

Options for the Continuing Evolution of the Earth Science Constellation

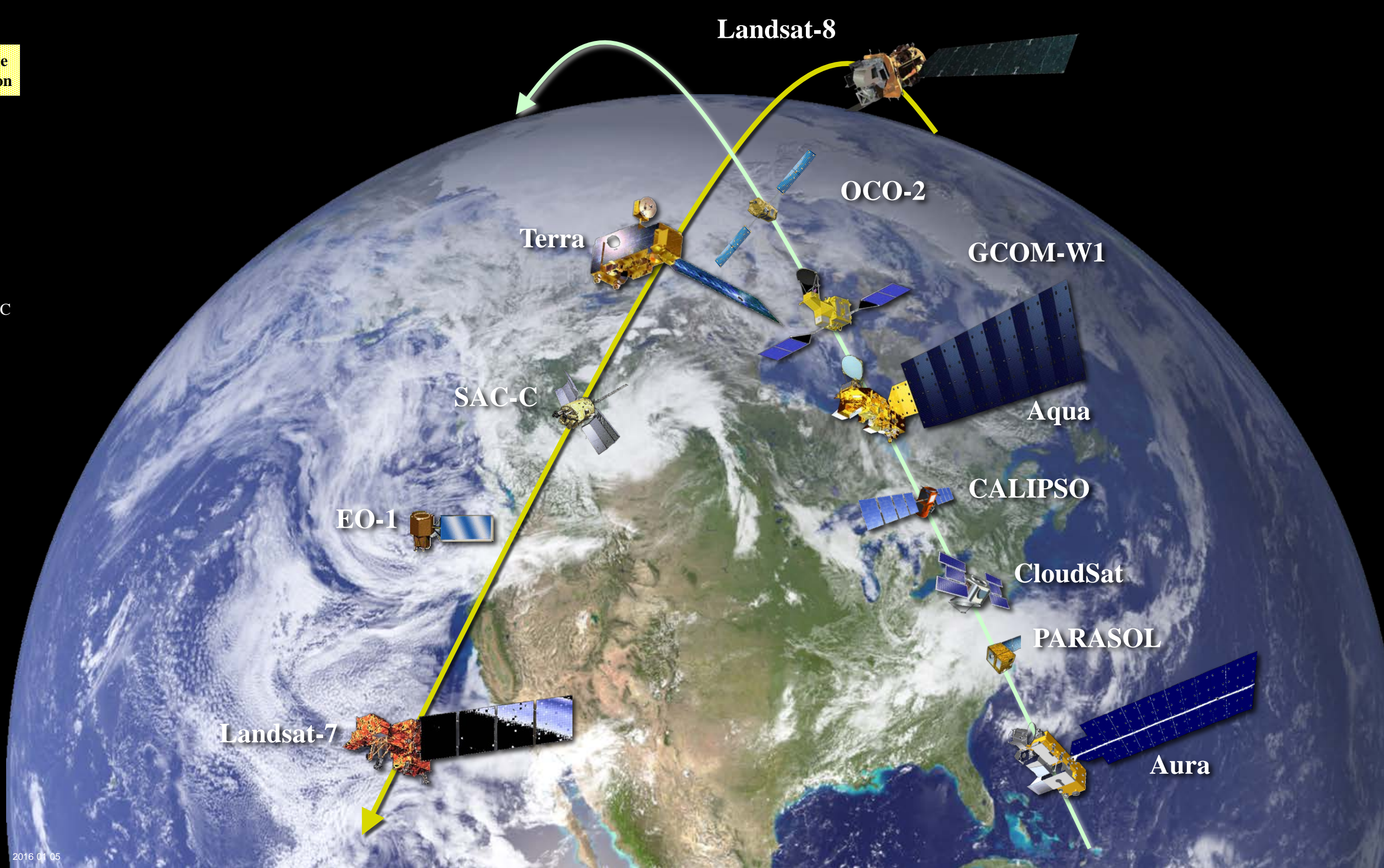
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Morning Constellation

| Satellite | Summary Of Mission | Instruments | Dates | 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 | 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 |
| EO-1 | Developed and validated a number of instrument and spacecraft bus breakthrough technologies designed to enable the development of future earth imaging observatories that will have a significant increase in performance while also having reduced cost and mass. | ALI Hyperion ALI LEISA LAC and others | November 21, 2000 - March 30, 2017 | USGS |
| SAC-C | Study the structure and dynamics of the Earth's surface, atmosphere, ionosphere and geomagnetic field. | MMRS, HRTC, HSC, Orsted-2/SHM, IST, INES, GOLPE, ICARE, WTE, DCS | November 21, 2000 - August 15, 2013 | CONAE |
| 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 40-year Landsat land imaging data set. | OLI TIRS | February 11, 2013 | USGS |

