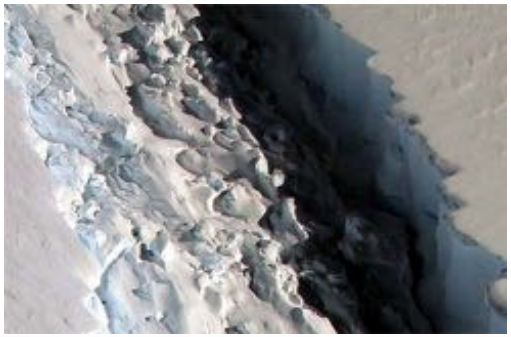
SCIENCE

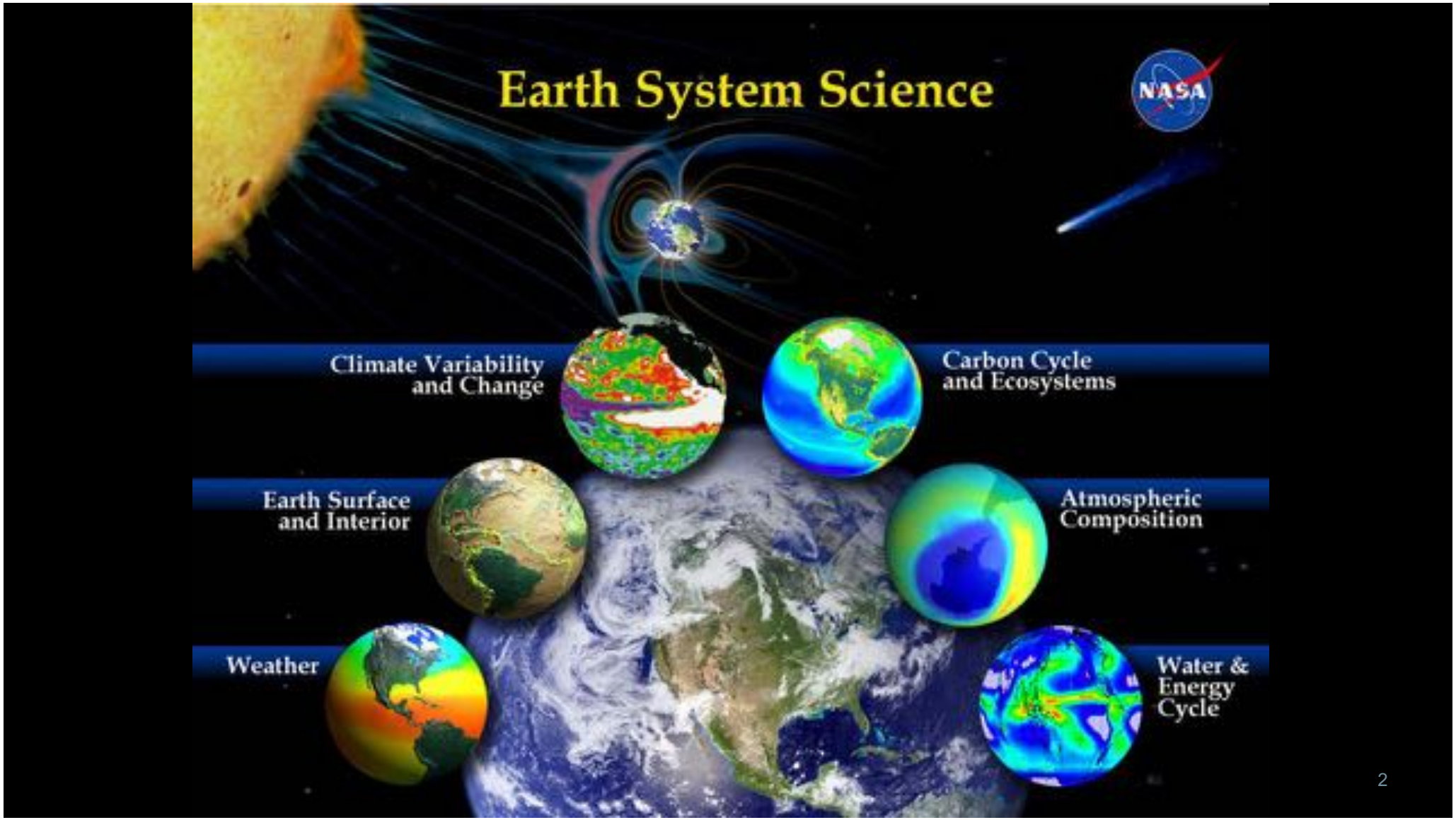





NASA Earth Science, Carbon Cycle & Ecosystems

Kathy Hibbard
CC&E FA Lead
Earth Science Division

March 27, 2018


Earth System Science
NASA
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

Outline

- FY18, FY19 Appropriation Status
- 2017 *Earth Science and Applications from Space* Decadal Survey
- *ESD Leadership Approach to Decadal Implementation*
- *CC&E Priorities in Research Opportunities: Past and Present*

NASA/ESD Funding/Appropriation: FY18; FY19

- **23 March 2018 Omnibus** was signed per Senate Appropriations at $**1.92B**, restoring DSCOVR, OCO-3, PACE, CLARREO-PF, called for RBI schedule/cost study, and was silent on the Carbon Monitoring System

- For FY18, R&A is down a little from ‘17 and down more from ‘16 which was a good year.

