Earth Science Division
Decadal Survey Briefing with Stakeholders

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ESD Director

November 12, 2020

Outline

1. Earth Science Division Overview
2. Decadal Survey Update
3. Update of DOs
    - ACCP – Aerosol, Cloud, Convection and Precipitation
    - MC – Mass Change
    - SGB – Surface Biology and Geology
    - SDC – Surface Deformation and Change
4. Incubation Program
5. Open Science Update
6. Cross Benefits of Applications and Research
7. Upcoming Calendar
8. Q&A

Questions Process

- During the Q&A, please type your question directly in the Q&A panel
- Or you can email questions to Amy Treat at Amy.A.Treat@nasa.gov
- Answers to relevant questions will be posted on our website: https://science.nasa.gov/earth-science/decadal-surveys

Earth Science Division Overview

Sentinel-6 Michael Freilich ◆ November 21, 2020


SENTINEL-6

Earth Science Division Diversity and Inclusion Task Force

Our Goal: Building a diverse, equitable, inclusive and accessible environment for marginalized communities within the Earth science community.

The Work Ahead

- We've established an ESD Diversity and Inclusion Task Force to identify the most effective and impactful actions that can be directly undertaken within and specifically benefit the Earth science community.
- Collect and analyze current data and metrics to level set our understanding of where we are as a community, and what specific actions we can take to grow.
- Champion Dual Anonymous Peer Review and other measures to address perceived bias in our panel review process.
- Further expand upon current footprint with STEM partnerships and increase participation with Historically Black Colleges and Universities and other Minority Serving Institutions.
- Highlight and amplify the accomplishments of our diverse NASA scientists and researchers – to encourage a more diverse generation of STEM professionals.

COVID-19 Update

https://earthdata.nasa.gov/covid19/

https://eodashboard.org/

Research & Analysis Response to COVID-19: Rapid Response and Novel Earth Science (ROSES-19)

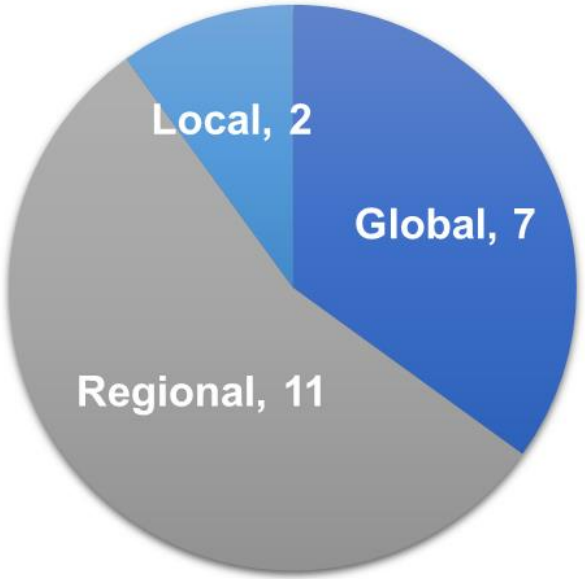
https://science.nasa.gov/earth-science/rrnes-awards