Afternoon Constellation

| Satellite | Summary Of Mission | Instruments | Dates | 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 | Studied the radiative and microphysical properties of clouds and aerosols. | POLDER | Dec. 18, 2004 - Dec. 18, 2013 | 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 |
| 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. | AMSU-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 |

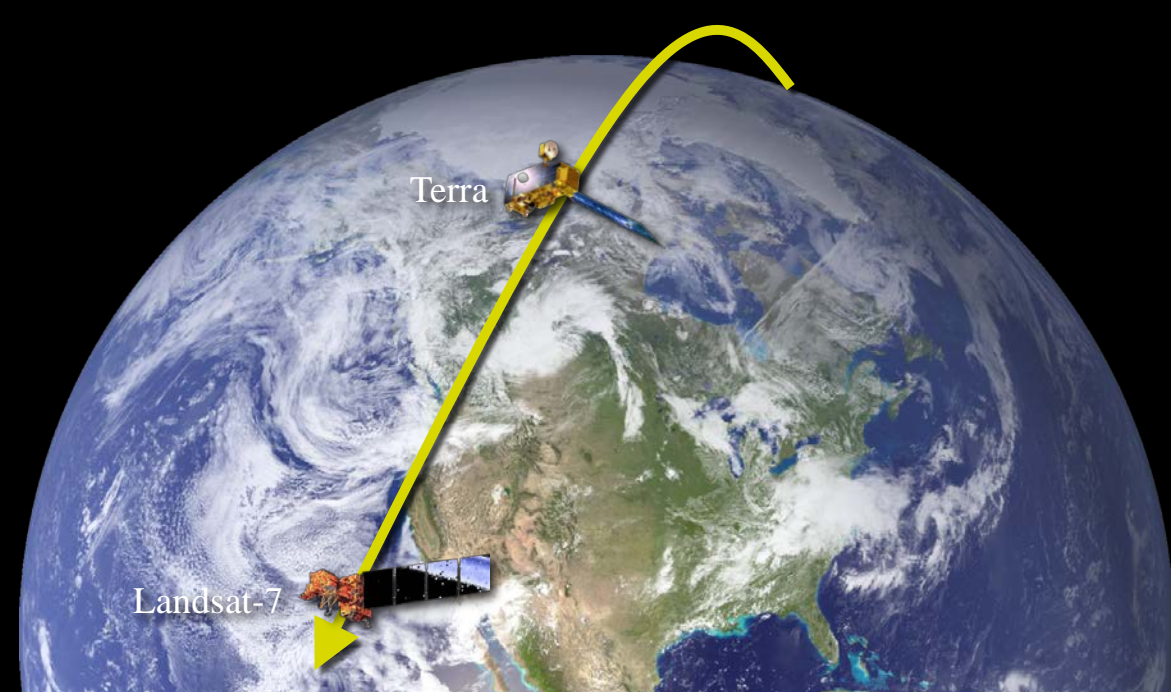


The Earth Science Constellation comprises the Morning Constellation and the Afternoon Constellations (A-Train)