- Overall impact of FY19 President’s Budget Proposal unclear based on Congressional Approps for FY18 – As of now, we lose $13M in ‘20 and $17m in ‘21

2017 Decadal Survey Snapshot

- Publicly released January 5, 2018
- Supports the ESD (and international) Program of Record
- Prioritized observations rather than specific missions
- Emphasis on competition
- Explicitly allows implementation flexibility – encourages competition as cost-control method
- Explicitly notes value of, and encourages, international partnerships
- Endorsed existing balances in ESD portfolio

2017 Decadal Survey Snapshot (cont.)

- Identified 5 ”Designated” observables for mandatory missions (*Aerosols; Clouds, Convection, & Precipitation; Mass Change*; *Surface Biology & Geology; Surface Deformation & Change)*
- Called for cost-capping on essentially all missions
- Introduced a new competed “Explorer” flight line with $350M cost constraint, 3 observables to be chosen by ESD from among 6 identified
- Recommended “Continuity Measurement” strand ($150M full mission cost cap) for existing Venture-class program
- Called for “Incubator Program” between Technology, R&A, and Flight to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal)
- ***ESD will conduct focused community forums for 12-18 months to translate the recommendations into an executable program and, for Flight, a portfolio of specific, realistic, launch-ordered missions and solicitations.***
  - With 15 - 20 missions/instruments now in development for launch before 2023, **Decadal budget wedge does not begin to open up until late FY21**; if appropriation is constrained to PBR levels, most decadal mission/new program recommendations will be unexecutable after 2023.

Observing System Priorities

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their direct and indirect effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, & Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology & Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation & Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	**CO_2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of source types	Multispectral short wave IR and thermal IR sounders; or lidar**		X	
Ice Elevation	**Global ice characterization** including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction	Lidar**		X	
Ocean Surface Winds & Currents	**Coincident high-accuracy currents and vector winds** to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.	Radar scatterometer		X	

Ozone & Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO_2, methane, and N_2O) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth & Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Radar (Ka/Ku band) altimeter; or lidar**		X	
Terrestrial Ecosystem Structure	**3D structure of terrestrial ecosystem** including forest canopy and above ground biomass and changes in above ground carbon stock from processes such as deforestation & forest degradation	Lidar**		X	
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			X
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar**			X

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

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

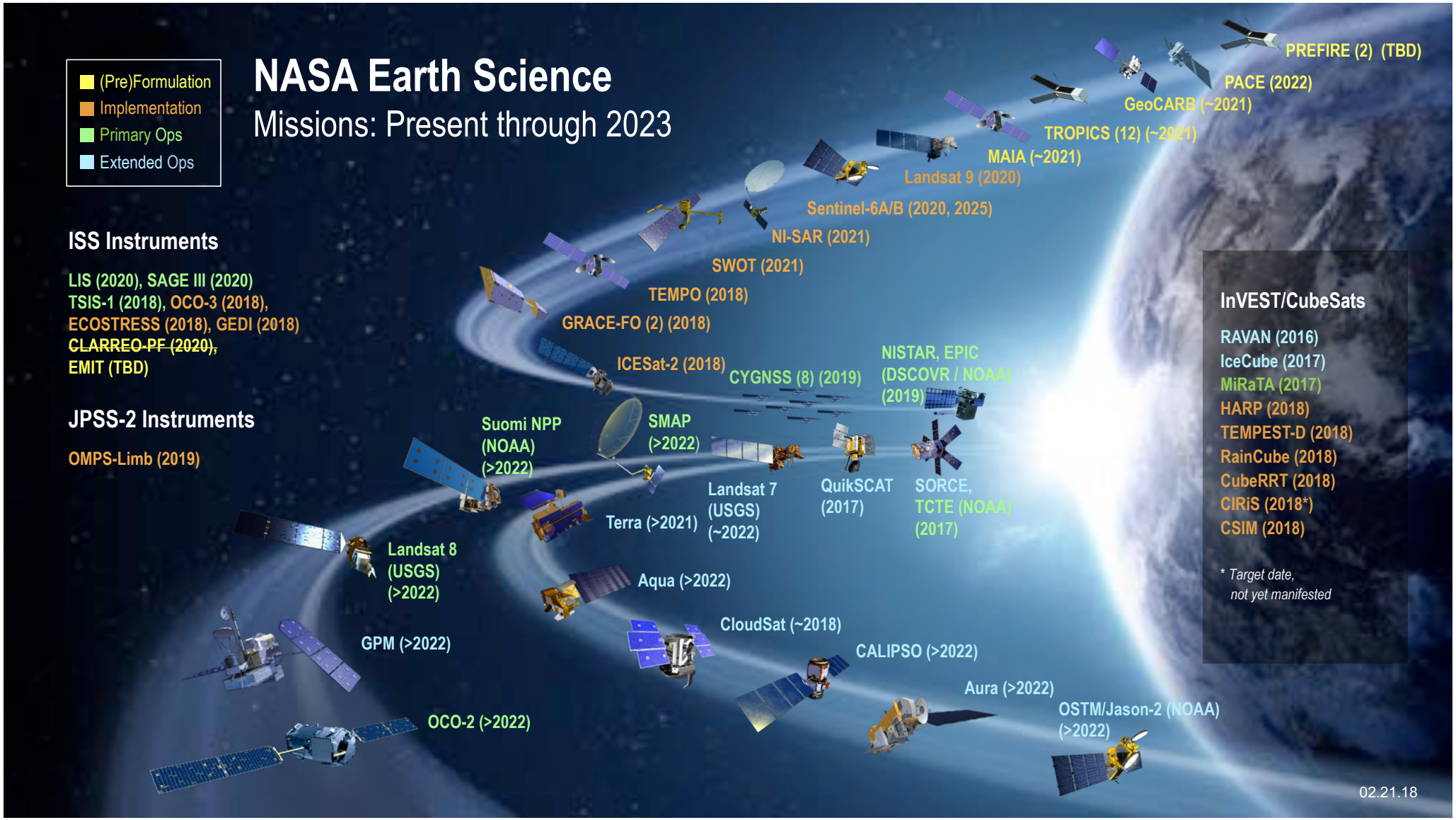
Aquatic Biogeochemistry	Radiance Intercalibration
Magnetic Field Changes	Sea Surface Salinity
Ocean Ecosystem Structure	Soil Moisture

