Science Mission Directorate

NOV 29 2018

Dr. Fiona Harrison
Space Studies Board
National Academies of Science, Engineering, and Medicine
500 5th Street, NW
Washington, DC 20001

Dear Dr. Harrison:

I would like to express my appreciation for the January 2018 delivery of the pre-publication Earth science and applications Decadal Survey, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space." I thank you for this comprehensive and insightful review of NASA's, NOAA's, and USGS's Earth remote sensing and research programs, including its articulation of the Decadal Community Challenge, and its carefully considered and inspiring recommendations for the future. The Survey's identification of essential elements for a successful structured approach and its focused and actionable programmatic suggestions are already having an impact on our programs – the NASA Earth Science Division (ESD) is taking substantial steps to initiate the recommended "Earth Venture – Continuity" strand of low-cost, competed missions to mitigate the scientific impact of the discontinuance of the Radiation Budget Instrument (RBI). Please express my appreciation to the Co-chairs, Drs. Waleed Abdalati and Bill Gail, and to all of the volunteers and staff who worked to bring this complex and comprehensive project to such a successful conclusion.

By and large, our existing programs and plans are aligned with the report's recommendations given expected budgets. However, the detailed scope and depth of the NASA-focused recommendations are significant, and we are actively engaged on an 18-month set of activities to develop complete strategic approaches and to initiate all of the report's suggested changes related to program substance and cadence.

The ESD leadership began analyzing the Survey's recommendations in detail immediately upon the pre-publication release. We have already established and begun exercising sustained, two-way communications channels with NASA, academic, and private sector, and international partner communities; initiated funded architecture studies for Designated Observables and future land imaging systems (with USGS); and released a draft solicitation for the first Earth Venture Continuity instrument/system. While we await formal release of the final Decadal Survey text by the Academies, as you can see we have initiated a broad and deep set of response activities based on the pre-publication release.
Owing to an unfortunate bureaucratic error, an early status report prepared in Spring 2018 was not transmitted to you. Therefore, in two attachments to this letter, we provide initial acknowledgement and preliminary assessments/responses to the complete set of the Survey’s NASA-focused recommendations, as well as a more detailed summary of decisions, status, and plans for predominately Flight-related recommendations that were presented to the SSB’s standing advisory Committee on Earth Science and Applications from Space (CESAS) on 25 October 2018. Please do not hesitate to contact Dr. Michael Freilich, who can be reached at (202) 358-7226 or at mhf@nasa.gov, with any questions.

Sincerely,

[Signature]

Thomas H. Zurbuchen, PhD.
Associate Administrator
Science Mission Directorate
THRIVING ON OUR CHANGING PLANET: A DECADAL STRATEGY FOR EARTH OBSERVATIONS FROM SPACE
(ESAS 2018 – Recommendations Summary with Preliminary Responses)

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.

Response: NASA acknowledges and enthusiastically supports this paradigm.

Decadal Community Challenge
Pursue increasingly ambitious objectives and innovative solutions that enhance and accelerate the science/applications value of space-based Earth observation and analysis to the nation and to the world in a way that delivers great value, even when resources are constrained, and ensures that further investment will pay substantial dividends.

Response: NASA acknowledges and enthusiastically supports this challenge.

RECOMMENDATIONS

Recommendation 2.1: Earth science and applications are a key part of the nation’s information infrastructure, warranting 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, as also recommended in ESAS 2007.

Response: NASA acknowledges and enthusiastically supports this overarching recommendation, noting that it follows from – rather than redirects – efforts developed to implement ESAS2007 recommendations.

Recommendation 2.2: NASA—with NOAA and USGS participation—should engage in a formal planning effort with international partners (including, but not limited to ESA, EUMETSAT, and the European Union via its Copernicus Program) to agree on a set of measurements requiring long-term continuity and to develop collaborative plans for implementing the missions needed to satisfy those needs. This effort to institutionalize the sustained measurement record of required parameters should involve the scientific community, and build on and complement the existing domestic and international Program of Record.

Response: NASA supports this overarching recommendation. NASA’s Earth Science Division already has strong, effective and productive relationships with ESA, EUMETSAT, the European Union, CNES, CSA, DLR, ISRO, ASI, NSC, and JAXA, among other international partner space agencies. NASA will continue to plan and conduct formal mission/activity collaborations through regular and sustained bilateral engagements and our active participation in multilateral international forums such as the Committee on Earth Observations from Satellites (CEOS).
NASA, NOAA, and USGS are active members of CEOS, as are community and scientific organizations that compile long-term measurement inventory requirements such as the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), the Global Geodetic Observing System (GGOS), the Global Terrestrial Observing System (GTOS), the Intergovernmental Oceanographic Commission (IOC), the International Geosphere-Biosphere Programme (IGBP), and the International Ocean-Colour Coordinating Group (IOCCG). NASA/ESD will continue to fund the focused work of the CEOS System Engineering Office to aid in the identification of gaps and the compilation of inventories and measurement requirements for long-term, spaceborne Earth observation systems.

**Recommendation 3.1:** 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 listed in Table S.1, "Science and Applications Priorities for the Decade 2017-2027"

**Response:** NASA supports this overarching recommendation, noting that NASA already has strong, effective, and productive relationships with NOAA and USGS. NASA will continue to foster the implementation of this recommendation through a variety of mechanisms, including formal agreements and our active participation in interagency (and international) forums.

**Recommendation 3.2:** NASA should implement a set of space-based observation capabilities based on this report’s proposed program by implementing its portion of the program of record and adding observations described in Table S.2, “Observing System Priorities.” The implemented program should be accomplished through five distinct program elements:

1. **Program of record.** The series of existing or previously planned observations, which must 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 fiscal year (FY) 2018-FY27 be capped at $3.6 billion. **Response:** NASA acknowledges and will continue to implement the Program of Record within the constraints of top-line funding and stakeholder priority direction that are imposed on the agency. NASA agrees that the overall mission portfolio cost and schedule constraints quantified in the Decadal are realistic.