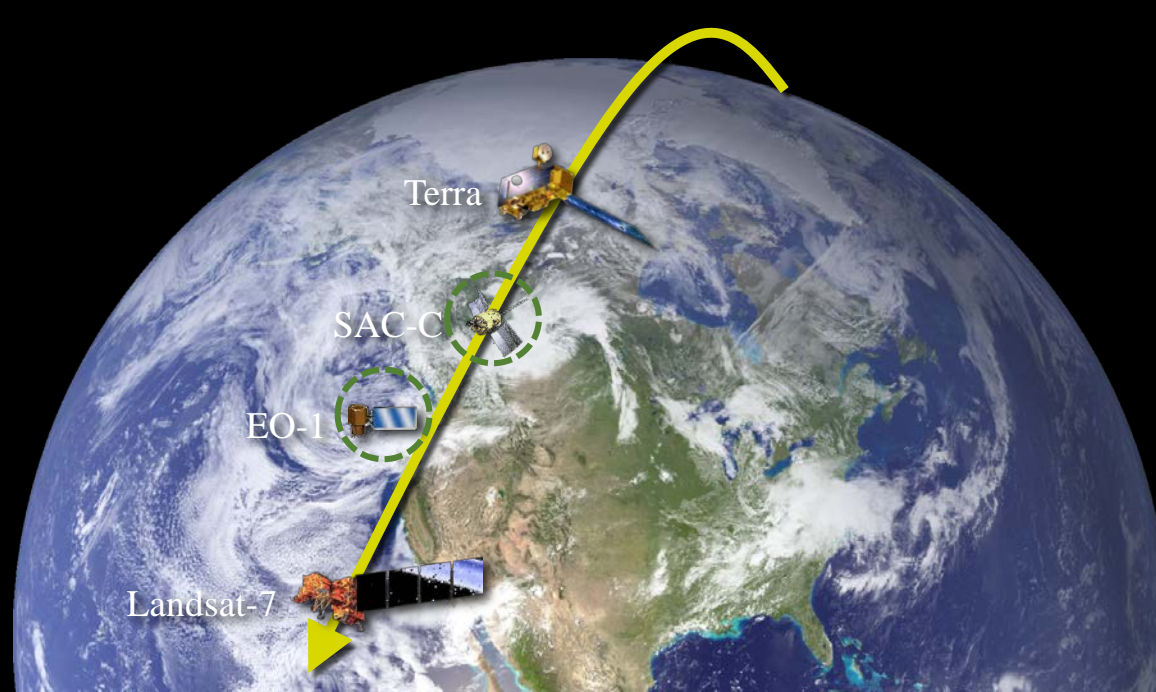
- **International in scope:** Member satellites/instruments from the U.S., France, Japan, Argentina, Canada, Brazil, Netherlands, Finland and the U.K.
- **Multiple U.S. Government Agencies:** Several NASA Centers, the United States Air Force (USAF), and the United States Geological Survey (USGS)

Constellation History and Future Changes

Morning Constellation



Year 1999
Formation with Landsat-7 and Terra

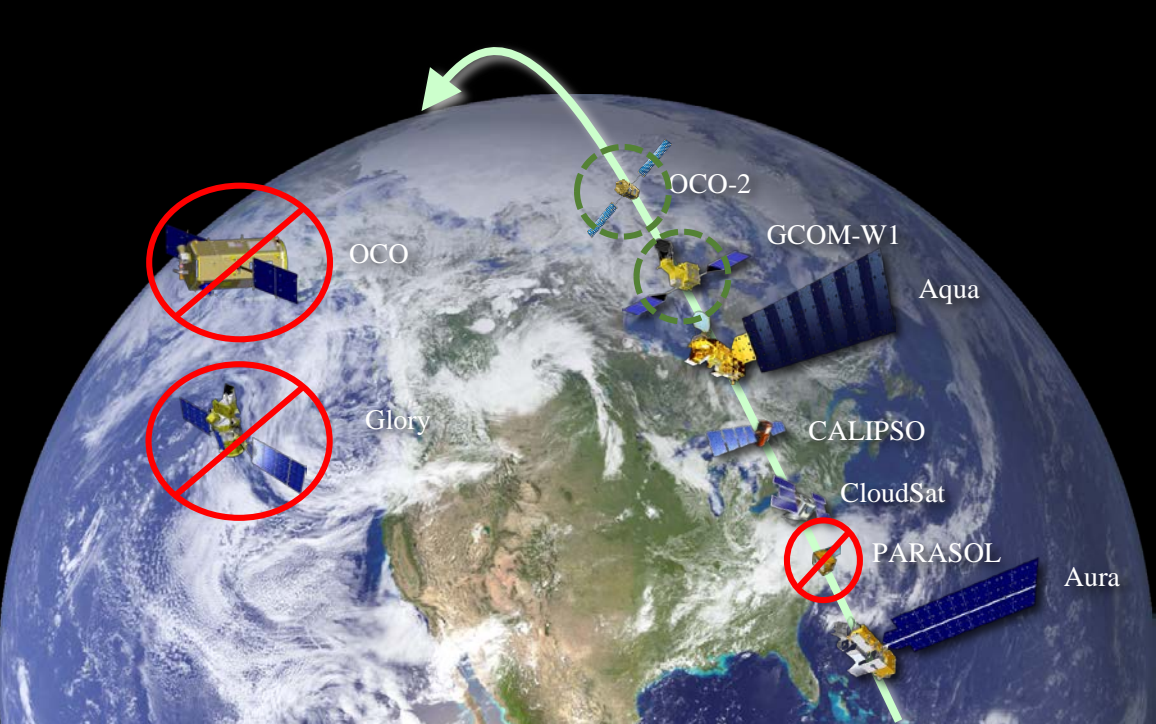


Year 2000
Added EO-1 and SAC-C

Afternoon Constellation



Years 2002 - 2006
Formation with Aqua, Aura, PARASOL, CALIPSO, and CloudSat



Years 2008 - 2014
OCO and Glory launches failed. PARASOL ended mission. CloudSat exits and returns behind CALIPSO. Added GCOM-W1 and OCO-2



