation Coincidental Science

Aura PARASOL CloudSat CALIPSO Aqua OCO-2



OMI – Cloud heights

OMI & HIRDLS – Aerosols

MLS & TES – H_2O & temp profiles

MLS & HIRDLS – Cirrus clouds

PARASOL POLDER – Aerosol and cloud polarization

CALIPSO CALIOP – Aerosol and cloud heights

CloudSat CPR - Cloud droplets

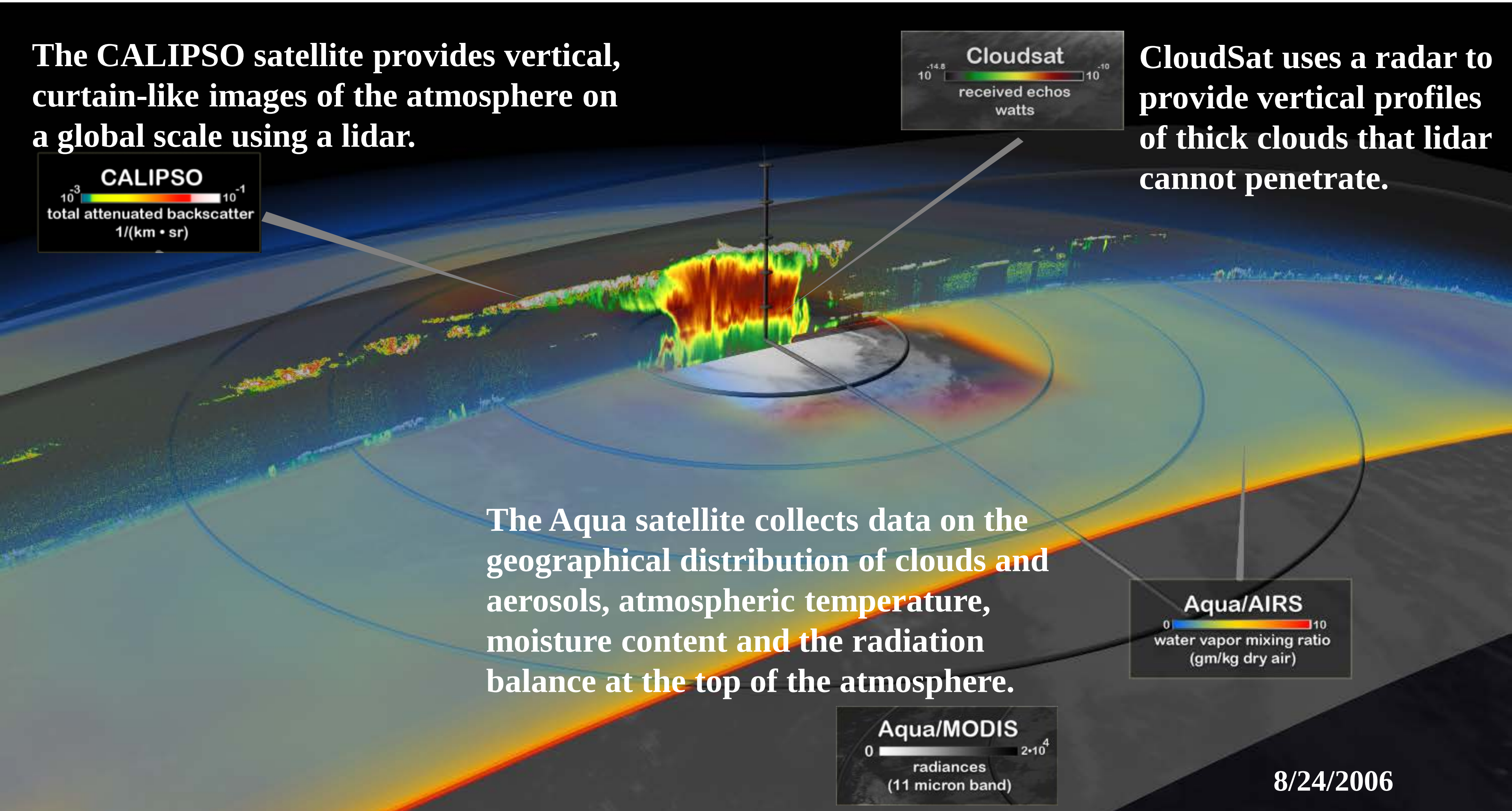
MODIS & CERES - IR Properties of Clouds