On-going Decadal Strategy Activities

- ESD leadership is meeting on a weekly basis.
- Identified and prioritized key elements to be addressed over the next 6 -18 months; starting with:
  - Strategies for Designated observables, Venture Class-Continuity, and Incubator program
  - Community engagement and communication
  - International partner communications

Pre-formulation Efforts

- ESD observable/mission studies will be aligned with the recommendations of the 2017 Decadal Survey; studies will also explore development approaches for future missions.
- Given the updated guidance from the 2017 Decadal, ESD decided to close the pre-formulation activities for HyspIRI, ACE, GEO-CAPE, CLARREO, and ASCENDS by the end of FY18.
- ESD will build on the HyspIRI and ACE teams to advance pre-formulation studies for 3 designated observables – Aerosols; Cloud, Convection and Precipitation; and Surface Biology and Geology.
- By July 2018 ESD will determine how to proceed with similar pre-formulation groups (involving multiple NASA centers and community members) for the other designated observables (Mass change, Surface Deformation and Change).
- Significant study funds exist in the FY19 – FY22 budget requests.


(Pre)Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science
Missions: Present through 2023
ISS Instruments
LIS (2020), SAGE III (2020)
TSIS-1 (2018), OCO-3 (2018),
ECOSTRESS (2018), GEDI (2018)
~~CLARREO-PF (2020),~~
EMIT (TBD)
JPSS-2 Instruments
OMPS-Limb (2019)
PREFIRE (2) (TBD)
PACE (2022)
GeoCARB (~2021)
TROPICS (12) (~2021)
MAIA (~2021)
Landsat 9 (2020)
Sentinel-6A/B (2020, 2025)
NI-SAR (2021)
SWOT (2021)
TEMPO (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (8) (2019)
NISTAR, EPIC
(DSCOVR / NOAA)
(2019)
Suomi NPP
(NOAA)
(>2022)
SMAP
(>2022)
Landsat 7
(USGS)
(~2022)
QuikSCAT
(2017)
SORCE,
TCTE (NOAA)
(2017)
Terra (>2021)
Landsat 8
(USGS)
(>2022)
Aqua (>2022)
CloudSat (~2018)
CALIPSO (>2022)
Aura (>2022)
OSTM/Jason-2 (NOAA)
(>2022)
GPM (>2022)
OCO-2 (>2022)
InVEST/CubeSats
RAVAN (2016)
IceCube (2017)
MiRaTA (2017)
HARP (2018)
TEMPEST-D (2018)
RainCube (2018)
CubeRRT (2018)
CIRiS (2018*)
CSIM (2018)
* Target date,
not yet manifested
02.21.18

International Engagement

- ESD has conducted focused Decadal Survey telecons/meetings with key international partners
  - ISRO, JAXA, CNES, DLR, ESA, EUMETSAT, CSA
  - Bilateral, HQ-level, face-to-face meetings planned over the next 6 months
  - Some directed international partnerships may originate from ESD/HQ
- Centers are explicitly encouraged to discuss and explore possible observable implementation approaches with international partners
  - Multi-center joint efforts appreciated
  - Keep ESD leadership informed
- ESD will make final partnership determinations and then codify necessary international agreements

Community Forums & Website

- We are developing mechanisms for communicating progress and for gathering external questions for our further consideration.
- A series of community forums to keep you – and all of us – in the loop as we go forward in implementing the Decadal Survey has been planned.
- Community forums inform/engage the internal HQ ESD Division (weekly), the centers (monthly), the community-at-large, including industry, universities, OGA, etc. (every 4 months) and our international partners.
- We are opening a website to allow the community to provide questions, comments, suggestions, and ideas related to implementation of the 2017 ESAS Decadal Survey.
  - Please submit your questions via this site, to go live by 30 March – specific link will be provided on the top-level ESD web portal https://science.nasa.gov/earth-science.

