



January 2018

## Thriving on Our Changing Planet

### A Decadal Strategy for Earth Observation from Space

Understanding our planet and how it is changing is critical for our nation's economy, security, and safety. As individuals, we rely on Earth information in our daily lives for applications ranging from internet mapping and weather forecasting to agricultural productivity and transportation. These ever-growing capabilities are due in large part to the United States' sustained commitment to satellite-based Earth observations. Satellite observations provide a global perspective of Earth that transforms our scientific understanding of the planet and enables powerful societal applications that help individuals, businesses, the nation, and the world.



Among the most important revelations from the past sixty years of space-based observation is the extent to which *Earth is changing, in multiple ways and for many reasons*.

These changes include daily fluctuations in weather and longer-term trends in Earth's climate. They also include changes in air quality, water availability, soil nutrients, and other resources. A changing Earth is one we cannot adequately understand just from past experience. Its evolving and emerging characteristics must be continually observed. Successfully managing risks and identifying opportunities associated with these changes requires a clear understanding of the processes, both natural and human-driven, that underlie them. Decisions we make this decade will be pivotal for predicting future changes and applying our knowledge effectively for society's benefit.

**Earth Science and Applications Paradigm for the Coming Decade:** *Earth science and derived Earth information have become an integral component of our daily lives, our business successes, and society's capacity to thrive. Extending this societal progress requires that we focus on understanding and reliably predicting the many ways our planet is changing.*

U.S. civilian space-based observations are primarily managed by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS). At the request of these agencies, the National Academies of Sciences, Engineering, and Medicine organized a study on Earth science and applications from space to identify key science priorities for the next decade. This is the second such decadal survey, with the first published in 2007. Our report highlights the ways

in which Earth science and applications are a key part of the nation's information infrastructure and calls for a U.S. program of Earth observations from space that is robust, resilient, and appropriately balanced. NASA, NOAA, and USGS, in collaboration with other interested U.S. agencies, should ensure efficient and effective use of U.S. resources by strategically coordinating and advancing this program at the national level.

## GOALS FOR THE DECADE

This report identifies the science and applications, observations, and programmatic support needed to understand our changing planet over the next decade. Building on the success and discoveries of the last several decades, the report's balanced program provides a pathway to realizing tremendous scientific and societal benefits from space-based Earth observations.

In order to *improve program efficiency within the agencies*, the proposed program will:

- *Increase Program Cost-effectiveness* by promoting expanded competition with medium-size missions to take better advantage of innovation and partnerships.
- *Institutionalize Sustained Science Continuity* by establishing methods to prioritize and facilitate the continuation of observations deemed critical to monitoring societally-important aspects of the planet after the initial scientific exploration.
- *Enable Untapped NASA-NOAA Synergies* by establishing more effective means for NASA-NOAA partnerships to develop the next generation of weather instruments and accelerate NOAA's integration of advanced operational capabilities.

In order to *enable new science and applications*, the proposed program will:

- *Initiate or Deploy More Than Eight New Priority Observations of our Planet* by developing instruments to address priority observation areas called out in this report.
- *Achieve Breakthroughs on Key Scientific Questions* by addressing critical unknowns about the Earth system and enabling new societal applications and benefits.

In order to *provide value to businesses and individuals*, the proposed program will:

- *Increase Benefits to Operational System End-Users* by enhancing NOAA and USGS processes to have greater impact on the user communities they

serve, and by leveraging low-cost commercial and international space-based observations to further that mission.

- *Provide Data for Innovative Commercial Uses* through new observations and related data.
- *Accelerate the Public Benefits of Science* by improving the national and international capacity to develop new applications that respond to societal needs.

## SCIENCE PRIORITIES

The scientific community involved in space-based Earth science observations includes researchers from a variety of disciplines focusing on topics including oceans, weather, climate, and Earth's surface and interior. In an effort to engage these researchers and practitioners in determining how the decadal survey should be organized and the key science and application priorities for Earth observations, the study committee held numerous town halls and distributed two different requests for white papers. Using the nearly 300 submitted white papers as well as input from five interdisciplinary panels, the committee identified **35 key Earth science and applications questions** that should be addressed over the next decade. In addition, the committee defined a set of underlying objectives and observational capabilities that must be achieved in order to answer each question. These questions and objectives form the foundation of the recommended science program and list the central science and applications priorities for the coming decade.