AIRS - Temperature and H_2O Sounding

OCO-2 - CO_2 column

Constellation Benefit – Enhanced Science

Aqua, CALIPSO, and CloudSat Observe Hurricane Debby

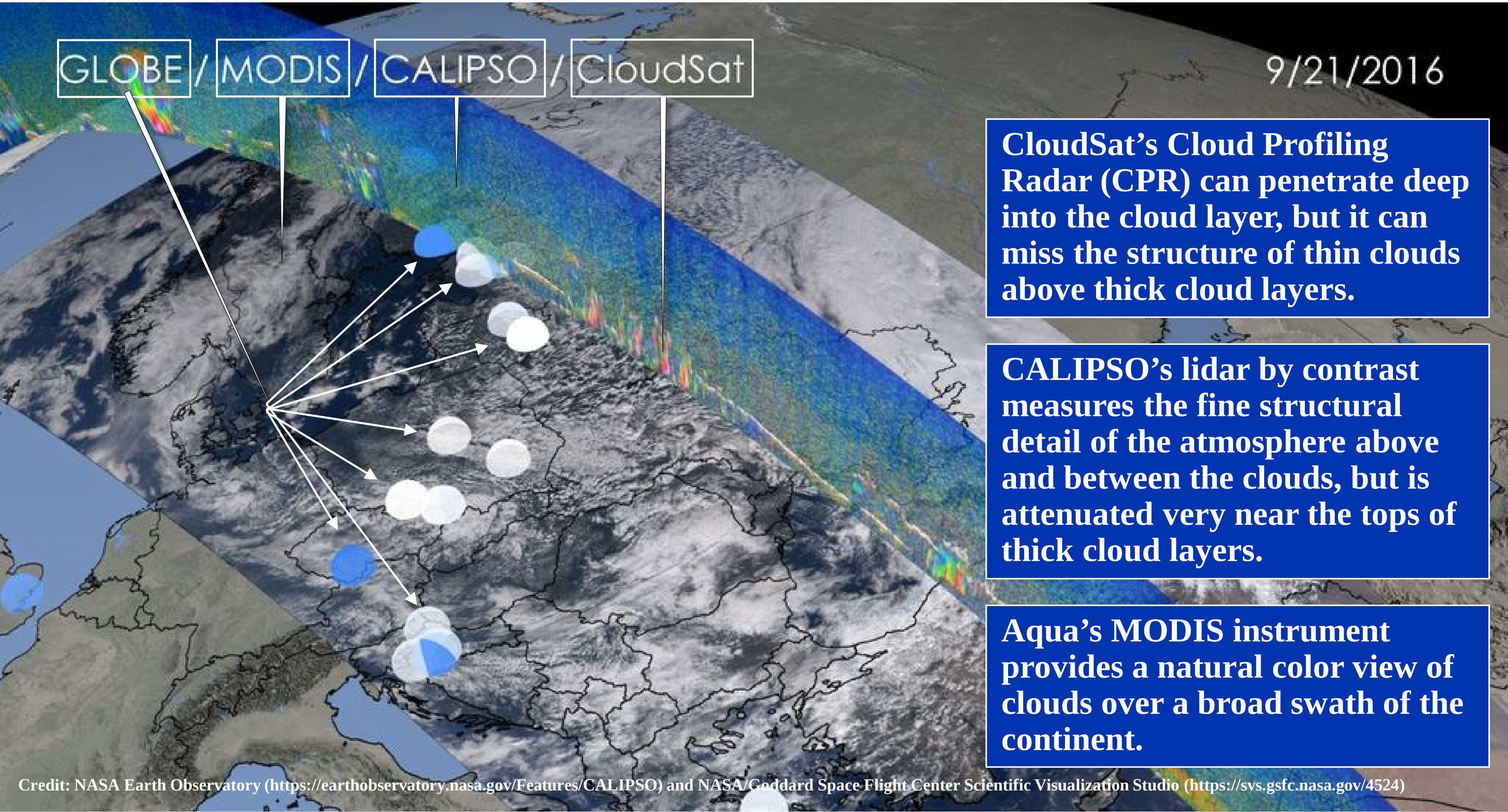


Credit: NASA Earth Observatory (https://earthobservatory.nasa.gov/Features/CALIPSO) and NASA/Goddard Space Flight Center Scientific Visualization Studio (https://svs.gsfc.nasa.gov/3437)

