EXPLOR EARTH

NASA Earth Science and National Academies Decadal Surveys

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* This talk draws on inputs from numerous colleagues from NASA HQ.
Overview of Talk

• NASA Science Decadal Surveys
• First (2007) Earth Science Decadal Survey
• NASA Response (and NAS response to our response!)
• Second (2017/2018) Earth Science Decadal Survey
• NASA Response
• Conclusion
NASA Science Decadal Surveys

• National Academy of Sciences has long history of leading community-based Decadal Surveys for NASA Space Science Disciplines.

• First Decadal Survey for Earth Science was conducted starting in early-mid 2000s, leading to publication in 2007 of *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. Significant community input (white papers) and panel work formed the basis of this effort.
  o Survey included parts of NOAA program as well; in this talk, focus will be on NASA recommendations and response.

• NASA implemented response in the ensuing years. Academy conducted mid-term review (2012) and provided feedback on status of NASA’s implementation.

• Work began on second Decadal survey (for NASA, NOAA, USGS). Tasking was VERY different for NASA part for this one – focus on science questions and required observations, NOT on missions to be implemented. Again, significant community input and participation formed the basis of this effort.

• Second Decadal Survey for Earth Science was released in late 2017/early 2018 (with final version released spring 2018): *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*.

• NASA has begun responding to the Survey with a mix of studies, an Announcement of Opportunity, a Research Solicitation, and community engagement, among other activities.
Decadal Survey 2007 Summary of Recommended Missions

### TABLE E5.2: Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

<table>
<thead>
<tr>
<th>Decadal Survey Mission</th>
<th>Mission Description</th>
<th>Orbit**</th>
<th>Instruments</th>
<th>Rough Cost Estimate (FY 04) (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tier One</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLIMBEQ (NASA portion)</td>
<td>Solar and Earth radiation studies, forcing and response of the climate system</td>
<td>EO, POO</td>
<td>Absolute, spectrally resolved interferometer</td>
<td>200</td>
</tr>
<tr>
<td>SNAP</td>
<td>Soil moisture and flow to the atmosphere for weather and water cycle processes</td>
<td>EO, SS</td>
<td>L-band radar</td>
<td>300</td>
</tr>
<tr>
<td>ICESat-2</td>
<td>Ice sheet height changes for climate change diagnosis</td>
<td>EO, NS</td>
<td>L-band altimeter</td>
<td>300</td>
</tr>
<tr>
<td>DESDynI</td>
<td>Surface and ice sheet deformation for understanding natural hazards and climate-vegetation structure for ecosystem health</td>
<td>EO, SS</td>
<td>L-band InSAR</td>
<td>700</td>
</tr>
<tr>
<td><strong>Tier Two</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HypVIS</td>
<td>Land surface composition for agriculture and natural characterization, vegetation types for ecosystem health</td>
<td>EO, SS</td>
<td>Hyperspectral spectrometer</td>
<td>300</td>
</tr>
<tr>
<td>ASCENDS</td>
<td>Day/night, all latitudes, all seasons CO2 column integrals for climate emissions</td>
<td>EO, SS</td>
<td>Multifrequency laser</td>
<td>400</td>
</tr>
<tr>
<td>SWOT</td>
<td>Ocean, lake, and river water levels for ocean and inland water dynamics</td>
<td>EO, SS</td>
<td>Ka- and Ku-band radar, Ku-band altimeter, Microwave radiometer</td>
<td>450</td>
</tr>
<tr>
<td>GIO-CAPE</td>
<td>Atmospheric gas columns for air quality forecasts, ocean color for coastal ecosystem health and climate emissions</td>
<td>GO</td>
<td>High-spatial-resolution hyperspectral spectrometer, Low-spatial-resolution Imaging spectrometer, IR correlation radiometer</td>
<td>550</td>
</tr>
<tr>
<td>ACE</td>
<td>Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry</td>
<td>EO, SS</td>
<td>Backscatter radar, Multispectral, Doppler radar</td>
<td>800</td>
</tr>
<tr>
<td><strong>Tier Three</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIST</td>
<td>Land surface topography for landslide hazards and water runoff</td>
<td>EO, SS</td>
<td>Laser altimeter</td>
<td>300</td>
</tr>
<tr>
<td>WIS</td>
<td>High frequency atmospheric temperature and humidity soundings for weather forecasting and sea surface temperature</td>
<td>GO</td>
<td>Microwave array spectrometer</td>
<td>450</td>
</tr>
<tr>
<td>GIBR-II</td>
<td>High-resolution gravity fields for tracking large-scale water movement</td>
<td>EO, SS</td>
<td>Microwave or laser ranging system</td>
<td>450</td>
</tr>
<tr>
<td>KCLP</td>
<td>Snow accumulation for freshwater availability</td>
<td>EO, SS</td>
<td>Ka- and X-band radars, X- and Ka-band radars</td>
<td>500</td>
</tr>
<tr>
<td>GACM</td>
<td>Ocean and related gases for intercontinental air quality and atmospheric ozone layer prediction</td>
<td>EO, SS</td>
<td>UV spectrometer, IR spectrometer, Microwave limb sounder</td>
<td>600</td>
</tr>
<tr>
<td>3D Winds (Deimos)</td>
<td>Topographic winds for weather forecasting and pollution transport</td>
<td>EO, SS</td>
<td>Topographic winds, Doppler lidar</td>
<td>450</td>
</tr>
</tbody>
</table>