2. **Designated Observables.** A program element for ESAS-designated cost-capped medium-to-large size missions to address observables essential to the overall program, directed or competed at the discretion of NASA. **Response:** Informed by inputs being actively collected from and discussed with the broad NASA, academic, private sector, and international communities, NASA will develop approaches – involving both directed and competed elements, along with selected partnerships – to define, build, and launch a series of up to 5 spaceborne missions/observing systems that together will address the five priority observables. Funded multi-center architecture studies for Aerosol/Clouds-Convection-Precipitation (combined), Surface Biology and Geology, Mass Change, and Surface Deformation and Change have already been initiated.
3. **Earth System Explorer.** A new program element involving competitive opportunities for cost-capped medium-size instruments and missions serving specified ESAS-priority observations. **Response:** NASA will develop a new program element to support the objectives of the Earth System Explorer, with a goal of identifying, initiating, and expeditiously launching observing systems that together substantially acquire at observables from the list of seven ESE observables provided in the Decadal Survey. At $350M per mission/observing system and with fully competitive selections in response to targeted solicitations, the ESE program will complement the existing Systematic Missions/Designated program and the lower-cost existing Venture-Class program. Owing to anticipated budget constraints,

4. **Incubation.** A new program element, focused on investment for priority observation capabilities needing advancement prior to cost-effective implementation, including a flexible, unallocated “Incubation Fund.” **Response:** NASA will identify and implement approaches for efficiently combining resources from the existing Flight, Research and Analysis (R&A), and Technology programs to support the development of priority observation capabilities in the areas of Planetary Boundary Layer and Land Surface Characterization that presently require technical advancement in order to yield sufficiently capable measurements. Note that Vertical Wind Profile observations will be included in the Earth System Explorer activities, rather than in both Explorers and Incubation as suggested in the Decadal recommendations. Appropriate balances between the required multi-year investments for identified needs, and flexibility to address emerging priorities, will be considered in conjunction with NASA’s advisory committees and stakeholders.

5. **Earth 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 sustained observations. **Response:** NASA will continue to support the Earth Venture series of competitive, science-based, PI-led, cost- and schedule-constrained solicitations and will add a new program element, Earth Venture-Continuity, to develop and demonstrate new techniques for acquiring low-cost, programmatically realistic, and scientifically capable sustained observations. While the new Earth Venture-Continuity program will provide tangible spaceborne demonstrations of the targeted measurements, the program will not be the vehicle by which the nation actually acquires the measurements over multi-mission and multi-decadal time scales. The first Earth Venture-Continuity solicitation will be focused on demonstration of affordable and capable radiation budget measurements to mitigate the future gap risk resulting from the discontinuance of the former RBI instrument development – text of the draft EVC-1 solicitation was released for community comment on 21 November 2018, with the full solicitation release scheduled for the end of CY2018.

**Recommendation 3.3:** NASA should manage development costs for each flight program element (including the Program of Record committed to prior to this report), and for each project within the Designated program element, so as to avoid impact to other program elements and projects.

- Innovative cost reduction, through programmatic or technological advances and partnerships, should be sought and incentivized where possible.
- By the time of the Midterm Assessment, NASA should report on steps it has taken (e.g.
use of innovative approaches and/or partnerships) to ensure cost-effective development in each program element, and if/how these steps translate to increased science opportunity across the program.

- NASA should consult its standing scientific advisory committees if the project cost of the Program of Record is expected to grow to consume more than $3.6B in the FY18-FY27 decade, if more than one mission in this Decadal Survey is delayed more than 3 years, or upon premature loss of a mission in the Program of Record or one required to make the measurements of this Decadal Survey.

- When appropriate, cost-effective, and consistent with recommended cost caps, NASA should consider instrument and mission designs that can increase science/applications return by combining Targeted Observables having common measurement technologies. **Response**: NASA recognizes the ESAS challenge to manage development costs and will employ various approaches to this end. NASA will aggressively pursue partnerships (including, where appropriate, with the private/commercial sector), maximize the use of competition, continue to employ overall observing system cost sensitivity and in many cases cost “caps,” expand the use of “design-to-cost” iterative mission design approaches, and explore the use of other programmatic and technical tools to control development costs. Among other approaches intended to expand commercial sector involvement, NASA has funded and is pursuing a “Commercial Small-Satellite Constellation Data Buy Pilot” in which NASA purchases existing Earth observation products from (presently 3) commercial suppliers for evaluation by NASA researchers to inform eventual valuation for long-term contracts.

**Recommendation 4.1**: NASA, NOAA, and USGS should reduce barriers to applied uses of remote-sensing research and seek innovative ways to accelerate the transition of scientific research into societal benefits.

**Response**: NASA supports this recommendation and will continue to implement approaches to reduce barriers to applied uses of Earth observations. As part of the efforts to improve the integration and cross-benefit of science and applications, the existing Applied Sciences and R&A programs will examine organizational processes to accelerate transitions. NASA will re-examine the topic of the science of applications mentioned in Chapter 4, and it is a planned topic for the June 2018 meeting of the Applied Sciences Advisory Committee. NASA will also work with NOAA in the context of Recommendation 4.10.

**Recommendation 4.2**: To ensure continued advances in modeling in conjunction with Earth observation:

- NASA should develop a long-term strategic plan for a strong sustained commitment to Earth system modeling in concert with observations. Success in observation-driven modeling holds the key for maintaining the end-to-end capability that has served NASA well in its effectiveness and service to society.

**Response**: To establish modeling priorities and to assess progress, NASA will work closely with its centers (GSFC/Global Modeling and Assimilation Office, GISS/Model E, JPL ECCO) that implement the major fraction of our Earth system modeling. The next five-year work plans from these groups will be informed by inputs from interagency activities including the annual Climate Modeling Summit of the US Global Change
Research Program (USGCRP) Interagency Group on Integrative Modeling (IGIM), and recent National Academies studies including the “2016 Next Generation Earth System Prediction: Strategies for Subseasonal to Seasonal Forecasts.” ESD program management staff will ensure coordination of these large efforts with smaller efforts at other NASA centers and from the broader community that are implemented through responses to periodic solicitations from the Modeling, Analysis, and Prediction (MAP) program. NASA’s overall modeling strategy and plans will continue to be reviewed periodically by the Earth Science Advisory Committee (ESAC) of the NASA Advisory Council.

- NASA, in collaboration with NOAA, should take a leadership role in developing fully coupled ESMs that assimilate comprehensive satellite, aircraft, ground-based, and in situ observations to advance understanding of the Earth system.

