# NASA UPDATES SINCE CGMS-51 AND REPORT ON MEDIUM TO LONG-TERM FUTURE PLANS ON EARTH OBSERVATIONS

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## Executive Summary

The National Aeronautics and Space Administration (NASA) continues to operate more than two dozen Earth-observing satellites and instruments. During the past year, NASA and its partners launched the Plankton, Aerosol, Cloud ocean Ecosystem (PACE) mission. The three instrument aboard the satellite are aimed at advancing our understanding of how the ocean and the atmosphere exchange carbon dioxide, and benefit society by improving the quality and timeliness of decisions related to fisheries health, harmful algal blooms, air pollution, and carbon sequestration.

In addition, NASA launched two small satellite technology demonstration missions to the International Space Station (ISS): the Hyperspectral Thermal Imager (HyTI) and the Signals of Opportunity P-band Investigation (SNOOPI). While HyTI will demonstrate the use of a 6U CubeSat for acquiring high-spectral and spatial resolution images in the long-wavelength infrared range, SNOOPI will show how a 6U CubeSat can use direct and Earth's reflected signals of opportunity in the P-band from geostationary telecommunications satellites to retrieve root zone moisture (RZSM) and snow water equivalent (SWE).

In early 2024, the NASA Earth Science Division introduced a "decouple, partner, and compete" approach that provides greater flexibility and maximizes the science achievable from the Surface Biology and Geology (SBG) and Atmospheric Observing System (AOS) missions. As a result, management of the two SBG instruments will be decoupled to allow the Thermal Infrared (TIR) component to launch when ready ahead of the Visible Short-Wave Infrared (VSWIR) component. The AOS mission, with a reduced cost target, will now be pursued through a mix of directed and at least one competed mission with multiple international partners and decoupled schedules. The international partner contributions for AOS consist of a Japan Aerospace Exploration Agency (JAXA) Ku-band Radar and Centre National d'Études Spatiales (CNES) tandem microwave radiometers in the inclined orbit; and an Agenzia Spaziale Italiana (ASI) multi-wavelength Lidar, and a Canadian Space Agency (CSA) Near Infrared Imaging Radiometer and a Limb-imaging observatory in the polar orbit. The competed component(s) will focus on cloud and precipitation profiling from the polar orbit. NASA directed missions will provide a space vehicle to host one of the CNES radiometers, and a polar mission with a suite of passive instrumentation.

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## 1 Introduction

The National Aeronautics and Space Administration (NASA) continues to operate more than two dozen Earth-observing satellites and instruments. Although all NASA missions are conceived as research systems (rather than as operational systems), their communication and ground data handling systems can support operational activities, although few satisfy near-real-time application needs.

Section 2 provides a listing of NASA Earth-observing satellites and instruments operating in Low Earth Orbit (LEO), highlighting recently launched missions. Section 3 provides a status update on a NASA satellite operating at Lagrange Point 1. Section 4 and Section 5 discuss issues related to formation flying, collision avoidance, space debris and space situation awareness. Section 6 provides updates on research and development satellites and instruments, including those on the International Space Station (ISS). Section 7 discusses future satellite systems development. Finally, Section 8 provides CGMS members a brief summary of activities that may be of interest to them, including NASA's Earth Science to Action Strategy, the Senior Review process, Open-source science initiative, Commercial Smallsat Data Acquisition (CSDA) program, Retirement of DC-8 and acquisition of B700-200ER Airborne Science platform, and the Federal-civil satellite Needs Assessment process.

## 2 Currently operating satellite systems

Table 1 provides a list of all currently operating NASA Earth-observing satellites. The recently launched Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is highlighted below.

### 2.1 Plankton, Aerosol, Cloud, ocean Ecosystem (PACE)

The Plankton, Aerosol, Cloud ocean Ecosystem (PACE) mission was launched on February 8, 2024 from Cape Canaveral Space Force Station in Florida aboard a SpaceX Falcon 9 rocket. PACE was developed by NASA with contributions from the University of Maryland, Baltimore County and a Dutch consortium led by Netherlands Institute for Space Research, Airbus Defence, and Space Netherlands. The PACE mission includes several advanced instruments: the Ocean Color Instrument (OCI) which will enable scientists to identify the composition and distribution of phytoplankton communities on a daily basis at a global scale for the first time from space; the second generation Hyper-Angular Rainbow Polarimeter (HARP-2), and the Spectro-polarimeter for Planetary Exploration (SPEXone) instrument which collectively will provide information about aerosols, small atmospheric particles that are important for air quality and climate studies. The three instrument aboard the satellite will advance our understanding of how the ocean and the atmosphere exchange carbon dioxide, and benefit society by improving the quality and timeliness of decisions related to fisheries health, harmful algal blooms, air pollution, and carbon sequestration.

PACE successfully completed its commissioning phase and began prime operations in April 2024. First light images, shown in Figure 1, demonstrate OCI's unique ability to differentiate between communities of phytoplankton. Data is freely available to the public through the Ocean Biology Distributed Active Archive Center (DAAC) (https://oceancolor.gsfc.nasa.gov/data/pace/format/). The PACE Early adopters program is aimed at accelerating the use of PACE data products, and provides a mechanism through which users can provide feedback.

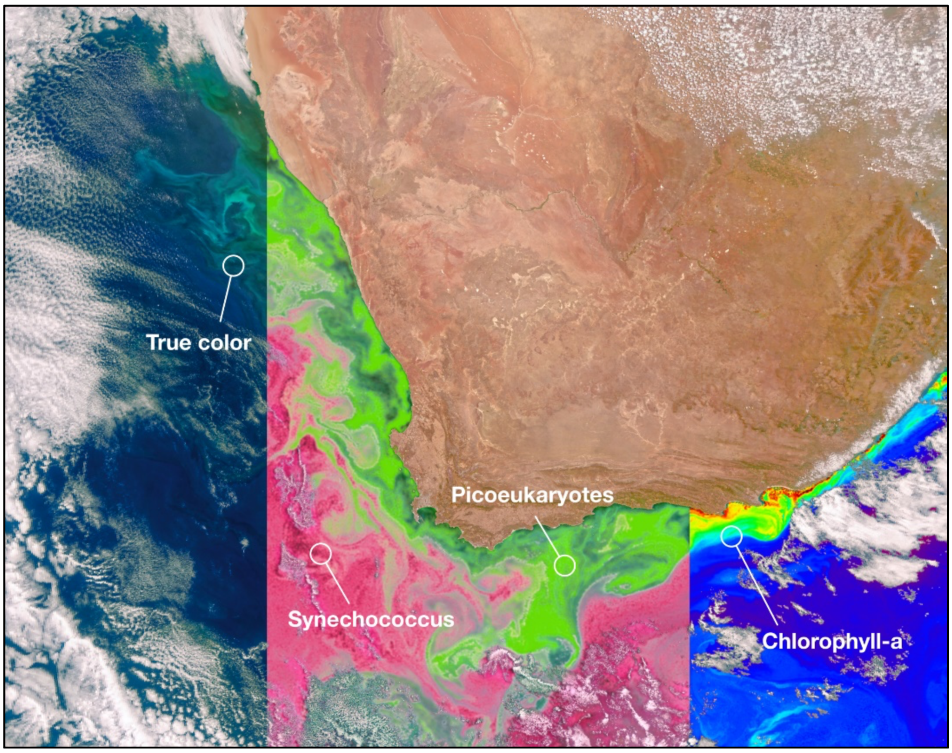


Figure 1: This first image released from PACE's OCI identifies two different communities of phytoplankton off the coast of South Africa on Feburary 28, 2024. The central panel of this image shows Synechococcus in pink and picoeukaryotes in green. The left panel of this image shows a natural color view of the ocean, and the right panel displays the concentration of chlorophyll-a, a photosynthetic pigment used to identify the presence of phytoplankton. Credit: NASA

Table 1: Current NASA ESD satellites and instruments in Low Earth and Geostationary Orbits (continued)

| Mission | Science and Application | ECT/Inclination & Mean Altitude | Launch Date | Instruments | Data Access |
|---|---|---|---|---|---|
| **Landsat-7**[1] | Provide continuity land surface observations to study, predict, and understand the consequences of land surface dynamics | 10:00 (D)<br>705 km | 15 Apr 1999 | ETM+ | USGS |
| **Terra**[2] **(EOS AM-1)** | Collect measurements of Earth's atmosphere, land, snow and ice, ocean, and energy balance to understand Earth's climate and climate change and to map the impact of human activity and natural disasters on communities and ecosystems | 10:30 (D)<br>Drifting<br>705 km | 18 Dec 1999 | ASTER, MODIS, MOPITT, MISR, CERES | Terra Data<br>Direct Broadcast |
| **Aqua (EOS PM-1)** | Measure the water cycle, radiative energy fluxes, aerosols, vegetation cover on the land, phytoplankton and dissolved organic matter in the oceans, and air, land, and water temperatures to enhance understanding of the climate system and improve weather forecasting | 13:30 (A)<br>Drifting<br>705 km | 04 May 2002 | MODIS, AIRS, CERES, AMSU-A, AMSR-E, HSB | EOSDIS<br><br>Direct Broadcast |
| **Aura**[3] | Measure atmospheric chemistry to better understand ozone trends, air quality changes, and linkage to climate change | 13:40 (A)<br>Drifting<br>705 km | 15 Jul 2004 | MLS, TES, HIRDLS, OMI | GES DISC |
| **Landsat-8**[1] | Provide continuity land surface observations to study, predict, and understand the consequences of land surface dynamics | 10:11 (D)<br>705 km | 11 Feb 2013 | OLI, TIRS | USGS |

