The National Academies of SCIENCES ENGINEERING MEDICINE

THRIVING ON A CHANGING PLANET

The 2017-2027 U.S. National Academies "Decadal Survey" for Earth Science and Applications from Space

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Scientific and Technical Subcommittee: 2018
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The National Academies of SCIENCES ENGINEERING MEDICINE

Advising the Nation
Advancing the Discussion
Connecting New Frontiers

- The National Academy of Sciences (NAS) was established on March 3 1863 by Act of Congress, signed into law by President Lincoln in the midst of the Civil War.

- **NAS was established to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government.** The National Academy of Engineering (NAE) was established in 1964 and the Institute of Medicine (now the National Academy of Medicine) in 1970. We now call ourselves the **National Academies of Sciences, Engineering, and Medicine**.

- **The National Academies provide independent, objective analysis and advice to the nation and conducts other activities to solve complex problems and to inform public policy decisions.** The National Academies also encourage education and research, recognize outstanding contributions to knowledge, and increase public understanding in matters of science, engineering, and medicine.

Space at the National Academies

- **The Space Studies Board (SSB) was established in 1958 to serve as the focus of the interests and responsibilities in space research for the National Academies. The SSB provides an independent, authoritative forum for information and advice on all aspects of space science and applications, and it serves as the focal point within the National Academies for activities on space research.** It oversees advisory studies and program assessments, facilitates international research coordination, and promotes communications on space science and science policy between the research community, the federal government, and the interested public. The SSB also serves as the U.S. National Committee for the International Council for Science Committee on Space Research (COSPAR).

- **The Aeronautics and Space Engineering Board (ASEB) was established in 1967 "to focus talents and energies of the engineering community on significant aerospace policies and programs." In undertaking its responsibility, the ASEB oversees ad hoc committees that recommend priorities and procedures for achieving aerospace engineering objectives, and offers a way to bring engineering and other related expertise to bear on aerospace issues of national importance.** Among these issues are: research and development aspects of the Next Generation Air Transportation System (NextGen); NASA's aeronautics research program; national aeronautics R&D policy and its implementation; space policy and programs, with a focus on human spaceflight and space operations; commercial space activities; and other aerospace engineering topics.

Why Undertake a "Decadal Survey"

- **Community-led assessment** of the state of knowledge in the field; identify and prioritize questions for the next decade
- Provide **recommendations for programmatic directions** and explicit priorities for government investment in research and facilities, including space flight missions
- **Provide a forum** to address issues of advanced technology, infrastructure, interagency coordination, education, and international cooperation
- **Requested by US Congress** under the 2005 & 2008 NASA Authorization Acts

