“Thriving on our Changing Planet: A Decadal Strategy for Earth Observations from Space”


Satellite Development Lifecycle

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Statement of Task

OVERARCHING TASKS

- Assess progress from 2007
- Develop a prioritized list of top-level science and application objectives for 2017-2027
- 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
Integrating Themes

I. Global Hydrological Cycles and Water Resources
II. Weather and Air Quality: Minutes to Subseasonal
III. Marine and Terrestrial Ecosystems and Natural Resource Management
IV. Climate Variability and Change: Seasonal to Centennial
V. Earth Surface and Interior: Dynamics and Hazards

Water & Energy Cycle
Carbon Cycle
Extreme Events
Other
Strategic Framework for Leveraging Resources & Advancing

ELEMENTS OF DECADAL STRATEGY

1. Commit to Sustained Science and Applications
2. Embrace Innovative Methodologies for Integrated Science/Applications
3. Amplify the Cross-Benefit of Science and Applications
4. Leverage External Resources and Partnerships
5. Institutionalize Programmatic Agility and Balance
7. Expand Use of Competition
8. Pursue Ambitious Science, Despite Constraints
# Prioritization Criteria

<table>
<thead>
<tr>
<th>AREA</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>Science Questions</td>
<td>Science objectives that contribute to answering the most important basic and applied scientific questions in Earth System science. These questions may span the entire space of scientific inquiry, from discovery to closing gaps in knowledge to monitoring change.</td>
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<tr>
<td>Applications &amp; Policy</td>
<td>Science objectives contributing directly to addressing societal benefits achievable through use of Earth System science.</td>
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<tr>
<td>Interdisciplinary Uses</td>
<td>Science objectives with benefit to multiple scientific disciplines, thematic areas, or applications.</td>
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<tr>
<td>Long-Term Science and/or Applications</td>
<td>Objectives that can support scientific questions and societal needs that may arise in the future, even if they are not known or recognized today.</td>
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<tr>
<td>Value to Related Objectives</td>
<td>Science objectives that complement other objectives, either enhancing them or providing needed redundancy.</td>
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<tr>
<td>Readiness</td>
<td>Are we in a position to make meaningful progress to advance the objective, regardless of measurement?</td>
</tr>
<tr>
<td>Timeliness</td>
<td>Is now the time to invest in pursuing this objective? Examples include recently occurring phenomena that require focused near-term attention and the existence of complementary observing assets that may not be available in the future.</td>
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## Summary of Top Science & Applications Priorities*

<table>
<thead>
<tr>
<th>Science &amp; Applications Topic</th>
<th>Science &amp; Applications Questions addressed by MOST IMPORTANT Objectives</th>
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| **Coupling of the Water and Energy Cycles** | **(H-1)** How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods?  
**H-2)** How do anthropogenic changes in climate, land use, water use, and water storage interact and modify the water and energy cycles locally, regionally and globally and how are the short- and long-term consequences? |
| **Ecosystem Change** | **(E-1)** What are the structure, function, and biodiversity of Earth’s ecosystems, and how and why are they changing in time and space?  
**E-2)** What are the fluxes (of carbon, water, nutrients, and energy) between ecosystems and the atmosphere, the ocean and the solid Earth, and how and why are they changing?  
**E-3)** What are the fluxes (of carbon, water, nutrients, and energy) within ecosystems, and how and why are they changing? |
| **Extending & Improving Weather and Air Quality Forecasts** | **(W-1)** What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean and sea ice) exchanges of energy, momentum and mass, and how do these impact weather forecasts and air quality simulations?  
**W-2)** How can environmental predictions of weather and air quality be extended to seamlessly forecast Earth System conditions at lead times of 1 week to 2 months?  
**W-4)** Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do?  
**W-5)** What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems? |
| **Reducing Climate Uncertainty & Informing Societal Response** | **(C-2)** How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies? |
| **Sea Level Rise** | **(C-1)** How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage?  
**S-3)** How will local sea level change along coastlines around the world in the next decade to century? |
| **Surface Dynamics, Geological Hazards** | **(S-1)** How can large-scale geological hazards be accurately forecasted and eventually predicted in a socially relevant timeframe? |

* Complete set of Questions and Objectives in Table 3.3
NASA Portfolio Balance

- **Earth Science research and analysis**: _maintain_ at approximately 24% of the ESD budget (22-26%)
  - Includes 18% for openly competed research and analysis
  - Includes approximately 3% each for computing and administration
- **Flight program (including Venture)**: _maintain_ at 50-60% of the ESD budget
- **Mission operations**: _maintain_ at 8-12% of the ESD budget
- **Technology program**: _increase_ from current 3% to about 5% of the ESD budget
- **Applications program**: _maintain_ at 2-3% of the ESD budget
Path from Science & Applications to Observational Priorities

Blue: Science & Applications; Green: Observables

Appendix A
Program of Record
Fundamental to achieving many of the prioritized science and applications objectives

Table 3.3
24 of 103 Science & Applications Objectives identified as Most Important

Appendix B - SATM
103 Science & Applications Objectives supporting 35 Science & Applications Questions