Constellation Benefit – Enhanced Science

Aqua, CALIPSO, and CloudSat data used for the GLOBE Program

The Global Learning and Observations to benefit the Environment (GLOBE) Program, 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.



Credit: NASA Earth Observatory (https://earthobservatory.nasa.gov/Features/CALIPSO) and NASA/Goddard Space Flight Center Scientific Visualization Studio (https://svs.gsfc.nasa.gov/4524)

Effective and Efficient Operation

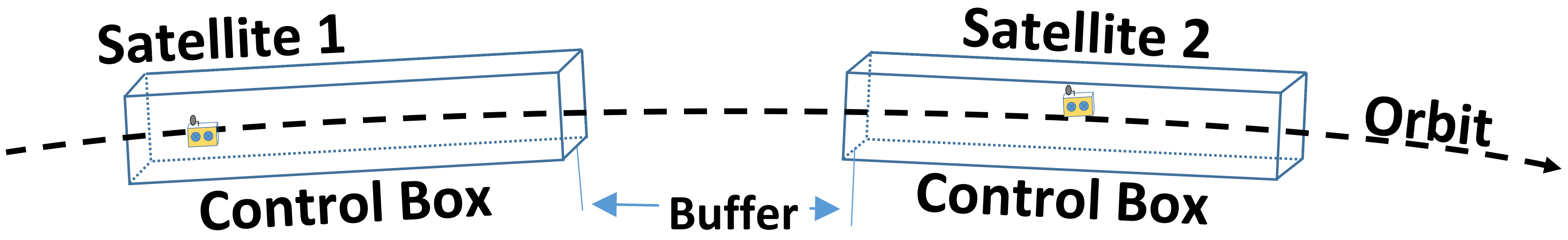
Key Goal:

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

Institutional Advantages

- **Coordination systems and procedures are in place**
- **Experienced teams are ready to lend a hand to new members**
    - Flight dynamics expertise
    - Orbital debris collision avoidance interface