Table 1: Current NASA ESD satellites and instruments in Low Earth and Geostationary Orbits (continued)

| Mission | Science and Application | ECT/Inclination & Mean Altitude | Launch Date | Instruments | Data Access |
|---|---|---|---|---|---|
| **GPM Core[2] (Global Precipitation Measurement)** | Observe rain and snowfall worldwide every three hours, to facilitate monitoring and forecasting weather events such as droughts, floods, and hurricanes, and enable research on precipitation and climate change | 65-deg<br>Non Sun-synchronous<br>435 km | 27 Feb 2014 | GMI, DPR | PMM Data |
| **OCO-2 (Orbiting Carbon Observatory)** | Collect measurements of atmospheric carbon dioxide to characterize sources and sinks on regional scales and over seasons | 13:30 (A)<br>705 km | 02 Jul 2014 | Grating Spectrometer | GES DISC |
| **SMAP (Soil Moisture Active Passive)** | Measure water in surface soil everywhere on Earth and determine if the ground is frozen or thawed to help monitor drought, predict floods, improve weather forecasting, and assist agriculture planning | 18:00 (A)<br>685 km | 31 Jan 2015 | L-band Radar, L-band Radiometer | ASF (radar)<br>NSIDC (Cryosphere and land microwave) |
| **CYGNSS[4] (Cyclone Global Navigation Satellite System)** | Measure wind speeds over Earth's oceans, increasing the ability to understand and predict hurricanes | 35-deg<br>Non Sun-synchronous<br>500 km | 15 Dec 2016 | Eight[4] SmallSats with GPS | PO.DAAC |
| **GRACE-FO[5] (Gravity Recovery and Climate Experiment Follow-On)** | Measure changes in Earth's gravity field to monitor variations in terrestrial water storage, ice mass, ocean bottom pressure, and sea level to improve weather and drought forecasting | 89-deg<br>Non Sun-synchronous<br>490 km | 22 May 2018 | MWA, LRI, Accelerometer, GPS RO | PO.DAAC |

Table 1: Current NASA ESD satellites and instruments in Low Earth and Geostationary Orbits (continued)

| Mission | Science and Application | ECT/Inclination & Mean Altitude | Launch Date | Instruments | Data Access |
|---|---|---|---|---|---|
| **ICESat-2 (Ice, Cloud, and Land Elevation Satellite)** | Measure surface elevation to track height changes of glaciers, sea ice, and forests to estimate future changes and impacts | 92-deg Non Sun-synchronous 500 km | 15 Sep 2018 | ATLAS | NSIDC |
| **Sentinel-6 Michael Freilich** | Measure ocean surface height to monitor global sea level; provide tropospheric temperature and humidity data to improve weather forecasts, climate models, and hurricane tracking | 66-deg Non Sun-synchronous 1336 km | 21 Nov 2020 | Poseidon-4 SAR Radar Altimeter, AMR-C, GNSS-RO, GNSS-POD, DORIS, LRA | PO.DAAC |
| **Landsat 9**[1] | Provide continuity in land surface observations to study, predict, and understand the consequences of land surface dynamics | 98.2-deg Near-polar, Sun-synchronous 705 km | 27 Sep 2021 | TIRS-2, OLI-2 | USGS |
| **SWOT (Surface Water and Ocean Topography)** | Provide high-resolution ocean and terrestrial surface water topography measurements to observe circulation and storage changes to better understand ocean processes in regulating climate change and the consequence of climate change on the distribution of water on land | 78-deg Non Sun-synchronous 873 km | 16 Dec 2022 | KaRIn, Jason-class Altimeter, DORIS Antenna, Microwave Radiometer, X-band Antenna, LRA, GPS Receiver | PO.DAAC |
| **TEMPO (Tropospheric Emissions: Monitoring of Pollution)** | Measure tropospheric ozone, ozone precursors, aerosols, and clouds over North America to increase understanding and improve prediction of air quality and climate forcing | Geosynchronous 37,000 km | 7 Apr 2023 | Scanning UV/visible spectrometer | ASDC |

Table 1: Current NASA ESD satellites and instruments in Low Earth and Geostationary Orbits

| Mission | Science and Application | ECT/Inclination & Mean Altitude | Launch Date | Instruments | Data Access |
|---|---|---|---|---|---|
| **TROPICS[6] (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats)** | Collect 3D temperature and humidity observations to improve understanding of cyclone lifecycles and cyclone intensification | 30-deg<br>Non Sun-synchronous<br>530 km | 7 May 2023 &<br>25 May 2023 | Four[6] CubeSats with Multi-channel passive compact microwave radiometers | GES DISC |
| **PACE (Plankton, Aerosol, Cloud, and ocean Ecosystem)** | Observe aerosols, clouds, and ocean color to enable energy budget and carbon cycle science and support fishery management, air quality forecasting, and disaster response mitigation efforts | 98-deg<br>Sun synchronous<br>676.5 km | 8 Feb 2024 | OCI, HARP2, SPEXone | OB.DAAC |

1. NASA supports operations through the science instrumentation. Partners include U.S. Geological Survey (USGS) for Landsat
2. Support for operation of the GPM Dual-frequency Precipitation Radar (DPR) and Terra ASTER is provided by JAXA.
3. Support for operation of the Aura OMI instrument is provided by the Royal Netherlands Meteorological Institute (KNMI).
4. CYGNSS lost contact with one of eight spacecraft in November 2022 with minimal impacts to science requirements.
5. GRACE-FO mission is comprised of two identical satellites.
6. TROPICS 7 experienced a communications anomaly and hasn't been collecting science data since November 2023.

*Instruments in red are failed/decommissioned or have reduced functionality, as follows:

| Failed/Decommissioned Instruments: | Reduced Functionality Instruments: |
|---|---|
| HSB and AMSR-E on Aqua | ASTER on Terra (SWIR module not functioning) |
| HIRDLS and TES on Aura | AMSU on Aqua (channels 1, 2, 4, 5 and 7 failed) |
| L-band Radar on SMAP | MLS on Aura (190 GHz Receiver operations reduced to ~ 1 week/month) |

## 3 Status updates for satellite systems operating at the Lagrange Point

The Deep Space Climate Observatory (DSCOVR) was launched on February 11, 2015, to the Sun-Earth first Lagrange (L1) point, 1.5 million kilometers from Earth toward the Sun, to provide continuous solar wind measurements for accurate space weather forecasting and to observe the full sunlit disk of Earth from a new and unique vantage point. While NOAA operates the DSCOVR spacecraft and its space weather instruments, NASA operates and calibrates the two Earth science instruments onboard: the Earth Polychromatic Imaging Camera (EPIC) and National Institute of Standards and Technology Advanced Radiometer (NISTAR). EPIC and NISTAR have been operating almost continuously with only minor interruptions relying only on the star tracker for spacecraft attitude determination, which allows DSCOVR to maintain an approximately 0.02 degree pointing accuracy, like its pre-gyro-failure operations, keeping Earth fully in the EPIC field-of-view. Unlike data acquired from LEO, the DSCOVR Earth science data products cover the whole sunlit face of Earth every 1 or 2 hours, providing a unique, sunrise-to-sunset synoptic view at a single GMT.

Recent EPIC and NISTAR calibrations show no change in the performance or calibration constants of the instruments. DSCOVR's vantage point allows the generation of a number of unique data products: total column ozone, cloud reflectivity, $SO_2$ plume from a volcanic eruption, and sunlit leaf area index (SLAI). Ozone and cloud reflectivity are directly used to estimate the amount of UV radiation reaching the ground with the addition of another EPIC products: aerosol optical depth and absorption. Ozone and aerosol retrievals are uniquely enhanced using the retrieval of cloud and aerosol plume height from EPIC's $O_2$ A- and B-bands. In addition to the EPIC RGB color images (http://epc.gsfc.nasa.gov) that continue to enjoy significant popularity with public and media, the photosynthetically available radiation (PAR) product released in April 2021, and sun glint product released in 2023 highlight the benefits of observing the Earth from L1.

## 4 Formation Flying

Several NASA and U.S. satellites operate in close proximity at approximately 705 km altitude and ascending equator crossing times of 13:30. Known as the A-Train, this constellation was built up over a decade, starting with the launch of Aqua in 2002, and continuing with Polarization and Anisotropy of Reflectance for Atmospheric Sciences coupled with Centre National d'Études Spatiales (CNES) Observations from a Lidar (PARASOL), which was launched in 2004 and decommissioned in 2013; Aura (launched in 2004); CloudSat (launched in 2006, exited the A-train in 2018 and ended science operations in 2023); Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) (launched in 2006, exited the A-Train in 2018 and ended science operations in 2023); the Japanese GCOM-W1 "SHIZUKU" satellite (launched in 2012); and the Orbiting Carbon Observatory-2 (OCO-2) (launched in 2014). The proximity of these spacecraft enables nearly simultaneous measurements although the data are contributed by multiple platforms from multiple providers. The broad range of complementary techniques (e.g., different wavelengths and viewing geometries) used across these platforms are particularly valuable for studying atmospheric chemistry and physics because they enable comprehensive measurement of trace gasses and particle composition.

Aqua and Aura no longer have enough fuel to maintain their positions in the A-Train and are drifting with respect to their original mean local crossing times. After two decades of operations and producing excellent complementary science, many of the A-Train missions have reached or are near the end of their mission life and will be decommissioned over the next few years. OCO-2 and GCOM-W1 continue to maintain their locations in the A-Train.

Aqua, Aura, and OCO-2 participated in the 2023 Earth Science Senior Review for mission extensions (Section 8.2). Aqua and Aura were extended through their predicted end of life and OCO-2 was extended until the next Senior Review in 2026.

## 5 Collision avoidance monitoring, orbital debris and space situation awarness

All NASA missions are required by NASA Procedural Requirements (NPR) 8079.1 to protect the orbital environment they operate in by utilizing Conjunction Assessment Risk Analysis (CARA) services and to perform risk mitigation, when appropriate, for potential close approaches with orbital debris and other operational satellites. The NPR is freely available at: https://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8079&s=1.

In December 2020, NASA released the Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook to improve global awareness of space activity and share NASA's lessons learned regarding close approach coordination and mitigation. In February 2023, the handbook was updated to reflect NPR 8079.1. This handbook is freely available at: https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_51.pdf.

A recent history of collision avoidance maneuvers is shown in Figure 3. The number of maneuvers of CARA supported missions per year have increased significantly with the addition of many large satellite constellations operating in LEO. Furthermore, the intensity of the solar cycle is greater than anticipated, resulting in an operational environment that is very dynamic and requires additional maneuvers to counteract drag effects. As the number of potential conjunctions between satellites that have maneuver capabilities and are still actively being managed increases, so does the necessity for improved communications between satellite operators to coordinate proposed orbits prior to launch and avoidance maneuver planning post launch. Figure 3 shows the total number of unique conjunction events has more than quadrupled from December 2019 to December 2023 and the number of catalogued objects is steadily increasing.

