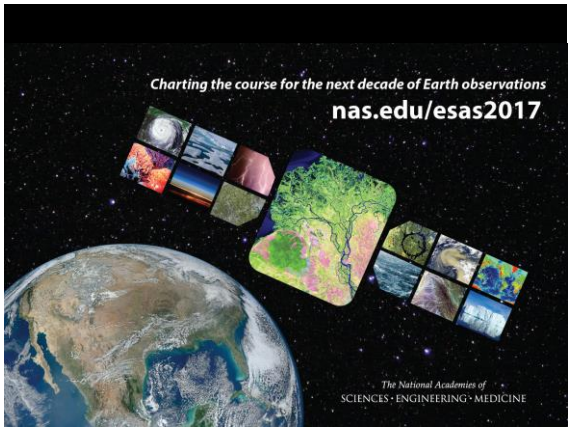


The National Academies of
SCIENCES • ENGINEERING • MEDICINE

ESAS 2017: The 2017-2027 Decadal Survey for Earth Science and Applications from Space

Art Charo, Ph.D.
Senior Program Officer &
ESAS 2017 Study Director
Space Studies Board

2016 AMS Washington Forum

Why Undertake a Decadal Survey?

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

Facilitates Planning, Coordination, Advocacy, and Outreach

Decadal Surveys Provide a Better Vehicle for Building Consensus

Supports a process that is less prone to single-point failure …

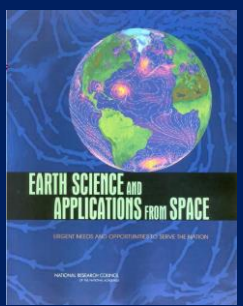
Praying for Barbara Mikulski

ESAS 2007, the Inaugural Decadal Survey

Advancing Earth System Science to Benefit Society

"Understanding the complex, changing planet on which we live, how it supports life, & how human activities affect its ability to do so in the future is one of the greatest intellectual challenges facing humanity. It is also one of the most important for society as it seeks to achieve prosperity & sustainability."

-- Interim Report of the Decadal Survey, April 2005



Scientific and Societal Challenges

- **Ice sheets and sea level.**
  - Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur? What will be the time patterns of sea level rise as a result?
- **Large-scale and persistent shifts in precipitation and water availability.**
  - Will droughts become more widespread in the western US, Australia, and Sub Saharan Africa? How will this affect the patterns of wildfires? How will reduced amounts of snowfall change the needs for water storage?
- **Transcontinental air pollution.**
  - How will continuing economic development affect the production of air pollutants, and how will these pollutants be transported across oceans and continents? How are these pollutants transformed during the transport process?
- **Shifts in ecosystem structure and function in response to climate change.**
  - How will coastal and ocean ecosystems respond to changes in physical forcing, particularly those subject to intense human harvesting? How will the boreal forest shift as temperature and precipitation change at high latitudes? What will be the impacts on animal migration patterns and invasive species?
- **Human health and climate change.**
  - Will previously-rare diseases become common? How will mosquito-borne viruses spread with changes in rainfall and drought? Can we better predict the outbreak of avian flu? What are the health impacts of an expanded "Ozone Hole" that could result from a cooling of the stratosphere, which would be associated with climate change?
- **Extreme events, including severe storms, heat waves, earthquakes and volcanic eruptions.**
  - Will tropical cyclones and heat waves become more frequent and more intense? Are major fault systems nearing release of stress via strong earthquakes?

7

Organization of ESAS 2007

- Steering Committee (18 members)
  - 7 Thematically-Organized Study Panels (each ~ 12)

Panel on Weather (including "chemical weather")

- Susan Avery, chair
- Tom Vonder Haar, vice-chair
- Edward Browell, NASA LaRC
- William Cade, Air Force Weather
- Brad Colman, NWS Seattle
- Jenni Evans, Penn State
- Eugenia Kalnay, Univ. of Maryland
- Roger Pielke, Jr., Univ. of Colorado
- Christopher Ruf, Univ. of Michigan
- Carl Schueler, Raytheon Santa Barbara Research Center
- Jeremy Usher, Pres. and CEO of Weathernews Americas
- Chris Velden, Univ. of Wisconsin
- Robert Weller, WHOI