Appendix D
290 total Community RFI Responses describing desired science & applications and related observations

ESAS-Recommended Observing System Priorities 2017-2027

Community (Oct 2015 – May 2016)
Steering Committee (2016-17)

Objectives satisfied by existing space-based observations

8 Targeted Observables to be implemented in support priority science & applications objectives (of 22 final Observable candidates)
# NASA Observing System Priorities

<table>
<thead>
<tr>
<th>Targeted Observable</th>
<th>Science/Applications Summary</th>
<th>Candidate Measurement Approach</th>
<th>Designated/Incubation</th>
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<tbody>
<tr>
<td><strong>Aerosols</strong></td>
<td>Aerosol properties, aerosol vertical profiles, and cloud properties to understand their direct and indirect effects on climate and air quality</td>
<td>Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform</td>
<td>X</td>
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<tr>
<td><strong>Clouds, Convection, &amp; Precipitation</strong></td>
<td>Coupled cloud-precipitation state and dynamics for monitoring global hydrologic cycle and understanding contributing processes</td>
<td>Radar(s), with multi-frequency passive microwave and sub-mm radiometer</td>
<td>X</td>
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<tr>
<td><strong>Mass Change</strong></td>
<td>Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth’s atmosphere, oceans, ground water, and ice sheets</td>
<td>Spacecraft ranging measurement of gravity anomaly</td>
<td>X</td>
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<tr>
<td><strong>Surface Biology &amp; Geology</strong></td>
<td>Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass</td>
<td>Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR</td>
<td>X</td>
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<tr>
<td><strong>Surface Deformation &amp; Change</strong></td>
<td>Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost</td>
<td>Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction</td>
<td>X</td>
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<tr>
<td><strong>Greenhouse Gases</strong></td>
<td>CO2 and methane fluxes and trends, global and regional with quantification of point sources and identification of source types</td>
<td>Multispectral short wave IR and thermal IR sounders; or lidar**</td>
<td>X</td>
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<tr>
<td><strong>Ice Elevation</strong></td>
<td>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</td>
<td>Lidar**</td>
<td>X</td>
</tr>
<tr>
<td><strong>Ocean Surface Winds &amp; Currents</strong></td>
<td>Coincident high-accuracy currents and vector winds to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.</td>
<td>Radar scatterometer</td>
<td>X</td>
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| **Ozone & Trace Gases** | Vertical profiles of ozone and trace gases (including water vapor, CO, NOx, methane, and N2O) 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, scatometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar** | X                     |
| **Planetary Boundary Layer** | Diurnal 3D PBL thermodynamic properties and 2D PBL structure to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights. | Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height | X                     |
| **Surface Topography & Vegetation** | High-resolution global topography including bare surface land topography, ice topography, vegetation structure, and shallow water bathymetry | | X                     |

**Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables**

### Other ESAS 2017 Targeted Observables, not Allocated to a Flight Program Element

- Aquatic Biogeochemistry
- Radiance intercalibration
- Magnetic Field Changes
- Sea Surface Salinity
- Ocean Ecosystem Structure
- Soil Moisture
Programmatics - NASA

Rec 4.6 Apply **decision rules** (included) to maintain programmatic balance (programmatic balance was a high priority)

Rec 4.7 Small scope changes to **applications & technology programs**

Rec 4.8 Reevaluate **Ventures structure** at mid-term

Rec 3.3 **Avoiding cost growth** is critical to program’s success (capability and reliability are where the flexibility must be found)
NASA Activities in Support of Decadal Survey Implementation

• Weekly meetings of Earth Science Division Leadership Team to plan implementation

• Initial focus has been on closing out prior pre-formulation work and beginning transition to new efforts in support of designated observations, begin development of approach to Earth Venture continuity, incubator, and explorer lines

• Weekly internal meetings at HQ to receive questions from staff and discuss considerations

• Monthly discussions with Earth Science leadership at NASA centers

• Periodic community fora (WebEx) – first one was May 10, 2018

• Develop “90-day letter” response to National Academies
Backup
Quick Summary: Recommendations

VISION & STRATEGY

“Thriving on our Changing Planet”

SCIENCE & APPLICATIONS

Address 35 key science/applications questions, from among hundreds suggested. Those with objectives prioritized as most important fell into six categories:

- Coupling of the Water and Energy Cycles
- Ecosystem Change
- Extending & Improving Weather and Air Quality Forecasts
- Sea Level Rise
- Reducing Climate Uncertainty & Informing Societal Response
- Surface Dynamics, Geological Hazards and Disasters

OBSERVATIONS

Augment the Program of Record with eight priority observables:

- Five that are specified to be implemented:
  - Aerosols
  - Clouds, Convection, & Precipitation
  - Mass Change
  - Surface Biology & Geology
  - Surface Deformation & Change
- Three others to be selected competitively from among seven candidates
- Structure new NASA mission program elements to accomplish this
- Methods for new NASA capabilities to be leveraged by NOAA and USGS

PROGRAMMATICS

- CROSS-AGENCY
- NASA
  - Flight
  - Technology
  - Applications
- NOAA
- USGS