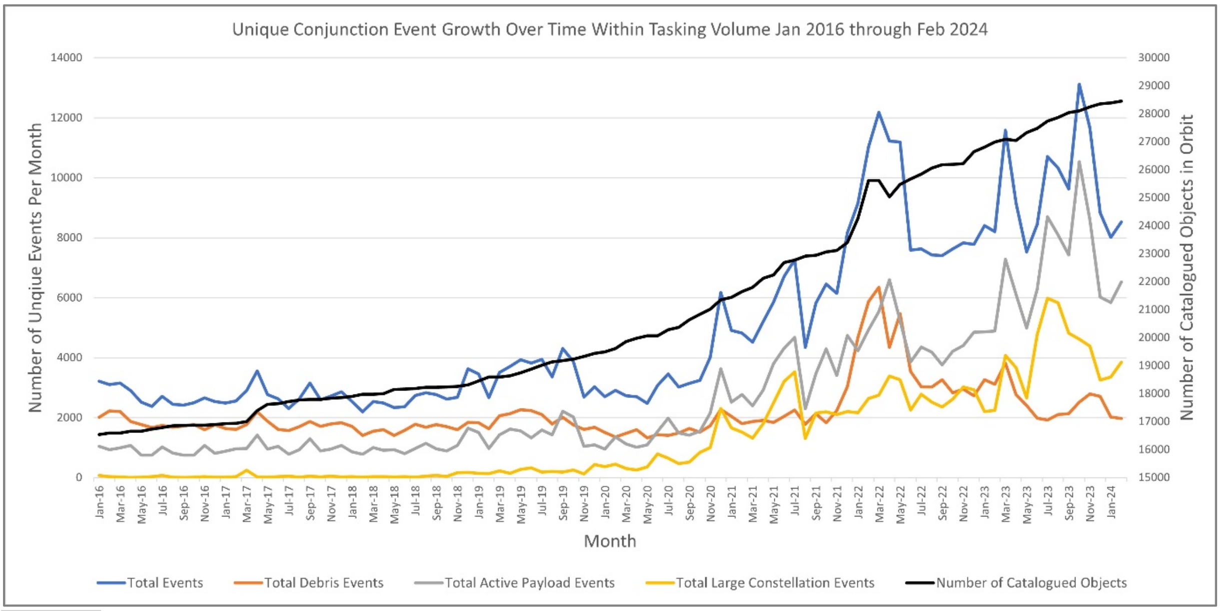


Figure 3: Number of conjunction events since 2016. The blue line shows the total number of unique conjunction events with debris, active satellites, and large constellations. The black line shows the total number of objects (debris & active satellites, including large constellations) on orbit. The RIC (Radial, In-Track, Cross-Track) defines the screening volume around CARA supported NASA missions. It's a 0.5km x 5km x 5km ellipsoid centered at the spacecraft with radial being 0.25km above and below, In-track being 2.5km in front and behind, and Cross-Track being 2.5km on either side. Credits: CARA

NASA has agreements with a variety of mega-constellation organizations, including SpaceX and OneWeb, that formalize coordination and sharing of information necessary to maintain and improve space safety. The orbital debris environment is rapidly changing, and with the addition of large constellations, the need for close coordination between all satellite operators has significantly increased the workload for missions and the CARA team. In February 2022, NASA submitted a letter to the Federal Communications Commission (FCC) regarding concerns about a significant increase in the frequency in conjunction events and potential impacts to NASA science and human spaceflight missions. Aside from conjunction events, other concerns such as sun-glint, electromagnetic interference, and field of view blockages from the thousands of satellites orbiting the Earth could negatively impact various NASA science measurements. The full letter is available at: https://www.scribd.com/document/557924666/NTIA-NASA-NSF-letter-to-FCC-regarding-Starlink-Gen-2.

In addition, NASA's Heliophysics Division's Orbital Debris and Space Situational Awareness (OD-SSA) activity formally became part of the Space Weather Program in 2023. The full "Space Working Environment" is now considered part of the space weather environment, including natural and anthropogenic dust, micro-meteorites, and small debris less than three centimeters. These small debris are potentially mission-ending objects that are not observable from the ground. The OD-SSA program element supports orbital debris instrument development, tech-demo rideshare opportunities for two orbital debris instrument concepts, and a research & development component supporting the science of signatures of objects moving through a space plasma.

# 6 Status Updates for Research and Development Satellites

## 6.1 Small satellite technology demonstration

### 6.1.1 Hyperspectral Thermal Imager

A thermal imaging instrument, the Hyperspectral Thermal Imager (HyTI) will demonstrate the acquisition of high-spectral and spatial resolution images in the long-wavelength infrared range from a 6U CubeSat platform. Built by University of Hawaii at Monoa, HyTI was launched to the International Space Station (ISS) on March 21, 2024, and subsequently deployed in April 2024. Spacecraft commissioning is ongoing.

The instrument uses a spatially-modulated interferometric imaging technique to produce spectro-radiometrically calibrated image cubes, with 25 channels between 8-10.7 ųm, at a ground sample distance of approximately 60 meters. The HyTI performance model indicates narrow band NE∆Ts of less than 0.3 Kelvin. The small form factor of HyTI is made possible via the use of a no-moving-parts Fabry-Perot interferometer and cryogenically-cooled High Operating Temperature – Barrier Infrared detector (HOT-BIRD) focal plane array (FPA) technology developed at Jet Propulsion Laboratory (JPL). The value of HyTI for Earth science research and applications will be demonstrated via on-board processing of the raw instrument data for producing L1 and L2 products, with a focus on rapid delivery of data for volcanic degassing, land surface temperature, and precision agriculture applications.

### 6.1.2 Signals of Opportunity P-band Investigation

The Signals of Opportunity P-band Investigation (SNOOPI) is a reflectometry microwave instrument built by Purdue University in partnership with Goddard Space Flight Center (GSFC) and Jet Propulsion Laboratory (JPL). SNOOPI was launched to the International Space Station (ISS) alongside HyTI. Spacecraft commissioning is ongoing.

The project will show how a 6U CubeSat can use direct and Earth's reflected signals of opportunity in the P-band from geostationary telecommunications satellites to retrieve root zone moisture (RZSM) and snow water equivalent (SWE). The mission will use P-band receivers to collect direct and Earth reflected signals and cross-correlate the data to extract RZSM and SWE measurements. These data are vital for applications like food security and water resources management. SNOOPI will be the first in-orbit demonstration of the P-band signals of opportunity technique and will advance the prototype instrument to Technology Readiness Level (TRL) 7.

### 6.1.3 Aerosol Radiometer for Global Observation of the Stratosphere

The Aerosol Radiometer for Global Observation of the Stratosphere (ARGOS) project is currently under development and is led by Science Systems and Applications Incorporated (SSAI), in partnership with Goddard Space Flight Center (GSFC). This hosted-payload instrument will collect limb scattering data at several wavelengths in multiple viewing directions simultaneously. Observations of the same location along the orbit track at different scattering angles will provide more balanced measurement sensitivity throughout the orbit compared to Ozone Mapping and Profiling Suite (OMPS) Limb Profiler (LP) on the Suomi National Polar-orbiting Partnership (S-NPP) satellite. These data also help constrain the aerosol phase function, and thus the particle size distribution, enabling more accurate retrieval of extinction profiles from limb scattering measurements. The multiple limb views of ARGOS provide additional sampling of the inhomogeneous aerosol field. Such denser sampling has been shown to reduce the uncertainty in model calculations of post-volcanic eruption global aerosol loading by a factor of 2-3. Launch of ARGOS is currently planned not earlier than October 2024.

### 6.1.4 Active Cooling for Methane Earth Sensors

The Active Cooling for Methane Earth Sensors (ACMES) project aims to demonstrate Long Wave infrared measurements while validating two new technologies onboard a 12-Unit CubeSat. The project is led by Utah State University. The first technology – an active thermal architecture (ATA) – could be a complete solution for active thermal control of cryogenic instruments on nano and small satellites. The second technology is the Filter Incidence Narrow-band Infrared Spectrometer (FINIS), a sensor designed for space-based detection of methane sources. FINIS uses the differential absorption technique to achieve sensitivity equivalent to larger missions such as ESA's TROPOspheric Monitoring Instrument (TROPOMI), but with a much finer spatial resolution and in a compact form factor suitable for a CubeSat. The on-orbit demonstration should raise the readiness of both technologies to TRL 7. Launch is expected not earlier than 2025.

## 6.2 Instruments aboard the International Space Station (ISS)

The ISS is an extremely important platform for ESD's mission portfolio and supports operations of seven Earth-observing instruments (Table 2). Because it operates in a non-Sun-synchronous orbit that permits observations over a range of local times, the ISS provides a unique vantage point for observing Earth from space. At the same time, the dynamic operating environment of ISS requires external payloads to continually adapt to interruptions in science observations due to visiting vehicles, platform maneuvers, power outages, and maintenance activities, as well as structural blockages and sources of glint. In 2019, the ISS began increasing its altitude eventually settling at an altitude with a 4-day orbit repeat cycle. While this repeat cycle is useful when planning for visiting vehicles, it created a significant challenge for several Earth observing instruments that were anticipating global coverage but were unable to do so due to the repeating orbit tracks and limitations in their pointing capabilities. In January

2022, the ISS lowered its orbit to allow for the Earth observing instruments to increase their coverage. Temporary altitude raises continue to impact science observations.