**Response:** NASA and NOAA will work together in advancing the science and applications of Earth System Models, introducing coupling between models of earth system components and incorporating new classes of observations taking into account mutually agreed-upon priorities and available resources. Strategic approaches will be defined and model improvements will be implemented through existing bilateral and multilateral entities including the Joint Center for Satellite Data Assimilation and the Earth System Prediction Capability, USGCRP IGIM. Progress will be reported and assessed as part of revitalized, regular bilateral discussions held between NASA/ESD and NOAA/NESDIS and OAR upper level management (division-level at NASA/ESD).

**Recommendation 4.3:** NASA, NOAA, and USGS should continue to advance data science as an ongoing priority within their organizations in partnership with the science/applications communities by: a) identifying best practices for data quality and availability; b) developing data architecture designs that are effective and agile; c) exploring new data storage/dissemination strategies to facilitate more interdisciplinary collaborations.

**Response:** NASA continues to develop open source, cloud-enabled software. NASA, NOAA and USGS are jointly creating standards and best practices to guide the development of data systems as part of the USGEO Data Management Working Group, Earth Science Information Partnership (ESIP) and through direct interaction focused on the sharing of information and open source software. Informed by previous and on-going directed and competed experiments with public cloud computing, machine learning, and other advanced open source and commercial data analysis, NASA will continue to evolve and infuse modern data science technologies into NASA/ESD data and analysis systems to accelerate their adoption by the broad suite of Earth science communities.

**Recommendation 4.4:** NASA should complete planned improvements to its Global Geodetic Observing System (GGOS) sites during the first half of the decadal survey period as part of its contribution to the establishment and maintenance of the International Terrestrial Reference Frame (ITRF).

**Response:** NASA will continue to invest in the deployment of GGOS instruments with next-generation measurement capabilities. NASA is in the process of upgrading 3 domestic sites, and will continue to upgrade the remaining 4 international sites to the
maximum extent allowed by budget appropriations and the need to preserve overall balance across the ESD portfolio. To the extent feasible, NASA will participate through direct investment and in-kind knowledge sharing in enabling the upgrading of additional sites administered by international and domestic partners.

**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.

**Response:** NASA fully agrees and will continue to pursue multiple top-down and bottom-up approaches to identifying, formalizing, and executing international partnerships covering the full range of flight mission collaborations, data system interoperability collaborations, research/analysis scientific collaborations including field campaigns and major interdisciplinary/multi-mission analyses (such as IMBIE), technology demonstrations, and applications development and testing.

**Recommendation 4.6:** NASA ESD should employ the following guidelines for maintaining programmatic balance:

- Decision Rules. Needed adjustments to balance should be made using the decision rules included in this report.
- Flight vs. Non-Flight. Flight programs should be approximately 50-60% of the budget.
- Within Non-Flight:
  - R&A Program. Maintain at its current level of the ESD budget.
  - Technology Program. Increase from its current level of 3% to 5% of the ESD budget.
  - Applications Program. Maintain at its current level of the ESD budget.
- Within Flight:
  - Program Elements. Ensure no flight program element is compromised by overruns in any other element.
  - New vs. Extended Missions. Continue to use the present method of “senior review”, consistent with NAS guidance (NAS, 2016).
  - New Measurements vs. Data Continuity. Lead development of a more formal continuity decision process (as in NRC, 2015) to determine which satellite measurements have the highest priority for continuation, then work with US and international partners to develop an international strategy for obtaining and sharing those measurements.
  - Mission-Enabling Investments vs. Focused Missions. Other than additional investments in the Technology Program and the new Incubation program element, no change in balance is recommended.

**Response:** NASA appreciates these guidelines and the specific considerations of programmatic balance provided in the ESAS. NASA will continue to maintain a balanced program, and will remain mindful of these decision rules and budgetary balance.
recommendations in annual and long-range planning processes, in concert with the guidance provided through the federal appropriations process.

**Recommendation 4.7:** NASA should make the following scope changes to its program elements:

- Technology Program. Establish a mechanism for maturation of key technologies that reduce the cost of continuity measurements.
  
  **Response:** NASA acknowledges this recommendation, and notes its alignment with the spirit and intent of our technology development efforts. Over the coming months, ESD will consider how best to further the maturation of key technologies in support of continuity measurements

- Applications Program. Redirect a small portion to new funding opportunities that focus specifically on taking early-stage ideas and exploring how to move them into applications, including co-sponsorship with NOAA and USGS.
  
  **Response:** NASA acknowledges this recommendation. The Applied Sciences Program will continue to support early-stage ideas and feasibility studies, and it will continue to examine new and additional methods for moving proven concepts into applications more quickly and broadly.

**Recommendation 4.8:** The Midterm Assessment, with a longer program history than is available to ESAS2017, should examine the value of each Venture strand and determine if the cadence or number of selections of any strand should be modified. In particular, the Venture-Suborbital strand should be compared to the approach of executing comparable campaigns through the research and analysis Program to assess which approach serves the community better.

  **Response:** ESD will support the Mid-Term Assessment’s review of the existing 3 strands of Venture Class (EV-Suborbital, EV-Instrument, and EV-Mission) with particular emphasis on determining and quantifying the scientific and programmatic values of EV-Suborbital relative to classical facility field campaigns that are designed by NASA HQ rather than by PIs. Between now and the Mid-Term Assessment in 2022, ESD will continue to solicit, select, and implement Venture-Class missions in all three original strands – as well as initiate the new Earth Venture-Continuity strand on an accelerated basis as discussed above in the response to Recommendation 3.2.5.

**Recommendation 4.10:** NOAA should further leverage use of NASA, USGS, and international satellite observations to meet diverse needs of its line organizations, including those unrelated to weather—and thus not lose the opportunity to capitalize on substantial investments made by other organizations. As one step to accomplish this, NOAA should establish a budget line [similar to what is done for JPSS and GOES-R] in order to: a) facilitate access to and use of data from these non-NOAA sources, and b) demonstrate resulting benefits through broadened collaboration with the NASA Applications and similar programs.
Response: At NOAA's initiation and subject to the agreement of all parties, NASA stands ready and willing to engage with NOAA and to consider ways to expand formal and specific collaborations between NASA Applications-funded and NOAA-funded investigations.

