Small Satellites for NASA Earth Science

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Abstract: NASA's Earth Science Division (ESD) seeks to develop a scientific understanding of Earth and its response to natural and human-induced changes. Earth is a system comprised of diverse components interacting in complex ways. Understanding Earth's atmosphere, surface and interior, oceans and surface water, ice and snow, and life as a single connected system is necessary in order to improve our predictions of climate, weather, and natural hazards. The ESD's Flight Program consists of a coordinated series of satellite and airborne systems providing long and short-term, global and regional observations. In addition, the Flight Program provides infrastructure for operating these missions, processing their scientific data, and distributing them on a free and open basis to researchers, operational users, and the public. The Flight Program currently has 24 operating Earth observing space missions and instruments. There are 18 more missions and instruments planned for launch over the next five years. These comprise missions recommended by the National Academies 2017 Earth Science Decadal Survey, missions and selected instruments to ensure availability of key climate data sets, operational missions to sustain the land imaging provided by the Landsat system, and small-sized competitively selected orbital and instrument missions of opportunity belonging to the Earth Venture (EV) program. The Earth Science Decadal Survey, released in early 2018, recommended four new Flight Program elements in addition to the above activities that comprise the Program of Record (POR). Small satellites (~500 kg or less) are essential components of these activities. Presently, there is an increasing use of micro and nanosatellites (or CubeSats) in constellations to support NASA ESD's scientific objectives. These include the Cyclone Global Navigation Satellite System (CYGNSS) for observing tropical cyclone intensification and genesis factors, the Timed-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission, and the Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE) CubeSat mission. ESD small satellite initiatives like the Small Satellite Constellation Data Buy and Venture Class Launch Services (VCLS) are also underway. The Earth Science Technology Office's (ESTO) In-Space Validation of Earth Science Technologies (InVEST) and the Venture Technology program elements have launched seven 3U and 6U CubeSat missions to validate advanced instruments and related technologies. An equivalent number of InVEST and other technology demonstration CubeSats are being prepared for launch in the next year. An overview of plans and current status including topics related to small satellite enabling activities will be presented.

1. NASA'S EARTH SCIENCE DIVISION

The study of the Earth from space is a key element of the National Aeronautics and Space Act of 1958 and the National Aeronautics and Space Administration's (NASA) Strategic Plan. The National Aeronautics and Space Act of 1958 (as amended), which established NASA, states the objective of "The expansion of human knowledge of the Earth and of phenomena in the atmosphere and space." Strategic Goal 1 in NASA's Strategic Plan is to "Expand human knowledge through new scientific discoveries" and its Strategic Objective 1.1 is to "Understand the Sun, Earth, Solar System, and Universe" with a core context of "Safeguarding and improving life on Earth." NASA's Earth Science Division (ESD) advances scientific understanding of the Earth in service to the United States and the world. This involves the pursuit of answers to fundamental science questions about the Earth system on all time scales to the benefit of humanity. Accordingly, NASA developed, in concert with the scientific research community, the following hierarchy of key science questions:

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

These science questions are associated with six scientific focus areas. These focus areas guide the ESD's selection of investigations and other programmatic decisions:

Climate variability and change	Atmospheric composition
Carbon cycle and ecosystems	Water and energy cycle
Weather	Earth surface and interior

NASA has key responsibilities in meeting United States (U.S.) civilian needs for Earth observations from space (excepting terrestrial and space weather). In this context, NASA responds through the interagency Satellite Needs Working Group (SNWG) to needs for sustained measurements from multiple Federal agencies. Through its partnerships with agencies that maintain forecast and decision support systems, such as the National Oceanic and Atmospheric Administration (NOAA) and the U. S. Geological Survey (USGS), NASA improves capabilities to predict weather, climate, natural hazards and to manage resources. NASA's Earth science activities are an essential part of national and international efforts to use Earth observations and scientific understanding in service to society. NASA maintains an expansive network of partnerships with foreign space agencies and international organizations to conduct scientific research and field campaigns, data sharing agreements, and joint development of satellite missions. NASA Earth science receives external guidance on its research, applications, and observational activities. In January 2018, the National Academies released the second Decadal Survey for Earth Science. It supersedes the 2007 Decadal Survey and endorses the current program of record (POR), as well as making recommendations for a number of future activities. NASA also receives input from the Earth Science Advisory Committee (ESAC) to ensure that proposed programs maximize scientific productivity within the general framework established by the National Academies [1,2,3,4,5].