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2007 Survey Final Report

- Overarching recommendation to the sponsors, NASA, NOAA, USGS: *Renew investment in satellite Earth observing systems*
- Recommended specific, integrated mission suite
  - Rolled-up panel recommendations preserve highest priorities
  - Sequenced 2010-2020+ launches
  - Full execution of the plan over the decade required NASA ESD yearly budgets to increase by ~ $550M and remain steady at this level (~ equal to the budget in 2000)
- Guidance on actions in the event of budget/technology problems

Recommendations build on current instruments & offer a new level of integration to address key science & yield critical societal benefits

Media Coverage

- Front page above the fold Wash Post
- Sunday New York Times Lead Op-Ed, "Blinding Ourselves in Space"
- Editorial in Washington Post and other papers
- Articles in Science Magazine, Nature, Eos, IEEE, others
- Picked up by wire services (AP, Reuters) and stories carried nationwide

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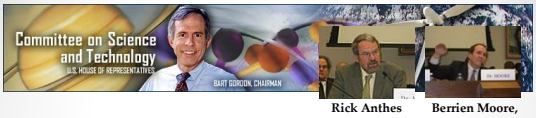
Immediate Congressional Reaction



Rick Anthes Survey Co-chair — **Berrien Moore,** Survey Co-chair

"When accurate weather forecasting & climate research is increasingly important to the well-being of our citizens, this distinguished panel of experts is warning in no uncertain terms that '*the United States' extraordinary foundation of global observations is at great risk.*"

"I don't think the National Academies could be clearer voicing its concern over the current state of affairs," added **Chairman Gordon**. "It's not easy to find the money, but given the consequences of inaction, we must try."

13 February 2007

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ESAS 2017—Overarching Tasks

- Assess progress in addressing the major scientific and application challenges outlined in the 2007 Earth Science Decadal Survey.
- Develop a prioritized list of top-level science and application objectives to guide space-based Earth observations over a 10-year period commencing approximately at the start of fiscal year 2018 (October 1, 2017).
- Identify gaps and opportunities in the programs of record at NASA, NOAA, and USGS in pursuit of the top-level science and application challenges—including space-based opportunities that provide both sustained and experimental observations.
- Recommend approaches to facilitate the development of a robust, resilient, and appropriately balanced U.S. program of Earth observations from space. Consider: Science priorities, implementation costs, new technologies and platforms, interagency partnerships, international partners, and the *in situ* and other complementary programs carried out at NSF, DoE, DoA, DoD.

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ESAS 2017 vs. ESAS 2007

- No longer appropriate to base recommendations on an aspirational budget
- Science-based vs. Mission-based
- Congressionally-mandated independent cost appraisal and technical evaluation (CATE) for big ticket items
- Likely that the science will be "valued" to avoid having one recommended activity grow at expense of all others
- Increased opportunities to consider "new space" ideas—new players, smaller and less costly platforms, constellations, hosted payloads
  - -- Challenge: developing *credible* evaluations of their potential
- Improved consideration of international partners
- Existence of high-level guidance regarding Earth observations: NASA Climate-centric Architecture; OSTP National Strategy for Civil Earth Observations (2014); 2nd National Earth Observation Assessment

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ESAS 2017 Steering Committee

Dr. Waleed Abdalati, Co-Chair
University of Colorado Boulder

Dr. Antonio Busalacchi, Co-Chair
University of Maryland

Mr. Steven J. Battel
Battel Engineering

Dr. Stacey W. Boland
Jet Propulsion Laboratory

Dr. Robert D. Braun
Georgia Institute of Technology

Dr. Shuyi S. Chen
University of Miami

Dr. William E. Dietrich
University of California, Berkeley

Dr. Scott C. Doney
Woods Hole Oceanographic Inst.

Dr. Christopher B. Field
Carnegie Institution for Science

Dr. Helen A. Fricker
Scripps Inst. of Oceanography

Dr. William B. Gail
Global Weather Corporation

Dr. Sarah T. Gille
Scripps Inst. of Oceanography

Dr. Dennis L. Hartmann
University of Washington

Dr. Anthony C. Janetos
Boston University

Dr. Everette Joseph
University at Albany, SUNY

Dr. Molly K. Macauley
Resources for the Future

Dr. Joyce E. Penner
University of Michigan

Dr. Soroosh Sorooshian
University of California, Irvine

Dr. Graeme L. Stephens
Jet Propulsion Laboratory

Dr. Byron D. Tapley
The University of Texas at Austin

Dr. W. Stanley Wilson
NOAA/NESDIS, Ret.