**NOTE:** Missions are listed by cost. Colors denote mission cost categories as estimated by the committee: Pink: low cost (<$500 million); Green: medium cost ($300 million to $1.6 billion); Blue: high cost ($1.6 billion to $2.5 billion); Brown: very high cost (> $2.5 billion). Missions, respectively. Detailed descriptions of the missions are given in Part II. Part I provides the foundation for their selection.

**EO** = Earth orbit; **POO** = polar orbiting orbit; **EO** = Earth orbit; **GO** = geosynchronous Earth orbit.

**Cloud independent, high temporal resolution, lower accuracy sea-surface temperature measurement to complement, not replace, global operational high accuracy sea-surface temperature measurement.**
NASA Earth Science Division (ESD) Actions Responding to 2007 Decadal Survey

• **Flight Program**
  • Advanced several of the recommended Tier 1 and 2 missions to development (and launch for 2!)
  • Initiated competed Venture Class line (EV-mission, EV-instruments, EV-suborbital) – multiple rounds of each were selected – first satellites/instruments are now in space
  • Provided study funds for Tier 1 and 2 missions that advanced science and technology, supported field campaigns, enabled engineering analysis of potential mission concepts

• **Research & Analysis Program** - Provided funding to advance scientific objectives for several of the Tier 2 missions that did not get advance very far
  • HyspIRI – analysis of precursor data, field campaigns in CA and HI with competed science teams
  • GEOCAPE – development of Tropospheric Ozone Lidar Network (TOLNet) to get time-resolved data as well as ozone profiles for use in algorithm testing/development
  • ACE – supported SEAC4RS field campaign for intensive integrated data acquisition

• **Applied Sciences** – created “Early Adopter” program to build relationships and facilitate/accelerate use of data from Decadal Survey mission

• **Technology** – oriented multiple solicitations around Decadal Survey missions, esp. Tiers 2/3
NASA Progress Towards Implementation of 2007 Decadal Survey Recommended Missions