This is LIVE: https://science.nasa.gov/earth-science/decadal-surveys and click on link to right to submit QUESTIONS: https://science.nasa.gov/earth-science-decadal-inputs

Research Opportunities in Space and Earth Sciences

Competitions in 2016-2017 (https://nspires.nasaprs.com/):

Overall impact of FY19 President's Budget Proposal unclear based on Congressional Approps for FY18 – As of now, we lose $13M in '20 and $17m in '21

- **NASA Data for Operation and Assessment – will not be recompeted**
  - Operational short-term weather prediction
  - Data and Methodology for climate projection assessment
  - Ecological forecasting for management

- **Ocean Biology and Biogeochemistry – not competed again until 2019/2020**
  - EXPORTS synthesis

Research Opportunities in Space and Earth Sciences

Competitions in 2016-2017 (https://nspires.nasaprs.com/):

- **Carbon Cycle Science – budget line scheduled to conclude**
  - Carbon research in critical regions, specifically: tropical terrestrial ecosystems, Arctic-boreal terrestrial ecosystems, North American continental margins
  - Blue Carbon and Carbon in Associated Ecosystems
  - Carbon dynamics across managed landscapes: urban-rural, forest-ag and terr-aquatic
  - The Impact of Rising CO2 on Ocean Ecology
  - Carbon cycle science synthesis research
- **Interdisciplinary Science – five topics – No Earlier Than 2019**
  - Understanding Earth System Vulnerabilities to Climate Extremes
  - Impacts of Changing Polar Ice Cover
  - Water and Energy Cycle Impacts of Biomass Burning
  - Impacts of Population growth on watersheds and coastal ecology
  - Role of Permafrost in a Changing Climate

Research Opportunities in Space and Earth Sciences
Competitions in 2017-2018 (https://nspires.nasaprs.com/):

- **The Science of Terra, Aqua, and Suomi National Polar-orbiting Partnership (NPP) Science Team (67/230 proposals selected January 2018)**
  - **Terra and Aqua Data include: MODIS (T, A), ASTER (T), MOPITT (T), MISR (T), CERES (T, A), AIRS/AMSU-A (A), AMSR-E (A), and EOS Direct Broadcast sites**
  - **Suomi NPP - ATMS, VIIRS, CrIS, OMPS, CERES**
  - **Science Data Analysis + Multiplatform and sensor data fusion**
  - **Algorithms – New Data Products**
  - **Real- or Near-Real-Time Data Algorithms**
  - **NASA Suomi NPP Science Team Leader and Terra, Aqua, Suomi NPP Discipline Leads**
  - **Planning for the MODIS-VIIRS Science Team Meeting in the US mid-October 2018**

- **Terra and Aqua – Algorithms – Existing Data Products – transition to Senior Review – selection in January 2018/PI's have been notified.**

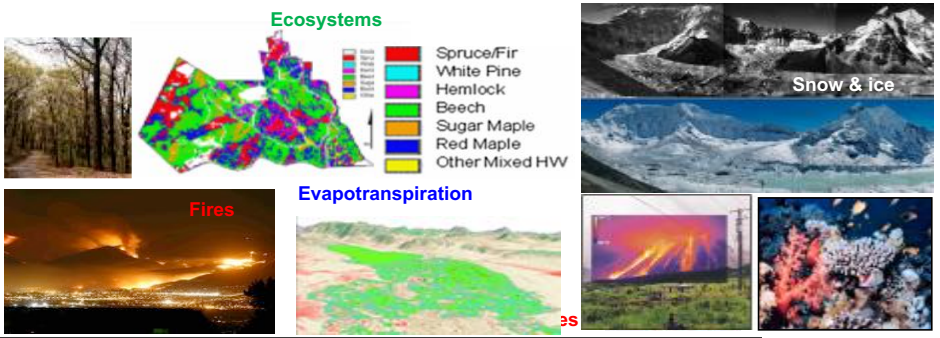
HyspIRI: Where We Ended Up

Key Global Science and Applications Research

Climate: Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/ice; biomass burning; evapotranspiration
Ecosystems: *Global* biodiversity, plant functional types, physiological condition, and biochemistry including agricultural lands
Fires: Fuel status; fire frequency, severity, emissions, and patterns of recovery *globally*
Coral reef and coastal habitats: *Global* composition and status
Volcanoes: Eruptions, emissions, regional and *global* impacts
Geology and resources: *Global* distributions of surface mineral resources and improved understanding of geology and related hazards
Applications: Disasters, EcoForecasting, Health/AQ, Water

Global Mission Urgency

The science and applications objectives are critical today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.