Recommendation 4.12: NOAA should establish, with NASA, a flexible framework for joint activities that advance the capability and cost-effectiveness of NOAA's observation capabilities. This framework should enable implementation of specific project collaborations, each of which may have its own unique requirements, and should ensure: a) clear roles, b) mutual interests, c) life-cycle interaction, d) multi-disciplinary methodologies, e) multi-element expertise, f) appropriate budget mechanisms.

Response: NASA agrees with the spirit of the recommendation, to enable and expand specific, equitable NOAA-NASA partnerships. We will continue to engage with NOAA/NESDIS in both formal and informal forums.

Recommendation 4.14: NASA should constrain cost growth in the development portion of the Sustainable Land Imaging (SLI) partnership, and ideally reduce cost from one generation to the next. USGS should ensure budget growth is minimal, to avoid strain on the overall USGS budget.

Response: Using the framework established by the existing NASA-Dol/USGS Space Act Agreement and the existing/continuing ESD SLI-Technology Program, ESD will invest in technology development activities for land imaging instruments and spacecraft/constellation components, and will coordinate with USGS to conduct studies and evaluate potential future architectures and partnerships for land imaging beyond Landsat-9 (present launch date targeted for 12/2020). A joint NASA-USGS "Landsat-10" Architecture Study Group has been constituted and was formally initiated in September, 2018 to examine and evaluate a wide range of potential land-imaging observing system architectures and approaches – including ground systems and overall program costs – with an initial report in time to influence the FY21 administration budget process.

Recommendation 4.15: Partnerships and user communities associated with Sustainable Land Imaging (SLI) program should be protected and continue to expand. USGS should:

- Ensure and continue to expand the benefits of SLI for its scientific and operational user communities.
- In partnership with NASA, further evaluate ways to more effectively cooperate with or use emerging commercial capabilities for data archiving and dissemination and for imagery acquisition.
- Work with NASA and international partners, continue to expand the use of international observation programs that complement and enhance SLI.

Response: Using the framework established by the existing NASA-Dol/USGS Space Act Agreement, ESD will coordinate with USGS to conduct studies and evaluate potential future architectures and partnerships for land imaging beyond Landsat-9 (present launch
date targeted for 12/2020). NASA continues to maintain a long-term Sustainable Land Imaging budget line to enable NASA development and launch of Landsat-type land imaging satellites in support of, and in collaboration with, USGS.
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<thead>
<tr>
<th><strong>Applied Sciences</strong></th>
<th><strong>Technology</strong></th>
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<tr>
<td>Building capacities and support disaster response activities. Includes public sector planning, decision-making, and actions. Develops, tests, and supports innovative uses of Earth observations and scientific knowledge to inform private and public decision-making.</td>
<td>Develops and demonstrates technologies for future Information Systems, Components, Instruments, and Satellites. Launches and operates NASA's fleet of CubeSat and small satellite technologies.</td>
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<td>Computing, plus field campaigns, modeling, and scientific knowledge of the Earth as a system. Six focus areas support integrative research that advances Earth Science Division Elements.</td>
<td>Products freely and openly available. Manages data systems to make data and information Earth-observing satellites, instruments, and aircraft. Develops, launches, and operates NASA's fleet of Intelligent Data Systems.</td>
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<tr>
<td>Research &amp; Analyses</td>
<td>Flight (incl. Data Systems)</td>
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The Earth Science Division funding request is substantial and is expected to remain that way given the House Appropriations Committee marked up the FY19 NASA/ESD request in June 2018. Senate Appropriations Committee recommended ESD at $1.9B in FY19. House Appropriations Committee recommended ESD at $1.9B in FY19. Committee's report is silent on DSCOVR ops, PACE, CLARREO-PF, and OCO-3. However, this includes restoration of OCO-3, DSCOVR ops, PACE, and CLARREO-PF. ESD recommended at $1.93B in FY19. Includes continued operations and development of FY17 Program of Record, including DSCOVR EPIC/NISSAR, PACE, CLARREO-PF, OCO-3 (to launch as manifested by February 2019).
Providing insight into plant-water dynamics & how ecosystems change with climate via high-resolution thermal infrared radiometer measurements of evapotranspiration (ET).

Obtaining high-resolution global models of Earth's gravity field, including how it varies over time.

The Total and Spectral Irradiance Sensor (TSIS-1) is measuring the total amount of sunlight that falls on Earth, and how that light is distributed among the ultraviolet, visible, and infrared wavelengths.

Recent and Near-Term Planned ESD Launches (1 of 2):

ECOSTRESS: June 29, 2018
GRACE-FO: May 22, 2018
TSIS-1: Dec 15, 2017
OCO-3

GEDI

Quantifying polar ice-sheet contributions to sea-level change & measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change dynamics, providing the first global, high-resolution observations of forest vertical structure to growing urban populations and changing patterns of fossil fuel combustion.

ICESat-2

November 2018

ICESat-2: Sep 15, 2018

GEDI

February 2019

OCO-3

Recent and Near-Term Planned ESD Launches (2 of 2)
ICE-2 successfully launched 15 September 2018

ICE-2A successfully launched 7 September 2018

GRAACE-FO successfully launched 22 May 2018

SII-TRMM-1 successfully launched 22 May 2018

ICE-2B, Micro-RADS, and Micro-MASS-2 launched 13 July 2018

NOAA's JPSS-1 mission successfully launched and operating

TSS-1 instrument successfully launched to ISS and operating

Calipso has joined CloudSat in gravestable orbit for synergistic science

CloudSat moved to lower orbit (IMU and readouts not on demand) - continues to provide high-quality science data

Jason-2/3/ST will remain on orbit until 2026

GRACE mission ended after 15 years

CARTS mission ended owing to instrument failure

IPE-3 instrument (2026)

LRI (Arctic Regional Mineralogy/Composition) and PREJPE (Arctic Regional Emissions from Dual Cubesats)
<table>
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<th>Release Date</th>
<th>Selection Date</th>
<th>Mission</th>
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Mission Type:
- EV: Earth Science Division's Venture Opportunities
- EVM: Earth Science Division's Major Momentum
- EVS: Earth Science Division's Sustained Thrust Opportunities
ECOSTRESS Los Angeles Surface Temps Through the Day
ENABLING