>130 inquiries

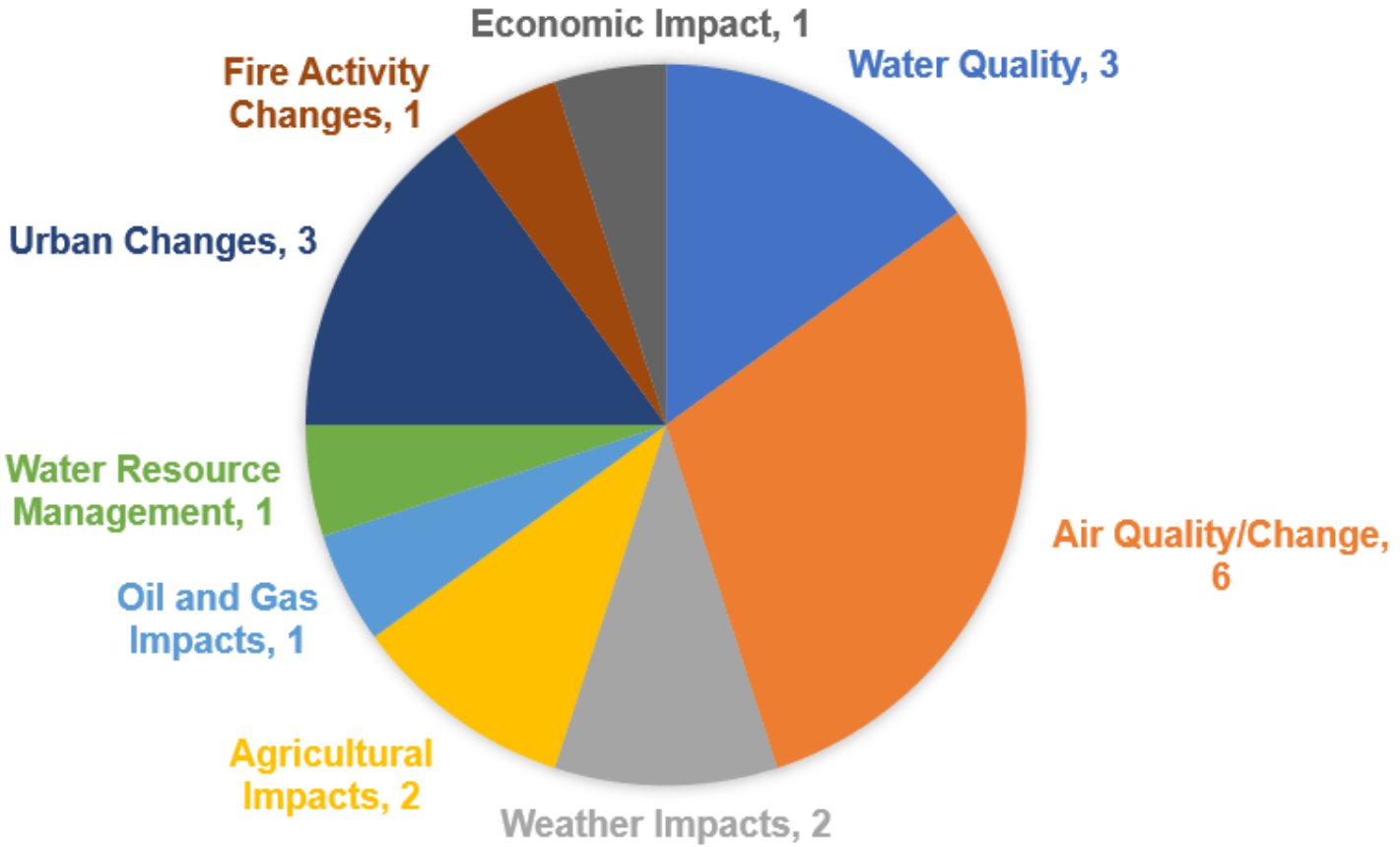
43 proposals submitted

20 selections to date

Geographic Extent of Research



Areas of Research of COVID-focused RRNES



NASA International Space Apps Challenge 2020

spaceappschallenge.org

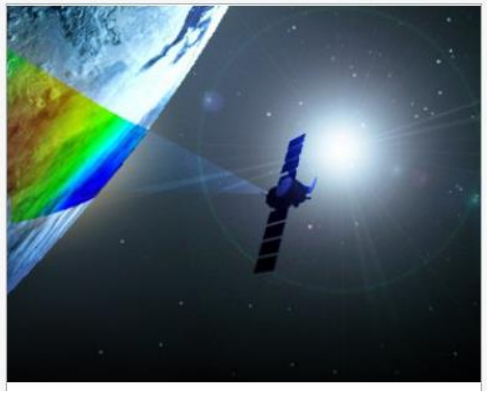
5 space agencies (NASA, CSA, CNES, JAXA, ESA)

26,000+ registered participants

Nearly **150** countries/territories represented

2,300+ projects submitted

Confront



Connect

Invent Your Own Challenge

Observe

Inform

Sustain

Create

2020 Senior Review Results

NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

SWOT (CNES)
LANDSAT-9 (USGS)
SENTINEL-6 Michael Freilich/B (ESA)
TROPICS (6)
GEOCARB
NISAR (ISRO)
MAIA
TSIS-2
TEMPO
PREFIRE (2)
PACE (NSO)
GLIMR
ICESAT-2
GRACE-FO (2) (GFZ)
CYGNSS (8)
NISTAR, EPIC (DSCOVR/NOAA)
CLOUDSAT (CSA)
TERRA (METI, CSA)
AQUA (JAXA, AEB)
AURA (NSO, FMI, UKSA)
CALIPSO (CNES)
GPM (JAXA)
LANDSAT 7 (USGS)
LANDSAT 8 (USGS)
OCO-2
SMAP
SUOMI NPP (NOAA)