<table>
<thead>
<tr>
<th>Decadal Survey Mission</th>
<th>Mission Description</th>
<th>Orbit*</th>
<th>Instruments</th>
<th>Rough Cost Estimate (FY 06 million)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLARREO-PF</strong> (radiation reference) under development for 2020 launch**</td>
<td>Solar and Earth radiation; spectrally resolved forcing and response of the climate system</td>
<td>LEO, Process</td>
<td>Absolute, spectrally resolved interferometer</td>
<td>200</td>
</tr>
<tr>
<td><strong>SMAP</strong> (soil moisture) launched 2015</td>
<td>Soil moisture and freeze-thaw for weather and water cycle processes</td>
<td>LEO, SS0</td>
<td>L-band radar</td>
<td>300</td>
</tr>
<tr>
<td><strong>ICESat-2</strong> (ice sheet changes for climate change diagnosis)</td>
<td>Ice sheet height changes for climate change diagnosis</td>
<td>LEO, Non-SS0</td>
<td>Laser alimeter</td>
<td>300</td>
</tr>
<tr>
<td><strong>DEOSat</strong> (surface and ice sheet deformation for understanding natural hazards and climate vegetation structure for ecosystem health)</td>
<td>Surface and ice sheet deformation for understanding natural hazards and climate vegetation structure for ecosystem health</td>
<td>LEO, SS0</td>
<td>L-band lidar, Laser alimeter</td>
<td>700</td>
</tr>
<tr>
<td><strong>HiWise</strong> (Land surface composition for agriculture and natural resources; vegetation types for ecosystem health)</td>
<td>Land surface composition for agriculture and natural resources; vegetation types for ecosystem health</td>
<td>LEO, SS0</td>
<td>Hyperspectral spectrometer</td>
<td>300</td>
</tr>
<tr>
<td><strong>ASCENDS</strong> (Dilution of all大楼s, all-season OCO columns integrates for climate emissions)</td>
<td>Oceans, Lake, and river water levels for ocean and inland water dynamics</td>
<td>LEO, SS0</td>
<td>Multiphysics laser</td>
<td>400</td>
</tr>
<tr>
<td><strong>SWOT</strong> (Ocean, Lake, and river water levels for ocean and inland water dynamics)</td>
<td>Ocean, Lake, and river water levels for ocean and inland water dynamics</td>
<td>LEO, SS0</td>
<td>Ka- and Ku-band radar</td>
<td>450</td>
</tr>
<tr>
<td><strong>GEO-CAP</strong> (Atmospheric gas columns for climate and ocean observations for climate and ocean observations)</td>
<td>Atmospheric gas columns for climate and ocean observations for climate and ocean observations</td>
<td>GEO</td>
<td>High-spatial-resolution hyperspectral spectrometer</td>
<td>550</td>
</tr>
<tr>
<td><strong>ACE</strong> (Assessment of climate and ocean observations for climate and ocean observations)</td>
<td>Assesment of climate and ocean observations for climate and ocean observations</td>
<td>LEO, SS0</td>
<td>Backscatter lidar, Multi-angle polarimeter, Doppler radar</td>
<td>800</td>
</tr>
<tr>
<td><strong>LIT</strong> (Land surface topography for landfills hazards and water runoff)</td>
<td>Land surface topography for landfills hazards and water runoff</td>
<td>LEO, SS0</td>
<td>Laser alimeter</td>
<td>300</td>
</tr>
<tr>
<td><strong>IND</strong> (High-frequency all-weather temperature and humidity sounding for wind forecasting and sea-surface temperature)</td>
<td>High-frequency all-weather temperature and humidity sounding for wind forecasting and sea-surface temperature</td>
<td>GEO</td>
<td>Microwave multi-sensor spectrometer</td>
<td>450</td>
</tr>
<tr>
<td><strong>GCAM</strong> (Ocean surface currents and rapid intersections for intercontinental air quality and atmospheric ocean layer prediction)</td>
<td>Ocean surface currents and rapid intersections for intercontinental air quality and atmospheric ocean layer prediction</td>
<td>LEO, SS0</td>
<td>UV spectrometer</td>
<td>600</td>
</tr>
<tr>
<td><strong>3D Winds</strong> (Tropospheric winds for weather forecasting and pollution transport)</td>
<td>Tropospheric winds for weather forecasting and pollution transport</td>
<td>LEO, SS0</td>
<td>Doppler lidar</td>
<td>650</td>
</tr>
</tbody>
</table>