Steering Committee Staff

Dr. Arthur Charo, Study Director
Ms. Lauren Everett, Program Officer
Mr. Charles Harris, Research Associate
Dr. Michael Moloney, Director, Space Studies Board

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ESAS 2017 Study Panels

I. Global Hydrological Cycles and Water Resources
The movement, distribution, and availability of water and how these are changing over time

II. Weather and Air Quality: Minutes to Subseasonal
Atmospheric Dynamics, Thermodynamics, Chemistry, and their interactions at land and ocean interfaces

III. Marine and Terrestrial Ecosystems and Natural Resource Management
Biogeochemical Cycles, Ecosystem Functioning, Biodiversity, and factors that influence health and ecosystem services

IV. Climate Variability and Change: Seasonal to Centennial
Forcings and Feedbacks of the Ocean, Atmosphere, Land, and Cryosphere within the Coupled Climate System

V. Earth Surface and Interior: Dynamics and Hazards
Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate

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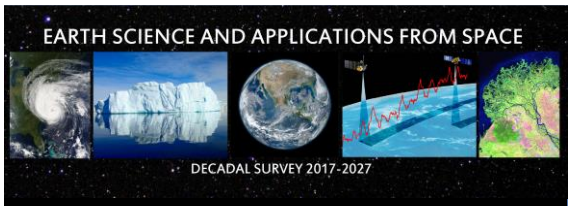

Survey Website: www.nas.edu/esas2017
Survey Mailbox: esas2017@nas.edu

Comments Welcome!

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BACKUP SLIDES

ESAS 2017 Timeline

- Provision of funds/formal start — August 17, 2015
- Appointment of survey chairs — August 20, 2015
- First RFI (ESS objectives) — September 28, 2015
- Steering Committee (SC) approved — December 2, 2015
- Panels appointed — by end of March 2016
- Town Halls: AGU, AMS, **Ocean Sciences** — Dec. 14th, Jan. 13th, and **Feb. 22nd**
- First meeting of the SC — January 18-20, 2016 in DC
- 2nd RFI (targets/measurement approaches) — May 15, 2016
- SC Meetings 2-4 — June – December 2016
- SC Meetings 4-6 — by end of April 2017
  - Additional splinter meetings likely
- Panel Meetings, all held with SC — 3 in 2016; 1st targeted for June 3-5
- Panel Outputs to Steering Committee — NLT January 2017
- **Pre-Pub Report approval** — **NLT July 31, 2017**

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ESAS 2017 Panels

WORKING GROUPS (Tentative)						
	Carbon Cycle Integrating Theme	Global Hydrological Cycles	Weather: Minutes to	Marine & Terrestrial	Climate Variability and Change	Earth Surface & Interior
	Water Cycle Integrating Theme	& Water Resources	Sub-seasonal	Eco-systems		
	Extreme Events Integrating Theme					
	Technology & Innovations Cross-Cut					
	Applications' Science Cross-Cut					

Agency Sponsors/Backdrop for ESAS 2017

- **NASA**: Has a backlog of missions recommended in the inaugural survey and increased responsibility—without commensurate budget increases— starting after the JPSS-1 era for vertical profiles of stratospheric and upper tropospheric ozone, solar irradiance, Earth radiation budget measurements, and altimetry (beyond Jason-3).
- **NOAA**: Stabilizing the weather satellite portfolio and avoiding a potential gap between the NPP spacecraft and the first of the next-generation POES systems, JPSS-1, is a top priority. "Climate"-related instruments moving to NASA.
- **USGS**: Landsat-8 launched Feb. 2013. USGS interested in future capabilities for a sustained land-imaging imaging program. However, Landsat-9 is projected to be a near-rebuild of L-8 for launch in in 2023. (TIRS on L-8 only has 3-year design life; NASA looked at Class-D TIR free-flyer for 2019 launch, but Senate & House have rejected this option and instead ask for acceleration of launch date of L-9.)

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Responding to the Statement of Task

- NASA: The committee will pay particular attention to prioritizing and recommending balances among the full suite of Earth system science research, technology development, flight mission development and operation, and applications/capacity building development conducted in the Earth Science Division (ESD) of the Science Mission Directorate.
- NOAA: The decadal survey recommendations will be framed around national needs. The survey will consider which scientific advances are needed to add to NOAA's future predictive capabilities, including the development of extended and diversified forecasts.

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What Happens to Missions Recommended in the Previous Survey?