Decadal Surveys Facilitate Planning, Coordination, Advocacy, and Outreach

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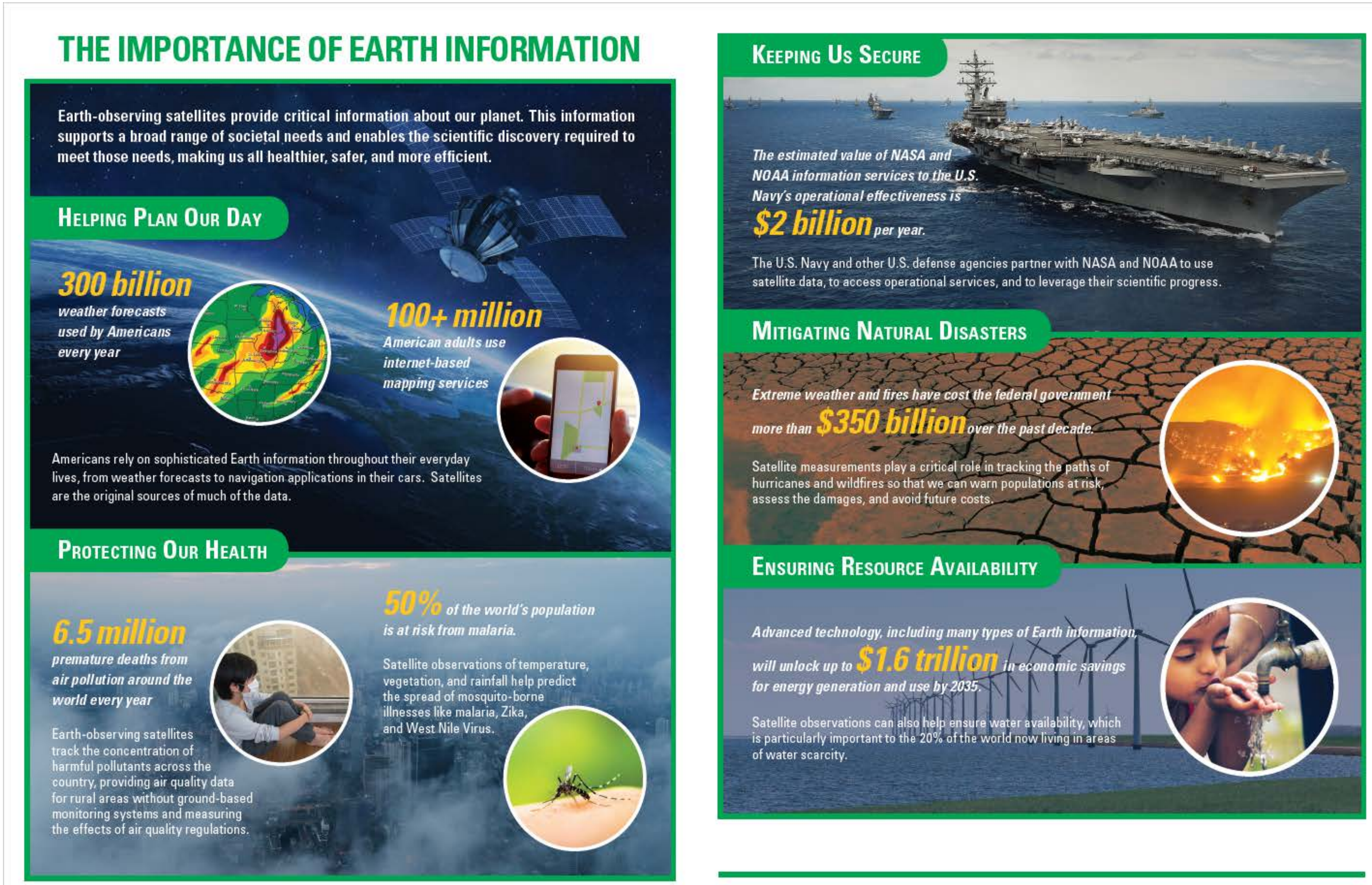
Study Sponsors

- National Aeronautics and Space Administration (**NASA**)
  - Earth Science Division
- National Oceanographic and Atmospheric Administration (**NOAA**)
  - NESDIS (responsible for satellite programs)
- U.S. Geological Survey (**USGS**)
  - Climate and Land-use Change Program (Sustained Land Imaging Program and Landsat)

Report Theme: Earth Information is Increasingly Critical to *Thriving* on our Planet



THE IMPORTANCE OF EARTH INFORMATION

Earth-observing satellites provide critical information about our planet. This information supports a broad range of societal needs and enables the scientific discovery required to meet those needs, making us all healthier, safer, and more efficient.

Helping Plan Our Day

300 billion *weather forecasts used by Americans every year*

100+ million *American adults use internet-based mapping services*

Americans rely on sophisticated Earth information throughout their everyday lives, from weather forecasts to navigation applications in their cars. Satellites are the original sources of much of the data.

Protecting Our Health

6.5 million *premature deaths from air pollution around the world every year*

Earth-observing satellites track the concentration of harmful pollutants across the country, providing air quality data for rural areas without ground-based monitoring systems and measuring the effects of air quality regulations.