The Earth Surface Mineral Dust Source Investigation (EMIT) instrument began operations in late September 2022, after being installed on the ISS in July; EMIT completed its prime operations and entered extended operations in November 2023. Total Spectral Irradiance Sensor 1 (TSIS-1) conducted its End of Prime Mission Review in June 2023, and along with Stratospheric Aerosol and Gas Experiment III (SAGE III), proposed mission extensions to the 2023 Senior Review (Section 8.2). TSIS-1 and SAGE III were granted mission extensions for the next 3 years; extensions beyond the next three years are dependent on the outcome of the 2026 Senior Review. ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Orbiting Carbon Observatory 3 (OCO-3), and Global Ecosystem Dynamics Investigation (GEDI) proposed to an accelerated Senior Review for mission extension in December 2022. All three missions were approved for extension through September 2026, in alignment with the next Senior Review cycle. To accommodate these extensions, the OCO-3 instrument was placed in storage on the ISS in November 2023, with an anticipated return in late June 2024, depending on launch and installation of other ISS instruments. In March 2023, the GEDI instrument was placed into temporary storage on the ISS, and as of April 2024, was successfully relocated to its operational location and is conducting an instrument checkout before resuming science operations. The Lightning Imaging Sensor (LIS) instrument, which helped to monitor lightning on Earth and explain the processes that cause it, was decommissioned and removed from its position on the ISS in November 2023.

NASA has committed to use and operate the ISS through 2030, which will allow for new Earth-observing instrument payloads to be added. ESD is developing an additional instrument to be installed on the ISS, the Climate Absolute Radiance and Refractivity Observatory Pathfinder (CLARREO-PF) instrument (Section 6.2; Table 2).

Table 2: NASA instruments currently on the International Space Station

| Mission | Science and Application | Launch Date | Instrument | Data Access |
|---|---|---|---|---|
| **SAGE-III (Stratospheric Aerosol and Gas Experiment)** | Measure the vertical distribution of aerosols, ozone, water vapor and other trace gases in Earth's stratosphere and troposphere to enhance understanding of ozone recovery and climate change processes in the upper atmosphere | 19 Feb 2017 | Solar Occultation Instrument | ASDC |
| **TSIS-1 (Total Spectral Irradiance Sensor)** | Measure total and spectral Solar irradiance (TSI & SSI) to better understand the Sun's natural influence on Earth's ozone layer, atmospheric circulation, clouds, and ecosystems | 15 Dec 2017 | Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM) | GES DISC |
| **ECOSTRESS (Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station)** | Measure evapotranspiration to provide insight to plant-water dynamics and how ecosystems change with climate | 29 Jun 2018 | Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) | LP.DAAC |
| **GEDI (Global Ecosystem Dynamics Investigation)** | Provide high-resolution observations of forest vertical structure to characterize the effects of changing climate and land use on ecosystem structure and dynamics and enable significantly improved quantification and understanding of the Earth's carbon cycle and biodiversity | 05 Dec 2018 | LIDAR | LP.DAAC (L1, L2) ORNL DAAC (L3, L4) |
| **OCO-3 (Orbiting Carbon Observatory)** | Collect measurements of atmospheric carbon dioxide to characterize sources and sinks on regional scales and over seasons | 04 May 2019 | Grating Spectrometer | GES DISC |
| **EMIT (Earth Surface Mineral Dust Source Investigation)** | Measure the different wavelengths of light emitted by minerals on the surface of deserts and other dust sources to determine their composition to better understand how dust warms or cools the atmosphere | 14 Jul 2022 | VSWIR spectrometer | VISIONS<br>LP DAAC |

# 7 Future Satellite Systems

## 7.1 Earth Systematic Mission Program

NASA's Earth Systematic Missions (ESM) program includes a broad range of multi-disciplinary science investigations aimed at developing a scientific understanding of the Earth system and its response to natural and human-induced forces and changes. The ESM program develops Earth-observing research satellite missions, manages the operation of NASA research missions once on orbit, and produces standard mission products in support of NASA and national research, applications, and policy communities. Many of the missions in the ESM portfolio are being developed with domestic and international partners.

The ESM program continues to oversee the development and launch of missions recommended by the 2007 Decadal Survey. These missions include NASA-ISRO Synthetic Aperture Radar (NISAR); Climate Absolute Radiance and Refractivity Observatory Pathfinder instrument on ISS (CLARREO-PF); and Total Spectral Solar Irradiance Sensor 2 (TSIS-2).

NASA is continuing its partnership with the U.S. Geological Survey (USGS) to extend the Landsat series with Landsat Next, which entered the formulation phase in Spring 2022. NASA is also continuing its partnership with the European Space Agency (ESA) on Sentinel-6B as well as Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL).

The ESM program is also responsible for overseeing formulation and implementation of Earth System Observatory (ESO) missions designed to address the Designated Observables identified in the 2017 Decadal Survey, including Gravity Recovery And Climate Experiment-Continuity (GRACE-C) (previously named Mass Change), Surface Biology and Geology (SBG), and Atmosphere Observing System (AOS); which are all in the formulation phase. Table 3 lists Earth Systematic Missions that are either in formulation or implementation.

Table 3: Earth Systematic Mission projects in formulation or implementation

| Mission | Science & Application | ECT/Inclination & Mean Altitude Orbit | Expected Launch Date | Instruments |
|---|---|---|---|---|
| **NISAR (NASA-ISRO Synthetic Aperture Radar)** | Measure changes in Earth's surface to improve risk and resource management by understanding the response of ice sheets to climate change; likelihood of solid earth hazards, like earthquakes; and dynamics of carbon storage in various ecosystems | 98.4<br>Sun synchronous<br>747 km | 2024 | L- and S-band Synthetic Aperture Radar (SAR) |
| **CLARREO-PF (Climate Absolute Radiance and Refractivity Observatory)** | Provide high-accuracy, SI-Traceable calibration measurements of Earth's solar reflectance to enable detection of climate change trends decades sooner | Onboard the International Space Station | NET 2027 | Hyper-Spectral Imager for Climate Science (HySICS) |
| **TSIS-2 (Total and Spectral Solar Irradiance Sensor-2)** | Measure total solar irradiance and spectral solar irradiance to maintain continuity from TSIS-1 to understand solar radiation impacts on Earth's climate | 98-deg<br>Sun synchronous<br>600 km | 2025 | Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM) |
| **Sentinel-6B[1]** | Measure ocean surface height to monitor global sea level; provide tropospheric temperature and humidity data to improve weather forecasts, climate models, and hurricane tracking | 66-deg<br>Non Sun synchronous<br>1336 km | 2026 | Poseidon-4 SAR Radar Altimeter, AMR-C, GNSS-RO, GNSS-POD, DORIS, LRA |

Table 3: Earth Systematic Mission projects in formulation or implementation (continued)

| Mission | Science & Application | ECT/Inclination & Mean Altitude Orbit | Expected Launch Date | Instruments |
|---|---|---|---|---|
| **CRISTAL[1] (Copernicus Polar Ice and Snow Topography Altimeter)** | Measure and monitor surface elevation of glaciers and ice caps and contribute to global ocean topography and coastal/inland water applications | 92-deg<br>Non Sun synchronous<br>760 km | 2027 | Ka/Ku-Band IRIS, GNSS Receiver, LRA, AMR-CR |
| **SBG (Surface Biology and Geology)** | Observe Earth surface features including terrestrial and aquatic ecosystems and species habitats, agriculture, the surface water cycle, the distribution of surface minerals and other natural resources, fires, and fluxes of carbon, water, nutrients, and energy within and among ecosystems, the atmosphere, the ocean, and the Earth to revolutionize scientific understanding of climate change | TIR<br>98.04-deg<br>Sun synchronous<br>665 km<br><br>VSWIR<br>97.83-deg<br>Sun synchronous<br>620 km | TIR<br>No Earlier Than (NET) 2028<br><br>VSWIR<br>NET 2032 | TIR<br>TIR, VNIR<br><br>VSWIR<br>VSWIR spectrometer |
| **PMM[2] (Precipitation Measuring Mission) (Atmosphere Observing System)** | Measure cloud, precipitation, and convection processes across a range of spatiotemporal scale to improve predictions of weather, severe storms, and climate | 55-deg<br>Non Sun synchronous<br>407 km | NET 2029 | Ku-band Doppler Radar, Microwave radiometers |

Table 3: Earth Systematic Mission projects in formulation or implementation

| Mission | Science & Application | ECT/Inclination & Mean Altitude Orbit | Expected Launch Date | Instruments |
|---|---|---|---|---|
| **AOS Sky[3] (Atmosphere Observing System)** | Measure cloud, precipitation, and aerosol processes across a range of spatiotemporal scale to improve predictions of weather, air quality, and climate | 97.2-deg<br>Sun synchronous<br>450 km | NET 2030 | Microwave radiometer, Polarimeter, FIR Imaging Radiometer |
| **GRACE-C[4] (Gravity Recovery And Climate Experiment-Continuity) (Formerly Mass Change)** | Provide continuity to measure changes in Earth's gravity field to monitor variations in terrestrial water storage, ice mass, ocean bottom pressure, and sea level to improve weather and drought forecasting | 89-deg<br>Non Sun synchronous<br>500 km | NET FY2029 | LRI, Accelerometers, GNSS Receiver |
| **Landsat Next** | Provide continuity land surface observations to study, predict, and understand the consequences of land surface dynamics | 98-deg<br>Sun synchronous<br>653 km | NET 2030 | Three identical satellites with VSWIR and TIR |

1 Partner led missions.
2 Formerly AOS Storm. Will consist of two satellites flying in tandem.
3 Will co-launch with CSA's HAWCsat.
4 GRACE-C mission is expected to be comprised of 2 satellites.

## 7.2 Earth System Science Pathfinder

The Earth System Science Pathfinder (ESSP) program provides an innovative approach to Earth science research by providing frequent, regular, competitively selected opportunities that accommodate new and emerging scientific priorities and measurement capabilities. These opportunities represent a series of relatively low-to-moderate cost, small-to-medium sized, principal investigator-led missions that focus on scientific objectives to support a selected subset of studies of the atmosphere, oceans, land surface, polar ice regions, or solid Earth.

Through ESSP, NASA funds the Earth Venture (EV) element that includes missions (EVM), instruments (EVI), and suborbital (EVS) airborne science campaigns recommended by the Decadal Survey. The 2017 Decadal Survey recommended adding a measurement continuity component to EV (EVC). These missions are part of a competitive program that complements strategic NASA Earth science missions. Beginning in 2026, NASA Earth Venture (EV) Announcement of Opportunities (AOs) will follow a 2-year cadence utilizing the "EVX" terminology, which will allow NASA leadership to have more budget flexibility and determine what mission class (EVI, EVM, or EVC) is commensurate with appropriations at the given time. This AO will be in conjunction with the Earth System Explorers (ESE) AOs (Section 7.3.2), which will follow a 3-year cadence beginning in FY2029, and the EVS AOs, which will follow a 4-year cadence.