TBD, but:

- In developing its recommendations, survey to "include reconsideration of the scientific priorities associated with the named missions from the 2007 decadal survey."
  - The 2007 survey did not prioritize among the 15 missions for NASA; placement in 1 of 3 time periods (Tiers I, II, III: 2010-13, 2013-2016, 2016-2020) based on factors including technical readiness; cost; synergy with existing, planned, or recommended missions; and consideration of int'l activities.
- ESD has expressed an interest in having the survey provide guidance on technology investments that will be needed to address recommended science targets.
- Previous surveys treated missions in formulation as part of the baseline program of record—they were not prioritized.

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Decadal Surveys and the NASA Authorization Acts of 2005 and 2008

2005

- "The Administrator shall develop a plan to guide the science programs of NASA through 2016 . . . In developing the plan . . . the Administrator shall draw on decadal surveys . . . developed by the [NAS/NRC]."
- "The performance of each division in the Science directorate shall be reviewed and assessed by the [NAS/NRC] at 5-year intervals."

2008

- "The Administrator shall enter into agreements on a periodic basis with the [NAS/NRC] for independent assessments, also known as decadal surveys, to take stock of the status and opportunities for Earth and space science . . . and to recommend priorities for research and programmatic areas over the next decade."
- "The agreement . . . shall include independent estimates of the life cycle costs and technical readiness of missions assessed in the decadal surveys whenever possible."
- "The Administrator shall request that each [NAS/NRC] decadal survey committee identify any conditions or events, such as significant cost growth or scientific or technological advances, that would warrant NASA asking the [NAS/NRC] to reexamine the priorities that the decadal survey has established.

Agency-Specific Tasks-I

NASA

- Recommend NASA research activities to advance Earth system science and applications by means of a set of prioritized strategic "science targets" for the space-based observation opportunities in the decade 2018-2027. (A science target in this instance comprises a set of science objectives that could be pursued and significantly advanced by means of a space- based observation.) ..... For each science target, the committee will identify a set of objectives and measurement requirements/capabilities for space-based data acquisitions.

  If appropriate and usually only for recommendations associated with major investments, the committee will (via a "CATE" process) assemble notional proof-of-concept missions with the recommended capabilities in order to better understand the top-level scientific performance and technical risk options associated with mission development and execution.

- Other NASA tasks include: The committee will pay particular attention to prioritizing and recommending balances among the full suite of Earth system science research, technology development, flight mission development and operation, and applications/capacity building development conducted in the Earth Science Division (ESD) of the Science Mission Directorate.

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Agency-Specific Tasks-II

NOAA & USGS

- The decadal survey committee's recommendations will be framed around national needs, including, but not limited to research priorities. …. Recommendations may be organized around 1) how new technology may enhance current operations, and 2) what new science is needed to expand current operations, either to enable new capabilities or to include new areas of interest. In making these recommendations, the committee will consider the need to bridge current operations and support a viable path forward for the uninterrupted delivery of public services through these generational changes.

- Other tasks include: suggest approaches for evaluating and integrating new capabilities from non traditional suppliers of Earth observations; may offer recommendations concerning "research to operations" (or "innovation for continuity and service improvements across agencies"); and consider the agencies' ability to replicate existing technologies to improve and sustain operational delivery of public services.

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Survey Initial RFI

responses at: www.nas.edu/esas2017

Issued in late September 2015 to inform the steering committee and the organization of the panels:

1. What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?
2. Why are these challenge/questions timely to address now especially with respect to readiness?
3. Why are space-based observations fundamental to addressing these challenges/questions?

> 200 Responses!

26

RFI Responses

Applications
- Integrating satellite data and methods for analysis into weather monitoring strategy
- Using private satellite companies' technologies to enhance monitoring and modeling capabilities
- Using scientific innovation from satellite remote sensing data to trigger durable and robust applications that do not require long-term incubation or external support

Atmospheric Sciences and Atmospheric Chemistry
- Monitoring change/trends in Stratospheric Temperature
- Cloud influences on climate change
- Human health relating to penetration of harmful UV radiation into atmosphere
- Air quality management, particularly urban population centers and in tropical/sub-tropical regions
- Characterizing aerosol masses

Biogeochemical Cycles
- Fire impacts on the carbon and water cycles and ecosystems
- Tracking methane emissions
- Measuring reactive Nitrogen
- Composition-Resolved Particulate Matter Monitoring for assessing Health Impacts Associated with Specific Pollution Sources
- Routine Planetary Boundary Layer Measurements