ISS INSTRUMENTS

EMIT
CLARREO-PF
GEDI
SAGE III
OCO-3
TSIS-1
ECOSTRESS
LIS

JPSS-2, 3 & 4 INSTRUMENTS

OMPS-Limb
LIBERA

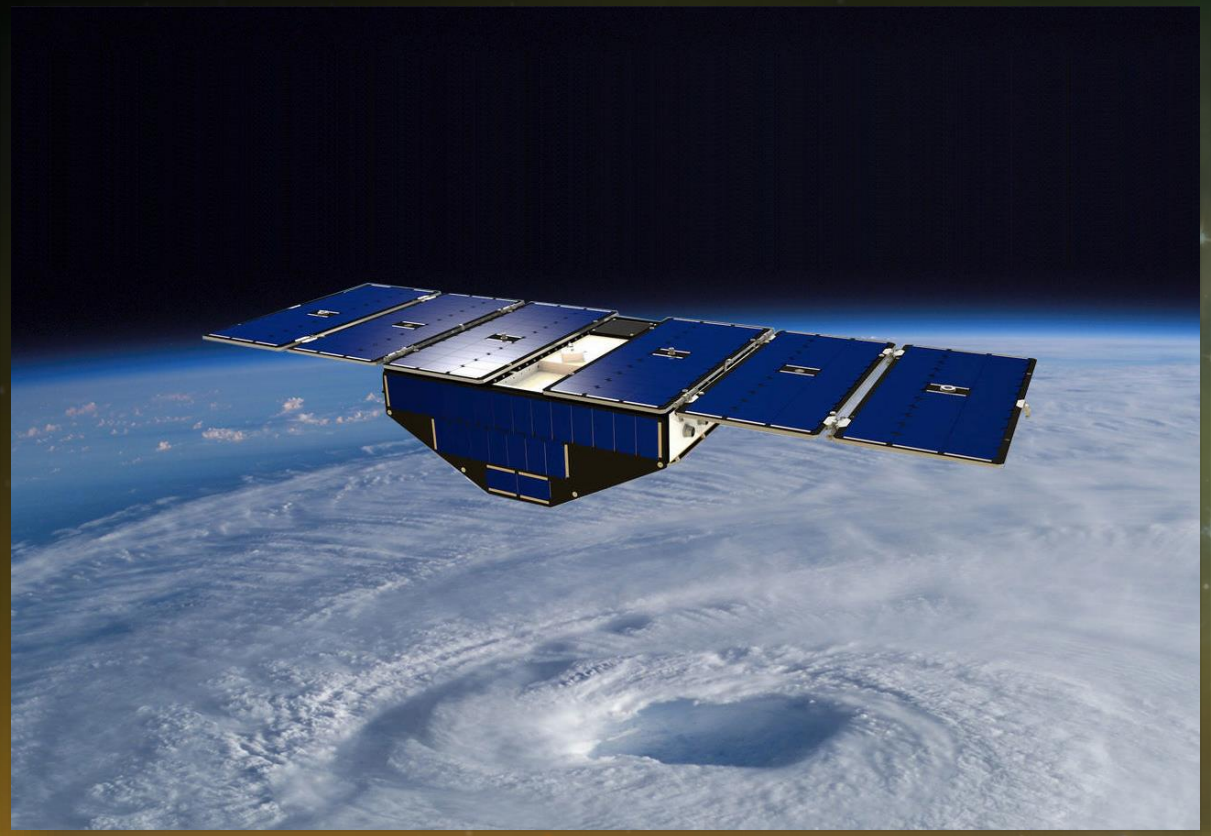
INVEST/CUBESATS

RainCube
CSIM-FD
HARP
TEMPEST-D
CIRiS
CTIM
HyTI
SNoOPI
NACHOS

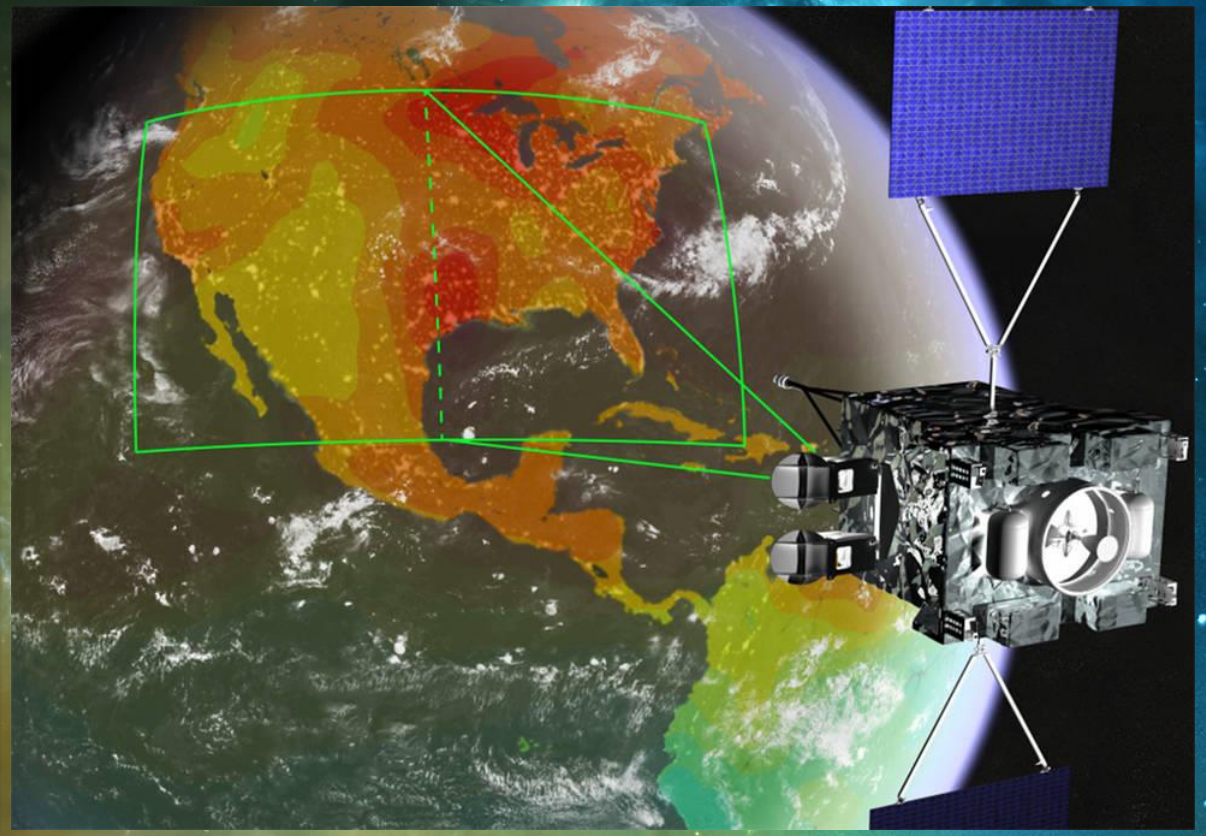
(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS

06.29.20

EVM-3 Announcement of Opportunity (AO)



EVM-1 (CYGNSS)

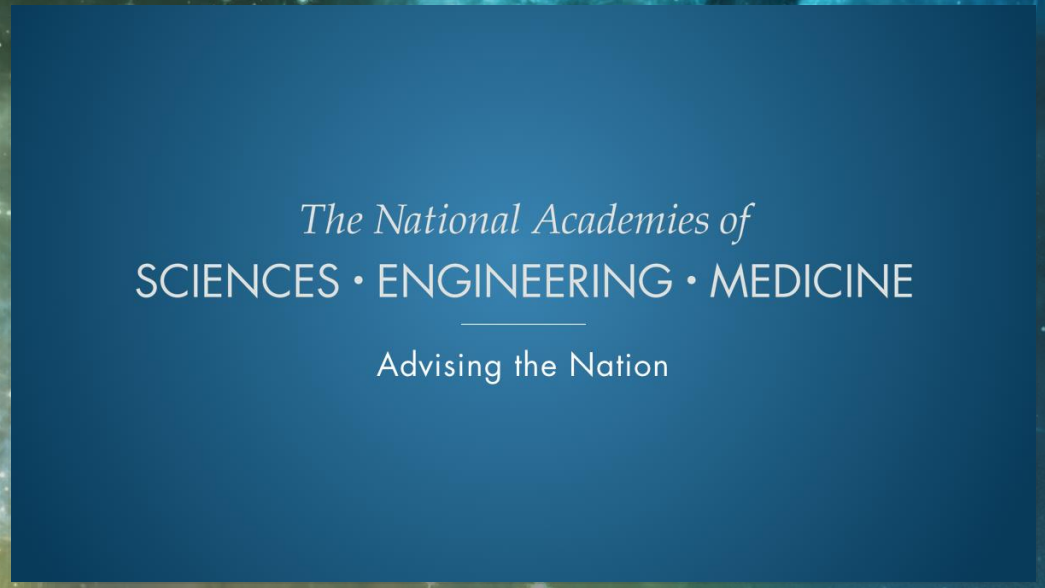


EVM-2 (GeoCarb)

Earth Venture & The National Academies

NASEM Workshop:
Lessons-Learned in the Implementation of the Earth Venture Mission (EV-M) and Earth Venture Instrument (EV-I)

The NASEM mid-term study:
Include a focused review of the Earth Venture Suborbital (EV-S) program as specified in the 2017 Decadal Survey.