In addition to the EV class missions, ESSP also oversees the operations of several legacy missions and other missions in development. EV class missions (excluding EVS) currently in development are listed in Table 4.

### 7.2.1 Earth Venture Missions

On November 14, 2023, the Investigation of Convective Updrafts (INCUS) mission entered Phase C. INCUS was the third EV Mission (EVM-3) selected in November 2021. It consists of three Smallsats each with a five beam, Ka-band radar based on RainCube heritage; a cross-track scanning microwave radiometer (middle Smallsat only) based on TEMPEST-D heritage; and a 1.6-m Ka-band antenna. The mission aims to answer why convective storms, heavy precipitation, and clouds occur exactly when and where they do. NASA ESD will select a launch provider for the estimated 2027 launch.

In 2022, NASA announced plans to cancel the development of Geostationary Carbon Cycle Observatory (GeoCarb) mission that was selected in 2016 under the second EV Mission (EVM-2) opportunity due to technical concerns, cost performance, and availability of new alternative data sources, as well as to keep the NASA Earth Science portfolio aligned with overall science priorities. The primary goal of the GeoCarb mission was to probe, in unprecedented detail, the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere. Due to the importance of greenhouse gas observations, NASA is prioritizing the selection of at least one of the four estimated awards to address this important observable under the recently released Earth System Explorers Announcement of Opportunity (See Section 7.3.3).

The Cyclone Global Navigation Satellite System (CYGNSS) mission selected under the first EV Mission (EVM-1) opportunity in 2012 and launched in December 2016 continues to provide science quality data despite losing contact with one of the eight spacecraft. CYGNSS is demonstrating the capability to measure the ocean surface wind field with unprecedented temporal resolution and spatial coverage, under all precipitating conditions, and over the full dynamic range of wind speeds experienced in a tropical cyclone.

### 7.2.2 Earth Venture Instruments

On May 23, 2023, the Polarized Submillimeter Ice-cloud Radiometer (PolSIR) instrument was selected under the sixth EV Instrument (EVI-6) opportunity. PolSIR will consist of two identical CubeSats flying in orbits separated by three to nine hours to study ice clouds that form at high altitudes throughout tropical and subtropical regions to determine how and why they change throughout the day. These measurements will provide crucial information about how to accurately simulate these high-altitude clouds in global climate models.

In late 2019, under the fifth EV Instrument (EVI-5) opportunity, funding was awarded to the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) instrument, a hyperspectral ocean color sensor capable of repeat coverage and operating as a hosted payload in a geosynchronous orbit. The spectrometer achieves a high signal-to-noise ratio across the entire 340-1040 nm spectral range. While the primary mission focuses on ecosystem processes in the Gulf of Mexico, GLIMR will also have a clear view of the continental U.S. coastal waters, and other areas of interest, such as the Caribbean and Amazon River plume. The GLIMR instrument recently entered the implementation phase and launch will be determined at a later date once an access-to-space solution is determined.

In early 2018, two selections were made under the fourth EV Instrument (EVI-4) opportunity: the Polar Radiant Energy in the Far Infrared Experiment (PREFIRE) and the Earth Surface Mineral Dust Source Investigation (EMIT). EMIT was launched and installed on the ISS in 2022 (Table 2). PREFIRE is a pair of CubeSats designed to document, for the first time, the variability in spectral fluxes from 5-45 microns on hourly to seasonal timescales and reveal fluctuations in Earth's thermostat by capturing the full spectrum of Arctic radiant energy. The PREFIRE CubeSats are anticipated to launch in Spring 2024 from Māhia, New Zealand.

In 2016, two selections were made under the third EV Instrument (EVI-3) opportunity: the Time Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) and the Multi-Angle Imager for Aerosols (MAIA). TROPICS is a constellation of four identical CubeSats designed to observe tropical cyclones in a unique, inclined low Earth orbit over Earth's tropics – an orbit that allows them to travel over any given storm about once an hour. Two sets of two TROPICS CubeSats launched on May 8 and May 26, 2023 (Table 1). MAIA will seek to determine the relative toxicity of various airborne particulate matter types by size distribution, chemical composition, and concentration, and to assess their impacts on adverse birth outcomes, cardiovascular and respiratory disease, and premature deaths. The MAIA instrument will be hosted on the Italian space agency Agenzia Spaziale Italiana (ASI) PLATiNO-2 satellite and will be launched in 2025.

Two selections were made in 2014 under the second EV Instrument (EV-2) opportunity: the Global Ecosystem Dynamics Investigation (GEDI) and ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). ECOSTRESS is currently installed on the ISS and is collecting data on plant-water dynamics and how ecosystems change with climate via high spatiotemporal resolution thermal infrared radiometer measurements of evapotranspiration. GEDI was in temporary storage beginning in March 2023, and as of April 2024, has returned to its operational position onboard the ISS and is conducting instrument checkout before resuming science operations(Table 2). GEDI is designed to help determine how deforestation has contributed to atmospheric $CO_2$ concentrations, how much carbon forests will absorb in the future, and how habitat degradation will affect global biodiversity.

The Tropospheric Emissions: Monitoring of Pollution (TEMPO) was selected in 2012 under the first EV Instrument (EV-1) opportunity. TEMPO launched on April 7, 2023, as a hosted payload on a commercial communications satellite to geostationary orbit and is currently in prime operations. TEMPO's measurements from geostationary orbit of ozone, aerosols, and clouds will create a revolutionary dataset that provides understanding and improves prediction of air quality and physical effects on climate. (Table 1).

### 7.2.3 Earth Venture Continuity

In the 2017 Earth Science Decadal Survey (DS), the U.S. National Academies of Science, Engineering, and Medicine recommended adding a new Earth Venture program element focused on continuity observations.

In 2018, NASA released the first EV Continuity solicitation, EVC-1, and in February 2020, the Libera mission was selected to demonstrate an innovative and cost-effective approach to maintaining the 40-year data record of the balance between the solar radiation entering Earth's atmosphere and the amount absorbed, reflected, and emitted. Libera will measure solar radiation in wavelengths reflected by the Earth system (0.3 and 5 microns) and infrared radiation as it exits the top of the atmosphere (5 and 50 microns). The sensor will also measure the total radiation leaving the Earth system (0.3 to 100 microns). An innovative additional "split shortwave" channel (0.7 and 5 microns) was also added to the instrument. These measurements will improve climate certainty by a factor of two and will enable scientists to better understand changes to Earth systems, including whether the planet is getting brighter or darker and heating up or cooling down. Libera will fly on NOAA's operational Joint Polar Satellite System-4 (JPSS-4) satellite, which is scheduled to launch in 2027.

Table 4: Upcoming Earth Venture projects in formulation or implementation (continued)

| EV | Mission | Science and Application | Expected Launch Date | Instrument | Mission Website |
|---|---|---|---|---|---|
| EV-I | **MAIA (Multi-Angle Imager for Aerosols)** | Collect radiometric and polarimetric measurements to characterize sizes, compositions, and quantities of particulate matter in air pollution to combine with health records to better understand connections between air pollution and health problems | 2025 | Two push broom spectropolarimetric camera on a two-axis gimbal | https://maia.jpl.nasa.gov/ |
| | **PREFIRE (Polar Radiant Energy in the Far-InfraRed Experiment)** | Provide full spectral measurements of Far InfraRed (FIR) radiation over the Arctic and Antarctic to allow more accurate predictions of Arctic warming, sea ice and glacier melt, and influence on global sea level and weather systems | 2024 (First of a pair of CubeSats launched on 25 May 2024 NZT. | Two CubeSats with Thermal Infrared Spectrometers (TIRS) | https://prefire.ssec.wisc.edu/ |
| | **GLIMR (Geosynchronous Littoral Imaging and Monitoring Radiometer)** | Measure electromagnetic spectra from the Gulf of Mexico, southeast US coast, and Amazon River plume to observe and enable rapid response to coastal water disasters like harmful algal blooms and oil spills | TBD | Hyperspectral ocean color radiometer | https://eos.unh.edu/glimr |
| | **PolSIR (Polarized Submillimeter Ice-cloud Radiometer)** | Measure the radiant energy emitted by clouds to significantly improve our understanding of how ice clouds change and respond throughout the day in response to a changing climate | TBD | Two CubeSats with Polarized Submillimeter Ice-cloud Radiometers | https://earth.gsfc.nasa.gov/climate/missions/polsir |

Table 4: Upcoming Earth Venture projects in formulation or implementation

| EV | Mission | Science and Application | Expected Launch Date | Instrument | Mission Website |
|---|---|---|---|---|---|
| EV-C | **Libera on JPSS-4** | Collect shortwave, split shortwave, longwave, and total radiation measurements to continue and enhance the Earth radiation budget data record needed to recognize changes to the climate system and constrain future predictions | 2027 | Four electrical substitution radiometers (ESRs) | https://lasp.colorado.edu/home/libera/ |
| EV-M | **INCUS (Investigation of Convective Updrafts)** | Measure vertical transport of air and water, known as convective mass flux (CMF), to address why convective storms, heavy precipitation, and clouds occur exactly when and where they do | 2027 | Cross-track scanning microwave radiometer and Ka-band radar with five beams | https://www.nasa.gov/press-release/nasa-selects-new-mission-to-study-storms-impacts-on-climate-models |

## 7.3 2017 Decadal Survey for Earth Science Research and Applications from Space

### 7.3.1 Background

NASA relies on the scientific community to identify and prioritize leading-edge scientific questions and the observations required to answer them. In response to a request from NASA, NOAA, and USGS, the National Academies for Science, Engineering and Medicine appointed an ad hoc committee, the Committee on Earth Science and Applications from Space (ESAS), to carry out a decadal survey of Earth Science and Applications. In 2018, ESAS released the 2017 Decadal Survey (DS), Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space. The 700-page document is the second such Earth sciences decadal survey. It provides recommendations from the environmental monitoring, Earth science research, and applications communities for an integrated and sustainable approach to the conduct of the U.S. government's civilian space-based Earth-system science programs.