50% *of the world's population is at risk from malaria.*

Satellite observations of temperature, vegetation, and rainfall help predict the spread of mosquito-borne illnesses like malaria, Zika, and West Nile Virus.

Keeping Us Secure

The estimated value of NASA and NOAA information services to the U.S. Navy's operational effectiveness is **$2 billion** *per year.*

The U.S. Navy and other U.S. defense agencies partner with NASA and NOAA to use satellite data, to access operational services, and to leverage their scientific progress.

Mitigating Natural Disasters

Extreme weather and fires have cost the federal government more than **$350 billion** *over the past decade.*

Satellite measurements play a critical role in tracking the paths of hurricanes and wildfires so that we can warn populations at risk, assess the damages, and avoid future costs.

Ensuring Resource Availability

Advanced technology, including many types of Earth information, will unlock up to **$1.6 trillion** *in economic savings for energy generation and use by 2035.*

Satellite observations can also help ensure water availability, which is particularly important to the 20% of the world now living in areas of water scarcity.

Statement of Task

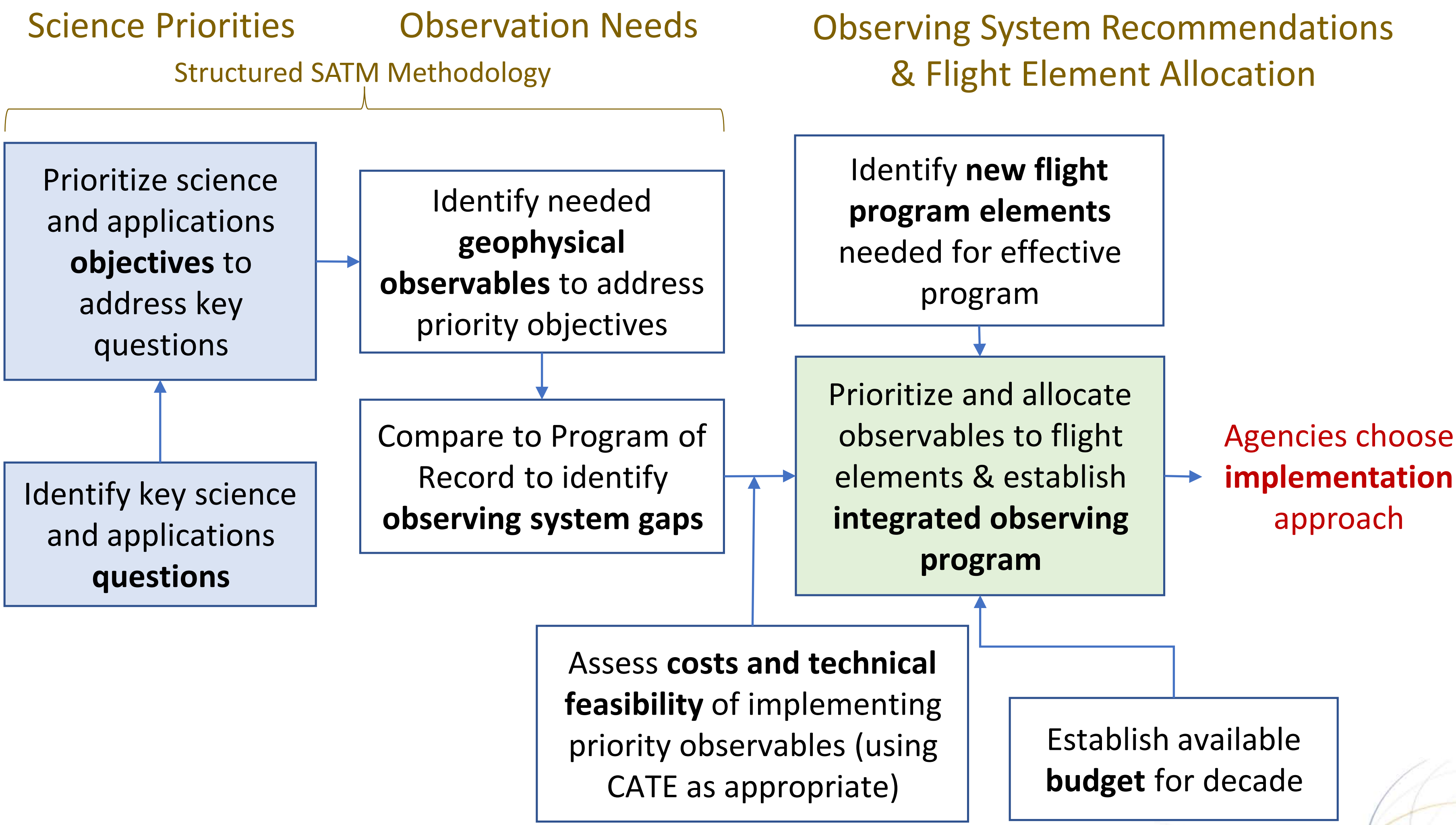
OVERARCHING TASKS

- Assess **progress from 2007**
- Develop a prioritized list of top-level **science and application objectives** for 2017-2027
  - Prioritize objectives, not missions
- Identify gaps and opportunities in the **programs of record** at NASA, NOAA, and USGS
- Recommend approaches to facilitate the development of a robust, resilient, and appropriately balanced U.S. **program of Earth observations** from space

GENERAL & AGENCY-SPECIFIC TASKS

- Cross-Agency
  - Enabling activities
  - Partnerships & synergies
- NASA
  - Program balance and scope
  - Ventures flight element
  - Decision principles and measurement continuity
- NOAA and USGS
  - Non-traditional observation sources
  - On-ramp of scientific advances
  - Research-to-operations
  - Technology replacement/infusion

From Science Priorities to Implementation



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International Opportunities