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RFI Responses, cont'd

Climate Variability and Change
- Impact on global ecosystems, biogeochemical cycles, resource sustainability, and human welfare
- Outlining integrated set of quantified, definitive measurements of change that will continue
- Making spaceborne measurements to quantify decadal scale climate trends for major regions
- Establishing a global benchmark of current climate from space
- Integrating near-real time monitoring tools into national climate adaption plans and mitigation strategies

Land-Use Change and Ecosystem Dynamics
- Improving remote sensing to measure fire impacts
- Measuring impact of industrial agriculture on local and global climate variability
- Identifying vegetation/fuel conditions and understanding changing fire regimes
- Using satellite data to avoid crop failure, pest outbreaks, and disease for small-holder farms
- Monitoring Global Forest Structure and Biomass from space

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RFI Responses, cont'd

Ocean Sciences
- Establishing new satellite observations to observe climate change effects on oceans
- Consistent decadal climate data record for ocean heat content products
- Near-shore salinity measurements
- Sea-level rise
- Sea surface temperatures
- Ocean-atmosphere coupling (wind/current coupling)

Polar Sciences and Cryosphere
- Decadal variability observed in 20th century changing to weak inter-annual changes
- Measuring speed of sea and land ice progress (melt and melt volume) and sensitivity to climate and ocean forcing
- Snow accumulation and mass redistribution processes, impacts on snow-atmosphere heat and chemical exchange from the ice sheet, sea ice, and ocean
- Assessing feedback loop contributions to cryosphere albedo, its contribution to climate change
- Arctic clouds reaction to expected sea ice-free Arctic summers, Arctic reaction to cloud changes

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RFI Responses, cont'd

Solid Earth Hazards and Dynamics
- Current geophysical changes happening on and within earth, their impacts on society
- Improving disaster Early Warning Systems and prediction of volcanic hazards
- Metrics of surface change prior to and after catastrophes or other unique events
- Assessing Earthquake Hazard
- Constraining Models of Interacting Fault Systems in Active Tectonic Zones
- Geodetic Imaging to Improve Hazard Analysis
- Impacts of Volcanic Eruptions on Climate and Atmospheric Chemistry

Technology
- Combining observational power of many Earth observing satellite missions (current and future)
- Adding a "Micro" Satellite program in the size range of 1 kg to 100 kg
- Constellation approaches to assessing earth radiation imbalance
- Using solar sails to create artificial LaGrange points for polar observations

30

RFI Responses, cont'd

Water Resources and Global Hydrological Cycle

- Sustainable use of marine and coastal resources
- Water cycle changes and relation to climate change
- Changes to marine ecosystems (coastal and inland)
- Availability of surface and underground water resources
- Freshwater quality/quantity changes in response to population growth and climate change
- Upcoming drought patterns, impact on wildlife and agriculture production

Weather Science and Applications

- Frequency and intensity of severe weather events
- Scientist access to free, higher resolution satellite datasets
- Fostering demand and market driven innovation, reflecting proprietary technology dev.
- Sea surface air pressure measurements for reliable longer-term storm predictions

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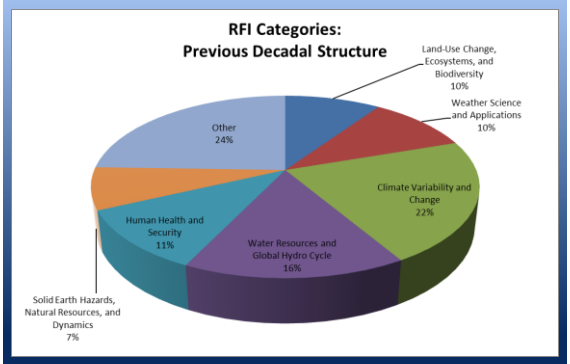

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RFI #2

"We now invite you to submit ideas for specific science and applications targets (i.e. objectives) that promise to substantially advance understanding in one or more Earth System Science themes…Submitted ideas will be reviewed by one or more of the survey's study panels, which are organized to address the above-mentioned themes. Suggested targets that are cross-cutting among these themes are particularly encouraged. **Submissions should also identify the key geophysical variables/measurements, and the observational requirements, needed to address the science and application targets**.