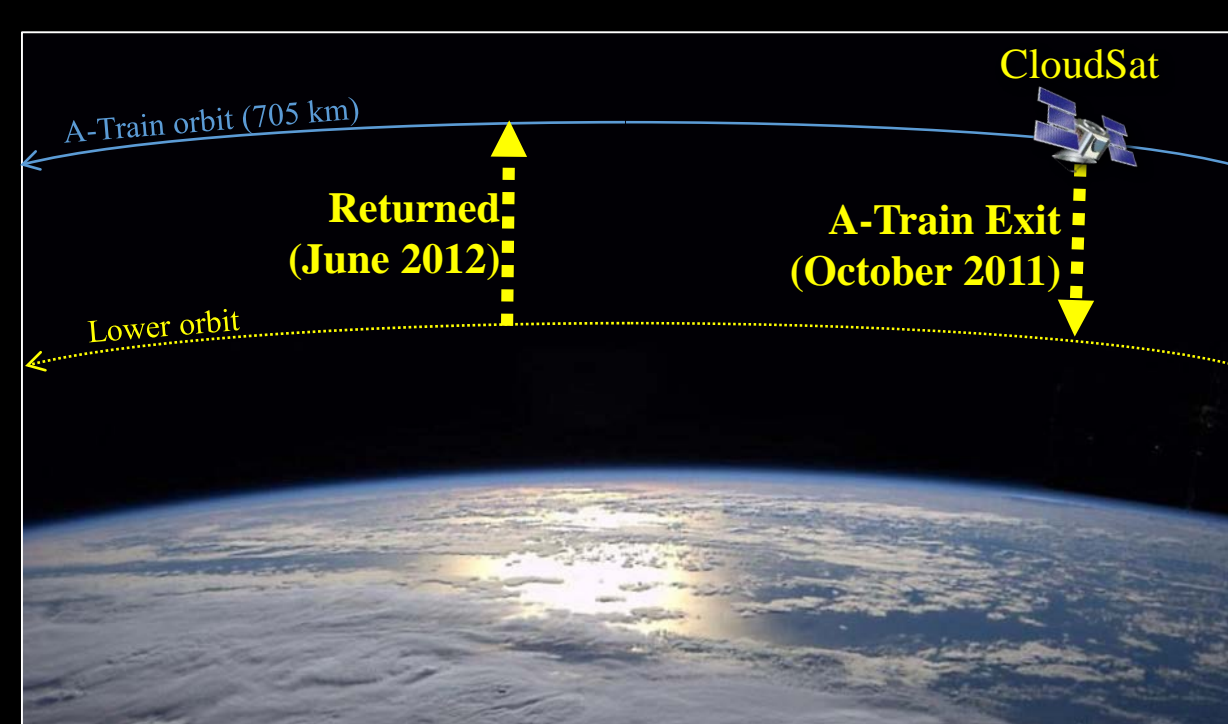
Years 2018 - 2023

Anticipated Changes:

- CloudSat orbit lowered (February 2018).
- Landsat-9 added
- Terra, CALIPSO, Aqua, Aura fuel reserves low - require orbit adjustments.
- Landsat-7 exits Constellation & prepares for Restore-L servicing.