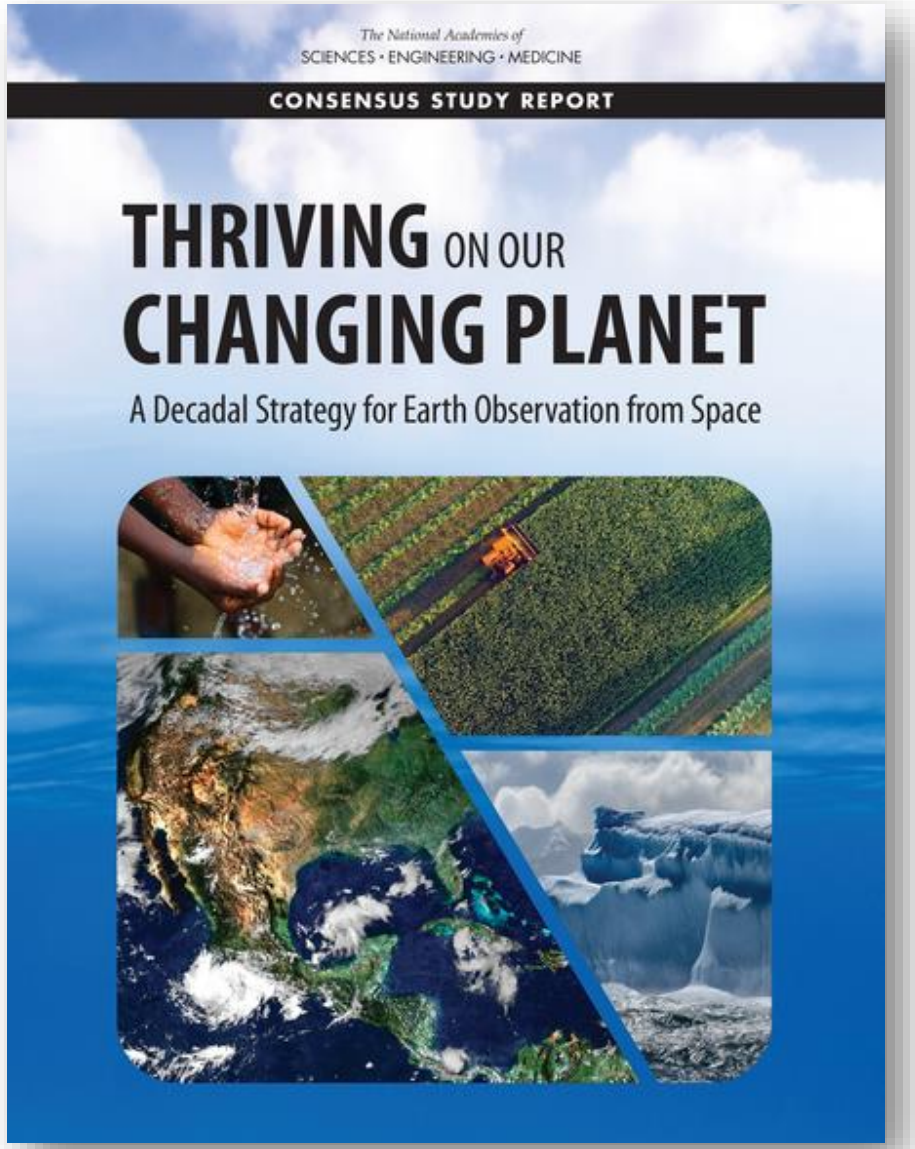


Decadal Survey Overview

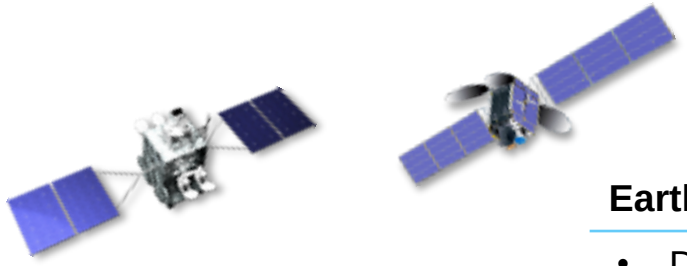
2017 Decadal Survey Snapshot

- Prioritizes observations rather than specific missions
- Identifies five “Designated” Observables
  - Aerosols; Clouds, Convection & Precipitation (ACCP)
  - Mass Change (MC)
  - Surface Biology & Geology (SBG)
  - Surface Deformation & Change (SDC)
- Introduces a new “Explorer” flight line
- Calls for “Decadal Incubation Program” on Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (ST&V)

ESD is working with the community to translate the recommendations into an executable program and, for Flight, a portfolio of specific, realistic, launch-ordered missions and solicitations



2017 Decadal Survey Progress Highlights



Earth Venture-Continuity

- DS recommended new Earth Venture Continuity Measurement strand ($150M full mission cost cap)
- In December 2018, ESD released EVC-1 solicitation targeted for radiation budget measurements
- In February 2020, Libera (LASP) selected

Earth System Explorers

- DS recommended a new competed Explorer flight line with $350M cost constraint
- Implement 3 of 7 Targeted Observables
- Framework for program established
- Implementation on hold pending budget developments

Designated Observables

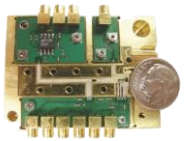
- DS identified 5 Designated Observables (DOs) for mandatory acquisition

  In 2018 ESD initiated 4 multi-center DO studies, continued in 2019:
  - Combined: Aerosols-Clouds, Convection & Precipitation
  - Mass Change
  - Surface Biology & Geology
  - Surface Deformation & Change

- First DO Architecture Down Select by the end of Calendar Year 2020 to enter pre-Phase A
- Fully funds a DO project to be initiated in FY21, and initiates two more in FY23, and FY26

Decadal Incubation

- DS calls for Incubation Program to mature specific technologies for important — but presently immature — measurements (preparation for next Decadal)
- Solicitations for Study Teams (PBL and STV) released on March 14, 2019; selections made on December 3, 2019
- Decadal Incubation initiated and funded



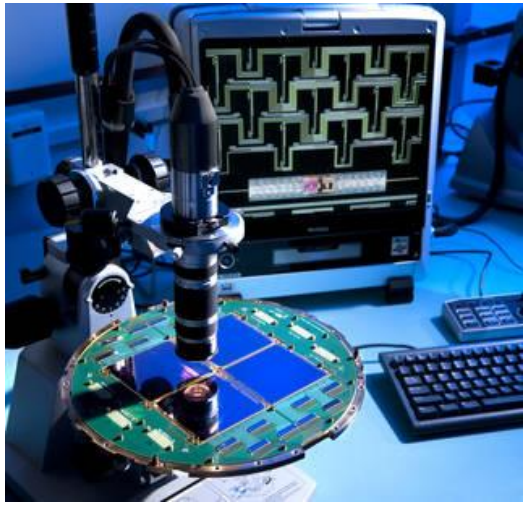
DO Industry Engagement: Updates on Solicitations

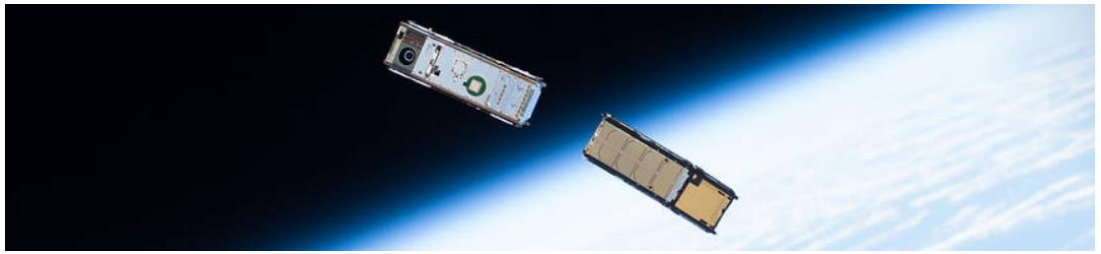
	Description	Supported Activity	Status
Category 1	Cross-Cutting Expertise in Specific Areas	All of the DOs	Underway
Category 2	Support to HQ	HQ Decadal Strategy	Pending
Category 3	Technology Demonstrations	Specific to each DO	Reporting by each DO study
Category 4	Applications Support	All of the DOs	Underway

