

# The NASA Earth Science Program and Small Satellites

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## ABSTRACT

Earth's changing environment impacts every aspect of life on our planet and climate change has profound implications on society. Studying Earth as a single complex system is essential to understanding the causes and consequences of climate change and other global environmental concerns. NASA's Earth Science Division (ESD) shapes an interdisciplinary view of Earth, exploring interactions among the atmosphere, oceans, ice sheets, land surface interior, and life itself. This enables scientists to measure global and climate changes and to inform decisions by Government, other organizations, and people in the United States and around the world. The data collected and results generated are accessible to other agencies and organizations to improve the products and services they provide, including air quality indices, disaster prediction and response, agricultural yield projections, and aviation safety. ESD's Flight Program provides the spacebased observing systems and supporting infrastructure for mission operations and scientific data processing and distribution that support NASA's Earth science research and modeling activities. The Flight Program currently has 21 operating Earth observing space missions, including the recently launched Global Precipitation Measurement (GPM) mission, the Orbiting Carbon Observatory-2 (OCO-2), the Soil Moisture Active Passive (SMAP) mission, and the International Space Station (ISS) RapidSCAT and Cloud-Aerosol Transport System (CATS) instruments. The ESD has 22 more missions and instruments planned for launch over the next decade. These include first and second tier missions from the 2007 Earth Science Decadal Survey, Climate Continuity missions to assure availability of key climate data sets, and small-sized competitively selected orbital missions and instrument missions of opportunity belonging to the Earth Venture (EV) Program. Small satellites (~500 kg or less) are critical contributors to these current and future satellite missions. Some examples are the aforementioned Orbiting Carbon Observatory-2 (OCO-2), the Gravity Recovery and Climate Experiment Follow On (GRACE FO), and the Cyclone Global Navigation Satellite System (CYGNSS) microsatellite constellation. Small satellites also support ESD in space validation and risk reduction of enabling technologies (components and systems). The status of the ESD Flight Program and the role of small satellites will be discussed.

## 1. NASA'S EARTH SCIENCE PROGRAM

The study of the Earth from space is a crucial element of the National Aeronautics and Space Administration's (NASA's) Strategic Plan. A key strategic goal is to "Advance understanding of Earth and develop technologies to improve the quality of life on our home planet." NASA's Earth Science Division (ESD) purpose is to develop a scientific understanding of Earth's system

and its response to natural or human-induced changes, and to improve prediction of climate, weather, and natural hazards. NASA addresses the issues and opportunities of climate change and environmental sensitivity by answering the following key science questions through its Earth science program:

- How is the global Earth system changing? (Characterize)
- What causes these changes in the Earth system? (Understand)
- How will the Earth system change in the future? (Predict)
- How can Earth system science provide societal benefit? (Apply)

These science questions translate into six focus areas to guide the ESD's selection of investigations and other programmatic decisions:

- |                                    |                                |
|------------------------------------|--------------------------------|
| (1) Climate variability and change | (2) Atmospheric composition    |
| (3) Carbon cycle and ecosystems    | (4) Water and energy cycle     |
| (5) Weather                        | (6) Earth surface and interior |

Through its partnerships with other agencies that maintain forecast and decision support systems, such as the National Oceanic and Atmospheric Administration (NOAA), U. S. Geological Survey (USGS), and Environmental Protection Agency (EPA), NASA improves capabilities to predict climate, weather, and natural hazards; to manage resources; and to develop environmental policy. NASA's Earth science activities are an essential part of national and international efforts to understand global change and use Earth observations and scientific understanding in service to society. NASA also maintains an expansive network of partnerships with foreign space agencies and international research organizations to conduct activities ranging from data sharing agreements to joint development of satellite missions. NASA is the U.S. civilian space agency and in this role has key responsibilities in meeting national needs for Earth observations from space. NASA provides the bulk of the global observations employed by the U.S. Global Change Research Program (USGCRP), and much of the observations and research that forms the basis of international scientific assessments of climate and other environmental change. NASA provides global ocean observations and research in partnership with the NOAA, the National Science Foundation (NSF), the U.S. Navy, and other agencies. NASA is a key participant in the interagency Climate Change Adaptation Task Force. NASA also has a longstanding mandate from the U.S. Congress to monitor and periodically report on the state of the Earth's protective stratospheric Ozone layer. NASA, together with NOAA, USGS, NSF, and the Office of Science and Technology Policy (OSTP) provides leadership for the interagency effort to develop America's contribution to the Global Earth Observation System of Systems (GEOSS) [1,2].