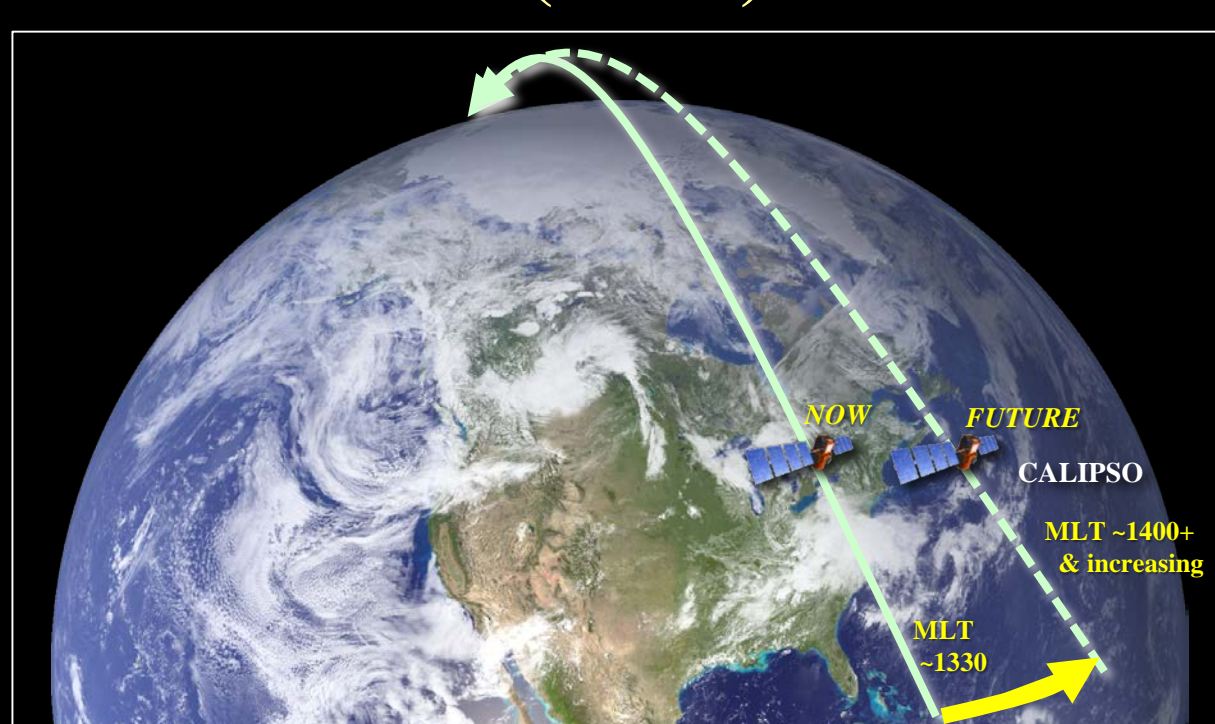
Options for Continued Evolution of the Constellation

Exit constellation and return



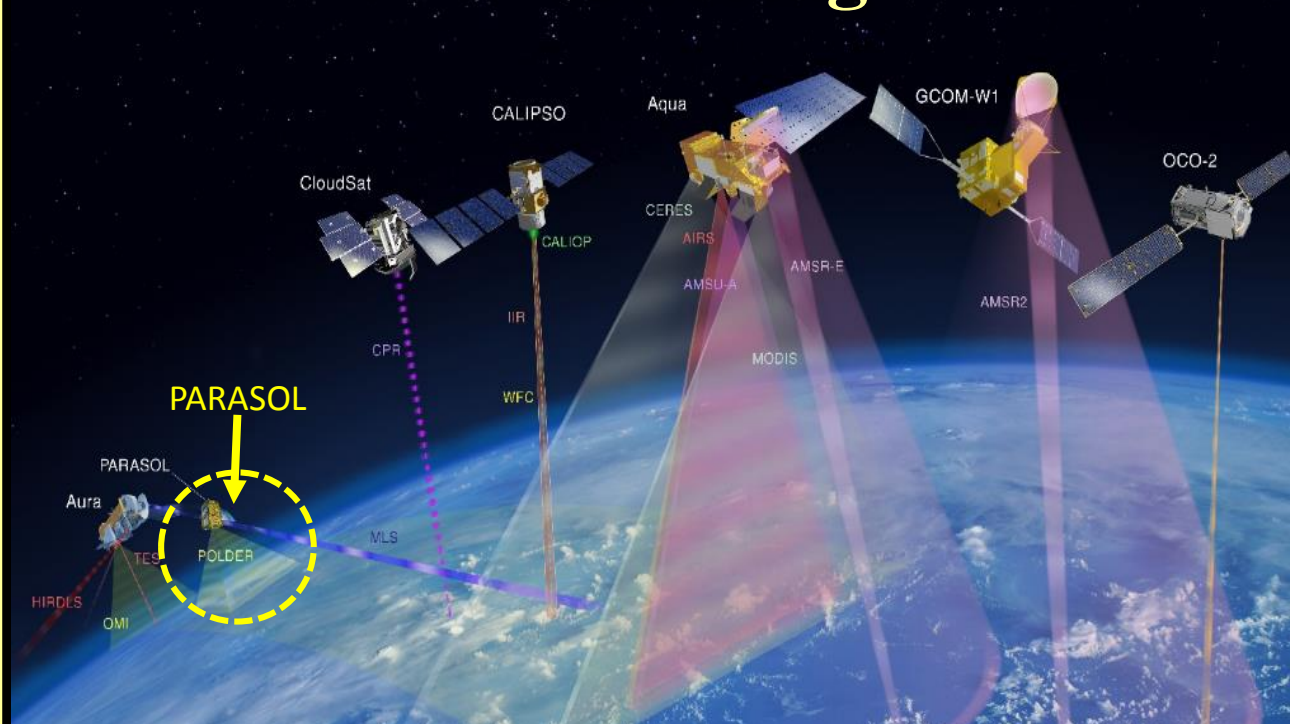
CloudSat was forced to exit A-Train in 2011. It returned in 2012 with new Ops concept.