The DS contained a strong endorsement of the Program of Record (POR), which comprises satellites or instruments currently on orbit, as well as those already in formulation and implementation, including directed missions and those selected as part of NASA's Earth Venture program. The DS recommended building on this observing system and identified the observations needed to address key science and application objectives and fill gaps in the POR. These observables are allocated to three new program elements: Designated, focused on the highest-priority observations; Explorer, a competed program to address the remaining targeted observables; and Incubation, intended to accelerate the readiness of cost-effective flight implementations not yet mature enough to deploy to capture high-priority observables.

Following release of the Decadal Survey (DS) report in early 2018, ESD initiated studies to explore implementation options for observing systems to address the DS's five Designated Observables (DO): Aerosols (A); Clouds, Convection, and Precipitation (CCP); Mass Change (MC); Surface Biology and Geology (SBG); and Surface Deformation and Change (SDC). Each study involved multiple NASA centers and, although details vary among the studies, each study team drafted a Science and Applications Traceability Matrix (SATM) as part of an overall value framework against which to assess potential architectures. Information used to develop the SATMs was drawn from the DS and expanded through research and applications community workshops.

After an extensive multi-year study phase to assess a broad trade space of potential architectures, NASA initiated pre-formulation studies in spring of 2021 for all except the SDC Designated Observable mission which will not advance to formulation during the current Decadal cycle in order to capture and incorporate lessons learned from the NISAR mission, which will inform and improve future planning. In pre-formulation, the ESO mission project offices established at NASA field centers further defined mission concepts, executed trade studies, and continued to develop opportunities for collaboration with international partners.

In spring 2022, AOS, SBG, and GRACE-C (formally named Mass Change) underwent Mission Concept Reviews that examined each mission's objectives and their ability to fulfill those objectives. In July 2022, following the Mission Concept Reviews, NASA established an Independent Review Board (IRB) to proactively assist with assessing mission-specific and cross-cutting elements of ESO, provide early-stage feedback, and ensure NASA adopts lessons learned from previous large, strategic science missions. The IRB examined the mission pre-formulation technical concepts for robustness and the ability to satisfy each mission's essential requirements. The IRB identified critical cross-cutting factors across ESO's organization and management, science priorities and integrated operations, technical approach, and schedule and cost. The review found the current designs are capable of achieving the basic science requirements set out by the 2017 Earth science Decadal Survey. The IRB report also suggested specific technical and organizational recommendations to ensure success. NASA continues to assess and incorporate the IRB recommendations through the formulation phase to ensure the success of each mission and overall ESO. As recommended by the IRB, NASA asked the National Academies of Sciences, Engineering and Medicine Committee on Earth Sciences and Applications from Space (ESAS) to review the current status of mission plans compared to Decadal Survey recommendations as part of the decadal midterm review process. The decadal midterm process began in mid-2023 and the report is in progress.

By early 2023, the AOS, SBG, and GRACE-C missions transitioned into Phase A formulation to further assess the feasibility of the mission architectures. Through 2023, as recommended by the IRB, the AOS mission initiated Phase-A architecture studies to identify cost-saving and risk reduction opportunities. Both the GRACE-C and SBG missions refined their mission concepts, system-level requirements, and technical management plans and passed their System Requirements Reviews. GRACE-C transitioned into Phase B formulation in late 2023 where it will work to further improve the fidelity and realism of the cost and schedule estimates prior to moving into implementation and establishing baseline requirements.

### 7.3.2 Earth System Observatory Updates

In early 2024, the NASA Earth Science Division introduced a "decouple, partner, and compete" approach that provides greater flexibility and maximizes the science achievable from the Surface Biology and Geology (SBG) and Atmospheric Observing System (AOS) missions. As a result, management of the two SBG instruments will be decoupled to allow the Thermal Infrared (TIR) component to launch when ready ahead of the Visible Short-Wave Infrared (VSWIR) component. The AOS mission, with a reduced cost target, will now be pursued through a mix of directed and at least one competed mission with multiple international partners and decoupled schedules. The international partner contributions for AOS consist of a Japan Aerospace Exploration Agency (JAXA) Ku-band Radar and Centre National d'Études Spatiales (CNES) tandem microwave radiometers in the inclined orbit; and an Agenzia Spaziale Italiana *(*ASI) multi-wavelength Lidar, and a Canadian Space Agency (CSA) Near Infrared Imaging Radiometer and a Limb-imaging observatory in the polar orbit. NASA directed missions will provide a space vehicle to host one of the Centre National d'Études Spatiales (CNES) radiometers, and a polar mission with a suite of passive instrumentation.

Over the past six decades, NASA's Earth science fleet has provided critical observations underpinning most of what we know about our planet's changing climate. With several key satellites nearing end of life, NASA's Earth System Observatory (ESO) is planned as the next generation of Earth-observing satellites, building on the successes of the current fleet. Each ESO satellite will be uniquely designed to target observables identified as key to answering the most urgent questions of our time. Collectively, through the integration of science between missions, the ESO will provide a multi-dimensional, holistic view of Earth, from bedrock to atmosphere. The information gained from each ESO mission will guide efforts related to understanding climate change, mitigating disasters, fighting forest fires, improving weather and air quality forecasts, and improving real time agricultural processes, among many other uses and applications.

### 7.3.3 Earth System Explorers Program

In summer 2023, NASA initiated the Earth System Explorers program designed to enable high quality Earth system science investigations through Principal Investigator-led missions that acquire and deliver measurements of one or more observables identified in the 2017 Decadal Survey as Earth System Explorer Targeted Observables (TO): Atmospheric Winds, Greenhouse Gases, Ice Elevation, Ocean Surface Winds and Currents, Ozone and Trace Gases, Snow Depth and Snow Water Equivalent, and Terrestrial Ecosystem Structure. These Explorer missions will conduct scientific investigations that can be developed relatively quickly and operate up to three years on-orbit.

In May 2023, NASA finalized a two step competitive process and released the final Announcement of Opportunity (AO) for the Earth System Explorers (ESE) missions. Proposal were received in August 2023. In May 2024, as the first step of a two step selection process, NASA selected four proposals for nine-month Phase A mission concept studies (https://www.nasa.gov/news-release/new-proposals-to-help-nasa-advance-knowledge-of-our-changing-climate/). After the study period, NASA will choose upto two proposals to go forward to launch with readiness dates expected in 2030 and 2032. The total mission cost cap is $310 million for each chosen investigation, excluding the rocket and access to space, which will be provided by NASA. A brief description of four selected proposals is provided below.

The **Stratosphere Troposphere Response using Infrared Vertically-Resolved Light Explorer (STRIVE)** mission would provide near global daily measurements of temperature, various atmospheric elements, and aerosol properties from the troposphere to the mesosphere. It would also measure vertical profiles of ozone and trace gasses to monitor and understand ozone recovery.

The **Ocean Dynamics and Surface Exchange with the Atmosphere (ODYSEA)** mission would measure ocean surface currents and winds to improve our understanding of air-sea interactions and surface current processes that impact weather, climate, marine ecosystems, and human wellbeing.

The **Earth Dynamics Geodetic Explorer (EDGE)** mission would observe the three-dimensional structure of terrestrial ecosystems and the surface topography of glaciers, ice sheets, and sea ice as they are changing in response to climate and human activity.

The **Carbon Investigation (Carbon-I)** mission would enable simultaneous, multi-species measurements of critical greenhouse gases and potential quantification of ethane to provide unprecedented spatial resolution and global coverage that would help better understand the carbon cycle and the global methane budget.

#### 7.3.4 Decadal Survey Incubation Activities

The Planetary Boundary Layer (PBL, https://science.nasa.gov/earth-science/decadal-pbl) and Surface Topography and Vegetation (STV, https://science.nasa.gov/earth-science/decadal-stv) Incubation Teams held community meetings in April 2024 and November 2023, respectively. The teams were established in 2022 to inform program strategy and decisions in pursuit of Decadal Survey Incubation (DSI) program goals, which is to accelerate the readiness of cost-effective flight implementations of PBL and STV targeted observables. DSI supports maturation of mission, instrument, technology, and/or measurement concepts to address specific high-priority science for the 2027-2037 decade. While overall management of the program was assigned to ESTO, program activities are closely coordinated with NASA Earth Science Division's Research and Analysis (R&A) Program.

In April 2022, 35 awards were made under a NASA ROSES solicitation, of which 6 were for Technology tasks; 25 were Science tasks; 3 were for conducting Observing System Simulation Experiments (OSSE's), and 1 for Incubation Team Co-leadership. Information regarding the awarded proposals is available at: https://esto.nasa.gov/project-selections-for-dsi-21/.

Decadal Survey Incubation (DSI) activities were initiated in 2019 to focus on investments for priority observation capabilities that need to be advanced prior to cost-effective implementation in the next decade. The program is focused on the Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) targeted observables only.

# 8 Additional Topics of interest to CGMS members

## 8.1 Earth Science to Action strategy

In early 2024, NASA Earth Science Division released the Earth Science to Action Strategy with the goal of better integrating its scientific knowledge, engineering assets, and partnerships to meet societal needs more comprehensively. Through this strategy, NASA will build the momentum to create a global framework that will allow constructing a comprehensive digital description of the Earth system. This approach will include the Earth environment's physical and geological systems, including surface and interior, biologic, and chemical components, as well as human and other relevant systems. The outcome will help answer challenging science questions posed by the community and allow a thorough understanding and monitoring of the Earth system and its interconnected nature. It will also allow the emergence of new applications and discoveries to benefit society.


Figure 4: A schematic representation of Earth Science to Action Strategy, highlighting the virtuous cycle through which foundational knowledge is employed to address user needs, and the unaddressed and emerging needs inform the next iteration of programs, missions, and initiatives.