We anticipate that some of the targets, and their associated measurements, recommended by the Panels will be selected by the Steering Committee for detailed technical and cost analysis of potential implementation architectures. **To assist those efforts, you are encouraged to provide information on measurement approaches, including technical, performance and maturity/heritage specifications, for relevant current and near-future instrumentation.**"

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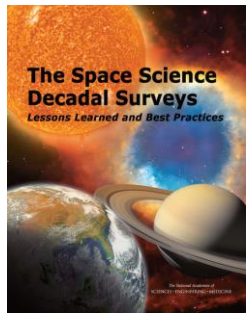

COMMITTEE ON SURVEY OF SURVEYS: LESSONS LEARNED FROM THE DECADAL SURVEY PROCESS

ALAN DRESSLER, Observatories of the Carnegie Institution for Science, Chair
DANIEL N. BAKER, University of Colorado Boulder
DAVID A. BEARDEN, The Aerospace Corporation
ROGER D. BLANDFORD, Stanford University
STACEY W. BOLAND, Jet Propulsion Laboratory
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ANTHONY C. JANETOS, Joint Global Change Research Institute
STEPHEN J. MACKWELL, Lunar and Planetary Institute
J. DOUGLAS MCCUISTION, X-energy, LLC
NORMANL H. SLEEP, Stanford University
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MICHAEL H. MOLONEY, Director, Space Studies Board

http://www.nap.edu/
Search for report 21788

About the Study

- Follow-on to the November 2012 Workshop "Lessons Learned in Decadal Planning in Space Science"
- Collects lessons learned from planetary, heliophysics, astronomy & astrophysics, and Earth science experiences with decadal surveys and mid-term assessments
- Written with future survey committees in mind
  - "Handbook" approach
  - Time-ordered discussion with collection of lessons learned and best practices as an appendix

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A Framework for Analyzing the Needs for NASA-Sustained Remote Sensing Observations of the Earth: Background

- NASA's Earth Science Division (ESD) faces difficult choices among competing priorities, including new responsibilities, without commensurate budget increases, for the continuation of existing measurements and developing new measurement capability to address new research priorities
- The problem is compounded by responsibility for existing missions from:
  - *Foundational Continuity Measurements*: Stratospheric and Upper Tropospheric Ozone (OMPS-L), Solar Irradiance (TSIS), Earth Radiation Budget (CERES), and Ocean Altimetry (Jason-3 FO)
  - *2010 Climate Architecture*: Global Temporal Mass Change(GRACE –FO, Polar Ice Mass Change(ICESat-2), Ocean Color and Clouds/Aerosols (PACE), Ozone and Aerosols(SAGE III) and Atmospheric CO_2(OCO-2)
  - *Federal Concerns:* Landsat Data Continuity (Landsat-8 FO)
- In 2013, at the request of the ESD, an ad hoc committee of the Academies was convened to recommend a framework for deciding when an ESD measurement or dataset should be collected for extended periods.

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STUDY COMMITTEE

BYRON D. TAPLEY, Univ. of Texas at Austin, Chair
MICHAEL D. KING*, Univ. of Colorado, Boulder, Vice Chair
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STEVEN A. ACKERMAN*, University of Wisconsin, Madison
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RANDALL R. FRIEDL, Jet Propulsion Laboratory
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KATHRYN A. KELLY, University of Washington
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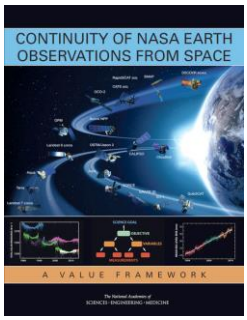
Staff

ARTHUR A. CHARO, Senior Program Officer, Study Director
LEWIS B. GROSWALD, Associate Program Officer

* Represents members of CESAS, the oversight committee for the decadal survey



http://www.nap.edu/catalog/21789/continuity-of-nasa-earth-observations-from-space-a-value-framework

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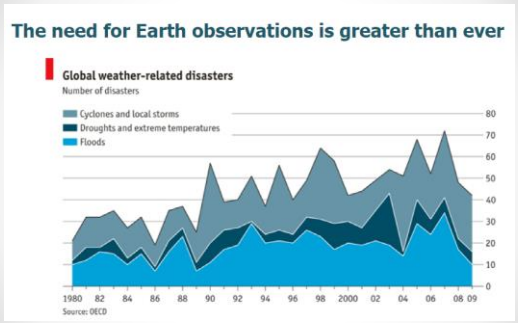

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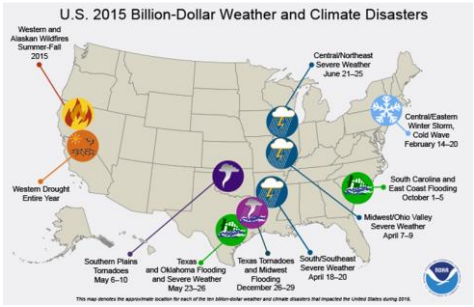