**RECOMMENDATION:** NASA, NOAA, and USGS, working in coordination, according to their appropriate roles and recognizing their agency mission and priorities, should implement a programmatic approach to advancing Earth science and applications that is based on the questions and objectives in this report's Science and Applications Priorities Table.

The effort to answer these questions and meet these objectives will enable substantial progress in the following areas, as well as others:

- Understanding clouds and aerosols and their impacts on climate and weather
- Assessing rates of and changes in sea level rise.
- Quantifying trends in water storage and the assessing the implications for irrigation and human consumption.
- Understanding alterations to surface characteristics and landscapes (e.g., snow cover, landslides, earthquakes, eruptions, and land use)

- Assessing the health of terrestrial vegetation and aquatic ecosystems.
- Examining movement of land and ice surfaces to study sea-level rise, earthquakes, volcanic eruptions, landslides and tectonic plate deformation.
- Understanding the sources and sinks of carbon dioxide and methane, and how they may change in the future.
- Understanding glacier and ice sheet contributions to rates of sea level rise and how they are changing.
- Improving our understanding of ocean circulation its impacts on weather and climate.
- Assessing changes in ozone and other gases and the associated implications for human health, air quality, and climate.
- Determining changes in snowpacks and the associated implications for water resources, weather, climate, flooding, and drought.
- Quantifying biomass and characterizing ecosystem structure.
- Providing critical insights into the transport of pollutants, wind energy, and cloud processes

## OBSERVATIONAL PROGRAM

This report recommends an innovative observing program that builds on the existing and planned instruments and satellites from the United States and the international community. Because leveraging emerging technologies is essential to advancing space-based observations, the recommended program puts forward a set of priority measurements for the decade rather than prescribing specific mission implementations. This approach allows the program implementation to evolve throughout the course of the decade in order to take advantage of new ideas such as constellations of small spacecraft, advances in sensor technology, and better computational techniques. The proposed program includes five distinct program elements:

1. **Program of Record.** The series of existing or previously planned observations, which must be completed as planned. Execution of this report's recommendations requires that the total cost to NASA of the Program of Record flight missions from FY18-FY27 be capped at \$3.6 billion.
2. **Designated.** Cost-capped medium- and large-size missions to address priority observables essential to the overall program, directed or competed at

the discretion of NASA. These missions should focus on five priority observables identified in the report:

- **Aerosols** and their effect on climate and air quality
- **Clouds, Convection, and Precipitation** and the global hydrological cycle
- **Mass Change**, specifically the distribution and movement of mass between oceans, ice sheets, ground water, and atmosphere
- **Surface Biology and Geology** to measure ground and water temperature, snow reflectivity, active geologic processes, vegetation, and algal biomass
- **Surface Deformation and Change** to measure Earth surface dynamics from earthquakes, landslides, ice sheets, and permafrost

3. **Earth System Explorer.** A new program element involving competitive opportunities for cost-capped medium-size instruments and missions focusing on priority observations called out in this report. These missions should target three of the following seven observables: **Greenhouse Gases, Ice Elevation, Ocean Surface Winds and Currents, Ozone and Trace gases, Snow Depth, Terrestrial Ecosystem Structure** (e.g. forest canopy), or **Atmospheric Winds**.
4. **Incubation.** A new program element, focused on investment for priority observation capabilities that need development prior to cost-effective implementation, including an Innovation Fund to respond to emerging needs. Areas in need of further incubation include measurements of Atmospheric Winds, the Planetary Boundary Layer, and Surface Topography and Vegetation.
5. **Earth Venture.** The Earth Venture program element, as recommended in the last decadal survey, with the addition of a new Venture-Continuity component to provide opportunity for low-cost sustained observations.

This proposed program was designed to both fit within anticipated budgets and ensure balance in the mission portfolio among program elements. As appropriate, candidate instruments and missions were formally subjected to a Cost and Technical Evaluation (CATE) to assess budget needs. Should budgets be more or less than anticipated, the report includes decision rules for altering plans in a manner that seeks to ensure the overall program integrity.

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