We will continue to coalesce and cultivate the diverse communities of Earth science, including working across sectors and across agencies, to generate the science-based decision support information needed by users. When appropriate, we will build efficient and interactive end-to-end tools, models, and assessment systems with the needed latencies, at the appropriate temporal and spatial scales, and with the appropriate uncertainty quantification to serve people, communities, decision- and policymakers, enabling them to take science-based actions. These activities will support efforts to build Earth resilience, including the development of strategies for mitigation, adaptation, and the assessment of various risks and contingencies associated with global change and its impacts. This approach will also include the investigation of potential risks due to crossing thresholds for climate tipping points and the possibilities for cascading environmental and societal impacts. We will tap into the NASA Earth science community's end-to-end capability as an open enterprise to incorporate innovation, scientific discovery, and emerging user needs to accelerate the use of Earth science and inform the next iteration of programs, missions, and initiatives.

## 8.2 Senior Review

The Earth Science Senior Review is the process by which Earth Science missions that have completed their prime missions seek to extend their operations. Initially implemented in 2005, the Senior Review was held every two years through 2017, at which point the cadence was changed to every three years. At the invitation of ESD, each mission submits a formal proposal that documents the goals of the extension, the health and status of the satellite(s) and instrument(s), and the budget required for an extension. ESD establishes several review panels to evaluate the scientific value, technical performance, proposed costs, and broader national interests associated with the proposed extensions.

The 2023 Senior Review evaluated 12 Earth Science missions for extension: Aqua, Aura, CYGNSS, DSCOVR Earth Science Instruments (EPIC and NISTAR), GRACE Follow-On, GPM, ICESat-2, OCO-2, SAGE III, SMAP, Terra, and TSIS-1. Overall, the science ratings for the missions were positive, with 9 missions rated Excellent, two rated Excellent/Very Good, and one as Good. The panel noted that these scores reflect the overall recognition by the panel of the continued excellence of NASA's Earth Science missions and their associated data products. The National Interests Panel found all missions to have at least "some utility" or value for "applied and operational uses", while Aura, CYGNSS, GPM, GRACE-FO, and OCO-2 were found to have "high utility" and Aqua, ICESat-2, SMAP and Terra were found to have "very high utility."

All missions were found to merit extensions and most missions were extended through fiscal year (FY) 2026, aligning them with the next Senior Review in 2026.

For International Space Station (ISS)-hosted missions, extended accommodations must be requested to support ISS processes. On occasion, Out-of-Cycle Senior Reviews are conducted when needed to align the schedules of the extensions and Senior Reviews and ensure timely confirmation of extended ISS accommodations. In late 2022 and 2023, four ISS-hosted missions proposed to Out-of-Cycle Senior Reviews for extension: ECOSTRESS, EMIT, GEDI, and OCO-3. All four missions' overall science ratings were at least Excellent/Very Good with most scoring "high utility" from the National Interests Panel and they were all extended through FY 2026 to align with the 2026 Senior Review.

The 2023 Senior Review final report can be found at: https://science.nasa.gov/earth-science/missions/operating, along with NASA's response to the 2022-2023 Out-of-Cycle Senior Review and the 2023 Senior Review findings.

### 8.3 Open-source Science

According to the White House Office of Science and Technology Policy (OSTP), open science is "the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity" (https://open.science.gov/). Open science involves a commitment to the open sharing of software, data, and knowledge (i.e., algorithms, papers, documents, ancillary information, etc.) as early as possible in the scientific process. The principles of open science are to make publicly funded scientific research transparent, inclusive, accessible, and reproducible. Furthermore, open science requires a culture shift to a more inclusive, transparent, and collaborative scientific process, which will increase the pace and quality of scientific progress. At the heart of open science, the federal government is aiming to advance national open science policy, to provide access to the results of the nation's taxpayer-supported research, to accelerate discovery and innovation, and to drive more equitable outcomes.

NASA has launched a 5-year mission called Transform to Open Science (TOPS), geared towards accelerating the adoption and understanding of open science through training and outreach. TOPS recently developed and publicly released and Open Source 101 curriculum (https://github.com/nasa/Transform-to-Open-Science/tree/main?tab=readme-ov-file#open-science-101-curriculum), which has five modules addressing different aspects of open science. The modules are Ethos of Open Science, Open Tools and Resources, Open Data, Open Code, and Open Results. Furthermore, TOPS has deployed the curriculum via a self-paced Massive Open Online Course (MOOC) at https://openscience101.org/, where anyone can work through the curriculum and earn a NASA Open Science digital badge, which can be added to resumes, personal websites, professional networking websites, or social media websites.

NASA's Science Mission Directorate (SMD) continues to abide by SPD-41a: Scientific Information Policy for the SMD (https://smd-cms.nasa.gov/wp-content/uploads/2023/08/smd-information-policy-spd-41a.pdf) which provides guidance on the open sharing of publications, data, and software created in pursuit of scientific knowledge. At the core of SPD-41a are the principles of openness, equity, and security for SMD-funded research. NASA's Earth Science Division has had an open, free, and accessible data policy since the mid-1990s, and SPD-41a, signed into effect in December 2022, extends openness to NASA scientific software and publications.
To advance open science, NASA launched the Open-Source Science Initiative (OSSI), which is a comprehensive program of activities to enable and support moving science towards openness, including policy adjustments, supporting open-source software,

and enabling cyberinfrastructure. OSSI is working to implement NASA's Strategy for Data Management and Computing for Groundbreaking Science 2019-2024, which was developed through community input.

### 8.4 Commercial Smallsat Data Acquisition (CSDA) program

The Commercial Smallsat Data Acquisition (CSDA) program will begin evaluating the useful of Radio Occultation (RO) data from Global Navigation Satellite System (GNSS) provided by PlanetiQ (https://planetiq.com/) and Synthetic Aperture Radar (SAR) data provided by Umbra (https://umbra.space/). Research proposals are currently being evaluated. Rewards are expected to be announced in June 2024.

PlanetiQ operates two satellites capable of measuring occultation derived from GNSS signals traveling through Earth's atmosphere. The satellites have been in sun-synchronous polar orbits, with the current satellite orbiting with a local time of the descending node (LTDN) at 1400 local time. Neutral atmosphere radio occultation products are available at both Level 1 (calibrated phase and signal-to-noise) and Level 2 (bending angle and refractivity). Grazing angle reflections are included as part of the Level 1 radio occultation data, but there are no Level 2 products for grazing angle data. Additionally, ionospheric products are available for both Level 1 (calibrated phase and signal-to-noise at 50 Hz or higher for scintillations) and Level 2 (Total Electron Content, or TEC, and S4 and sigma phi scintillation indices).

The four-satellite Umbra constellation in a sun-synchronous, repeat ground track orbit provides global X-band SAR observations. Spotlight imagery obtained at different imaging angles multiple times a day can provide diurnal information, while weekly repeat ground track imagery can provide interferometric deformation measurements. Imagery is provided in complex phase history data (CPHD), sensor independent complex data (SICD), sensor independent derived data (SIDD) or GeoTIFF format for analysis.

Later this year, CSDA will complete the evaluation of data from Capella Space (https://www.capellaspace.com/), ICEYE (https://www.iceye.com/en-us/), GHGSat (https://www.ghgsat.com/en/), GeoOptics (https://geooptics.com/). CSDA released evaluation report of the SAR data from Airbus U.S. ((https://us.airbus.com/en) in October 2023. Evaluation report of optical data acquired from Black Sky ((https://www.blacksky.com/) will be released later this year.

In 2018, under a pilot program, NASA selected researchers whose ongoing research could potentially benefit from commercial data, and who had the expertise to adequately evaluate the usefulness of data for advancing NASA Earth science research and application goals. NASA provided commercial data to researchers by signing a Blanket Purchase Agreement (BPA) and End User License Agreement (EULA) with Planet Labs, DigitalGlobe (now known as Maxar Intelligence), and Spire Global, Inc. In April 2020, NASA released the results of evaluations, which found the commercial data and imagery useful for advancing NASA's Earth science research and applications goals. Following the success of the pilot project, CSDA was transitioned into a sustained program. NASA fully recognizes the potential contribution data and imagery from commercial SmallSat constellations may have on advancing Earth science research and applications development. Significant new and existing partnerships include those with National Geospatial Agency (NGA), National Reconnaissance Office (NRO), United States Geological Survey, National Oceanic and Atmospheric Administration (NOAA), and ESA's Earthnet Data Assessment Project (EDAP). In 2023, CSDA's contract vehicle transitioned from BPAs to Multiple-Award Indefinite-Delivery, Indefinite-Quantity (IDIQ) contracts with Firm-Fixed-Price (FFP) task orders. NASA archives all data acquired from commercial vendors and will continue to require science use the EULAs that enable broad levels of dissemination and shareability of the commercial data with the US government agencies and partners. Data acquired by CSDA have been made available at no cost to researchers and are subject to scientific use licenses. Users may search, discover, and access NASA's commercial SmallSat data holdings, via the web based Smallsat Data Explorer (https://csdap.earthdata.nasa.gov/) tool. Planet, Spire, and Airbus U.S. data acquired under CSDA contract vehicles are currently mirrored in SDX, which also includes EarthDEM data products produced by the Polar Geospatial Center (PGC) at the University of Minnesota. CSDA is also archiving these data, beginning with Maxar data holdings, in Earthdata Cloud making commercial data discoverable and accessible alongside NASA mission data.

### 8.5 Retirement of DC-8 and acquisition of B777-200ER

The NASA Airborne Science Program supports the maintenance and operations of uniquely modified aircraft to support sensor development, calibration of Earth Observing satellite instruments, and in support of process studies that validate data product and models. The NASA DC-8 has been a foundational platform for the scientific community for nearly four decades. With several downward and upward looking ports, gas sample inlets, onboard computing and communications, room for 50 investigators, and a range of more than 5,000 miles, the DC-8 has supported instrument development and process studies across nearly every Earth science discipline and conducted missions around the world.