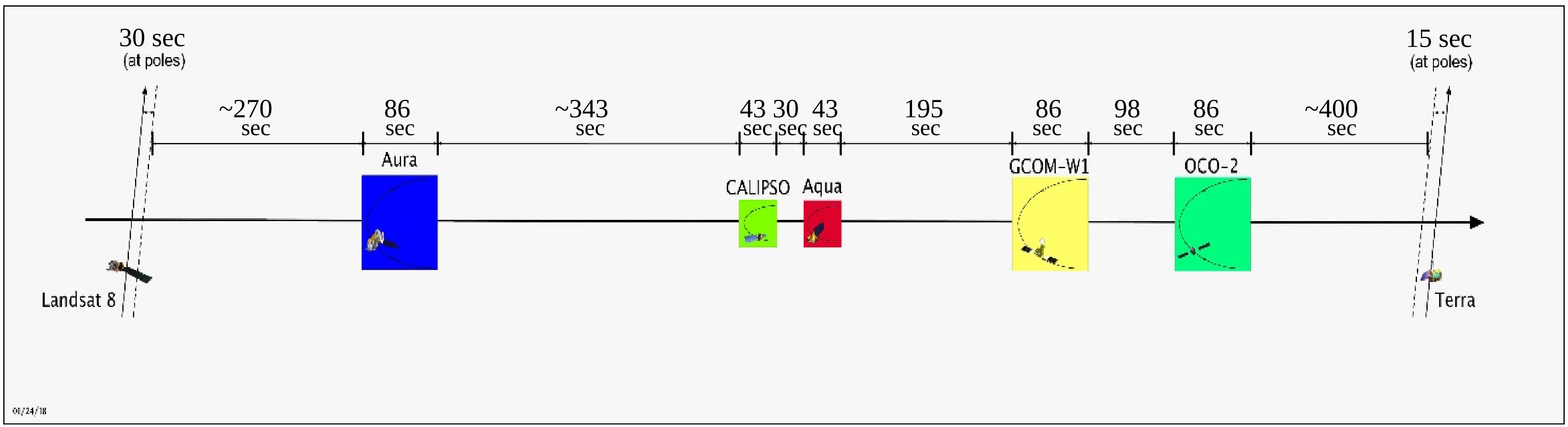
Control Boxes



- **Control Boxes minimize the amount of coordination between missions**
  - As long as the spacecraft stays inside its control box, little or no daily coordination is required
  - No complex interfaces

A-Train Control Box Configuration
(based on equator crossing times)

A-Train Control Box Configuration
(Based on relative equator crossing times)



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**
- **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 status and coordinate plans**

Constellation Coordination System (CCS)

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

- **Exchanges ephemeris data**
- **Monitors constellation**
- **Sends out alerts as required**
- **Generates plots and reports to analyze orbital safety and develop "what-if analysis"**
- **Performs ephemeris conversions and comparisons**

CCS Analyses

- 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

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Home

Status Flags

EOS Afternoon Constellation

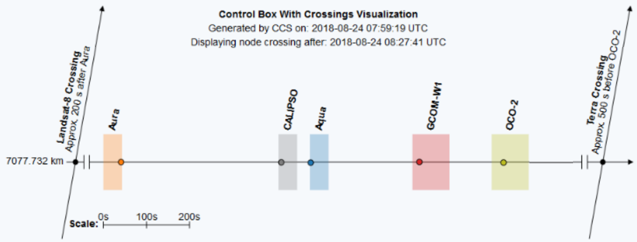
Categories	Aura	CALIPSO	Aqua	GCOM-W1	OCO-2
Satellite	Green	Green	Green	Green	Green
Instrument	Green	Green	Green	Green	Green
Constellation	Green	Green	Green	Green	Green

EOS Morning Constellation

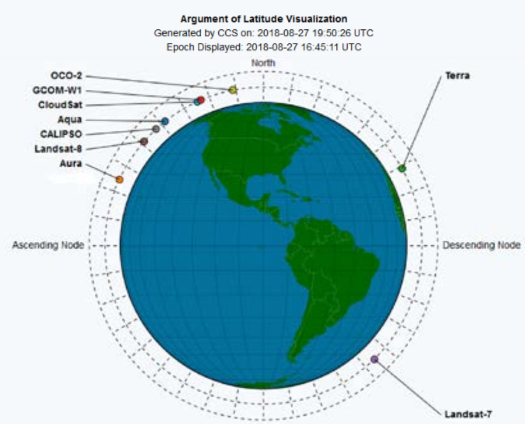
Categories	Landsat-8	Landsat-7	Terra
Satellite	Green	Green	Green
Instrument	Green	Green	Green
Constellation	Green	Green	Green

Automated Analyses

Control Box With Crossings Automated Analysis (Afternoon Constellation)

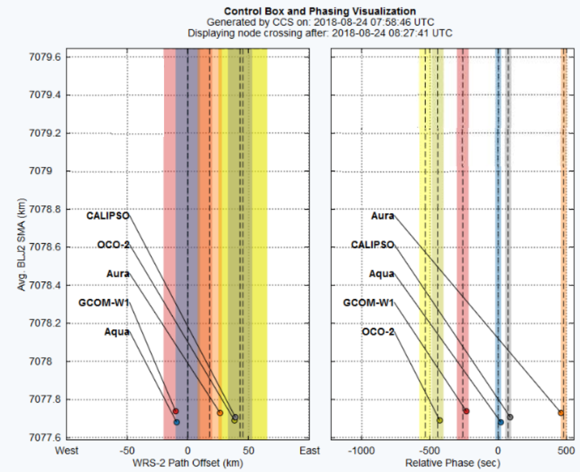


Argument Of Latitude Visualization



Predicted Current Control Box Visualization (Afternoon Constellation)