Venture Class Launch Services: Investment in new, low-cost ($1.5M/launch), commercial launch vehicles capable of orbiting small payloads to LEO – science control of launch schedule and orbits

TECHNOLOGY

In-Space Validation of Earth Science Technologies (Invest) on-orbit CubeSat-based technology validation and risk reduction that could not otherwise be fully tested using ground/airborne systems

PrePRe: 2-satellite CubeSat constellation to measure Far-IR Emissions Primarily from the Arctic

SCIENCE

TROPICS (Time-Resolved Observations of Precipitation Structure and Storm Intensity With a Geosynchronous-Equatorial Paleographic System): Homogeneous Tropical constellation of 8 micro-satellites using reflected GPS to measure surface winds/air-sea interactions, especially valuable/unique in extreme environments

CYGNSS (CYclone Global Navigation Satellite System): Homogeneous Tropical constellation of 8 micro-satellites is pursuing a tech program of orbital missions using small satellites

NASA Small-Satellite Programs
miniaturized Ka-band precipitation radars. The radar was successfully acquired from PolarRadar, an investment in collaboration with the Science and Technology (INVEST) program, for demonstrating a new architecture for monitoring

The TEMPEST-D radar mission was able to image Hurricane Florence, two days before it landed in the Carolinas. Florence’s winds were recorded at up to 160 mph, and the mission captured detailed images of the storm’s intensity and movement. The radar images showed the storm’s eye and confirmed its category 4 status.

On 28/29 September 2018, the two CubeSats overflew Typhoon Trami, capturing images of the typhoon’s eye and circling winds. The images showed the typhoon’s impact on the region, highlighting the importance of such missions in understanding and monitoring extreme weather events.

Invest and Venture CubeSats Observe Typhoon Trami
Convection water vapor and strong clouds, precipitation.

Scattering signature of inner core through ice convection around.

165 GHz images.
Similar asymmetry observed in depth of eyewall

convection between TEMPEST-D and RainCube (strongest

on west side and to the south)

profile

TEMPEST-D Sounding Channels provide 4 levels of vertical resolution to "slice" precipitation and compare with RainCube
Earth Observations from Private Sector Small Satellite Constellations Pilot: Data buys or existing data

For advancing NASA research and applications activities and objectives; pilot buys in 2018 minimum constellation, full longitude coverage; for evaluation by NASA researchers to determine value products related to ECYS, derived from private sector-funded small-satellite constellations (3-satellite constellation)

R&A and Applications ROSES calls: R&A and Applied Sciences complement; research calls are data-source agnostic – use of measurements and information from small-satellite systems/constellations is welcomed if

Year solicitation cadence; frequent Launch opportunities using NASA CSLI and VCLS

Invest: Competitively selected Spaceborne Technology Validation that must use small-satellites or cubesats; 3-

Earth Venture-Mission and Instrument Programs: Science-driven, PI-led, cost/schedule constrained

Present ESD funding opportunities for use of small-satellites and resulting data

Private Sector Small-Satellite Constellation Pilot
Vendor plans for constellation maintenance/evolution
Data availability (latency) and subdistribution rights vs. cost
Quality of geophysical information
Written reports to ESD (not scientific papers)
Augmentation education
Participating primarily chosen from existing ESD-funded community – evaluation support & budget
1-year evaluation period

Geophysical information in the data products for advancing NASA research and applications objectives

Have identified a broad set of ESD-funded researchers who will be supported to assess the value of the
newly provided effective means to augment and complement the suite of Earth Observation data products.
Spire – constellation of 48 satellites; collecting Radio Occultation soundings and ship reports
DigitalGlobe – operates five satellite constellations that provide very high-resolution (31-50-cm) images
entire Earth

Planet – three satellite constellations including 200+ satellites; supplying imagery and derived products over the

evaluation by NASA researchers to determine value for advancing NASA research and applications objectives.
For sector-funded small-satellite constellations (e.g.-satellite minimum constellation, full longitudinal coverage), for
have signed contracts with three companies to buy existing data products related to ECVs, derived from private

Private Sector Small-Satellite Constellation Pilot - Update
Endorses existing balances in ESD portfolio.

Explicitly encourages and notes value of international partnerships.

Emphasizes on competition as cost-control method.

Explicitly allows implementation flexibility.

Prioritizes observations rather than specific missions.

Supports the ESD (and international) Program of Record.

Publicly released January 5, 2018.

2017 Decadal Survey Snapshot
next Decadal

but presentation immature – measurements (preparation for
and flight to mature specific technologies for important –
Calls for "Incubator Programs" between Technology, RGA,
ESD from among that identified
$350M cost constraint, 3 observables to be chosen by
introduces a new completed "Explorer" flight line with
Surface Deformation & Change
Precipitation; Mass Change; Surface Biology & Geology;
Identifies 5 "Designated" observables (DO) for
Venture-class Program
full mission cost cap (as in addition to the existing
Recommends "Continuity Measurement" Strand ($150M
Calls for "cost-capping" essentially all missions

2017 Decadal Survey Snapshot (cont.)
Mission Operations: Maintain at 8-12% of the budget

Flight Programs, including Venture: Maintain at 50-60% of the budget

Technology Programs: Increase from its current 3% to about 5%

Applications Programs: Maintain at 2-3% of the budget

Includes approximately 3% each for computing and administration

Includes 18% for openly completed research and analysis

Earth Science Research: Maintain at approximately 24% of the budget (22-26%)
View records of progress and decisions
Find answers to questions, as they become available
Ask questions
See meeting and telecon announcements
Use the web page to:

Town halls at professional society meetings
Engagement with Interagency and International Partners
3/year (every 4 months) open webex/calls with external communities
Monthly webex/calls with NASA Centers

https://science.nasa.gov/earth-sciences/decadal-surveys

ESD's Decadal Survey web page:

Communicating our plans and progress:
Designated Observables Summary (from DS)