Drift Mean Local Time (MLT)



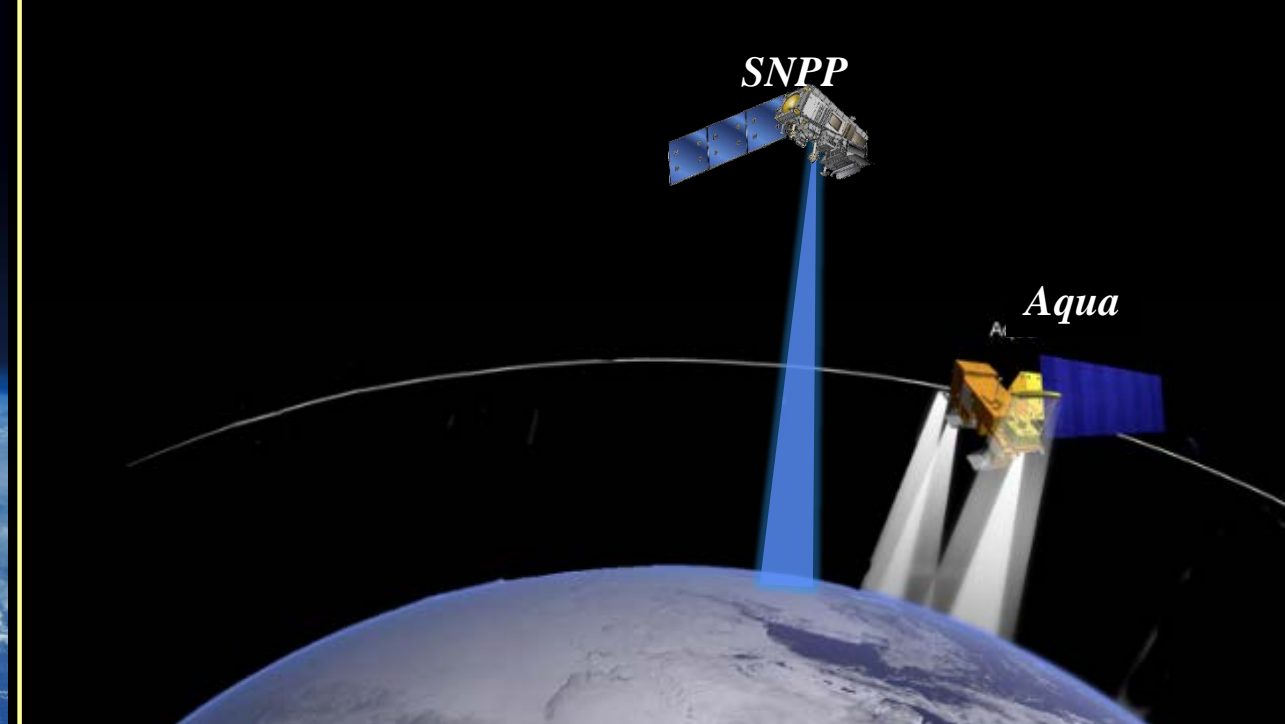
Results in deteriorating lighting conditions (CALIPSO to begin drifting in 2019)