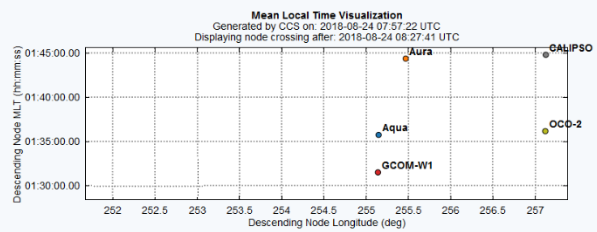
Predicted Current | Future

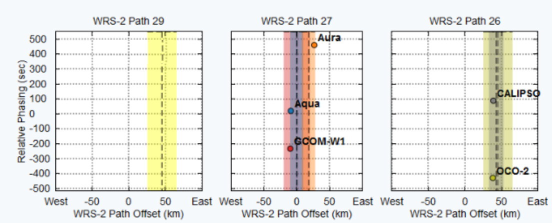


> Data for the Control Box Visualization (Afternoon Constellation):

Predicted Current Mean Local Time Visualization (Afternoon Constellation)

Predicted Current | Future



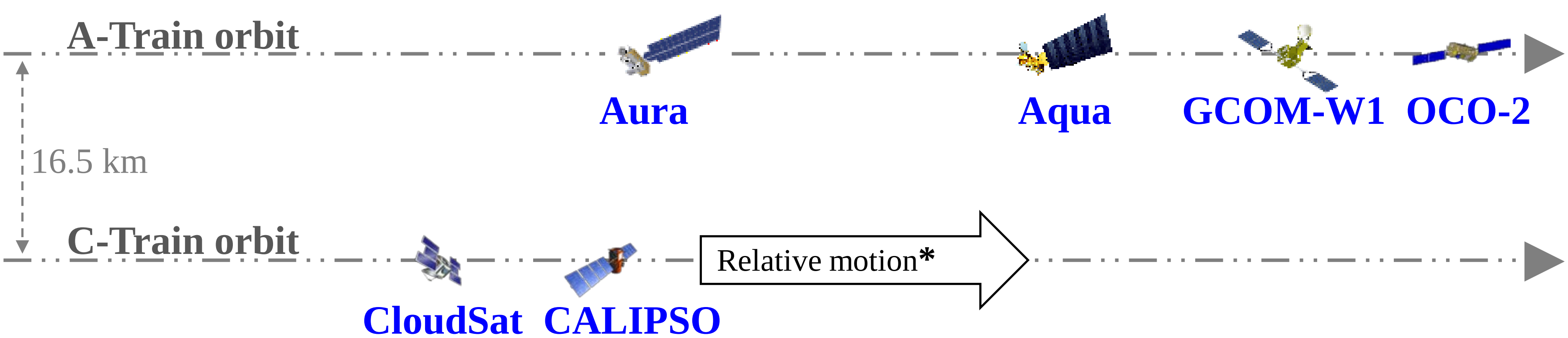


> Data for the Mean Local Time Visualization (Afternoon Constellation):

Recent changes
CloudSat and CALIPSO relocation

- CloudSat lowered its orbit on February 22, 2018
- CALIPSO plans to join CloudSat in September 2018
- This continues their strong coincident science in a new orbit thereby forming the “C-Train”.

A-Train and C-Train Relationship



*Once CALIPSO and CloudSat are in place, they will pass underneath the A-Train every ~20 days

Future ESC Changes

New Missions	The ESC has a process in place to accept new missions. For a new mission to join: • It needs to enhance the overall science • It requires approval from the existing MOWG teams and their space agencies
Constellation Exit	All teams have to determine when to leave the ESC based on their fuel reserves or spacecraft health

For example:

December 2020	Landsat-9 launches and joins the Morning Constellation
Sometime in 2022	RESTORE-L spacecraft refuels Landsat-7 as part of a technology demonstration. Landsat-7 subsequently de-orbits.