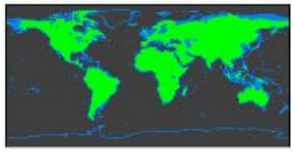


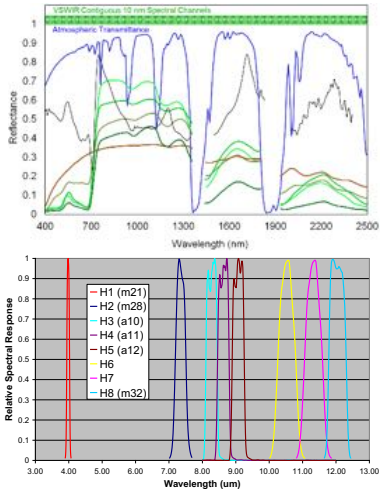
Measurement

Imaging Spectrometer (VSWIR)
- 380 to 2510nm in ≤10nm bands
- 30 m spatial sampling
- 16 days revisit
- Global land and shallow water

Thermal Infrared (TIR)
- 8 bands between 4-12 µm
- 60 m spatial sampling
- 5 days revisit; day/night
- Global land and shallow water

IPM-Low Latency data subsets





Mission Concept Status

Level 1 Measurement Requirements: Vetted by community at workshops and in literature (many refereed journal articles)
Payload: VSWIR Imaging Spectrometer, **TIR** Multi-spectral Radiometer, and **Intelligent Payload Module (IPM)**
Original 60 m option: Mature
ISS options: VSWIR & TIR Mature, ECOSTRESS EVI selected
Separate Smallsat Mission option: VSWIR and TIR solutions developed with TEAM I/X
2016 Option: HyspIRI VSWIR evolved to 30 m and 16 day global revisit. Requires F/1.8 Dyson spectrometer architecture and other current technologies.
Preparatory airborne campaigns: CA & HI measurements used to advance and refine science, applications, algorithms, and processing; AVIRIS-NG in India flights also relevant
2017 Decadal Survey: >25 related RFI inputs

AVIRIS-NG Campaign Status

Phase I campaign (Flights: 12/17/2016-3/8/2016)

Spectroscopy of 57 sites covering 315 flight lines

10 NASA investigations selected in 2017

ISRO-NASA collaborations initiated

Working Special Issue of Indian Journal *Current Science*

Phase II campaign (Flights: early 2018)

Implementing Arrangement valid through 9/2020

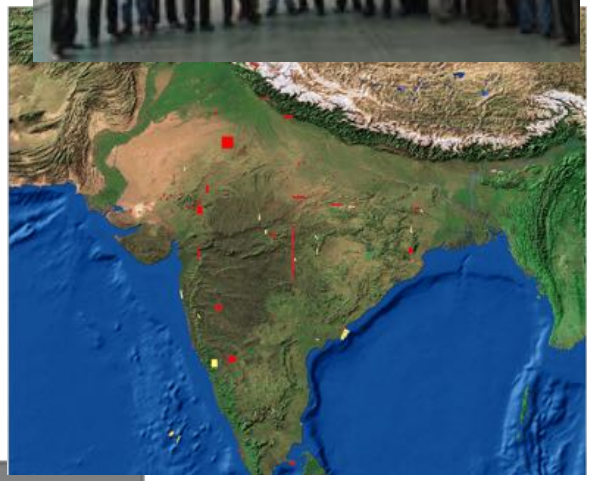
New targets and phenology investigations

SAC, NRSC, and JPL active weekly planning

Potential AGU special session

AVIRIS-NG flights began 2/24/2018

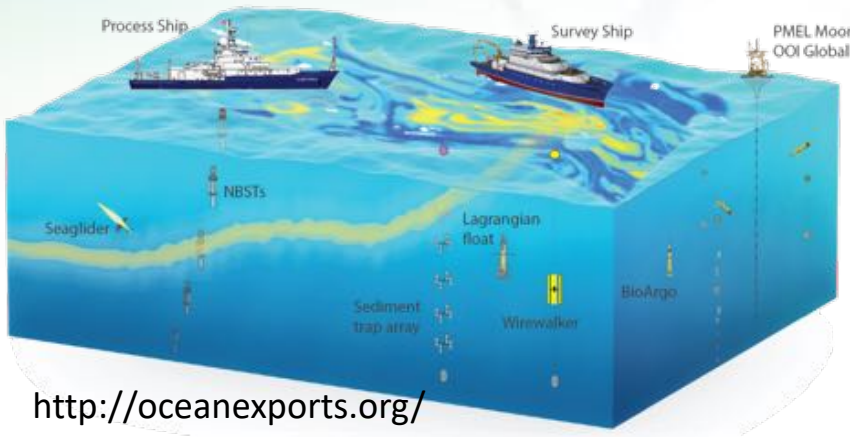
ISRO B200



D. R. Thompson, J. W. Boardman, R. O. Green, M. Eastwood. A Large Airborne Survey of Earth's Visible-Infrared Spectral Dimensionality. Optics Express, Vol. 25, Issue 8, pp. 9186-9195, 2017.

NASA OBB Field Program Support

EXPORTS
EXport Processes in the Ocean from RemoTe Sensing

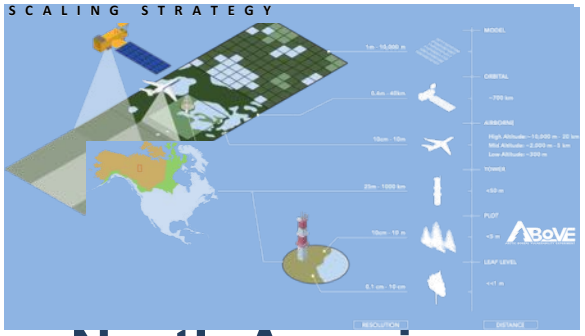


http://oceanexports.org/

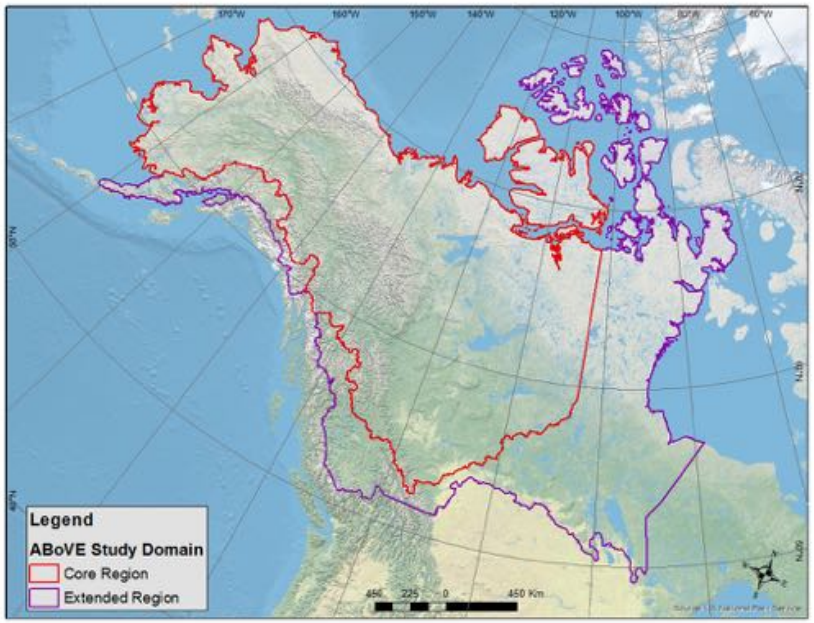
EXPORTS Science Plan:

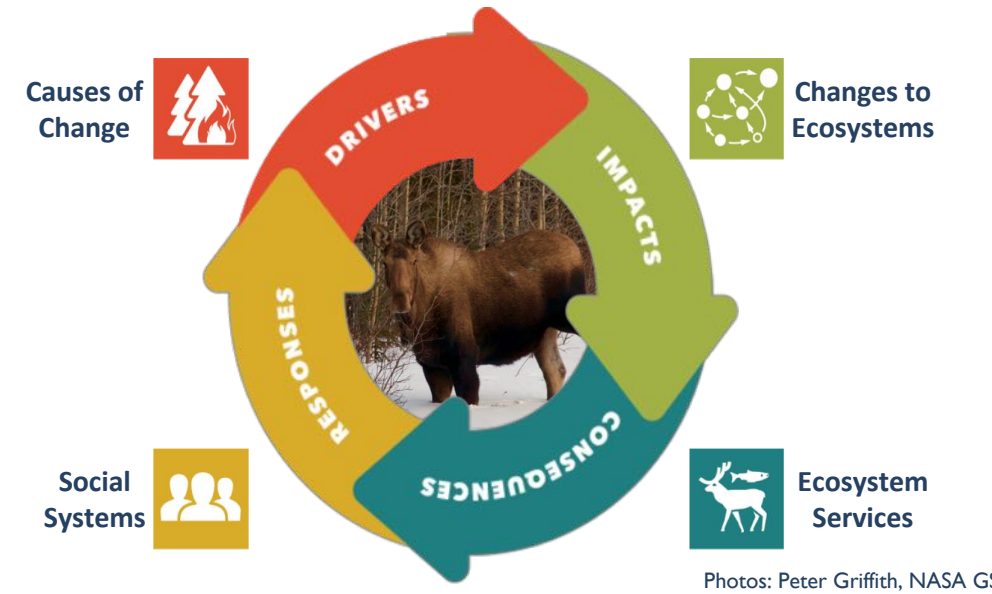
- Measure range of Ecosystem/C cycling <u>states</u>
- Create a modular template for observing NPP fate
- Conduct multiscale sampling w/ autonomous, ship & satellite platforms
- **Integrate modeling from the beginning**
- Choose sites w/ small large-scale spatial gradients
- Contribute to NASA's PACE mission
- Document measurement protocols & uncertainties

EXPORTS Science Questions focus on **processes and mechanisms** controlling the vertical transfer of organic matter from the surface ocean, and how to **improve current and future estimates and mechanisms for such estimates**



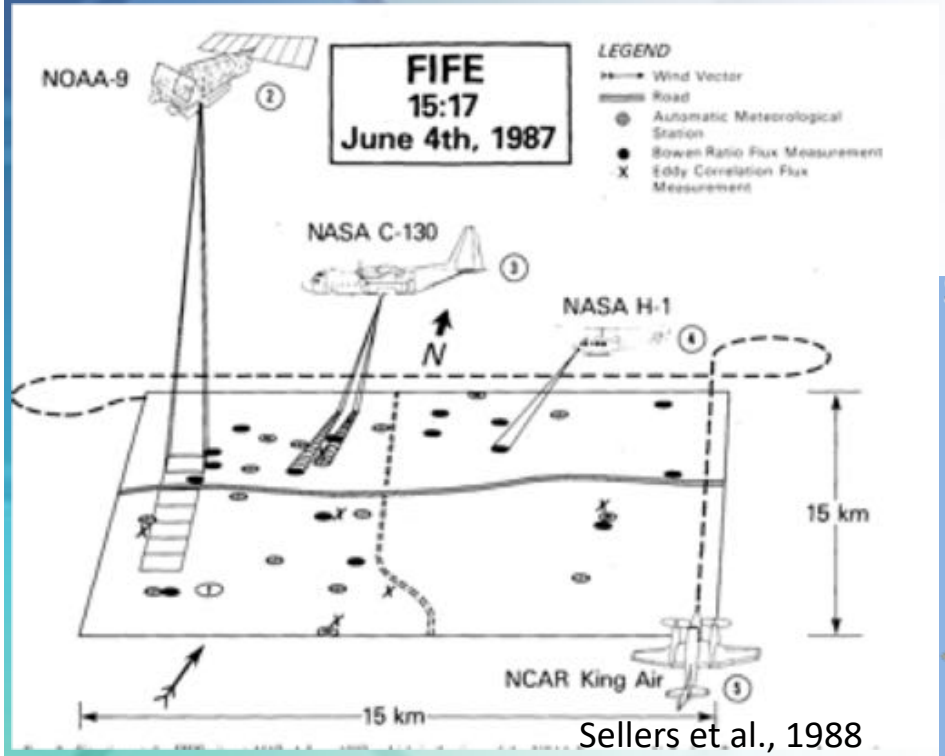
ABoVE is a large-scale study of environmental change in the Arctic and Boreal regions of western North America and its implications for ecological systems and society.



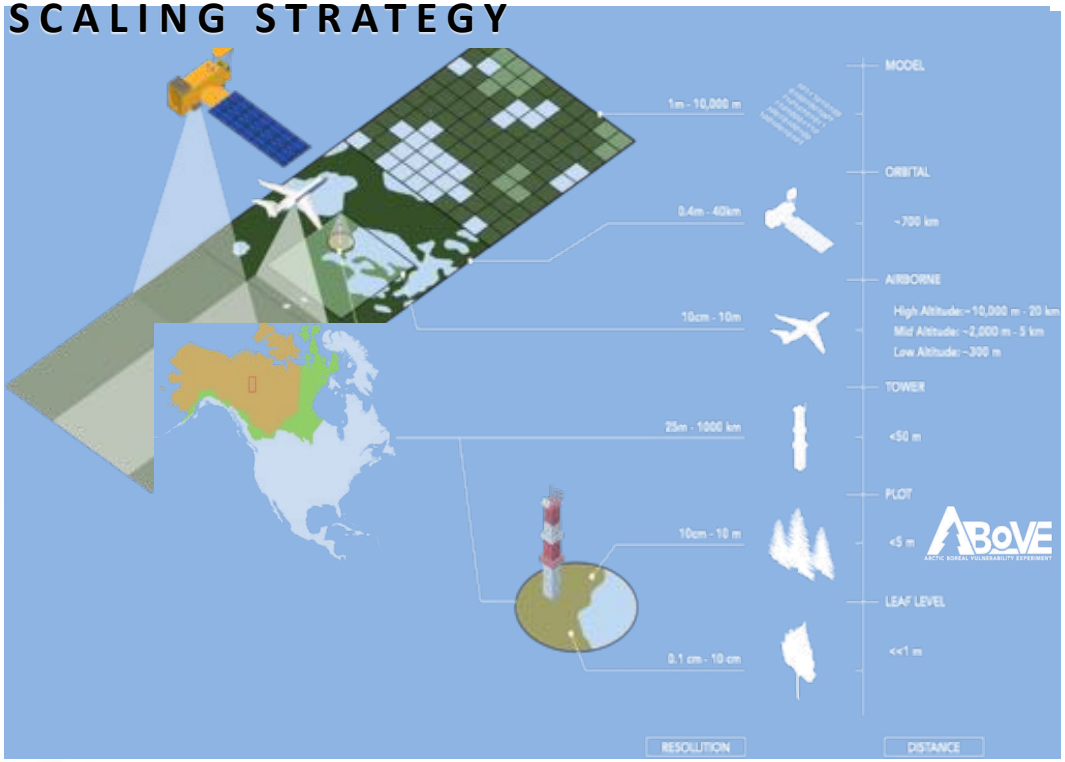


Photos: Peter Griffith, NASA GSFC

Thanks!



Sellers et al., 1988



BACKUP SLIDES

Panels

I. Global Hydrological Cycles and Water Resources

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

The movement, distribu5on, and availability of water and how these are changing over 5me

II. Weather and Air Quality: Minutes to Subseasonal

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

Atmospheric Dynamics, Thermodynamics, Chemistry, and their interac5ons at land and ocean interfaces

III. Marine and Terrestrial Ecosystems and Natural Resource Management

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

Biogeochemical Cycles, Ecosystem Func5oning, Biodiversity, and factors that influence health and ecosystem services

IV. Climate Variability and Change: Seasonal to Centennial

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

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

V. Earth Surface and Interior: Dynamics and Hazards

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

Core, mantle, lithosphere, and surface processes, system interac5ons, and the hazards they generate

Comparison to ESAS 2007

- **Prioritization Method.** Prioritize science and applications targets instead of missions
- **Budget Resources.** Align with planned budgets instead of aspirational
- **Large Missions.** Avoid having one recommended activity grow at expense of all others
- **Innovation.** Consider "new space" technology and business ideas
- **Policy.** Existence of recent high-level US government policy guidance regarding Earth observations
- **International.** Increased recognition of important role of international partners

Progress Since ESAS 2007

Mission	Geophysical Variables	Status
OSTM/Jason-2**	Ocean Surface Topography	Launched 2008, operating
OCO**	CO_2	Launch failure
Glory**	Aerosol and cloud particle size and optical thickness	Launch failure
Aquarius**	Sea surface salinity	Mission ended
Suomi NPP**	Multiple variables (ATMS, VIIRS, CrIS, OMPS, CERES)	Launched 2011, operating
LDCM**	Land use and land surface temperature	Launched 2013, operating
GPM**	Precipitation (rain and snow)	Launched 2014, operating
OCO-2	CO_2	Launched 2014, operating
CYGNSS*	Hurricane Winds	Launched 2016, operating
SMAP*	Soil moisture; freeze/thaw state; surface salinity	Launched 2017, operating
SAGE-III (on ISS)	Stratospheric O_3, aerosols	Launched 2017, operating
GRACE-FO	Changes in Gravitational Field	In Development (2017)
ICESat-2*	Ice sheet elevation change, sea ice thickness, vegetation canopy height	In Development (2018)
ECOSTRESS*	Plant temperature and water stress	In Development (2018)
GEDI*	Ecosystem structure and dynamics	In Development (2018)
TEMPO*	Air pollution (O_3, NO_2, …)	In Development (2018)
MAIA*	Aerosols	In Development (2021)
TROPICS*	Precipitation and storm intensity	In Development (2021)
GeoCARB*	Carbon exchanges between land and atmosphere	In Development (TBD)
PACE	Phytoplankton communities	In Development (2022)
NISAR*	Surface changes from ice-sheet collapse, earthquakes, tsunamis, volcanoes, and landslides	In Development (late 2021)
SWOT*	Ocean (and freshwater) high resolution elevation, providing water storage and ocean circulation	In Development (2021)
CLARREO-Pathfinder on ISS*	High accuracy spectral reflectance with on-board calibration	In Development (2021 timeframe)
OCO-3 (on ISS)	CO_2	In Development (2018)

Finding 2A: The **NASA ESD program has made important progress during the decade, par:ally recovering from the underfunded state it was in a decade ago . . .**

Finding 2B: NOAA progress during the decade was hampered by major programma:c adjustments . . .

Finding 2C: The **USGS has transformed the Landsat program via the Sustainable Land Imaging (SLI) program . . .**

Program of Record (example, 1 of 10)

NASA Flight Program Elements

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

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

NASA Portfolio Balance

- Earth Science Research: *maintain* at approximately 24% of the budget (22-26%)
  - Includes 18% for openly competed research and analysis
  - Includes approximately 3% each for computing and administraDon
- Applications program: *maintain* at 2-3% of the budget
- Technology program: *increase* from its current 3% to about 5%
- Flight programs, including Venture: *maintain* at 50-60% of the budget
- Mission Operations: *maintain* at 8-12% of the budget