Coincident science after orbit lowering



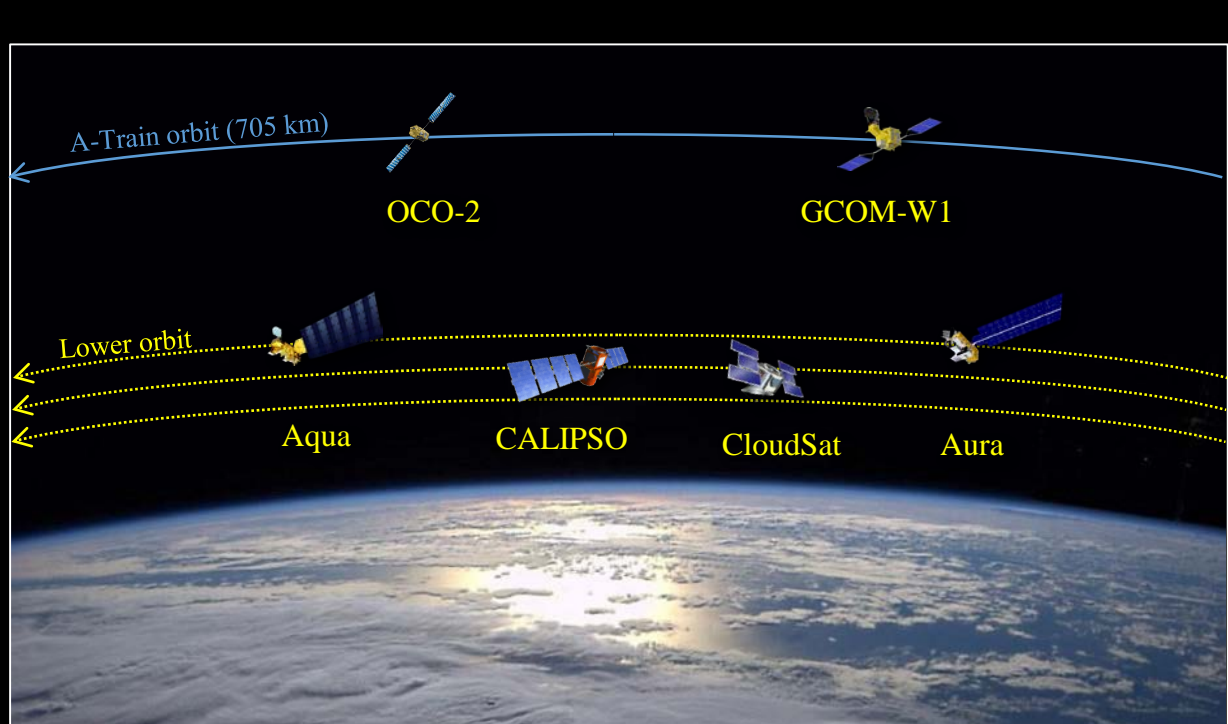
PARASOL lowered in December 2009 but continued coincident science observations

Coincident science with neighbor satellites



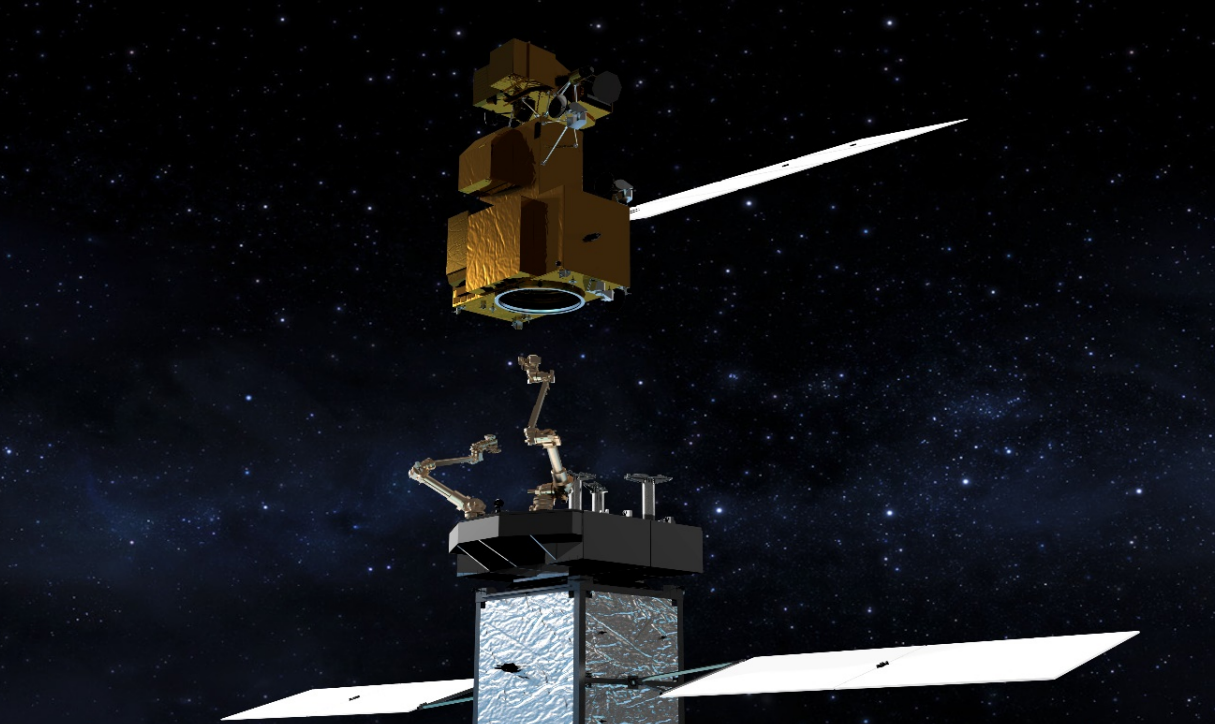
Observations overlap with SNPP overflights