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

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
MIS	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)

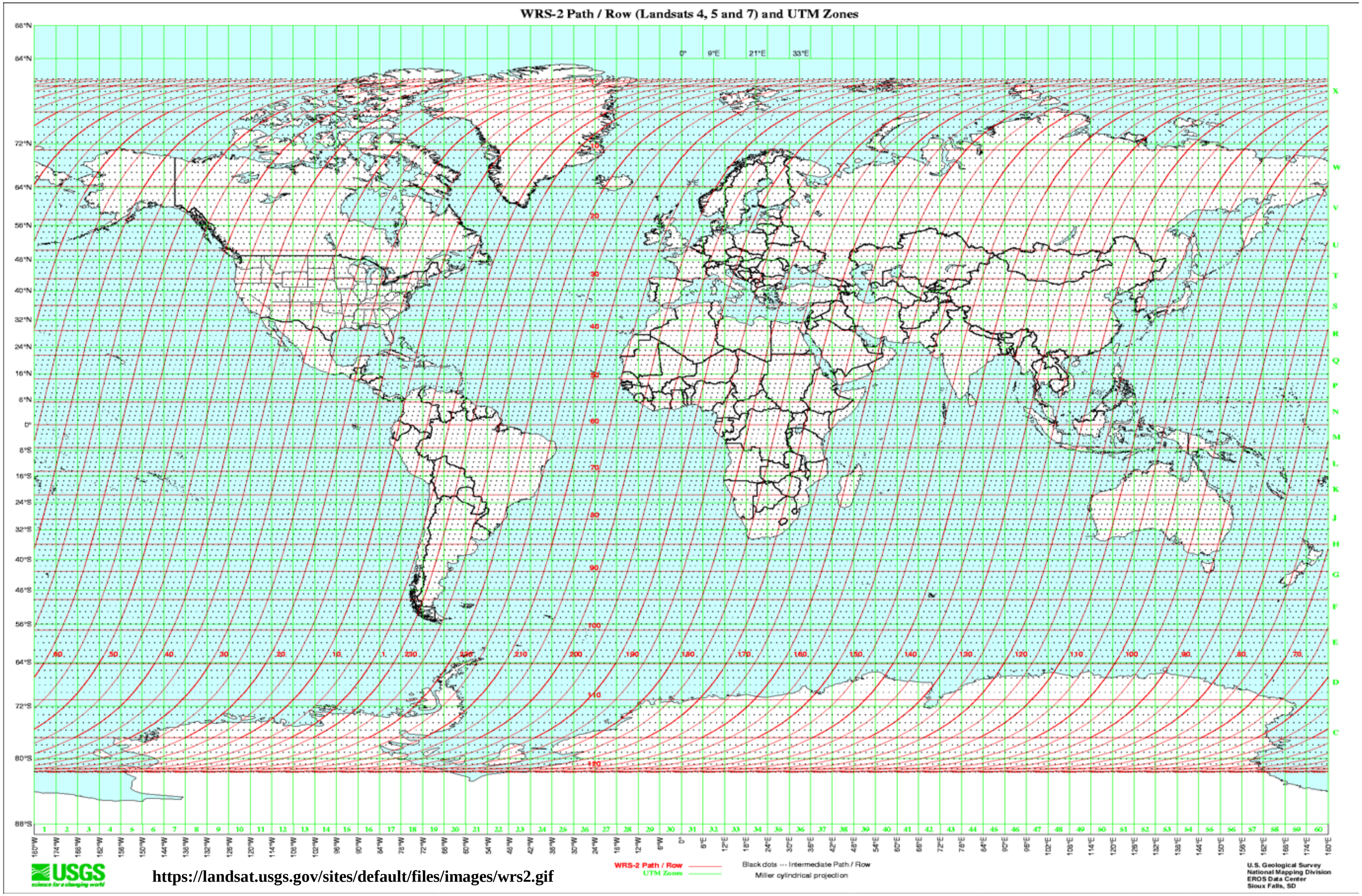
Satellite	Summary Of Mission	Instruments	Launch	Responsible Organization
GCOM-W1	The GCOM-W1 observes integrated water vapor, integrated cloud liquid water, precipitation, sea surface wind speed, sea surface temperature, sea ice concentration, snow water equivalent, and soil moisture.	AMSR-2	May 18, 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)



https://landsat.usgs.gov/sites/default/files/images/wrs2.gif

WRS-2 shown for ascending node orbits. Descending node orbit tracks are similar in nature.

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.