In 2018, the Airborne Science Program initiated a study on suitable replacement of the platform. The study was conducted by the Langley Research Center and determined that either a Boeing 767 or a Boeing 777 would be the best replacement for the aircraft. Following that study, the NASA Science Mission Directorate asked the National Academies of Science and Medicine (NASEM) to conduct an independent study to determine whether and how NASA might replace the DC-8 Flying Laboratory. Released in 2021, the NASEM report entitled, "Airborne Platforms to Advance NASA Earth System Science Priorities: Assessing the Future Need for a Large Aircraft ', was unequivocal in its recommendation that NASA replace the DC-8 with another large aircraft. The report emphasized the continued importance of supporting large multi-instrument science payloads for future satellite calibration and validations studies, interdisciplinary science, and science training efforts such as Student Airborne Research Program (SARP). The study recommended that NASA replace the DC-8 with a large aircraft that meets or exceeds the existing capability in terms of aircraft performance and payload accommodations. After nearly 40 years of service to NASA Science, DC-8 was retired from service at the end of March when it returned from Asia Air Quality (ASIA-AQ) campaign. The aircraft was donated to Idaho State University's Aircraft Maintenance Program by the Federal government, where it will help the university train highly-skilled technicians ready to meet industry needs.

Figure 5: The NASA DC-8 getting a water cannon salute upon it's arrival to the Pocatello Regional Airport on Wednesday, May 15.Credit: Shelbie Harris/Idaho State Journal

Accepting NASEM recommendations, NASA acquired a Boeing 777-200ER in December 2022. The aircraft is currently undergoing modifications and is expected to be ready for research flights in 2026. The modifications will mirror the DC-8's and in some cases exceed that capability (Table 5).

Table 5: Comparison of DC-8 and B777-200ER

| Aircraft | Payload Weight (pounds) | Fuel load (percent) | Range (miles) | Endurance (hours) |
|---|---|---|---|---|
| DC-8 | 50,000 | 100 | 5,000 | 11 |
| B777-200 ER | 50,000 | 55 | 5.400 | 11.7 |
| | 50,000 | 100 | 9,000 | 19 |
| | 100,000 | 85 | 7,400 | 15.6 |

Initial structural modifications are targeting six nadir ports, and four enhanced window ports all larger than the DC-8's. In addition, all unmodified windows are also available for smaller instruments and probes depending on mission requirements. The interior will be outfitted with communications networks, power, and operator stations along with a mission command area where scientists on board can plan and execute missions. The aircraft comes with integrated crew rest areas which will be required as scientist and operators explore the limits of the aircraft endurance. NASA to date has never conducted a crewed airborne mission matching the capabilities of the B777. Further modifications will address radar fairings, zenith ports and structure to allow instruments to sample atmosphere beyond the boundary layer of the aircraft (i.e. probes on wings or canards).

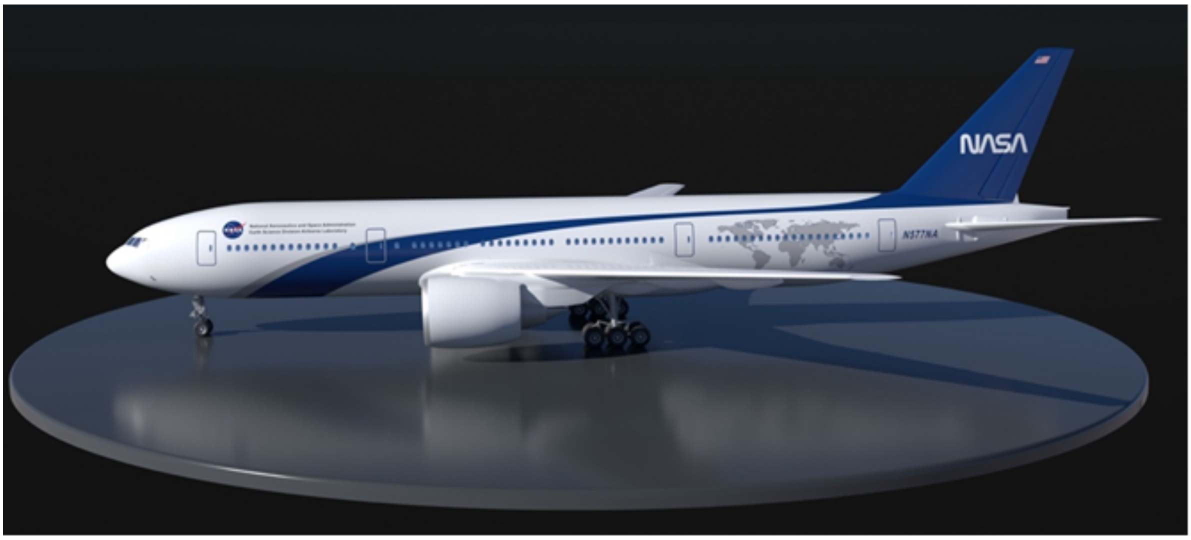


Figure 6: An artists renedition of NASA Earth Science Division's B700-200ER

To celebrate the achievements and contribution of DC-8 and airborne Earth system science that it enabled, a workshop is planned for Summer/Fall 2024. DC-8 missions focused on atmospheric sciences and Synthetic Aperture Radar (SAR) development. The Airborne Arctic Stratospheric Expedition (AASE) I & II missions in 1989 and 1991 provided important measurements that alerted scientists and the public to the trend of decreasing ozone in the polar stratosphere. During this time DC-8 was deployed for the Pacific Exploratory Missions (PEM-WEST) A/B and PEM-Tropics A/B missions, carrying a variety of gas analyzers and sampling systems to characterize carbon, nitrogen, cycling and transport in the northern Pacific. Other early DC-8 missions included the Tropical Ocean – Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE), a study on how El Nino impacts the global climate, and the Satellite Ozone Loss Validation Experiment (SOLVE). Jet Propulsion Laboratory's AirSAR instrument was the largest user of the DC-8 during its first decade of operations, enabling the development and refinement of multi-band and multi-polarimetric synthetic aperture radar with applications for geologic and ecological science.

With the launch of the Earth Observatory System, including the Aura satellite focused on Atmospheric processes, the DC-8 supported many atmospheric science calibration and validation studies including the Intercontinental Chemical Transport Experiments (INTEX-NA/B), the Tropical Composition, Cloud, and Climate Coupling (TC-4) experiment, and Arctic Research of the Composition of the Troposphere from Aircraft and Satellites (ARCTAS) experiment. These focused on improving understanding atmospheric transport as well as the changing arctic chemistry and dynamics. As the Global Precipitation Mission (GPM) came online the DC-8 supported

Weather focused studies including PolarWinds and they Olympic Mountains Validation Experiment (OLYMPEX).

In 2009, because of sooner than expected degradation of instruments onboard Ice, Cloud, and land Elevation Satellite (ICESat-1), the DC-8 team was called on to support Operation Ice Bridge as a means of assuring data continuity between ICESat-1 and ICESat-2. For a decade, the Cryospheric science community flew imagers, lidars, radars, magnetometers and gravimeters over Arctic Sea ice, Alaskan and Antarctic glaciers as a means to ensure a continuous data record over the most quickly changing regions. During this time, the DC-8 also supported several atmospheric chemistry and dynamics missions including Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC4RS), Korean United States Air Quality (KORUS-AQ) campaign, and Cloud Processes Experiment (CPEX), while also supporting development of atmospheric lidars for the Active Sensing of $CO_2$ Emissions over Nights, Days, and Seasons (ASCENDS) mission from 2013-2017, and supporting icing studies for the NASA Aeronautics Research Mission Directorate High Ice Water Content Program (2015-2022).

Over the past 12 years the DC-8 has also served an important role in training the next generation of Earth Scientists and Engineers through the Student Airborne Research Program (SARP). This highly competitive summer program draws students from all over the country to participate in a flight campaign, analyze data to support hypothesis testing, and deliver results at the American Geophysical Union Fall meeting. Over 95 percent of participants have been awarded doctorate degrees in their field.

### 8.6 Federal-civil Satellite Needs process

The Federal-civil Satellite Needs Assessment process is aimed at identifying and communicating federal civilian agencies' Earth observation data and information needs to the White House Office of Management and Budget (OMB), the White House Office of Science and Technology Policy (OSTP), and NASA. The process is managed by the Satellite Needs Working Group (SNWG) established by the United States Group on Earth Observations (USGEO) which includes representatives from non-military U.S. Government agencies who utilize satellite resources. Its purpose is to identify common satellite needs across U.S. Government agencies, promote the discovery of new and existing datasets/products with agency researchers and decision-makers, facilitate a focused discussion on potential creative approaches that help satisfy the agencies' needs where there are currently no data/capabilities, and recognize satellite needs that may be satisfied to some extent with future and upcoming NASA instruments and missions. Every two years, the SNWG formulates the survey, distributes it to all federal agencies, performs an initial analysis on the completed survey, and transmits it to NASA for an assessment. The assessment is undertaken by Program Scientists and/or Program Managers at NASA HQ with support from NASA field center staff scientists and engineers. The NASA-led assessment teams reach out to each of the survey respondents to ensure that the respective agency's satellite needs are fully understood and propose activities towards satisfying the department/agency needs. The proposed activities are presented for approval to OMB. Following approval, solution teams are designated to develop and implement the proposed activities within five years. These teams work closely with the Stakeholder Engagement Program (SEP) to co-develop the solutions alongside users, with sustainability, solution adoption, and impact in mind. This includes facilitating user and stakeholder engagement with the solutions throughout their development, developing case studies and impact stories, as well as developing and offering tailored training to further agency uptake. In addition, where possible, the SEP also considers where SNWG solutions may benefit broader communities beyond U.S. Government agencies.

In July 2023, following the most recently completed cycle (2022), NASA ESD proposed six new activities in a briefing to the OMB, OSTP and SNWG. These new activities will be implemented depending on available funding and budget appropriations. In March 2024, the SNWG released the fifth federal-civil satellite needs survey to participating agencies. Departments and agencies of the Federal government were asked to complete the survey by May 2024. A total of 179 survey forms were submitted (including draft submissions). Though the final number of surveys may ultimately be lower, this is a significant increase from the 2022 cycle. NASA expects to receive completed survey forms in June 2024 and to develop its response through May 2025. Details of activities undertaken as part of the previous four cycles are available at: [https://www.earthdata.nasa.gov/esds/impact/snwg/solutions](https://www.earthdata.nasa.gov/esds/impact/snwg/solutions).