<table>
<thead>
<tr>
<th>Observable</th>
<th>Science/Applications Summary</th>
<th>Candidate Measurement Approach</th>
<th>ESAS maximum cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</td>
<td>Aerosol properties, aerosol vertical profiles, and cloud properties to understand their effects on climate and air quality</td>
<td>Backscatter lidar and multichannel/multi-angle/polarization imaging radiometer flown together on the same platform</td>
<td>CATE Cap</td>
</tr>
<tr>
<td>Clouds, Convection, And Precipitation</td>
<td>Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback</td>
<td>Radar(s), with multi-frequency passive microwave and sub-mm radiometer</td>
<td>CATE Cap</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>Est Cap</td>
</tr>
<tr>
<td>Surface Biology and 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>CATE Cap</td>
</tr>
<tr>
<td>Surface Deformation and 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>Est Cap</td>
</tr>
</tbody>
</table>
System to be initiated

SBG or some combination of Aerosol/CCP will be first DO mission/observing

Objectives strongly encouraged

Contributions of each mission/observing system to other ESD science

Partnerships strongly encouraged

Satellite bus expected to be procured

Payloads will be competed by HQ

Each Mission/Observing System will be cost-constrained, informed by DS

Each DO Mission/Observing System will be directed to a Center

DO Mission/Observing System Implementation
Earlier than FY24.

- Other projects resulting from the DO studies are expected to be initiated (KDP-A) no

DO#2 - 4/2022

DO#1 - 10/2021

Follows:
The initiation (KDP-A) of at most 2 projects in the FY21/22 timeframe approximately as

- The SBG, Aerosols, CCP and Combined Aerosols/CCP studies are expected to result in

Study plans were submitted for ACCP (Combined), SGC, CDC and MC (4 total)

- MC: $>300M, fully NASA cost
- SGC: $>500M, fully NASA cost
- CDC: $>1,600M, fully NASA cost
- Implementation for $>1,600M, fully NASA cost
- Combined Aerosols and CCP study to address missions/observing systems approaches that can be

Combining Aerosols and CCP

- CCP: $>800M, fully NASA cost
- Aerosols: $>800M, fully NASA cost
- SGC: $>600M, fully NASA cost for Implementation (including Launch services and core science)

Cost-constrained DO:

ESD Requested multi-center study plans to perform studies associated with the following

Designated Observables Guidance Summary
decisions or policies potentially affected
impacts of the designated observables on society, including the actual
Each study will perform a (qualitative or quantitative) assessment of the
new technologies
innovative development approaches
the possible use of other sampling platforms (e.g., aircraft, suborbital, etc.),
constellation solutions, etc.;
non-traditional architectures (e.g., commercial solutions, partial solutions, smallsat
The studies will examine approaches for incorporating:

Guidance for DO Studies
<table>
<thead>
<tr>
<th>Lead</th>
<th>Program Applications</th>
<th>Program Scientist</th>
<th>Program Executive</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Pe', Ps', and Pa')</td>
<td>(ESD Points of Contact once Studies are Underway)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
International Agreements

ESD will make final partnerships determinations and then consult necessary

Keep ESD leadership informed

Multi-center joint efforts appreciated

Implementation approaches with international partners

Centers are explicitly encouraged to discuss and explore possible observable

Some direct international partnerships may originate from ESD/HQ

Bilateral, HQ-led, face-to-face meetings planned over the next 6 months

ISRO, JAXA, CNES, DLR, ESA, EUMETSAT, CSA, now GFZ

International Partners

ESD has conducted focused Decadal Survey Telecons/meetings with key

International Engagement
RFI was posted on September 4, 2018.

- In the architectural studies, it rather solicits inputs and ideas on how the private sector and other non-governmental organizations can best participate.
- The RFI does NOT invite ideas regarding the specific observing systems/solutions that are to come out of the studies.
- The RFI solicits input on how industry and other non-governmental organizations wish to be involved in the multi-year observing system architecture studies.
- The DOE studied aim to identify and evaluate observing system architectures and approaches that might improve the overall

**NASA Designated Observers**

Described herein are the observers who will be involved in the multi-year observing system architecture studies.

- The level of involvement desired; and
- Recommendations, including:
  - Ideas on ways they wish to participate in the planning processes/studies associated with implementing the DS.
  - Offers interested in participating in the multi-center DS studies are asked to submit short (≥ 10 pp) statements providing:

**Request for Information (RFI)**
Participants

- Commercial
- Other Expected US Participants: NOAA, EPA, Universities
- NASA Centers - GSFC, JPL, LARC, MSFC, ARC, GRRC
- Study Coordinators - Culinary (GSFC), Vane (JPL), Trefolino (LARC)
- NO - M.アジ, Jackson, Leiter, D. Edwards, Haynes

Goals

- Phase 4 - Preliminary Mission Concept Review
- Phase 3 - Develop A-CCP Design Concept(s) including
  - Preliminary STMs
- Phase 2 - Refine and Develop STMs
- Phase 1 - Develop Science Value Framework

Scope/Implementation

- Early 2022 - Final Report, Mission Concept Review
- April/May 2019 - Start Architecture Studies
- March 2019 - Blue Sky Study
- January/February 2019 - Meeting of Full A-CCP Study Team
- January 2019 - Complete STMs
- October 2018 - Initiate Science Group Work on STMs
- September 2018 - Start Development of Science Value Framework

Timeline

Objectives

- Designated Observable Study Plan
- Aerosol - Cloud, Convection and Precipitation (A-CCP)
Participating

Participants:

- US government (NOAA, USGS)
- International (DLR, ESA)
- Academia (U. of Texas, U. South Florida, U. Colorado)
- ARCSGF, LARC study partners
- JPL, Study Lead (B. Blenkins, Study Coordinator)
- NASA - L. Tresser, MC HQ Lead

Mission

Mission Concept Review: June 2020 - Phase 3 - Architecture Design of top architecture, evaluation

Candidate(s): Phase 4 - Building block to mission architecture

Step 2021 - Delivery of final report and end of study:

- Examine (1) novel approaches considering emerging capabilities,
- Positioning, information, complex low-Power electronic techniques, such as small satellite buses, communications systems, and "dual" opportunities, and (2) innovative approaches and enabling opportunities,
- Develop and enhance existing architectures and capabilities.

Scope/implementation

-地球型 mass movement.
- Special 3D/4D processing (drought, hazards, agriculture, etc).
- Candidate Mission Architectures will maintain continuity of architectures and drag combustion systems.