The critical importance of international cooperation and collaboration is recognized throughout the decadal survey report. Current and planned European Earth Observation programs (Earth Explorers, Copernicus-Sentinel missions, MetOp) and the Earth Observation programs carried out by JAXA, CNES, DLR, ISRO, CSA and others informed survey recommendations. They are *critical* elements of the current and future baseline "Program of Record." General opportunities for additional cooperation are identified, but the survey leaves it to the U.S. agencies to determine which collaborations to pursue.

- **Recommendation 4.5**: Because expanded and extended international partnerships can benefit the nation:
  - NASA should consider enhancing existing partnerships and seeking new partnerships when implementing the observation priorities of this Decadal Survey.
  - NOAA should strengthen and expand its already strong international partnerships, by: a) coordinating with partners to further ensure complementary capabilities and operational backup while minimizing unneeded redundancy; and b) extending partnerships to the more complete observing system life-cycle that includes scientific and technological development of future capabilities.
  - USGS should extend the impact of the Sustainable Land Imaging (SLI) program through further partnerships such as that with the European Sentinel program.

Recommended NASA Flight Program Elements

Program of Record. The series of existing or previously planned observations, which **should be completed as planned**. Execution of the ESAS 2017 recommendation requires that the total cost to NASA of the Program of Record *flight missions from FY18-FY27 be capped at $3.6B.*

- ***Designated.*** A new program element for ESAS-designated cost-capped medium- and large-size missions to address ***observables essential to the overall program*** and that are outside the scope of other opportunities in many cases. Can be competed, at NASA discretion. Five in coming decade
- ***Earth System Explorer.*** A new program element involving competitive opportunities for medium-size instruments and missions serving specified ESAS-priority observations. ***Promotes competition among priorities.*** Three in coming decade
- ***Incubation.*** A new program element, focused on investment for priority observation opportunities needing advancement prior to cost-effective implementation, including an Innovation Fund to respond to emerging needs. ***Investment in innovation for the future***.
- ***Venture.*** Earth Venture program element, as recommended in ESAS 2007 with the addition of a new Venture-Continuity component to provide ***opportunity for low-cost ($150 M) sustained observations***.