Maintain new MLT range



With fuel dwindling, missions may establish a lower orbit, possibly at other altitudes and MLTs with options for continued coordination.

Re-fuel existing missions



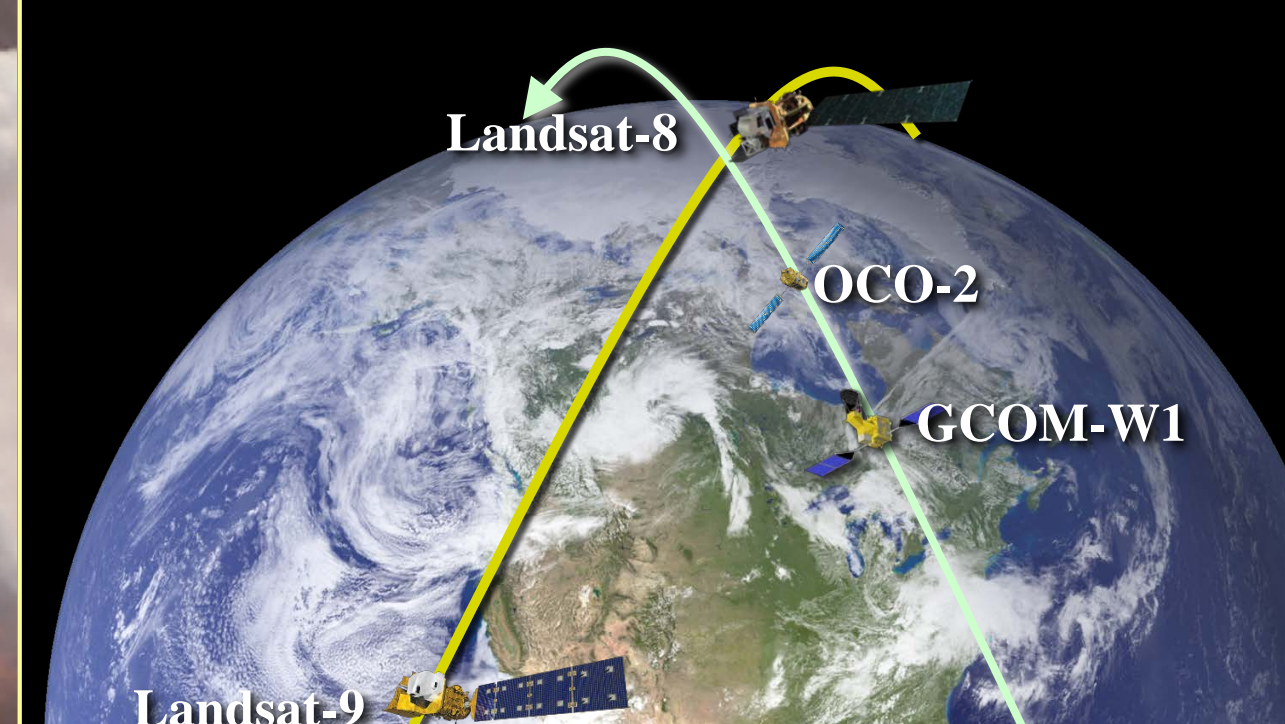
Landsat-7 to be re-fueled some time between December 2020 - September 2021

Launch new missions



Landsat-9 launch scheduled for December 2020

The Future?



Four missions are left in the constellation after 2023

Summary

Space agencies face significant challenges in order to extend the current observation capabilities and long-term climate record from the Earth Science Constellation