Category 1: Cross-Cutting Support to DOs

JPL released the Category 1 solicitations in cross-cutting areas (i.e. capabilities that could apply to multiple DOs) where industry has unique expertise:

- SmallSat/CubeSat Constellations – **awarded and underway**
- Payload hosting on Commercial Satellites – **awarded and underway**
- Ground System Architectures – **proposal declared nonresponsive**
- Data Processing/Data Storage/Cloud Computing – **no proposals**
- Market Research on out-of-the-box enabling commercial technologies – **awarded and underway**
- Research on non-traditional stakeholders and partnerships, such as philanthropists, non-profits, and foundations – **1st year final report received. Currently engaging with a select group of philanthropies.**





Category 1: Foundations & Philanthropies

[Exploiting] external trends might include… nontraditional partnerships such as philanthropists and nonprofits
Decadal Survey, p. 63

First stage completed Oct. 2020

- Global Trends affecting ESD and Philanthropies
- Characterization of the Foundation Landscape
- Assessment of Potential Partners
- Engagement with Select Entities

Second stage beginning for follow-up engagements with 10 selected entities

Contractor: The Metropolitan Group

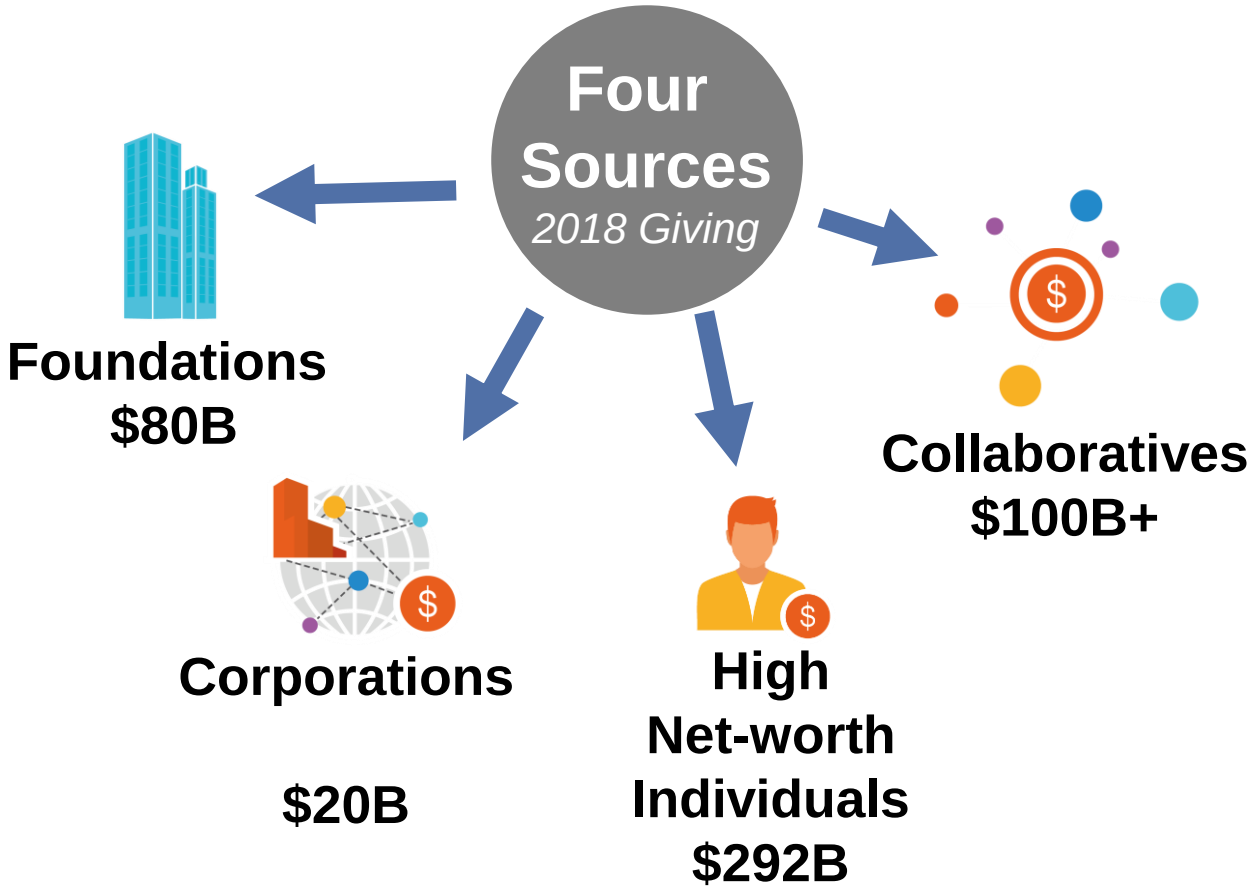
Metropolitan Group

In addition to support of the DOs, the results and potential partnerships may support activities across all of NASA Earth, including research, technology, diversity, applications, data systems, field campaigns, student support, etc.