Timeline:

- Identify and characterize a diverse set of high value MC observables.
- Perform sensitivity and system level analysis to determine requirements and establish an effective set of high value observables.
- Perform assessments of each of the studied architectures.
- Assess the cost effectiveness of each of the studied architectures.
- Focus the effort on the space craft(s).
- Fundamental approach that MC is observed through gravitational architecture to identify and determine priority observables.
Study Plan

Surface Biology and Geology (SBG) Designated Observable

Timeline

December 2019 - Final Report, Mission Concept Review

Phase 2 - Assessment of Potential Architectures for Cost

Scoping/Implementation

December 2019 to September 2021 - Assesment of candidates

December 2018 - Final Report, SBG Study Plan Funding

September 2018 - Initial SBG Final Report

August 2018 - Final SBG Workshop; Initial SBG Workshop

Phase 1 - Development of Candidate Architectures

Scope

Phase 3 - Design of Recommended SBG Architecture and Effective SBG Observations

Phase 4 - Preparation of End of Study Report

Participants

Phase 2 - Assessment of Potential Architectures for Cost

Phase 1 - Development of Candidate Architectures

Phase 0 - Preparation of Mission Concept Review Document

Industry

Academia

USGS, USDA, NOAA, etc. - Government Participants

GSFC, ARC, LARC, MSFC Study Partners

Study Coordinator - JPL/Jame Mesaril

H-Q - Turner, Phillips, Bontempi, Jerrett, Dorn SBG Leads

ESA, SRON, LAVCEI, etc. - International Participants

Objectives

Study Plan

- Develop concepts and design candidate architectures
- Explore domestic and international partnerships
- Explore systems design capabilities from questions
- Establish research and applications feasibility framework to derive the Decadal Survey and initial approaches for SBG looking to
- Establish research and applications questions for SBG looking to
Participates

Industry
Academic
USGS, NGA, NGA government participants
ARCO, ESFC, TFI, NGA, NGA study partners
JPL, Study Lead (P. Rosen, Study Coordinator)
NG Leads: P. Becceen, M. Marzillia, P. Stolzaker, P. Green

Phase 1 - Engage user communities to define requirements and science/applications of observables beyond geodesics in three
Include SAR-based architectures that support broader

Scope/Implementation
Reduce cost
Explore international partnerships to leverage capability and

Objectives

Phase 2a - Phase 1 study leading to mission concept refinement

Phase 3 - Conduct Mission Concept Review

Phase 4 - Final Report and MCR Prep

December 2023 - Conduct Mission Concept Review
October 2023 - Deliver Final Report
March 2023 - Complete design concept
March 2022 - Domestical to concept
March 2021 - Begin assessment of candidate architectures
March 2020 - Complete Requirements Definition
October 2019 - Complete Performance Tool Development
October 2018 - Study Kickoff

Timeline

Observables and Change
Surface Deformation and Change (SDC) designated

Surface Deformation and Change (SDC) designated
Framework for implementing Earth Venture (EVC) Continuity
The ESD objective will be to fly 3 EVC missions in the decade

-$1.50M total cost constraint

Interleaved with EY-Instrument - EYI or EVC solicitation every 18 months

Additional on-orbit acquisition will not be under the cost cap

Minimum demonstration period is 1 year beyond on-orbit commissioning

EVC will NOT address continuity beyond the demonstration

Payload classification will be Class C or D

Ease of technology infusion (optional)

Productivity

Accommodability

Cost of future copies

Capability of the instrument/characteristics of the data

Criteria for selecting an EVC Project:

ESD will use EVC to demonstrate a technique/approach for making long-term measurements

ESD Top-Level Approach to EVC
NASAs-owned RBL hardware made available to proposers as GFE

- Lifetime target
  Fall 2018: EVC-1 will allow right on JPPSS-3; will have extraordinary 5-year
  Preparing EVC solicitation for release Dec 2018 (draft AO for comment during
  Completed strand targeted for radiation budget sensor/RBL replacement
  Defined and accelerated implementation of Earth Venture Continuity

Targeted Solicitation: EVC-1
However, once we know what we want to do with the next EV/ESD, ESD will alert the community to our intentions.

- ESD will maintain the flexibility to pursue either of the above options, but it is expected that most will be single observation targeted.

- Target a set of observatories (e.g., solar irradiance, ozone, and CO2)

- Target a single observation for a given imperative (similar to EVC-1)

Future EVC Solicitations May:
Incubator Program (preliminary)
Plans for incubation program implementation continue to mature high during the next decade.

The incubation investment should achieve sufficient risk reduction to achieve readiness for space.

- Surface Topography and Vegetation (STAV)
- Planetary Boundary Layer (PBL) and
- Atmospheric Winds (AWW), also listed under ESE

Specific high-priority science (for 2027-2037 decade) of the 3 targeted observable areas:

Support maturation of mission, instrument, technology, and/or measurement concepts to address end-to-end time scales.

- Innovation fund to respond to emerging needs described as unexpected opportunities that occur on sub-
  - Suggested funding $20M/year maintaining innovation fund
  - Advancement prior to cost-effective implementation, including an innovation fund

A new program element, focused on investment for priority observation capabilities needing incubation as described in the DS.
<table>
<thead>
<tr>
<th>Measurement Requirements</th>
<th>With Seasonal Repeat</th>
<th>Aircraft</th>
<th>LIDAR (50m vertical accuracy from continuous in-sampling with 0.5m vertical accuracy from above)</th>
<th>Radar or LIDAR</th>
<th>High-resolution Global Topography and Surface Topography (STG)</th>
<th>Vegetation (pBL)</th>
<th>Boundary Layer Planetary Explorability</th>
</tr>
</thead>
<tbody>
<tr>
<td>km horizontal resolution</td>
<td>Temporal resolution of 20</td>
<td>Higher</td>
<td>DIAL lidar and lidar for PBL</td>
<td>Higher: Water Vapor Profiling and temperature and humidity collected for a full PBL (6.5% of total: 200 m vertical resolution from high-resolution and 2D/3D dimly resolved)</td>
<td>Moisture and heights</td>
<td>Temporal profiling of PBL temperature, moisture and AC throughout high vertical and horizontal resolutions of PBL.</td>
<td>2D PBL structure to understand the micrometeorological properties of the PBL.</td>
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<td>second)</td>
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</table>
Framework for implementing Earth Science Explorers (ESE)
**From the ESAS Report: Could potentially be addressed by a multi-function lidar designed to address ESE Observables, which includes both ESE Observables and Measurement Observables.**