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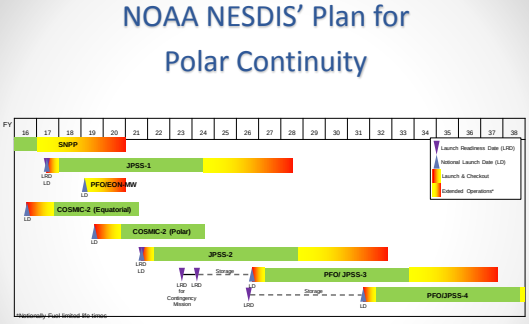

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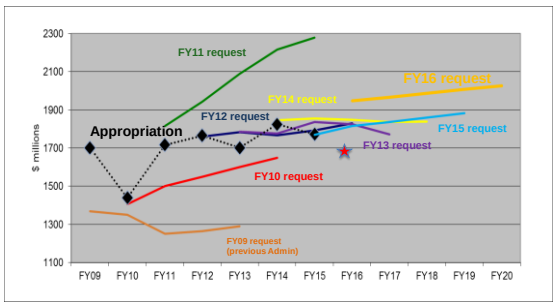
Earth Science Budget: FY16 Request/FY15 Appropriation



★ FY16 House CJS Appropriations mark

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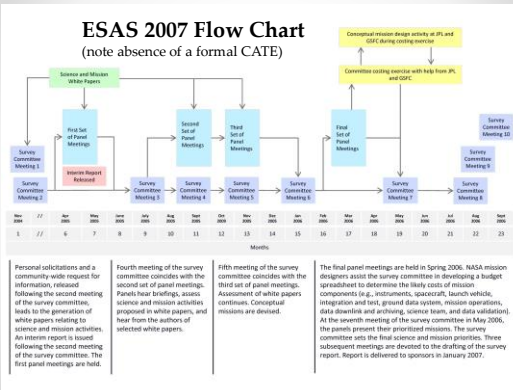

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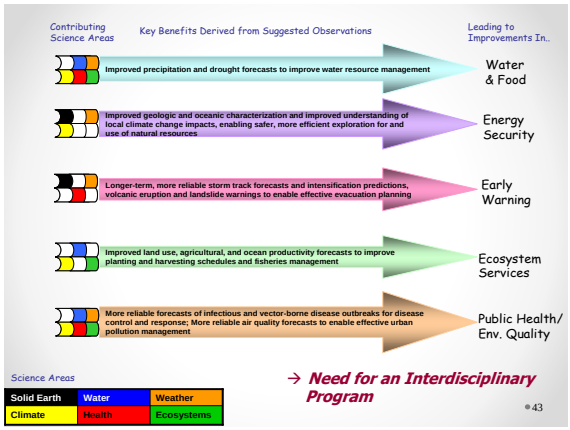

Study Panels for ESAS 2007

1. Earth Science Applications and Societal Needs
   - » Tony Janetos, PNL/Univ. of Maryland, chair
   - » Roberta Balstad, Columbia Univ, vice-chair
2. Land-use Change, Ecosystem Dynamics and Biodiversity
   - » Ruth DeFries, Columbia, chair
   - » Otis Brown, Univ. of Miami, vice-chair
3. Weather (including space weather and chemical weather)
   - » Susan Avery, Univ. of Colorado, chair
   - » Tom Vonder Haar, Colorado State, vice-chair
4. Climate Variability and Change
   - » Eric Barron, Penn State, chair
   - » Joyce Penner, Univ. of Michigan, vice-chair
5. Water Resources and the Global Hydrologic Cycle
   - » Dennis Lettenmaier, Univ. of Washington, chair
   - » Anne Nolin, Oregon State Univ., vice-chair
6. Human Health and Security
   - » Mark Wilson, Univ. of Michigan, chair
   - » Rita Colwell, Univ. of Maryland, vice-chair
7. Solid-Earth Hazards, Resources and Dynamics
   - » Brad Hager, MIT, chair
   - » Susan Brantley, Penn State, vice-chair