Global Trends Identified

Rise of Alternative Science	Drowning in Data	Emergence of Stakeholder Capitalism	Big Funding for Big Bets
			
Pseudoscience and misinformation spread through social media threaten to deepen polarization and undermine policies to tackle large-scale challenges, but public trust in science can still be built in an era of social media by focusing on science applications that people understand improve their lives.	A gap is growing between the amount of data generated and the human capacity, skills and technology needed to effectively use data, but there is no coordinated strategy to address the gap even as data development accelerates.	Corporations are increasingly recognizing that their long-term profitability is tied to achievement of the U.N.'s Sustainable Development Goals, but there is no standardized measurement and accountability system to ensure that capitalism benefits its full diversity of stakeholders.	Philanthropy is teaming up like never before to pool resources needed to pursue the world's biggest challenges, but where and how government fits into the pursuit of these big bet collaboratives remains an open question.

Philanthropy Typology



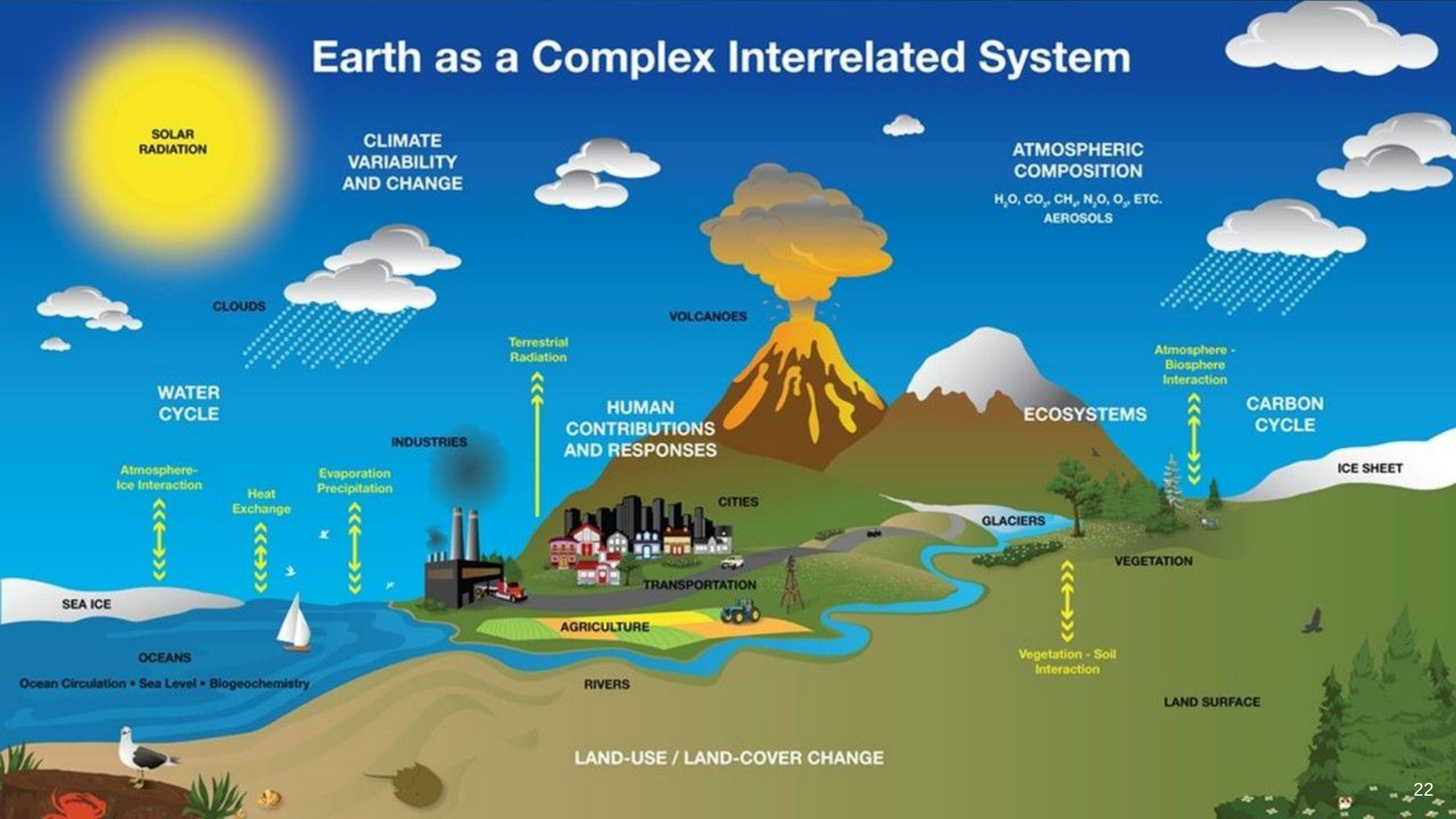
How Philanthropy is Changing

Privatization of problem-solving

Small pools of high-net worth

Strategic philanthropy

Hunger for science


Earth as a Complex Interrelated System
SOLAR RADIATION
CLIMATE VARIABILITY AND CHANGE
ATMOSPHERIC COMPOSITION
H_2O, CO_2, CH_4, N_2O, O_3, ETC.
AEROSOLS
CLOUDS
VOLCANOES
Terrestrial Radiation
WATER CYCLE
HUMAN CONTRIBUTIONS AND RESPONSES
ECOSYSTEMS
Atmosphere - Biosphere Interaction
CARBON CYCLE
INDUSTRIES
Atmosphere-Ice Interaction
Heat Exchange
Evaporation Precipitation
CITIES
ICE SHEET
GLACIERS
VEGETATION
TRANSPORTATION
SEA ICE
AGRICULTURE
Vegetation - Soil Interaction
OCEANS
Ocean Circulation • Sea Level • Biogeochemistry
RIVERS
LAND SURFACE
LAND-USE / LAND-COVER CHANGE