<table>
<thead>
<tr>
<th>Candidate Measurement Approach</th>
<th>Active Sensing (Lidar, Radar, Scatterometry)</th>
<th>Passive Imaging of radiometery-based atmo. motion vectors</th>
<th>Measurement of trace gases (including water vapor, N2O, CO2, CH4, and O3), aerosols, and surface parameters</th>
<th>3D winds in troposphere/pl for transport of pollutants/carbon/erosal</th>
<th>3D Structure of terrestrial ecosystem including forest canopy and above-ground biomass and changes in above-ground carbon stock from growth and decay</th>
<th>Water Equivalent Snow Depth and Snow Water Equivalent</th>
<th>Vertical profiles of ozone and trace gases (including water vapor, CO, N2O)</th>
<th>Ocean Currents and Surface Winds</th>
<th>Ice Elevations</th>
<th>Greenhouse Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Lidar</strong></td>
<td><strong>Lidar</strong></td>
<td><strong>Lidar</strong></td>
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<tr>
<td></td>
<td><strong>Doppler Scatterometer</strong></td>
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<tr>
<td></td>
<td><strong>Candidate Measurement Summary</strong></td>
<td></td>
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</tbody>
</table>
Late in the decade, budget constraints may make it unlikely that Earth Science Explorer will be initiated until

New Earth System Explorers Program Office to be established developments

The first ESE solicitation will be planned for release no earlier than FY20, pending budget aspects of the DS-recommended ESD portfolio. ESD will encourage solicitations that address more than one ESE Observable and that support other

Subsequent ESE solicitations will likely restict primary observable topics on previous selections.

First solicitation will likely allow proposals for any observable from the DS Explorers list.

9-14 month Phase A prior to down-select.

$350M cost-capped, including launch services, observing systems/missions to be solicited.

ESE will use a two-step AO process, similar to mission solicitations in other SMD divisions.

Atmospheric Winds is eligible for DS Explorers Focus list - removed from Incubator list.
International

Earth observations

Policy: Existence of recent high-level US government policy guidance regarding

Innovation: Consider "new space" technology and business ideas

all others

Large Missions: Avoid having one recommended activity grow at expense of

Budget Resources: Align with planned budgets instead of aspirational

Missions

Prioritization Method: Prioritize science and applications instead of

Comparison to ESAS 2007
<table>
<thead>
<tr>
<th>Elements of Decadal Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pursue Ambitious Science, Despite Constraints</td>
</tr>
<tr>
<td>Expand Use of Collaboration</td>
</tr>
<tr>
<td>Explore External Trends in Technology and User Needs</td>
</tr>
<tr>
<td>Institutionalize Programmatic Agility and Balance</td>
</tr>
<tr>
<td>Leverage External Resources and Partnerships</td>
</tr>
<tr>
<td>Amplify the Cross-Benefit of Science and Applications</td>
</tr>
<tr>
<td>Commit to Sustained Science and Applications</td>
</tr>
<tr>
<td>Embrace Innovative Methodologies for Interdisciplinary Science/Applications</td>
</tr>
</tbody>
</table>

Advancing Leveraging Resources & Strategic Framework
Progress Since ESAS 2007

Finding 2A: The NASA ESD Program has

Finding 2B: NOAA progress during the decade was hampered by major

Finding 2C: The USGS has transformed the LandSat program via the Susustainable Land

Imagining (SLI) Program.
Three other mission program elements to accomplish this:

- Surface Deformation & Change
- Surface Biology & Geology
- Mass Change
- Clouds, Convection, & Precipitation
- Aerosols

Five that are specified/designed to be implemented:

**Observables**

- Program of Record with highest priority
- Augment the Program

**Observations**

- Surface dynamics, geological hazards and disasters
- Reducing climate uncertainty & informing societal response
- Sea level rise
- Extremes & improving weather and air quality forecasts
- Ecosystem change
- Cycles of the water and energy cycles

**Vision & Strategy**

- Highest priority objectives fall into six categories:
  - Address 35 key science/applications questions, from among hundreds
  - Highest priority objectives fall into six categories:
  - Surface dynamics, geological hazards and disasters
  - Reducing climate uncertainty & informing societal response
  - Sea level rise
  - Extremes & improving weather and air quality forecasts
  - Ecosystem change
  - Cycles of the water and energy cycles

**Science & Applications**

Quick Summary of Recommendations
<table>
<thead>
<tr>
<th>Surface Dynamics</th>
<th>Sea Level Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geocentric Hazards</td>
<td>Response</td>
</tr>
<tr>
<td>Initial Climate Uncertainty</td>
<td>Reduction Climate Uncertainty</td>
</tr>
<tr>
<td>Forecasts and Air Quality</td>
<td>Extending a Climate Change</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Apps to Topic</th>
<th>Science &amp; Applications Priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete set of Questions and Objectives in Table 3.3</td>
<td>Summary of Top Science and Applications Priorities</td>
</tr>
<tr>
<td>Ocean Ecosystem Structure</td>
<td>Environmental Changes</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Climate Change</td>
</tr>
<tr>
<td>Ecosystem Function</td>
<td>Sea Level Rise</td>
</tr>
<tr>
<td>Biogeochemical Cycles</td>
<td>Coral Bleaching</td>
</tr>
</tbody>
</table>

**Observing System Priorities**

- **Objective**: Monitoring and observing key ocean properties to address two of the Ocean Acidification
- **Methods**: Remote sensing, in-situ measurements, modeling
- **Areas of Focus**:
  - Ocean Currents
  - Ocean Acidification
  - Ocean Waves

**Candidate Measurement**

- **Approach**: Remote sensing, in-situ measurements, modeling
- **Targeted Observations**: Ocean Currents, Ocean Acidification, Ocean Waves

**Key Ocean Properties**

- Ocean Currents
- Sea Level Rise
- Coral Bleaching
- Ocean Waves
- Ocean Acidification
- Ocean Currents
- Ocean Acidification
- Ocean Waves