**Tier Two**

**Tier Three**

**Table E5.2** Launch, Orbit, and Instrument Specifications for Missions Recommended to NASA

- CLARREO-PF (radiation reference) under development for 2020 launch** to ISS
- SMAP (soil moisture) launched 2015
- ICESat-2 (ice sheet thickness) launched 2018
- NISAR (surface radar) under development, GEDI (lidar on ISS) launched 2018 (Earth Venture Instrument)
- ECOSTRESS (evapotranspiration) launched to ISS 2018 (Earth Venture Instrument)
- SWOT (high resolution altimetry) under development for 2021 launch (Int’l partnership)
- TEMPO (geostationary air quality) selected under EV-I (2018 ready, launch TBD)
- PACE (hyperspectral ocean biology/biogeochemistry) under development for 2022 launch**
- GRACE-FO (gravity measurements) launched 2018 (mostly duplicated original GRACE technology)
- Airborne demonstration of wind lidar and use in field campaigns

*Proposed for termination in FY20 budget request

**Proposal for termination in FY20 budget request

**Mission are listed by cost. Colors denote mission cost categories as estimated by the committee: Pink, green, and blue shading indicates large-cost ($100 million to $300 million), medium-cost ($300 million to $600 million), and small-cost (<$100 million) missions, respectively. Detailed descriptions of the missions are given in Part E and Part III provides the foundation for their selection.

1. LEO; low Earth orbit, SS0, Sun-synchronous orbit; GEO, geostationary Earth orbit
2. High independent, high-temporal resolution, lower accuracy sea-surface temperature measurement to complement, not replace, global operational high accuracy sea-surface temperature measurement
Selected Highlights from Mid-Term Review (2012)

• Finding: NASA responded favorably and aggressively to the 2007 decadal survey, embracing its overall recommendations for Earth observations, missions, technology investments, and priorities for the underlying science…

• Finding: Funding for NASA’s Earth science program has not been restored to the $2 billion per year (in fiscal year [FY] 2006 dollars) level needed to execute the 2007 decadal survey’s recommended program…

• Recommendation: NASA’s Earth Science Division (ESD) should implement its missions via a cost-constrained approach ….

• Finding: The Earth Venture-class program is being well implemented by NASA and is a crucial component of fulfilling the 2007 decadal survey’s objectives.

• Finding: Aligned with the intent of the 2007 decadal survey, NASA’s Applied Sciences Program has begun to engage applied researchers and governmental (federal and state) operational users on some decadal survey mission science definition and applications teams….

• Finding: The suborbital program, and in particular the Airborne Science Program, is highly synergistic with upcoming Earth science satellite missions and is being well implemented. NASA has fulfilled the recommendation of the decadal survey to enhance the program.

• Finding: ESTO has organized its proposal solicitations around the 2007 decadal survey and is investing to advance technological readiness across the survey mission queue.

• Finding: NASA has maintained a healthy investment in R&A activities and has protected the budgets of both mission-specific and non-mission-specific R&A programs….
2017 Decadal Survey for Earth Science

- Second Decadal Survey for Earth Science was organized very differently from first one – focus for NASA was on scientific questions and required observations – NOT missions
- Decision rules about how to respond to programmatic challenges and recommendations about program balance were requested
- Note that tasking for NOAA and USGS parts were more focused than that for NASA
- Significant community engagement took place to generate ideas; disciplinary panels winnowed those down to a reasonable number, and then an overall steering committee provided a limited set of desired observations, and made a number of recommendations
# 2017 Decadal Survey Targeted Observables

