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

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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
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

Project Scientists

Mission Operations
ESC Orbits

- 705 km nominal equatorial altitude
  - Benefit: Provides near global coverage
- Polar at 98 deg. Inclination
  - Benefit: Easier to see changes
- Repeating (233 orbits/16 days)
  - Benefit: Consistent lighting
- Sun-synchronous
  - Benefit: Near-simultaneous observations
- Satellites in close proximity
- Follows the Worldwide Reference System-2 (WRS-2) developed by USGS for Landsat
  - Benefit: Observations overfly the same ground tracks
Morning Constellation

Landsat 8
Terra
SAC-C
EO-1
Landsat 7

Afternoon Constellation

Aqua
CALIPSO
CloudSat
OCO
PARASOL
GCOM-W1
OCO-2

Mission no longer operational

1999
2000
2002
2004
2006
2009
2011
2012
2013
2014
2017

ESC Evolution
February 2018: CloudSat lowered its orbit

September 2018: CALIPSO lowered its orbit

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

The C-Train
Orbiting about 17 km below the A-Train

Credit: S. Platnick/NASA
Historical view of “A-Train” Nadir Footprints

- 6 x 7 km PARASOL POLDER
- Cloud
- 1.4 km CloudSat CPR
- 0.09 km CALIPSO CALIOP
- 13.5 km Aqua AIRS IR; AMSU & HSB m wave
- 5.3 x 8.5 km Aura TES
- OCO-2 1x1.5 km
- 0.5 km Aqua & Terra MODIS Band 3-7
- Washington DC USGS Map
MODIS & CERES - IR Properties of Clouds
AIRS & AMSR-E - Temp and H₂O Sounding
Aqua
CloudSat
PARASOL
CALIPSO
GCOM-W1
OCO-2
Aura
OMI – Cloud heights
OMI & HIRDLS – Aerosols
MLS & TES – H₂O & 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
AMSR-2 - Temp and H₂O Sounding
AIRS & AMSR-E - Temp and H₂O Sounding
OCO-2 - CO₂ column

Historical View of Afternoon Constellation Coincidental Science
The CALIPSO satellite provides vertical, curtain-like images of the atmosphere on a global scale using a lidar.

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

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.
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.
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 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.
*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.*
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 policies, procedures, status, and plans
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

### 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
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)
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?
<table>
<thead>
<tr>
<th>Satellite</th>
<th>Summary Of Mission</th>
<th>Instruments</th>
<th>Launch</th>
<th>Responsible Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aqua</td>
<td>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.</td>
<td>AIRS, AMSU-A, HSB, AMSR-E, CERES, MODIS</td>
<td>May 4, 2002</td>
<td>NASA/GSFC</td>
</tr>
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<td>Aura</td>
<td>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.</td>
<td>HIRDLS, MLS, OMI, TES</td>
<td>July 15, 2004</td>
<td>NASA/GSFC</td>
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<td>CALIPSO</td>
<td>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.</td>
<td>CALIOP, IIR, WFC</td>
<td>April 28, 2006</td>
<td>NASA/GSFC, NASA/LaRC, CNES</td>
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</tr>
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<td>GCOM-W1</td>
<td>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.</td>
<td>AMSR-2</td>
<td>May 18, 2012</td>
<td>JAXA</td>
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<td>OCO-2</td>
<td>Three grating spectrometers will make global, space-based observations of the column-integrated concentration of carbon dioxide, a critical greenhouse gas.</td>
<td>Three grating spectrometers</td>
<td>July 2, 2014</td>
<td>NASA/JPL</td>
</tr>
</tbody>
</table>
### Morning Constellation

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<thead>
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<th>Instruments</th>
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</tr>
</thead>
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<td>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).</td>
<td>ETM+</td>
<td>April 15, 1999</td>
<td>US Geological Survey (USGS)</td>
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<td>Terra</td>
<td>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.</td>
<td>MISR, CERES, MOPITT, ASTER, MODIS</td>
<td>December 18, 1999</td>
<td>NASA/ GSFC</td>
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<td>Landsat 8</td>
<td>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.</td>
<td>OLI, TIRS</td>
<td>February 11, 2013</td>
<td>USGS</td>
</tr>
</tbody>
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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/
<table>
<thead>
<tr>
<th>Detailed Analyses Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ad Hoc Analysis</strong></td>
</tr>
<tr>
<td><strong>Argument of Latitude</strong></td>
</tr>
<tr>
<td><strong>Close Approach Analysis</strong></td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td><strong>Phasing at the Poles</strong></td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>Single Orbit Altitude Versus Latitude</strong></td>
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