## **2. THE NASA EARTH SCIENCE FLIGHT PROGRAM**

The ESD's spaceflight mission development - from advanced concept studies, to flight hardware development, to on-orbit operation - is managed within the Earth Systematic Missions (ESM) and Earth System Science Pathfinder (ESSP) Programs. The ESM Program includes a broad range of multidisciplinary science investigations aimed at developing a scientific understanding of the Earth system and its response to natural and human-induced forces. The ESM Program im-

plements the strategic missions, including the Earth Observing System (EOS) and foundational missions. The program also includes the systematic missions recommended by the National Research Council's Decadal Survey and most of the missions providing additional sustained measurements, including sustainable land imaging and climate continuity missions. The ESSP Program implements low to moderate cost research and applications missions that foster revolutionary science and train future leaders in space-based Earth science and applications fields. This program includes the Earth Venture missions recommended in the Earth science decadal survey which consist of low-cost, Principal Investigator (PI)-led, competed suborbital and orbital missions, as well as instruments for Missions of Opportunity (MoOs). The ESSP program also includes operating missions that were competitively selected, including the recently launched Orbiting Carbon Observatory-2 (OCO-2) [3,4,5].



Figure 1. Currently Operating NASA Earth Science Missions

Figure 1 illustrates the 21 ESD missions and instruments that are currently operating including the recently launched Global Precipitation Measurement (GPM), OCO-2, and SMAP missions. An additional 22 missions and instruments are planned for the next decade. These are pictured in Figure 2. The Stratospheric Aerosols and Gas Experiment-III (SAGE-III) on International Space Station (ISS), the Orbiting Carbon Observatory-3 (OCO-3), the Lightning Imaging Sensor (LIS), the Global Ecosystem Dynamics Investigation (GEDI) LIDAR, the ECOSYSTEM Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and the CLARREO Pathfinder are scientific instruments to fly as attached payloads on the ISS. The EVI-3 Earth Venture Instruments for Flights of Opportunity and EVM-2, the second low cost small satellite mission, are expected to fly in this time frame. Of these 42 missions, 10 fall into the small satellite (~500 kg or less) category. The CYclone Global Navigation Satellite System (CYGNSS), the Gravity Recovery and Climate Experiment Follow On (GRACE FO), and the Thermal-Infrared Free Flyer (TIR-FF) are related upcoming space missions.

### 3. THE ROLE OF SMALL SATELLITES IN NASA EARTH SCIENCE

In implementing the Decadal Survey and Climate Continuity next generation space-based remote sensing systems, the ESD is using the increasing capabilities of small satellites and their constellations. CYGNSS will make measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, which could help lead to better weather forecasting. It will use a constellation of eight microsatellites (18 kg each) small satellites to probe key air-sea interaction processes that play large roles in the genesis and intensification of hurricanes [5]. The greatest near-term continuity risk in the present Landsat system will be addressed by developing and launching the TIR-FF thermal infrared small satellite to fly in formation with Landsat 8 or an international partner land imaging satellite such as Sentinel 2A [6]. Small satellites also feature prominently in plans for other near term NASA Earth Science missions.



Figure 2. Planned NASA Earth Science Research Missions (2015-2023)

The Earth Science Technology Office's (ESTO) In-Space Validation of Earth Science Technologies (InVEST) program provides in-space, orbital technology validation and risk reduction for components and systems that could not otherwise be fully tested on the ground or in airborne systems. Small, ride-sharing spacecraft, like cubesats, are a core part of the program [7].

#### 4. REFERENCES

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