2. EARTH SCIENCE FLIGHT PROGRAM

The ESD is organized around four programmatic areas: flight, research, applied sciences, and technology. The Flight Program is responsible for collecting and disseminating space and airborne observations. It provides management of all ESD spaceflight missions from advanced concept studies through flight hardware development to on-orbit operations. These activities are managed within the Earth Systematic Missions (ESM) and Earth System Science Pathfinder (ESSP) Programs. The ESM Program includes a broad range of multidisciplinary science missions aimed at understanding the Earth system. The ESM Program implements legacy missions, including the Earth Observing System (EOS) and other missions that predate and include those recommended by the 2007 Decadal Survey. In addition, the program implements sustainable land imaging missions, and climate continuity missions. The ESSP Program implements low to moderate cost missions through

competitive selections to accommodate new and emerging scientific and applications priorities. It includes Earth Venture (EV) program elements consisting of low-cost Principal Investigator (PI) led suborbital and orbital missions, instruments for participation on spaceflight missions of opportunity, and CubeSats. The ESSP program also includes operating missions that were competitively selected including the Orbiting Carbon Observatory-2 (OCO-2) small satellite and other legacy missions. These activities represent the POR, as noted above, endorsed by the 2017 Decadal Survey. The Decadal Survey has also recommended four new Flight Program elements: Designated, Earth Explorer, Incubation, and Earth Venture Continuity (EVC). The ESD is actively planning for these new elements and has initiated four major Designated studies, planning for the first EVC solicitation, and planning for the first Earth Explorer and Incubation solicitations [6].

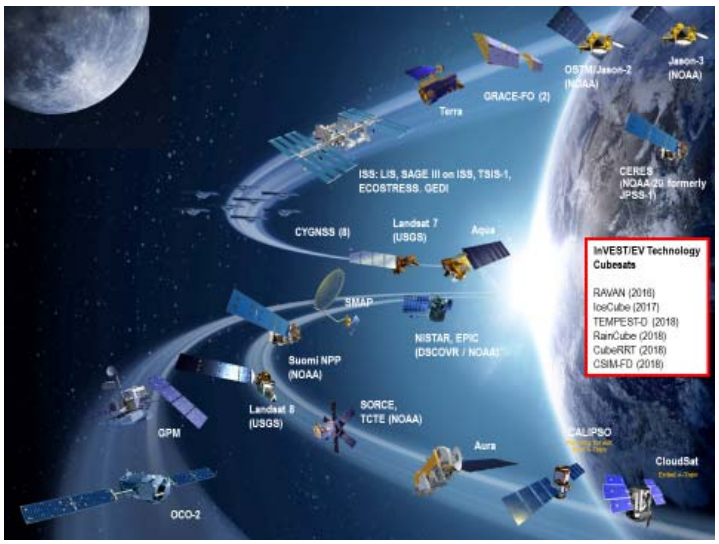

Figure 1. Currently Operating NASA Earth Science Missions

Figure 1 illustrates the 24 ESD missions and instruments that are currently operating. An additional 18 missions and instruments are planned for launch by 2024 and are pictured in Figure 2. Eight passive optical and LIDAR instruments are operating or scheduled to fly on the International Space Station (ISS). The Tropospheric Emissions: Monitoring of Pollution (TEMPO), Geostationary Carbon Cycle Observatory (GeoCARB), and Multi-angle Imager for Aerosols (MAIA) instruments will be hosted on GEO and LEO commercial satellites. The fifth Earth Venture Instruments for Flights of Opportunity (EVI) selection is planned to fly by 2024. Of these 42 missions, 11 fall into the small satellite (~500 kg or less) category. These include NASA's first and second Earth science CubeSat constellation missions, Timed-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) and Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE) [7,8]. Numerous CubeSats are also being used for technology validation and measurement demonstration.

3. SMALL SATELLITES SUPPORTING NASA EARTH SCIENCE

In implementing the Decadal Survey, POR, and EV satellite missions, the ESD is levaraging the increasing capabilities of small satellites and their constellations. The eight sat-

ellite (18 kg each) CYGNSS constellation mission completed its baseline mission of tropical storms and hurricane surface wind measurements and is in extended operations. The EVI program element includes the TROPICS mission with six 3U CubeSats (4 kg each) to determine the relationships between rapidly evolving storm structures and storm intensity and other attributes. The EVI PREFIRE mission uses a pair of 3U CubeSats (7 kg each) to measure the first full spectral measurements of far infrared radiation over the Arctic. The Designated studies underway are considering small satellite architecture options. To leverage increasing commercial small satellite constellation capabilities, the ESD awarded three contracts under the Small Satellite Constellation Data Buy initiative. Improved access to space for small satellites has been demonstrated through recent Rocket Labs Electron rocket launches funded through the joint ESD-NASA Launch Services Program (LSP) Venture Class Launch Services (VCLS) initiative [9,10].

Figure 2. Planned NASA Earth Science Research Missions (2019-2024)

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. Ten CubeSat flights are in operations or are in development in this program. The Flight Program has also funded several technology demonstration CubeSat missions through the Earth Venture Technology program [11].

4. REFERENCES

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