*ESD decided to only treat observable under the Explorer program element

<table>
<thead>
<tr>
<th>TARGETED OBSERVABLE</th>
<th>SCIENCE/APPLICATIONS SUMMARY</th>
<th>CANDIDATE MEASUREMENT APPROACH</th>
<th>Designated Explorer Inculation</th>
<th>Ozone &amp; Trace Gases (including water vapor, CO, NOx, methane, and N2O) globally and with high spatial resolution</th>
<th>Vertical profiles of ozone and trace gases</th>
<th>UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</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>
<td>Most sensitive instrument for surface-based lidar measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Clouds, Convection, &amp; Precipitation</td>
<td>Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes</td>
<td>Radar(s), with multi-frequency passive microwave and sub-mm radiometer</td>
<td>X</td>
<td>Most sensitive instrument for surface-based passive microwave measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Mass Change</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>
<td>Most sensitive instrument for space-based ranging measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Surface Biology &amp; Geology</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>
<td>Most sensitive instrument for surface-based hyperspectral imaging measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Surface Deformation &amp; Change</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>
<td>Most sensitive instrument for surface-based interferometric synthetic aperture radar measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Greenhouse Gases</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>
<td>Most sensitive instrument for surface-based multispectral short wave IR and thermal IR measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ice Elevation</td>
<td>Global ice characterization including elevation change of land ice to assess sea level contributions and freeboard height of ice to assess sea ice/ocean/atmosphere interaction</td>
<td>Lidar**</td>
<td>X</td>
<td>Most sensitive instrument for surface-based lidar measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ocean Surface Winds &amp; Currents</td>
<td>Coincident high-accuracy currents and vector winds to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and seafloor drift.</td>
<td>Radar scatterometer</td>
<td>X</td>
<td>Most sensitive instrument for surface-based radar scatterometer measurements for science and operational applications</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

** 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 Intercomparison
- Magnetic Field Changes
- Sea Surface Salinity
- Ocean Ecosystem Structure
- Soil Moisture
Earth Science Division  Responses to 2017 Decadal Survey

- Multi-center study teams were created to assess possibilities for Designated Observables
  - Aerosols-Clouds/Convection/Precipitation (combined!)
  - Surface Biology and Biogeochemistry
  - Surface Deformation and Change
  - Mass Change

- Announcement of Opportunity released for first Earth Venture Continuity (EVC) mission, focused on Earth’s radiation budget

- ROSES element released for development of science plans for Incubator (Planetary Boundary Layer, Surface Topography & Vegetation)

- Developing RFPs for awards to facilitate program implementation and enhance community participation

- Major communications effort internally and with community
  - Weekly meetings of ESD leadership team
  - Biweekly listening sessions for ESD staff
  - Creation of web site and opportunity for community to pose questions and get answers
  - Monthly (now bi-monthly) webinars with NASA centers
  - Webinar with full community held every four months (on-site first few times) and town hall sessions at meetings.

- Limited funding flexibility (“Budget Wedge”) while completing Program of Record has precluded release of Announcement of Opportunity for Explorer Missions
Conclusion

- Decadal surveys have been very valuable in gathering community input and bring together to ESD in a coherent way that has trust from Congress, stakeholders, and community.
- Decadal surveys have helped to keep community unified. Meaningful and continuing agency interactions with community around decadal survey are important.
- Decadal surveys are not the only source of guidance, however – NSTC-derived interagency plan(s) can become important guiding document(s) as well.
  - USGCRP, SOST, IARPC, GEO, etc., plus related activities (Satellite Needs Working Group).
- Budget and costing assumptions in decadal surveys do not necessarily match up with ultimate reality and having understanding and flexibility in responding is important
  - Inability to release AO for Explorer Obs. while completing Program of Record is a prime example of these limitations.
- The lessons learned from the first decadal survey for ESD led to significant changes for the second one, which are helping to avoid some of the challenges associated with the first one. Clear decision rules and prioritization criteria that can guide investments in face of scalable budgets are helpful.
- It is important to avoid “dueling decadal surveys” (e.g., if “disciplinary-oriented” surveys overlap with those focused on a specific agency)