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Charge to Panels

1. Identify needs and opportunities for observations from space to advance Earth science and applications for the next decade and beyond;
2. Propose programs or missions to meet these needs and opportunities, in priority order;
3. Describe each proposed mission in terms of
   - Contributions to science and applications
   - How it meets prioritization criteria
   - Benefits to society
   - Technical aspects
   - Schedule
   - Costs
4. Briefly identify needs for obs that are needed to complement space-based obs
5. Identify essential other components (telemetry, data processing, management and stewardship

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Steering Committee's Criteria for Prioritization

- Contributes to the most important scientific questions facing Earth sciences today (scientific merit-discovery, exploration);
- Contributes to applications and policy making (societal benefits);
- Contributes to long-term observational record of the Earth;
- Complements other observational systems, including national and international plans;
- Affordable (cost considerations, either total costs for mission or costs per year);
- Degree of readiness (technical, resources, people);
- Risk mitigation and strategic redundancy (backup of other critical systems);
- Makes a significant contribution to more than one thematic application or scientific discipline.

Above not in priority order

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FINAL REPORT

- Recommends a Path Forward that Restores US Leadership in Earth Science and Applications and Averts the Potential Collapse of the System of Environmental Satellites
- Presents an Integrated Suite of Missions
  - Panel recommendations rolled-up
  - Missions sequenced
  - Overall cost matched to anticipated resources plus reasonable growth
- Highest Priorities of Each Panel Preserved
- Some Guidance on How To Handle Budget or Technology Development Problems

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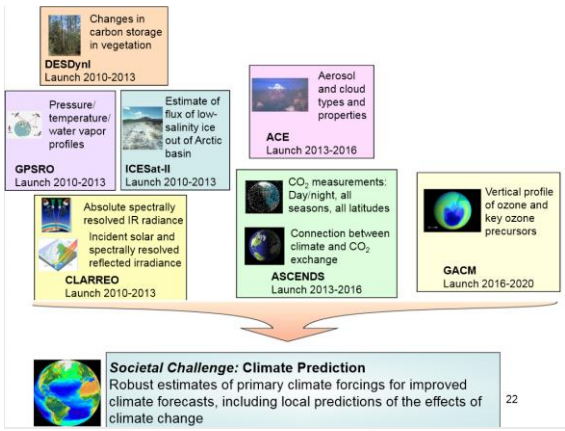

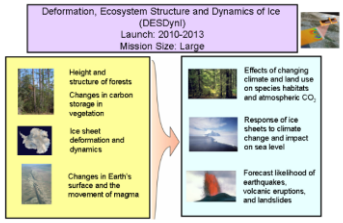

Mission and Payload: This mission combines two sensors that, taken together, provide observations important for solid-Earth (surface deformation), ecosystems (terrestrial biomass structure) and climate (ice dynamics). The sensors are: 1) an L-band Interferometric Synthetic Aperture Radar (InSAR) system with multiple polarization, and 2) a multiple beam lidar operating in the infrared (~ 1064 nm) with ~ 25 m spatial resolution and 1 m vertical accuracy. The mission using InSAR to meet the science measurement objectives for surface deformation, ice sheet dynamics, and ecosystem structure has been extensively studied. It requires a satellite in 700-800 km sun-synchronous orbit in order to maximize available power from the solar arrays. An eight day revisit frequency balances temporal decorrelation with required coverage. Onboard GPS achieves cm-level orbit and baseline knowledge to improve calibration. The mission should have a 5 year life time to capture time-variable processes and achieve measurement accuracy.

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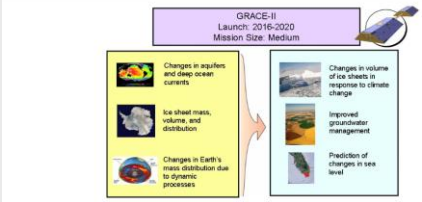

GRACE-II would provide information about variations in groundwater storage at spatial resolutions sufficient to help improve resource characterization and management in those portions of the world (which include most underdeveloped countries) where groundwater is not actively managed. A more indirect benefit will be improved characterization of water storage in the subsurface, which affects weather and climate model estimates of water recycling to the atmosphere, and hence precipitation prediction at both weather and climate time scales. At present, the dynamics of water storage in surface soils vs. deeper storage as groundwater is not discriminated in land surface models, as there is little observational basis for doing so. Hence, essentially all variations in subsurface storage are attributed to soil moisture, and the lower frequency variations associated with groundwater are ignored. GRACE-II data would help foster a new generation of land surface models, which would better represent subsurface moisture variations, and, in turn, the recycling of moisture to the atmosphere.

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