NOAA Observation System Opportunities

EXPECTED NOAA "UNSATISFIED PRIORITIES"	EXPECTED NOAA PRIORITY AND RATIONALE	RELATED ESAS 2017 PROGRAMS OR TARGETED OBSERVABLES
Instrument Cost Reduction	HIGH – Reducing cost of any system element enables greater system capability. NOAA has limited capacity to invest in development activities that eventually reduce production cost.	Incubation program element NASA ESTO
3D Winds in Troposphere and Lower Stratosphere	HIGH – High cost and low technology readiness impede inclusion in NOAA operational system.	*Atmospheric Winds*
Global Precipitation Rate	HIGH – High cost and low technology readiness impede inclusion in NOAA operational system.	*Clouds, Convection, & Precipitation*
Seasonal Forecasting	MEDIUM – Multiple new and often difficult observations needed, notably upper ocean and ocean-atmosphere coupling, along with assurance of continuity and ongoing cost reduction for existing observations.	Many ESAS 2017 Targeted Observables
Ocean Surface Vector Winds	MEDIUM – Coverage is likely to be less than desired, with high-volume coverage presently costly.	*Ocean Surface Winds & Currents*
Global Atmospheric Soundings	MEDIUM – Expect future systems to have more soundings of at least moderate precision/accuracy levels as compared to today, but high precision/accuracy IR and microwave soundings may be lacking.	*Planetary Boundary Layer*
GEO-based Regional IR and Microwave Sounding	LOW to MEDIUM – Useful for forecaster nowcasting, but generally considered less valuable than global sounding.	*Planetary Boundary Layer*

Recommended NASA Priorities: Designated

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

Recommended NASA Priorities: Explorer—3 to be Implemented

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		X	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		X	
Ocean Surface Winds & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.	Radar scatterometer		X	
Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**		X	
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X

Summary

- Satellite observations of Earth continually transform how we understand our planet, and these measurements are critical for our nation's economy, security, and safety. ***Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*** **highlights the ways in which Earth observations are a key part of the nation's information infrastructure and calls for a U.S. program of Earth observations that is robust, resilient, and appropriately balanced.**
- Assessing current programs and future needs, **the report recommends undertaking a series of measurements to address key aspects of the atmosphere, ocean, land, and ice with the goal of furthering our understanding of climate, weather, sea level rise, ecosystem health, and ocean circulation.**
- **The report recommends the creation of new program lines within NASA's Earth Science Division and discusses technology on-ramps, the use of commercial data providers, international cooperation, and other ideas to make optimal use of limited resources for the research and operational satellite programs of NASA, NOAA, and the U.S. Geological Survey.**

Thriving on Our Changing Planet

A Decadal Strategy for Earth Observation from Space

Supplemental Information

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- Space Studies Board (lead)
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Panels

Global Hydrological Cycles and Water Resources

Co-Chairs: Jeff Dozier, UC Santa Barbara and Ana Barros, Duke University

The movement, distribution, and availability of water and how these are changing over time

Weather and Air Quality: Minutes to Subseasonal

Co-Chairs: Steve Ackerman, University of Wisconsin and Nancy Baker, NRL

Atmospheric Dynamics, Thermodynamics, Chemistry, and their interactions at land and ocean interfaces

Marine and Terrestrial Ecosystems and Natural Resource Management

Co-Chairs: Compton (Jim) Tucker, NASA GSFC and Jim Yoder, WHOI

Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services

Climate Variability and Change: Seasonal to Centennial

Co-Chairs: Carol Anne Clayson, WHOI and Venkatachalam (Ram) Ramaswamy, NOAA GFDL

Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System

Earth Surface and Interior: Dynamics and Hazards

Co-Chairs: Dave Sandwell, Scripps and Doug Burbank, UC Santa Barbara

Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate