National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

Reply to Attn of: 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~~: Fiona

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,

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, space-borne 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 solicitiations 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.

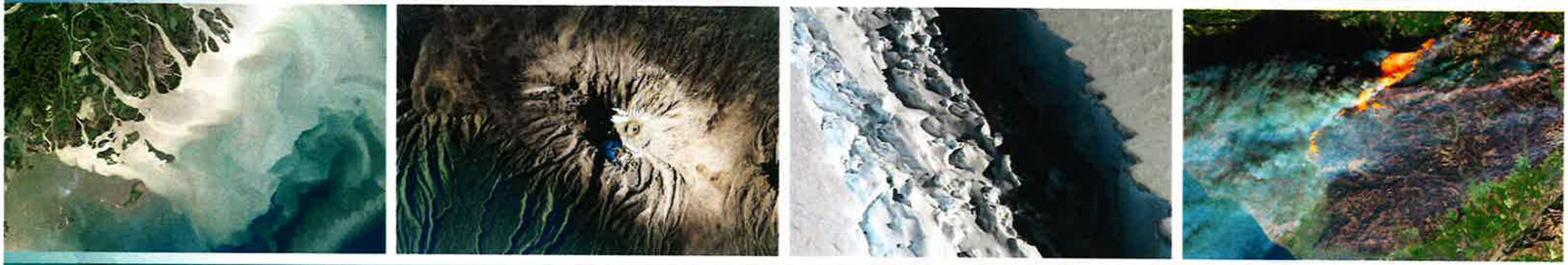
Response: *Using the framework established by the existing NASA-DoI/USGS Space Act Agreement and the existing/continuing ESD SLI-Technology Program, ESD will invest in technology development activities for land imaging instruments and spacecraft/constellation components, and will coordinate with USGS 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-DoI/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.*

SCIENCE



NASA Earth Science Division Overview for CESAS

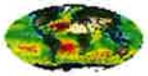
Michael Freilich
Division Director
Earth Science Division

October 2018

NASA Earth Science Division Elements

Flight (incl. Data Systems)

Develops, launches, and operates NASA's fleet of Earth-observing satellites, instruments, and aircraft. Manages data systems to make data and information products freely and openly available.

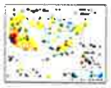


Research & Analysis

Supports integrative research that advances knowledge of the Earth as a system. Six focus areas plus field campaigns, modeling, and scientific computing.

Technology

Develops and demonstrates technologies for future satellite and airborne missions: Instruments, Information Systems, Components, InSpace Validation (cubesat and small-sat form factors).



Applied Sciences

Develops, tests, and supports innovative uses of Earth observations and scientific knowledge to inform private and public sector planning, decisions, and actions. Activities include disaster response support and capacity building.

NASA/ESD Appropriation: FY18 & FY19

- FY18 (1 Oct 2017 – 30 Sept 2018) funding – appropriated via an Omnibus – was at the **FY16/FY17** level (~$1.92B)
  - Includes continued operations and development of FY17 Program of Record, including DSCOVR EPIC/NISTAR, PACE, CLARREO-PF, OCO-3 (to launch as manifested by February 2019)

- House Appropriations Committee marked up the FY19 NASA/ESD request in May 2018
  - ESD recommended at $1.9B in FY19; Committee's report is silent on DSCOVR ops, PACE, CLARREO-PF, and OCO-3

- Senate Appropriations Committee marked up the FY19 NASA/ESD request in June 2018
  - ESD recommended at $1.931B in FY19
  - However, this ***includes*** restoration of OCO-3, DSCOVR ops, PACE, and CLARREO-PF

- **The Earth Science Division funding request is substantial and is expected to remain that way given the House and Senate marks for FY19; we continue under a Continuing Resolution through 7 December 2018 as we await a final appropriation level for FY19**

NASA Earth Science Research Missions

Missions: Present through 2023
(no DS new starts or future
Venture Class shown)

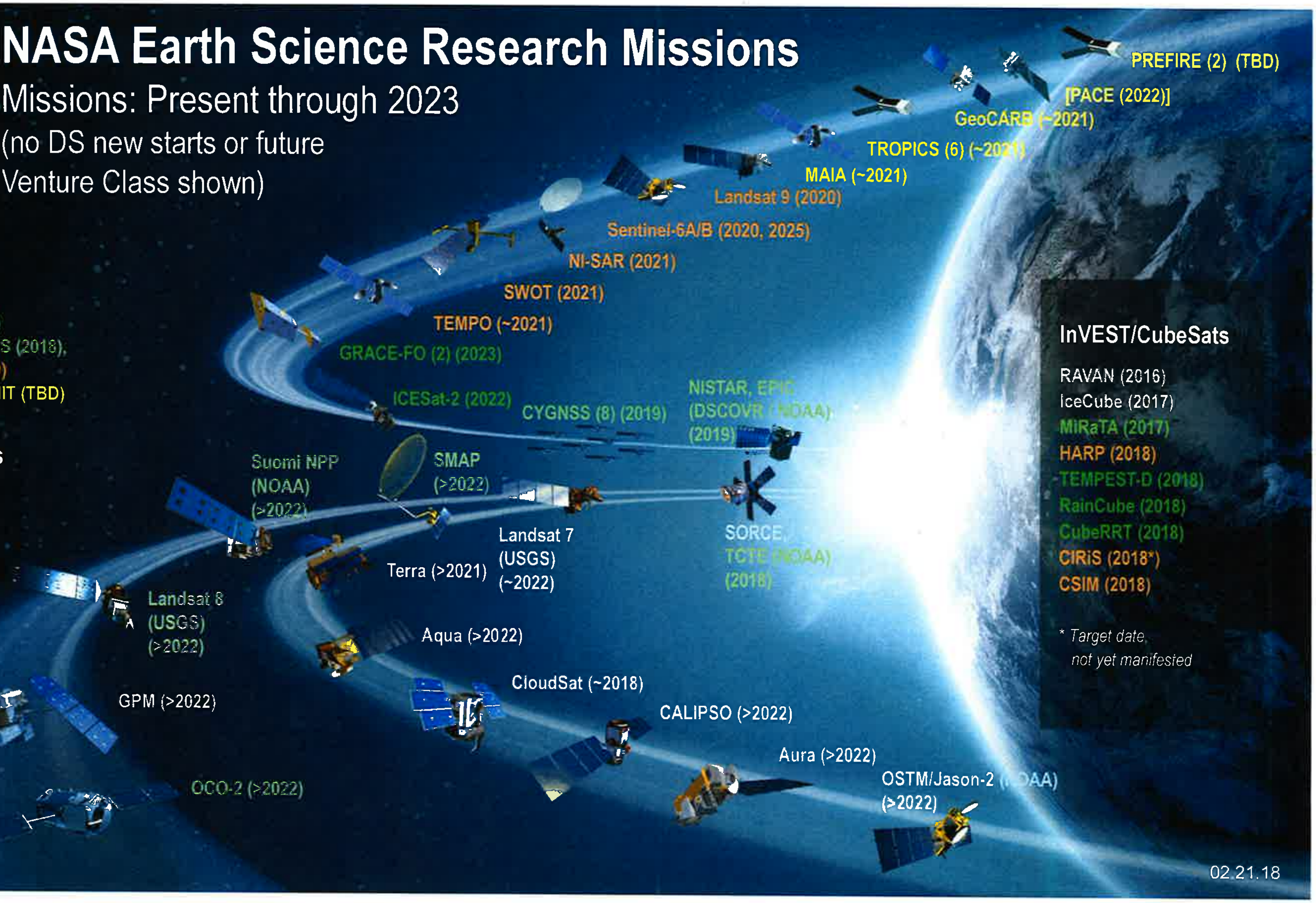
- 🟨 (Pre)Formulation
- 🟧 Implementation
- 🟩 Primary Ops
- 🟦 Extended Ops

ISS Instruments

LIS (2020), SAGE III (2020)
TSIS-1 (2018), ECOSTRESS (2018),
OCO-3 (2019), GEDI (2019)
[CLARREO-PF (2020)], EMIT (TBD)

JPSS-2 Instruments

OMPS-Limb (2019)



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

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

TSIS-1: DEC 15, 2017

GRACE-FO: May 22, 2018

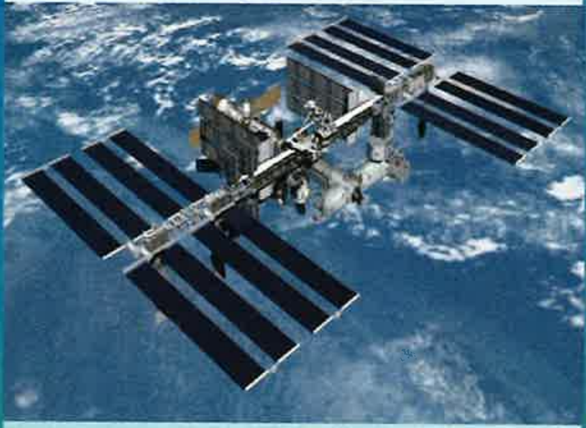
ECOSTRESS: June 29, 2018

TSIS-1	*The Total and Spectral Solar 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.*
GRACE-FO	*Obtaining high resolution global models of Earth's gravity field, including how it varies over time*
ECOSTRESS	*Providing insight into plant-water dynamics & how ecosystems change with climate via high spatiotemporal resolution thermal infrared radiometer measurements of evapotranspiration (ET)*

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

ICESat-2: Sep 15, 2018

GEDI



November 2018

OCO-3

February 2019

ICESat-2	*Quantifying polar ice-sheet contributions to sea-level change & measure vegetation canopy height as a basis for estimating large-scale biomass and biomass change*
GEDI	*Characterize the effects of changing climate and land use on ecosystem structure and dynamics, providing the first global, high-resolution observations of forest vertical structure*
OCO-3	*Investigate important questions about the distribution of carbon dioxide on Earth as it relates to growing urban populations and changing patterns of fossil fuel combustion.*

RECENT and UPCOMING NOTABLE FLIGHT PROGRAM EVENTS

- 2017 Senior Review recommended continuation of most on-orbit missions
- QuikSCAT mission was ended September 2018
- TES instrument on Aura discontinued (low availability resulting from hardware issues)
- RBI discontinued by NASA for technical, cost, schedule issues; work underway to develop an affordable and capable replacement for launch in JPSS-3 timeframe (2026)

- CATS (ISS) mission ended owing to instrument failure
- GRACE mission ended after 15 years

- Jason-2/OSTM moved to lower orbit (IMU redundancy/temperature issues) – continues to provide near-real-time and geodetic measurements
- CloudSat moved to safe orbit below A-Train (loss of hardware redundancy) – continues to provide high-quality science data
- Calipso has joined CloudSat in graveyard orbit for synergistic science

- TSIS-1 instrument successfully launched to ISS and operating
- NOAA's JPSS-1 mission successfully launched and operating
- ICECube, MIRATA CubeSats launched (MIRATA failed once on-orbit); MicroMAS-2 CubeSat successful on JPSS-1 launch
- TEMPEST-D, RainCube, CubeRRT, successfully launched on OA-9, 21 May 2018, to ISS, deployed 13 July 2018
- GRACE-FO successfully launched 22 May 2018 – ***significant commissioning anomalies***
- ECOSTRESS successfully launched 29 June 2018, installed (5 July), operating on ISS; ***significant commissioning anomalies (MSU)***
- ICESat-2 successfully launched 15 September 2018

- OCO-3 completion and delivery to storage August 2018 for launch by February 2019
- CSIM, HARP CubeSats/SmallSats manifested for launch in 2018 – *late-breaking HARP environmental test error jeopardizes its LRD*
- GEDI delivered and manifested for launch to ISS; 4 December 2018 (on SpX-16) is current estimate
- EVI-4 selections: EMIT (hyperspectral aerosol mineralogy/composition) and PREFIRE (Arctic Far-IR emissions from dual CubeSats)

Earth Science Division's Venture Opportunities

EVS
Sustained Sub-Orbital Investigations
(~4 years)

EVM
Complete, self-contained, small missions
(~4 years)

EVI
Full function, facility-class instruments Missions of Opportunity (MoO)
(~18 months)

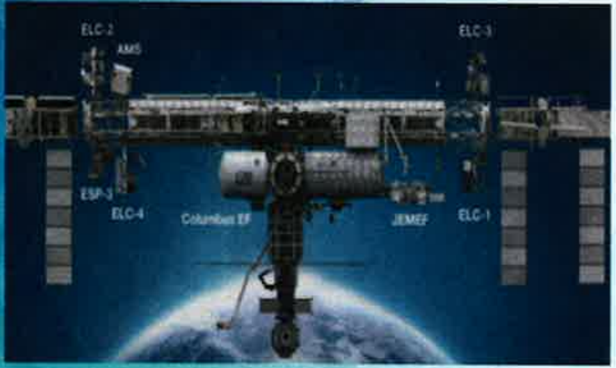
Mission	Mission Type	Release Date	Selection Date	Major Milestone
EV-1, aka EVS-1	5 Suborbital Airborne Campaigns	2009	2010	N/A
EVM-1, CYGNSS	SmallSat constellation	2011	2012	Launched Dec 2016
EVI-1, TEMPO	Geosynchronous hosted payload	2011	2012	Delivery NLT 2017
EVI-2, ECOSTRESS & GEDI	Class C & Class D ISS-hosted Instruments	2013	2014	Delivery NLT 2019
EVS-2	6 Suborbital Airborne Campaigns	2013	2014	N/A
EVI-3, MAIA & TROPICS	Class C LEO Instrument & Class D CubeSat Constellation	2015	2016	Delivery NLT 2021
EVM-2, GeoCarb	Geostationary hosted payload	2015	2016	Launch ~2021
EVI-4, EMIT & PREFIRE	Class C ISS-hosted instrument & Class D CubeSat Constellation	2016	2017	Delivery NLT 2021
EVS-3	Suborbital Airborne Campaigns	2017	2018	N/A
EVI-5	Instrument Only	2018	2019	Delivery NLT 2023
EVC-1	Radiation Budget Measurement	2018	2019	Delivery NLT 2024
EVM-3	Full Orbital	2019	2020	Launch ~2025
EVS-4	Suborbital Airborne Campaigns	2021	2022	N/A
EVI-6	Instrument Only	2020	2021	Delivery NLT 2026
EVC-2	Continuity Measurment	2021	2022	Delivery NLT 2027

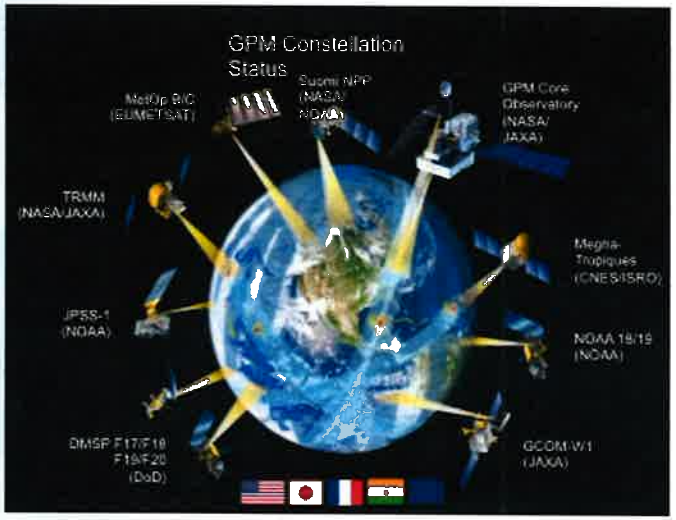
Selected 5 proposals → EVS-3

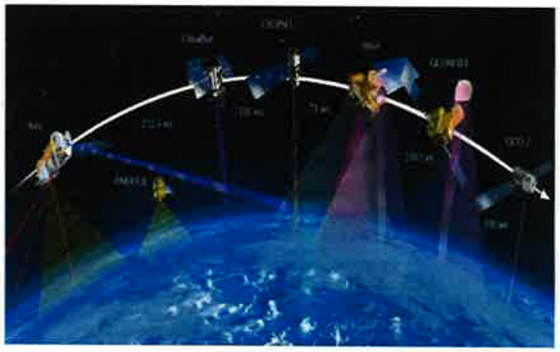
Targeting Dec 2018 release of EVC-1 → EVC-1

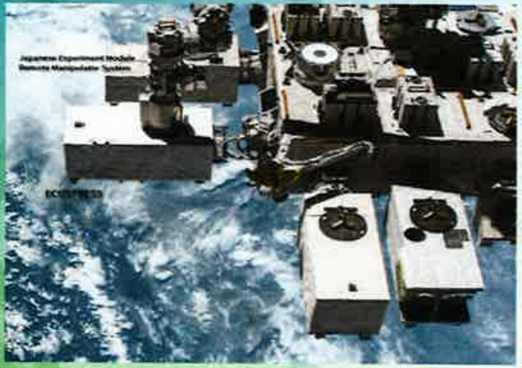
Open solicitation - In Review
Completed solicitation

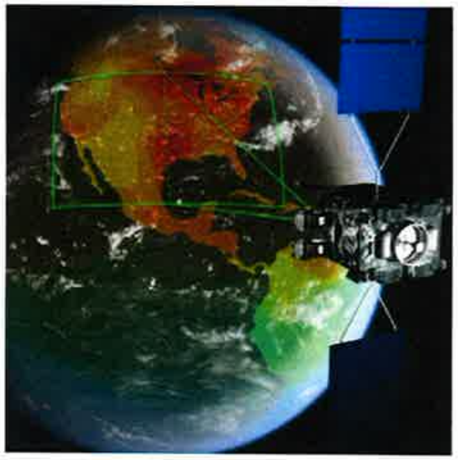
NASA Observing System *INNOVATIONS*



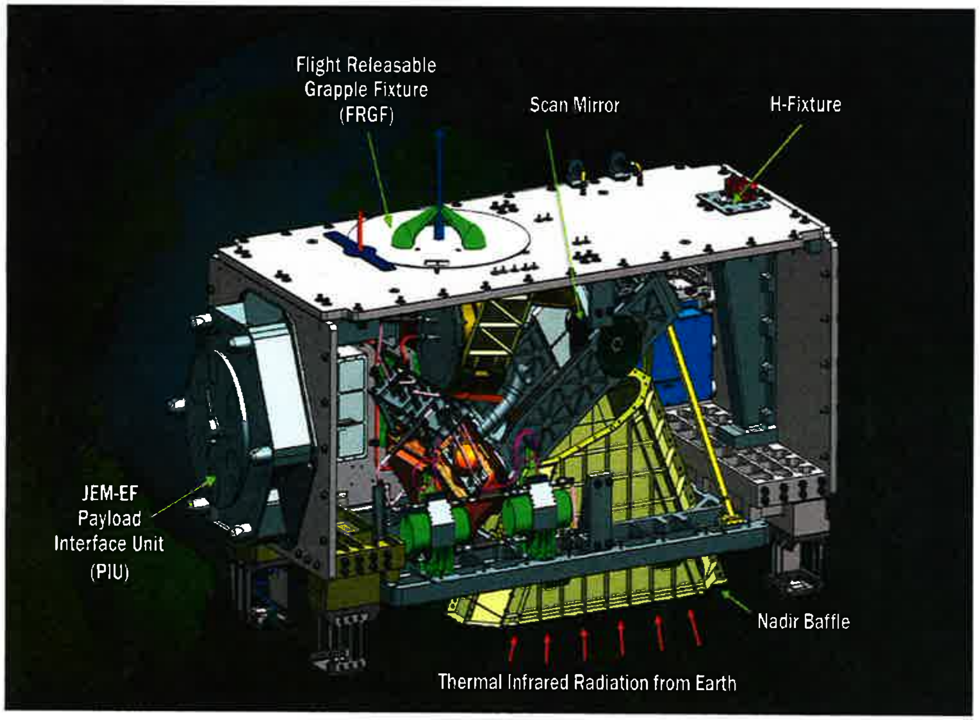






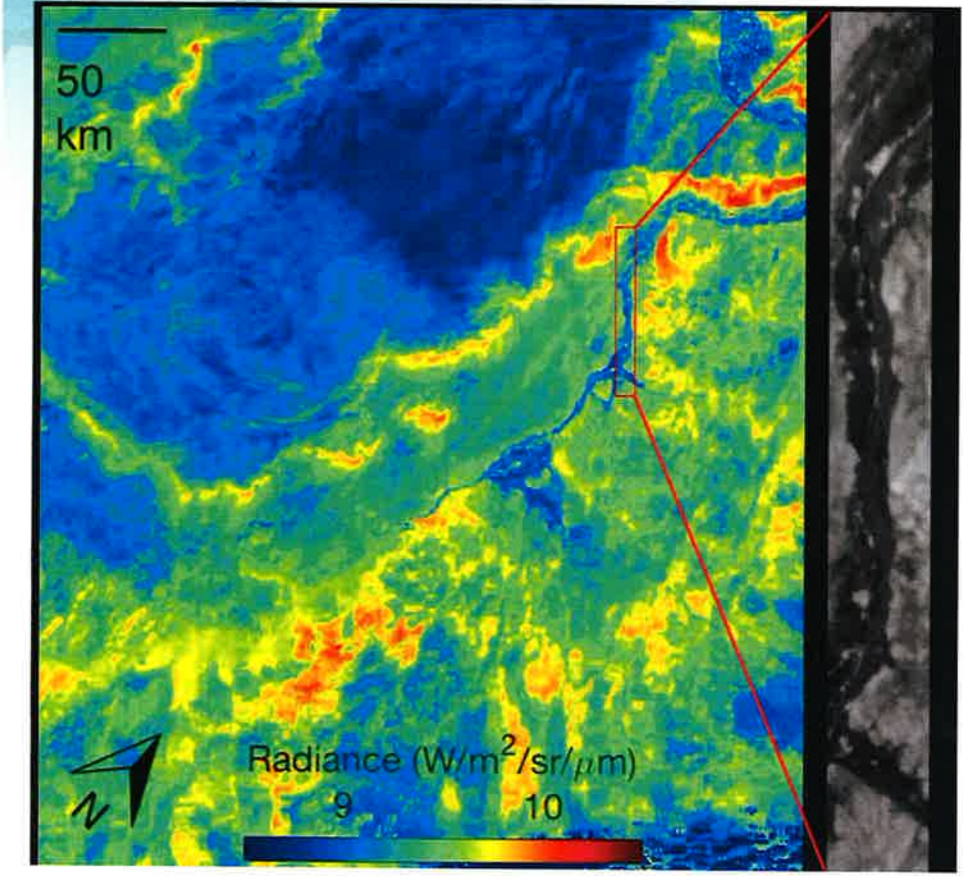


ECOSTRESS on the ISS

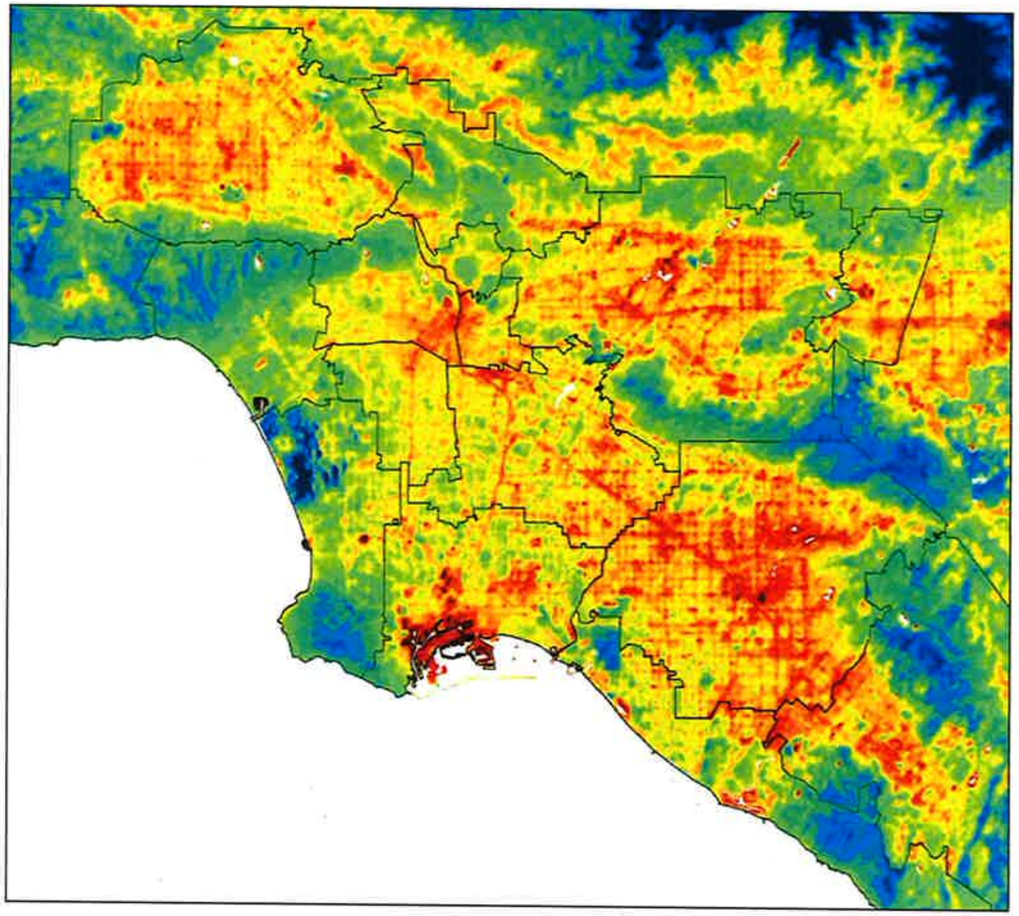


ECOSTRESS Early Imagery

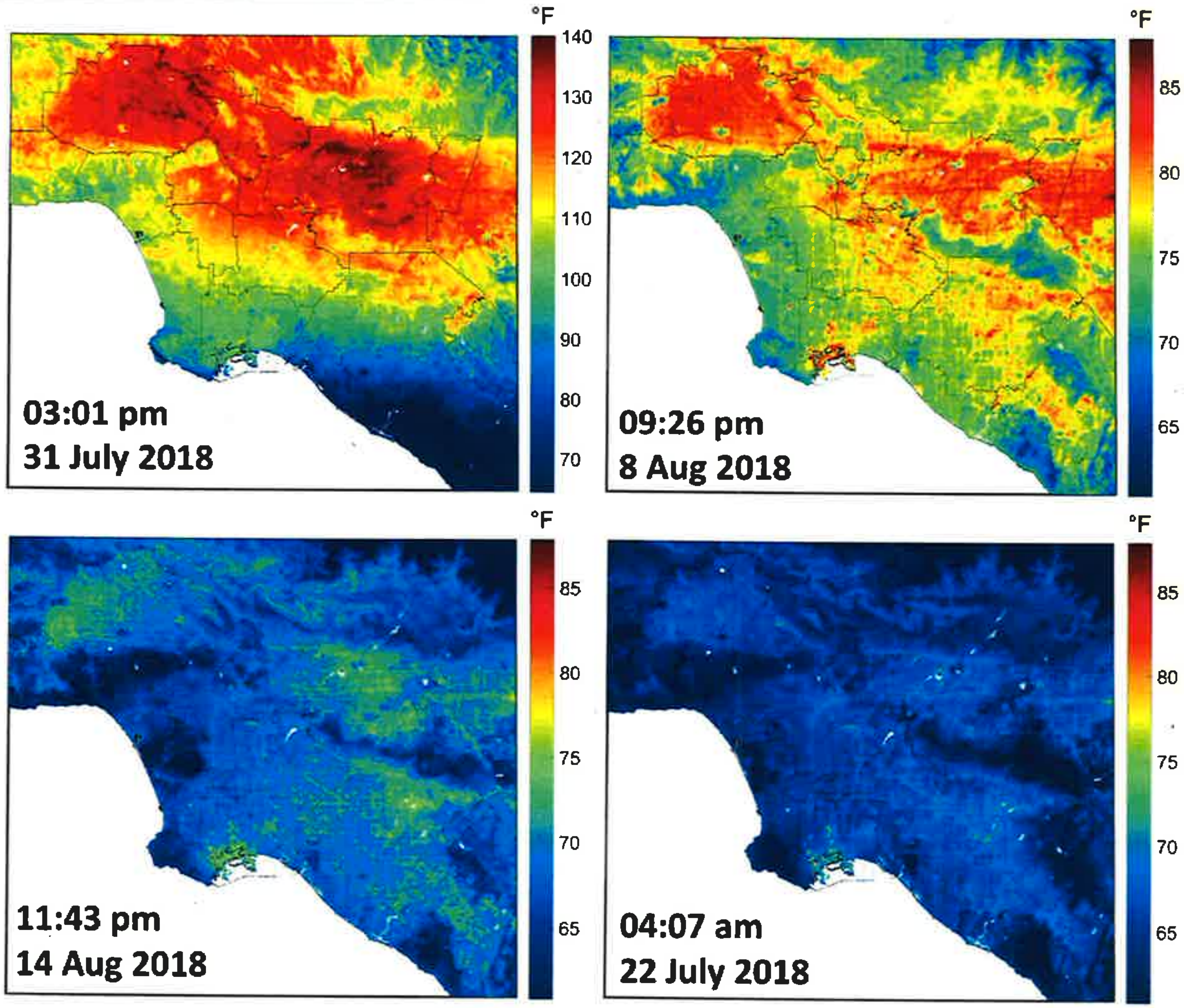
Nile River, Egypt



Los Angeles, CA



ECOSTRESS Los Angeles Surface Temps Through the Day



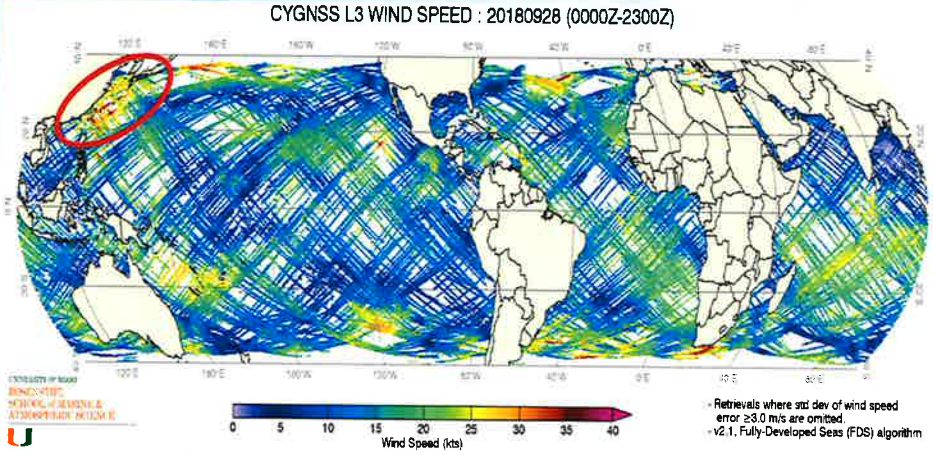
NASA Small-Satellite Programs

ESD is pursuing a rich program of orbital missions using small satellites

- **CYGNSS (Cyclone Global Navigation Satellite System)**: homogeneous tropical constellation of 8 ***micro-satellites*** using reflected GPS to measure surface winds/air-sea interactions, especially valuable/unique in the precipitation-dominated, dynamic, eyewalls of tropical storms and hurricanes – frequent tropical sampling from 1 orbit plane **SCIENCE**
- **TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats):** homogeneous tropical constellation of 6 ***CubeSats*** to measure atmospheric profiles in storms/hurricanes – frequent sampling from 2-3 orbit planes **SCIENCE**
- **PreFIRE:** 2-satellite CubeSat constellation to measure Far-IR emissions primarily from the Arctic **SCIENCE**
- **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 **TECHNOLOGY**
- **Venture Class Launch Services:** Investment in new, low-cost (<$15M/launch), commercial launch vehicles capable of orbiting small payloads to LEO – science control of launch schedule and orbits **ENABLING**

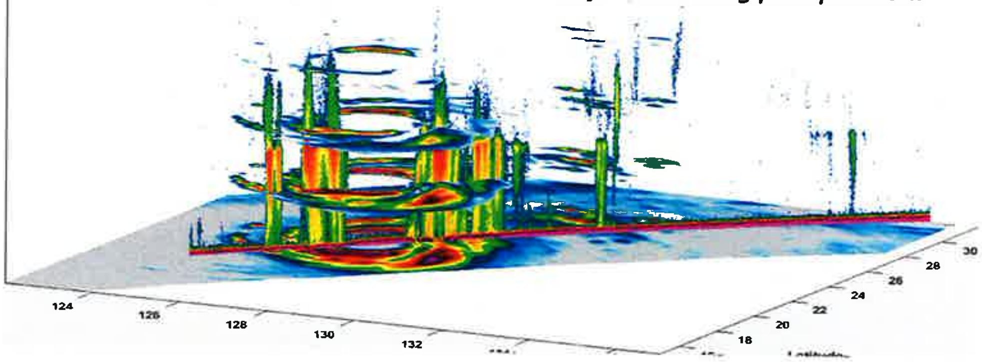
InVEST and Venture CubeSats/SmallSats Observe Typhoon Trami

CYGNSS wind speed measurements for 28 September 2018.



CYGNSS, launched in December 2016, is an 8-satellite constellation that measures surface wind speeds and related quantities using reflected GPS. Chris Ruf, U. Michigan, PI

On 9/28/18, the two CubeSats overflew Typhoon Trami shortly after it had weakened to a category 2 storm off the southern coast of Japan. Separated in time by less than five minutes, the RainCube nadir Ka-band reflectivity (vertical peaks) is shown overlaid on TEMPEST-D 165 GHz brightness temperature (horizontal layers), illustrating complementary nature of these sensors in a constellation for observing precipitation.

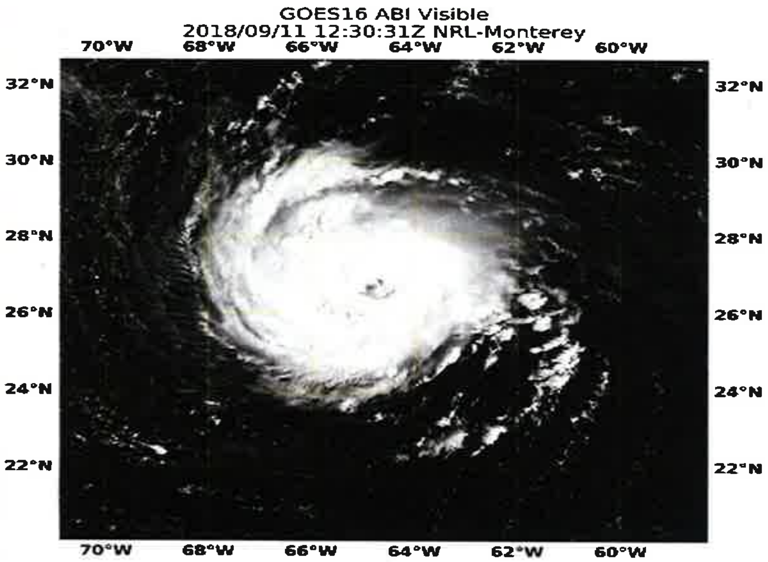


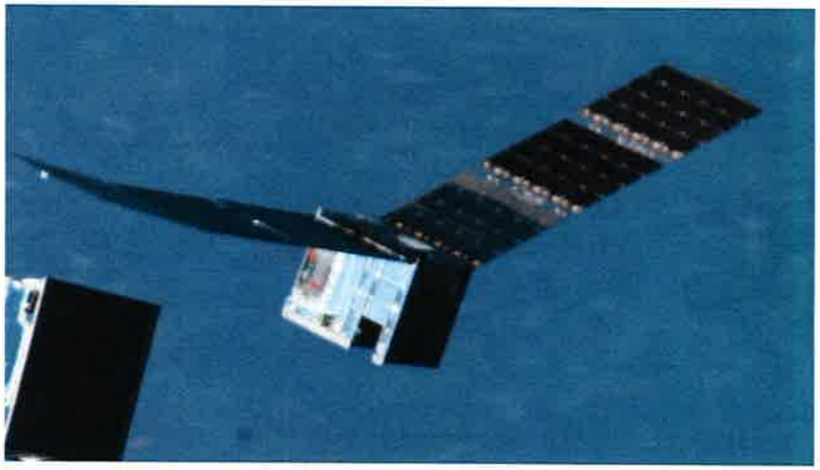
The Temporal Experiment for Storms and Tropical Systems Demonstration (**TEMPEST-D**: Reising, Colorado State), an Earth Venture Technology project, is testing a new five-frequency, millimeter-wave radiometer for observations of the time evolution of clouds and precipitation processes. Shortly after first light, TEMPEST-D's radiometer took data of Hurricane Norman on 9/5/18 off the coast of Hawaii. A week later, during its fully operational full-swath orbit on 09/11/18, TEMPEST-D was able to image Hurricane Florence two days before landfall in the Carolinas.

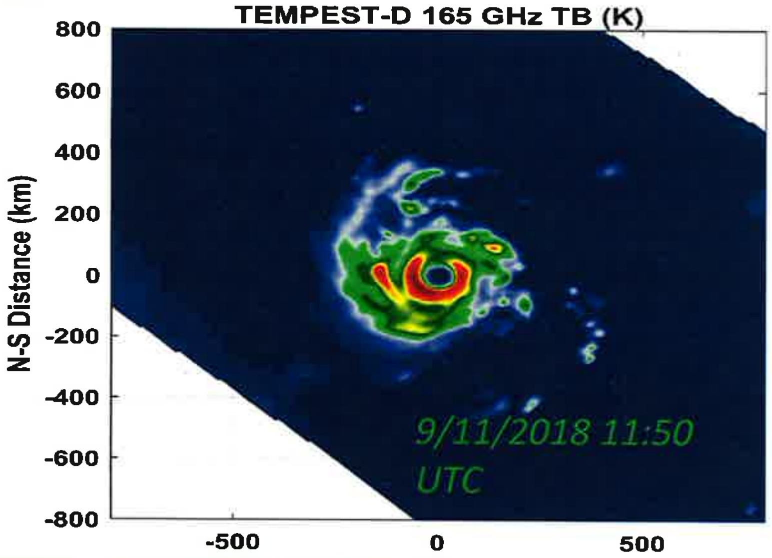
RainCube (Peral, JPL), developed through the In-Space Validation of Earth Science Technologies (InVEST) program, is demonstrating a new architecture for miniaturized Ka-band precipitation radars. The radar has successfully acquired nadir precipitation measurements since early September.

TEMPEST-D and CubeRRT Deployment from ISS

[redacted]

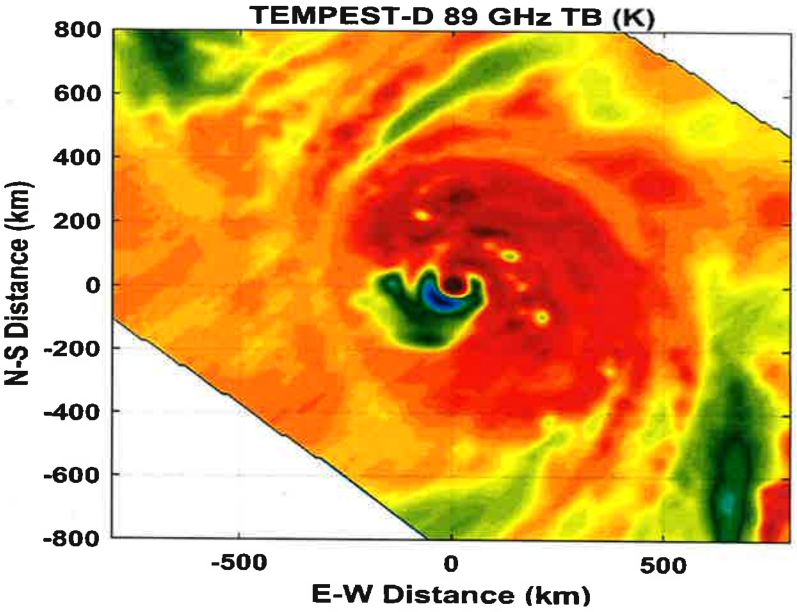






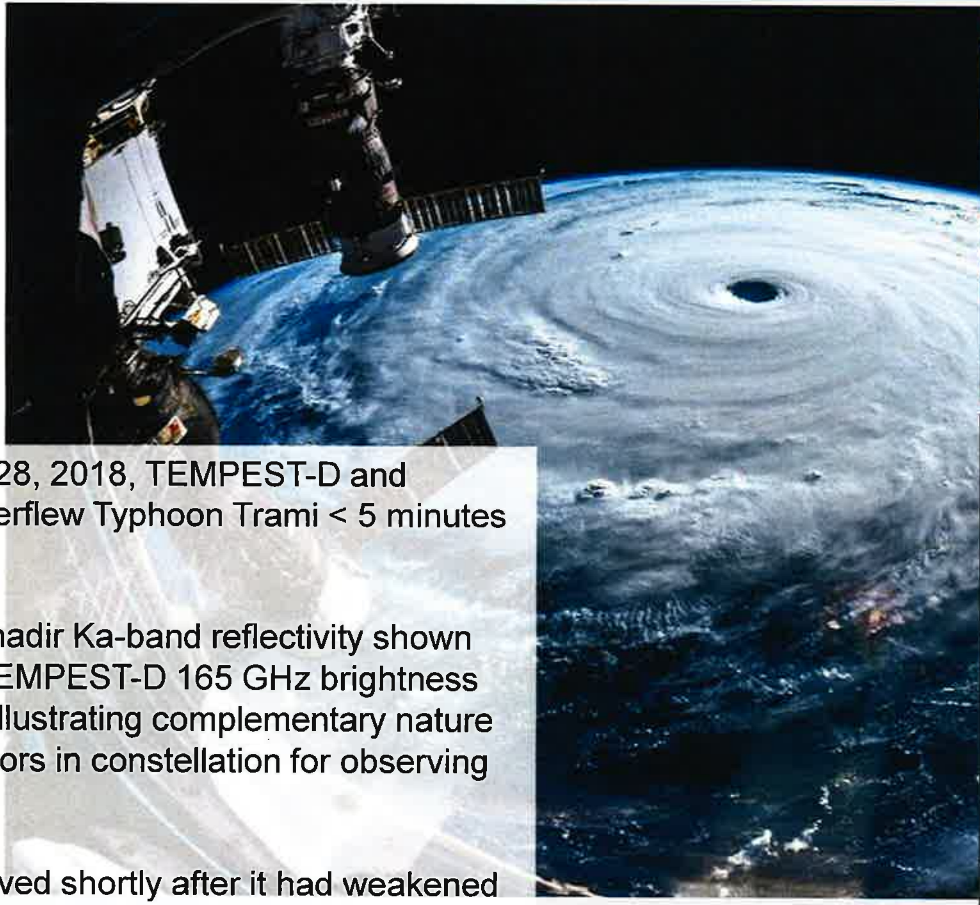
165 GHz images convection around inner core through ice scattering signature

89 GHz sensitive to clouds, precipitation, water vapor and strong convection



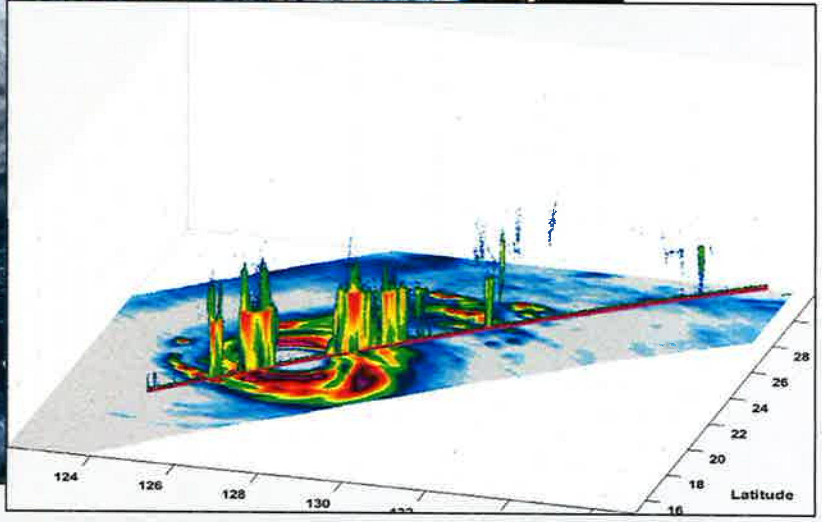
Radar Mesh Antenna Deploy: RainCube, 27 July 2018

• TEMPEST-D and RainCube

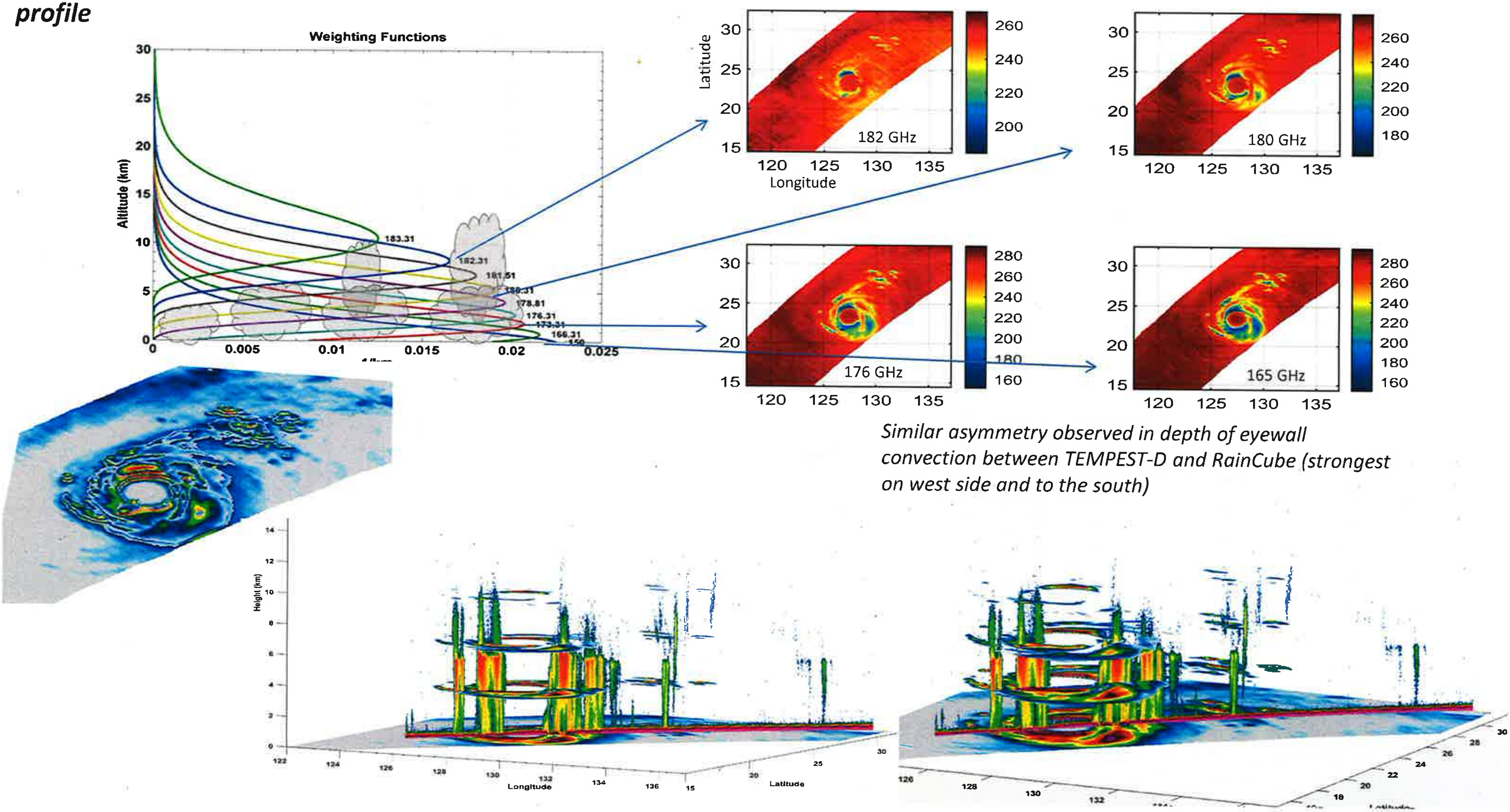


- September 28, 2018, TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart
- RainCube nadir Ka-band reflectivity shown overlaid on TEMPEST-D 165 GHz brightness temperature illustrating complementary nature of these sensors in constellation for observing precipitation
- Trami observed shortly after it had weakened from Cat 5 to Cat 2

- RainCube
- 0.5m mesh
- antenna deploy



TEMPEST-D Sounding Channels provide 4 levels of vertical resolution to "slice" precipitation and compare with RainCube profile



Similar asymmetry observed in depth of eyewall convection between TEMPEST-D and RainCube (strongest on west side and to the south)

Private Sector Small-Satellite Constellation Pilot

Present ESD funding opportunities for use of Small-Satellites and resulting data

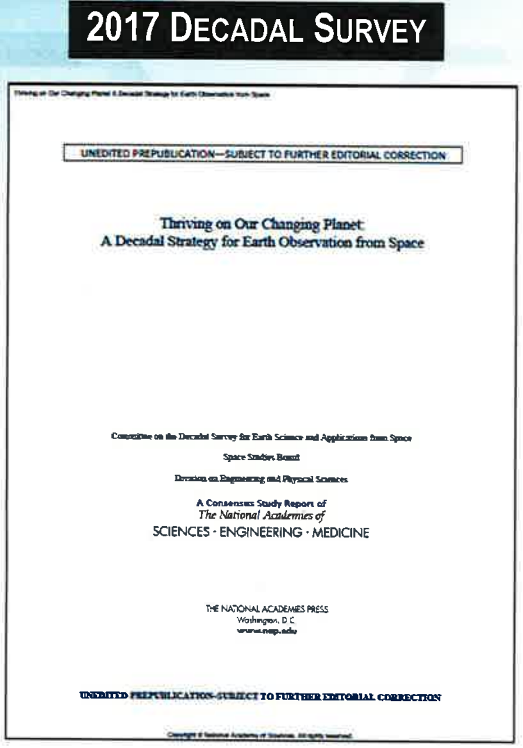
- **Earth Venture–Mission and –Instrument programs:** Science-driven, PI-led, cost/schedule constrained, competitively selected, frequently solicited (every 4 years for EVM, every 18 months for EVI); proposals using small-sats have been selected for both EVM and EVI
- **InVEST:** Competitively selected spaceborne technology validations that ***must use*** small-sats or cubesats; 3-year solicitation cadence, frequent launch opportunities using NASA CSLI and VCLS
- **R&A and Applications ROSES calls:** R&A and Applied Sciences competitive research calls are data-source agnostic – use of measurements and information from small-satellite systems/constellations is welcomed if their scientific and applications value to the research is justified in the proposal
- **Earth Observations from Private Sector Small Satellite Constellations Pilot:** Data buys of ***existing*** data products related to ECVs, derived from private sector-funded small-satellite ***constellations*** (3-satellite minimum constellation, full longitude coverage); ***for evaluation by NASA researchers to determine value*** for advancing NASA research and applications activities and objectives; ***pilot buys in 2018***

Private Sector Small-Satellite Constellation Pilot - Update

- Have signed contracts with three companies to buy ***existing*** data products related to ECVs, derived from private sector-funded small-satellite ***constellations*** (3-satellite minimum constellation, full longitude coverage); ***for evaluation by NASA researchers to determine value*** for advancing NASA research and applications activities and objectives;
  - Planet – three satellite constellations including 200+ satellites supplying imagery and derived products over the entire Earth
  - DigitalGlobe – operates five satellite constellations that provide very high-resolution (31-50-cm) images
  - Spire – constellation of 48 satellites collecting Radio Occultation soundings and ship reports
- May provide a cost-effective means to augment and complement the suite of Earth Observations
- **Have identified a broad set of ESD-funded researchers who will be supported to *assess the value of the geophysical information in the data products for advancing NASA research and applications objectives***
  - 1 year evaluation period
  - Participants primarily chosen from existing ESD-funded community – evaluation support as budget augmentation
  - Written reports to ESD (not scientific papers)
  - Quality of geophysical information
  - Data availability (latency) and subdistribution rights vs. cost
  - Vendor plans for constellation maintenance/evolution

"Sustainable Land Imaging" – Moderate Resolution, Multi-Spectral

2017 Decadal Survey Snapshot



2017 DECADAL SURVEY

UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space

Space Studies Board

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

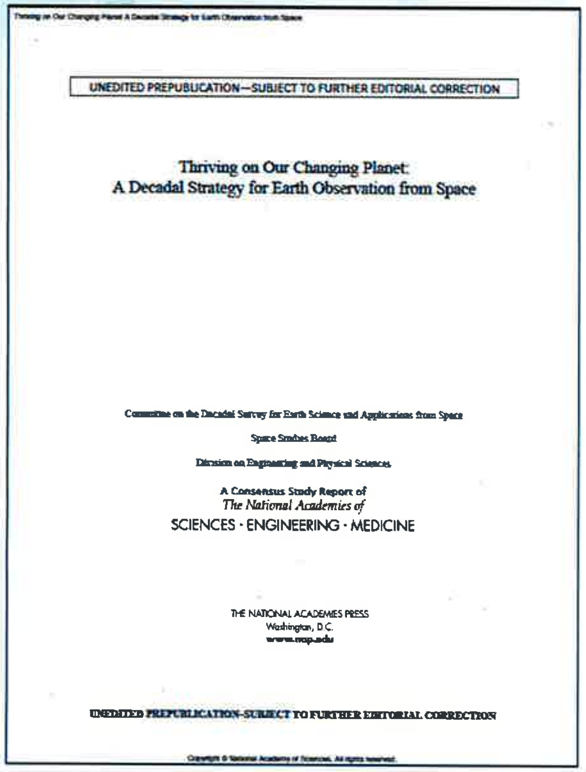
THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION

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

2017 Decadal Survey Snapshot (cont.)

2017 DECADAL SURVEY



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UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION

- Calls for “cost-capping” essentially all missions
- Recommends “Continuity Measurement” strand ($150M full mission cost cap) as an addition to the existing Venture-class program ✓
- Identifies 5 ”Designated” observables (DO) for mandatory acquisition (*Aerosols; Clouds, Convection, & Precipitation; Mass Change; Surface Biology & Geology; Surface Deformation & Change)* ✓
- Introduces a new competed “Explorer” flight line with $350M cost constraint, 3 observables to be chosen by ESD from among 7 identified ?
- Calls for “Incubator Program” between Technology, R&A, and Flight to mature specific technologies for important – but presently immature – measurements (preparation for next Decadal) ✓

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 administration
- 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

Communicating our plans and progress:

- ESD's Decadal Survey web page:
  https://science.nasa.gov/earth-science/decadal-surveys
- Monthly webex/calls with NASA Centers
- 3/year (every 4 months) open webex/calls with external communities
- Engagement with interagency and international partners
- Town halls at professional society meetings
- Use the web page to…
  - See meeting and telecon announcements
  - Ask questions
  - Find answers to questions, as they become available
  - View records of progress and decisions

Designated Observables Summary (from DS)

Observable	Science/Applications Summary	Candidate Measurement Approach	ESAS maximum cost
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multichannel/multi-angle/polarization imaging radiometer flown together on the same platform	CATE Cap $800M
Clouds, Convection, And Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	CATE Cap $800M
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	Est Cap $300M
Surface Biology and 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	CATE Cap $650M
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	Est Cap $500M

DO Mission/Observing System Implementation

- Each DO Mission/Observing System will be directed to a Center
- Each Mission/Observing System will be cost-constrained, informed by DS
- Payloads will be competed by HQ
- Satellite bus expected to be procured
- Partnerships strongly encouraged
- Contributions of each mission/observing system to other ESD science objectives strongly encouraged
- SBG or some combination of Aerosol/CCP will be first DO mission/observing system to be initiated

Designated Observables Guidance Summary

- ESD requested multi-center study plans to perform studies associated with the following cost-constrained DOs:
  - SBG: <$650M, full NASA cost for implementation (including launch services and core science)
  - Aerosols: <$800M, full NASA cost …
  - CCP: <$800M, full NASA cost …
  - Combined Aerosols and CCP study to address missions/observing systems approaches that can be implemented for <$1,600M, full NASA cost …
  - SDC: <$500M, full NASA cost …
  - MC: <$300M, full NASA cost …
- Study plans were submitted for ACCP (Combined), SBG, SDC and MC (4 total)
- The SBG, Aerosols, CCP and Combined Aerosols/CCP studies are expected to result in the initiation (KDP-A) of at most 2 projects in the FY21/22 timeframe approximately as follows:
  - DO#1 - 10/2021
  - DO#2 - 4/2022
- Other projects resulting from the DO studies are expected to be initiated (KDP-A) no earlier than FY24.

Guidance for DO Studies

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

ESD Points of Contact once Studies are Underway (PE, PS, and PA)

Study	Program Executive	Program Scientist	Program Applications Lead
A-CCP	Mitra Dutta	Hal Maring (Alternates: Gail Skofronick-Jackson, Barry Lefer)	John Haynes (Alternate: David Green)
SBG	Dave Jarrett	Woody Turner (Alternate: Ben Phillips)	Woody Turner (Alternate: Brad Doorn)
SDC	Richard Slonaker	Gerald Bawden (Alternate: Hank Margolis)	David Green
MC	Mayra Montrose	Lucia Tsaoussi (Alternate: Jared Entin)	Brad Doorn

International Engagement

- ESD has conducted focused Decadal Survey telecons/meetings with key international partners
  - ISRO, JAXA, CNES, DLR, ESA, EUMETSAT, CSA, now GFZ
  - 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

Request for Information

- The DO studies aim to identify and evaluate observing system architectures and approaches that might improve the overall observing systems (increased capability and/or resilience, and/or reduced costs).
- ESD is taking a broad approach to addressing the observation architectures for the DOs. The studies will initially examine and evaluate the costs and benefits of observing system architectures that include a mix of NASA, international, interagency, and/or commercial spaceborne assets and data products, as appropriate.
- The RFI solicits input on ***how industry and other non-governmental organizations wish to be involved in the multi-year NASA Designated Observables observing system architecture studies***.
- Offerors interested in participating in the multi-center DO studies are asked to submit short (< 10 pp) statements providing:
  - Ideas on ways they wish to participate in the planning processes/studies associated with implementing the DS recommendations;
  - The level of involvement desired; and
  - Aspects that they can contribute to the studies.
- ***The RFI does NOT invite ideas regarding the specific observing systems/solutions that are to come out of the studies***. It rather solicits inputs and ideas on how the private sector and other non-governmental organizations can best ***PARTICIPATE in the architecture studies***.
- Informed by the RFI input, NASA ESD intends to issue small contracts with multiple non-government/private sector entities to secure their participation in the studies.
- RFI was posted on September 4, 2018: https://www.fbo.gov/index?s=opportunity&mode=form&tab=core&id=95da1d67e34c9094907c688d1cb2897b

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

Objectives

- Refine Science Traceability Matrices (STM) from ACE and add STMs for aerosol air quality, convection and precipitation
- Engage NASA center, university, US government agencies, commercial and international partners
- Use refined STMs as the scientific basis to design, develop and assess viable candidate architectures for making necessary observations utilizing satellite remote sensing, airborne measurements and surface-based sensors

Scope/Implementation

- **Phase 1** – Develop Science Value Framework
- **Phase 2** – Refine and Develop STMs
- **Phase 3** – Develop A-CCP DO Architecture(s) including documentation for Mission Concept Review
- **Phase 4** – Preparation of Final Study Report

Timeline

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

Participants

- HQ – Maring, Jackson, Lefer, Dutta, Edwards, Haynes
- Study Coordinators – Cutlip (GSFC), Vane (JPL), Trepte (LaRC)
- NASA Centers - GSFC, JPL, LaRC, MSFC, ARC, GRC
- Other Expected US Participants NOAA, EPA, Universities, Commercial
- Hoped for International Partners – CNES, JAXA, ESA, SRON, …

Mass Change (MC) Designated Observables Study Plan

Objectives

- Identify and characterize a diverse set of high value MC observing architectures responsive to Decadal Survey, preserving the fundamental approach that MC is observed through gravitational forces acting on the space craft(s).
- Assess the cost effectiveness of each of the studied architectures.
- Perform sufficient in-depth design of one or two select architectures to enable rapid initiation of a Phase A study

Scope/Implementation

- Examine (1) novel approaches considering emerging capabilities, such as industry spacecraft, launch vehicles, and "data buy" opportunities, and (2) innovative approaches and enabling techniques, such as small satellite buses, constellations using only positioning information, compact, low-power electronic accelerometers and drag compensation systems.
- Candidate Mission Architectures will maintain continuity of measurements and/or explore:
  - Ground water and water storage mass change
  - Land ice contributions to seal level rise
  - Ocean mass change & heat content (when combined w/altimetry)
  - Glacial isostatic adjustment
  - Earthquake mass movement.
  - Operational applications (drought, hazards, agriculture, etc.)

Timeline

- **Oct 2018 – Phase 1 – Develop Candidate Architectures:** Engage user communities to define requirements and establish capabilities, and create value framework
- **Oct 2019 – Phase 2 – Assessment of Candidate Architectures:** Evaluate science and applications value, down-select to top candidates for detailed evaluations
- **June 2020 – Phase 3 – Architecture Design of top candidate(s):** Phase A study leading to Mission Concept Review
- **Jan 2021 – Phase 4 – Develop final report and Preparation of Mission Concept Review**
- **Sept 2021 – Delivery of final report and end of Study:** includes required observational capabilities of mission concept that may be used for competitive procurement of mission components.

Participants

- NASA – L. Tsaoussi, MC HQ Lead
- JPL – Study Lead (B. Bienstock, Study Coordinator)
- ARC, GSFC, LaRC study partners
- Academia (U. of Texas, U. South Florida, U. Colorado)
- International (DLR, ESA)
- US government (NOAA, USGS)
- Industry

Surface Biology and Geology (SBG) Designated Observable Study Plan

Objectives

- Establish research and applications questions for SBG looking to the Decadal Survey and prior HyspIRI questions
- Engage SBG end users and stakeholders in the above process
- Use a science and applications traceability framework to derive observing system desired capabilities from questions
- Explore domestic and international partnerships
- Develop, assess, and design candidate architectures

Scope/Implementation

- **Phase 1** – Development of Candidate Architectures
- **Phase 2** – Assessment of Potential Architectures for Cost-effective SBG Observations
- **Phase 3** – Design of Recommended SBG Architecture and Preparation of Mission Concept Review Material
- **Phase 4** – Preparation of End of Study Report

Timeline

- August 2018 – Final HyspIRI Workshop/Initial SBG Workshop
- September 2018 – HyspIRI Final Report
- October 2018 – Initiate SBG Study Plan Funding
- December 2018 – Parallel and connected activities of the Research and Applications, Architecture Formulation, and Cost Estimation technical teams
- January 2019 to September 2021 – Assessment of candidate architectures and design of SBG observing system concept
- December 2021(?) – Final Report, Mission Concept Review

Participants

- HQ – Turner, Phillips, Bontempi, Jarrett, Doorn SBG Leads
- Study Coordinator – JPL/Jamie Nastal
- GSFC, ARC, LaRC, MSFC study partners
- USGS, USDA, NOAA, SI, etc. – Government Participants
- Academia
- Industry
- ESA, SRON, IAVCEI, etc. – International Participants

Surface Deformation and Change (SDC) Designated Observables Study Plan

Objectives

- Determine cost-effective SAR-based architecture to implement the Surface Deformation and Change Observable
- Keep other science and applications that SAR can enable in the trade space
- Engage emerging best and new practices in industry to maximize engagement and exploitation of commercial sector capabilities and interests, including smallsat constellations
- Explore international partnerships to leverage capability and reduce cost

Scope/Implementation

- Include SAR-based architectures that support broader science/applications observables beyond geodetics in trades
- **Phase 1** – Engage user communities to define requirements and 5-6 candidate architectures; establish value framework
- **Phase 2** – Evaluate science/applications value; down-select to 2 top candidates for detailed evaluation; down-select to concept
- **Phase 3** – Phase A study leading to Mission Concept Review
- **Phase 4** – Final Report and MCR prep

Timeline

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

Participants

- HQ Leads: PS–Bawden, Margolis: PE–Slonaker: PA– Green
- JPL – Study Lead (P. Rosen, Study Coordinator)
- ARC, GSFC, LaRC, MSFC study partners
- USGS, NOAA, NGA government participants
- Academia
- Industry

Framework for implementing Earth Venture Continuity (EVC)

ESD Top Level Approach to EVC

- ESD will use EVC to demonstrate a technique/approach for making long-term measurements with the appropriate characteristics (a "continuity demonstration")
- Criteria for selecting an EVC project:
  - Capability of the instrument/characteristics of the data
  - Cost of future copies
  - Accommodability
  - Producibility
  - Ease of technology infusion (optional)
- Payload Classification will be Class C or D
- EVC will NOT address continuity beyond the demonstration
  - Minimum demonstration period is 1 year beyond on-orbit commissioning
  - Additional on-orbit acquisition will not be under the cost cap
- Interleaved with EV-Instrument - EVI or EVC solicitation every 18 months
- ~$150M total cost constraint
- The ESD objective will be to fly 3 EVC missions in the decade

Targeted Solicitation: EVC-1

- Defined and accelerated implementation of Earth Venture Continuity competed strand targeted for radiation budget sensor/RBI replacement
- Preparing EVC solicitation for release Dec 2018 (draft AO for comment during Fall 2018); EVC-1 will allow flight on JPSS-3; will have extraordinary 5-year lifetime target
- NASA-owned RBI hardware made available to proposers as GFE

Future Solicitations

- Future EVC solicitations may:
  - Target a single observation for a given imperative (similar to EVC-1)
  - Target a set of observations (e.g., solar irradiance, ozone, and CO2)
- ESD will maintain the flexibility to pursue either of the above options, but it is expected that most will be single observation targeted
- However, once we know what we want to do with the next EVC, ESD will alert the community to our intentions

Incubator Program (preliminary)

Incubation as Described in the DS

- A new program element, focused on investment for priority observation capabilities needing advancement prior to cost-effective implementation, including an innovation fund
  - Suggested funding $20M/year ~~including innovation fund~~
  - ~~Innovation fund to respond to emerging needs described as unexpected opportunities that occur on sub-decadal time scales~~
- Support maturation of mission, instrument, technology, and/or measurement concepts to address specific high priority science (for 2027-2037 decade) of the 3 targeted observable areas:
  - ~~Atmospheric Winds (AW), also listed under ESE~~
  - Planetary Boundary Layer (PBL), and
  - Surface Topography and Vegetation (ST&V)
- The Incubation investment should achieve sufficient risk reduction to achieve readiness for space flight during the next decade
- Plans for Incubation Program implementation continue to mature

Strikeouts indicate ESD decisions to NOT implement Recommendations at this time

Incubation Observables Summary from DS

Observable	Science/Applications Summary	Candidate Measurement Approach	Measurement Requirements
Planetary Boundary Layer (PBL)	**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	• From High resolution and diurnally resolved 2D/3D measurements of PBL - 200 m vertical resolution for 3D variables (Temperature, Humidity and Horizontal wind vector) with 2-3 hourly temporal resolution and 20 km horizontal resolution
Surface Topography and Vegetation (ST&V)	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar; or lidar*	• Contiguous 5m sampling with 0.1m vertical accuracy from space • Contiguous 1m sampling with 0.1m vertical accuracy from aircraft • With seasonal repeat

* **Notable that both observables list a multi-function lidar for candidate measurement approach**

Framework for implementing Earth Science Explorers (ESE)

ESE Observables Summary (from DS)

Observable	Science/Applications Summary	Candidate Measurement Approach
Greenhouse Gases	**CO2 and methane fluxes and trends,** global and regional with quantification of point sources and identification of sources and sinks	Multispectral short wave IR and thermal IR sounders; or lidar**
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**
Ocean Surface Winds and 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	Doppler scatterometer
Ozone and Trace Gases	**Vertical profiles of ozone and trace gases** (including water vapor, CO, NO2, methane, and N2O) globally and with high spatial resolution	UV/Vis/IR microwave limb/nadir sounding and UV/Vis/IR solar/stellar occultation
Snow Depth and Snow Water Equivalent	**Snow depth and snow water equivalent** including high spatial resolution in mountain areas	Snow depth and snow water equivalent including high spatial resolution in mountain areas
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 and forest degradation	Lidar**
Atmospheric Winds*	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and largescale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**

*Atmospheric Winds is listed as BOTH an ESE Observable ~~and Incubation Observable~~

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

ESE Decisions

- Atmospheric Winds is eligible for DS Explorers focus list - removed from Incubator list
- ESE will use a two-step AO process, similar to mission solicitations in other SMD Divisions
  - $350M cost-capped (including launch services) observing systems/missions to be solicited
  - 9-14 month Phase A prior to down-select
  - First solicitation will likely allow proposals for any observable from the DS Explorers list
  - Subsequent ESE solicitations will likely restrict primary observable foci based on previous selections
  - ESD will encourage solicitations that address more than one ESE Observable and that support other aspects of the DS-recommended ESD portfolio
- The first ESE solicitation will be planned for release no earlier than FY20, pending budget developments
- New Earth System Explorers Program Office to be established
- Budget constraints may make it unlikely that Earth Science Explorer will be initiated until late in the decade.

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

Strategic Framework for Leveraging Resources & Advancing

ELEMENTS OF DECADAL STRATEGY

I. Embrace **Innovative Methodologies** for Integrated Science/Applications
II. Commit to **Sustained Science and Applications**
III. Amplify the **Cross-Benefit of Science and Applications**
IV. Leverage **External Resources and Partnerships**
V. Institutionalize **Programmatic Agility and Balance**
VI. Exploit **External Trends** in Technology and User Needs
VII. Expand Use of **Competition**
VIII. Pursue **Ambitious Science**, Despite Constraints

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, partially recovering from the underfunded state it was in a decade ago . . .**

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

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

Quick Summary of Recommendations

1

VISION & STRATEGY

"Thriving on our Changing Planet"

2

SCIENCE & APPLICATIONS

Address **35 key science/applications questions,** from among hundreds suggested. Highest priority objectives fell into **six categories**:

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

3

OBSERVATIONS

Augment the **Program of Record** with **eight priority observables**:

- **Five** that are specified/designated to be implemented:
    - *Aerosols*
    - *Clouds, Convection, & Precipitation*
    - *Mass Change*
    - *Surface Biology & Geology*
    - *Surface Deformation & Change*
- **Three** others to be selected competitively from among six candidates
- Structure **new mission program elements** to accomplish this

4

PROGRAMMATICS

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

Summary of Top Science and Applications Priorities*

* Complete set of Questions and Objectives in Table 3.3

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

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**