Progress Thus Far

- Development of mission options and analyses by strong, multi-Center teams
- Industry engagement, RFIs & funded studies
- Community engagement
- Exploring range of international partnerships
- Preliminary cost analysis for US elements
- Cross-cutting Data & Open Science strategy

Alignment Principles to Guide Next Steps

- Accomplish Decadal objectives, within constraints
- Be intentional about NASA strategic leadership
- Pursue strategic international partnerships
- Incorporate speed and innovation cross the entire value chain
- Leverage US space industry and commercial capabilities
- Establish reserves, within cost targets, consistent with risk posture and prior experience

Aerosol, Cloud, Convection and Precipitation (ACCP)

Mission Study on Aerosol and Clouds, Convection & Precipitation

ACCP Science Objectives

Mission Study on Aerosol and Clouds, Convection & Precipitation

ACCP Enabled Applications

Climate Modeling
12. Parametrization of clouds and particle distribution for aerosols and precipitation
13. Global climate smoke aerosol transport and aerosol and aerosol/cloud feedback

Weather Forecasting
1. Tropical Cyclone Dev
2. Monitoring Convective Storms & Hazards
3. Atmospheric Rivers
4. Aviation Hazards
5. Pre-fire weather monitoring for wildfire response and management.

Numerical Weather Prediction
6. Representation of initial conditions and data assimilation
7. Coupling of aerosols within numerical weather prediction modeling
8. Development and verification of cloud/convective parameterizations

Operational Air Quality Forecasting
9. Tracking dust, wildfire smoke, and volcanic plumes
10. Forecast initialization and verification

Aerosol & Precipitation Interactions
11. Air quality modeling and forecasting

Study Status Update

- **Science and Applications Traceability Matrix** (SATM) Release F, used for scoring, Release G update in draft/pending release
- **Architecture Design Complete** (GSFC, JPL, LaRC, and MSFC Design Centers January-October 2020).
  - Special Studies March and May 2020 to include JAXA radar contribution
- **Architectures Frozen 30** September 2020 (except for minor tweaks)
- **Architecture Evaluations Ongoing** with Science Community Committee (SCC) February-December 2020 (iterative)
  - Full team review of Architecture initial Science, Programmatic (Cost, Risk and Other Programmatic Factors), and Applications evaluations completed 12-13 **February 2020 (Medium Satellite Configuration)**
  - Architecture Evaluation Review #1—**April 2020 (Medium and Distributed ESPA Grande)**
  - Architecture Evaluation Review #2–**June 2020 (Lidar Trade Study)**
    - Special Study to include CNES HSRL with UV
  - Architecture Evaluation Review #3—**August 2020 (JAXA Radar Study Results and SmallSat Configurations)**
  - Architecture Evaluation Review #4—**September 2020 (Initial Cut Science Narratives, Final Architecture Freeze)**
  - Architecture Evaluation Review #5—**October 2020 (Updated Science Scores & Narratives)**
  - Architecture Evaluation Review #6—**December 2020 (Architecture Scoring Freeze, Updated Narratives)**
- **Down-Selected from ~75 Architectures to ~10 Candidate Architectures which are within Cost Cap**
- **Finalizing Science Benefit Scoring and Recommendation of Final 3 Architectures from ~10 Viable Candidates**

Study Status Update (cont)

- Sub-Orbital Working Group (SOWG) Workshop (~75 participants) 11-13 March 2020
- ACCP Community Forums 22 June 2020 & 29 September 2020
- HQ Annual Reviews
  - 1 October 2020 - DO Overview
  - 5 October 2020 - International Partnership & Risk Assessment
  - 19 October 2020 - Path Forward
  - 29 October 2020 - Constellations
  - 2 November 2020 - Accelerating Science and Applications
  - 16 November 2020 - Mission Assurance, Mission Classification & Risk Tolerance
  - 18 November 2020 - Summary
- Applications Transportation Logistics Workshop (~100 participants) - 2, 4 & 5 November 2020
- SBG Synergy Workshop - 4 & 16 November 2020
- Modeling Working Group Virtual Workshops “Bringing models and observations together for clouds and aerosols” – lead by Andrew Gettelman of NCAR – (~230 participants) - 10 & 12 November 2020

Study Upcoming Events

- 2-4 December 2020 — Final Internal Architecture Evaluation Review
- December 2020 TBS — Architecture Review with Earth Science Community Members
- December 2020 TBS — Center Level Workshops/Reviews Instruments and Final 3 Architectures
- 11 January 2020 — ACCP Community Forum
- 27-28 January 2020 — ACCP Down Select Meeting with HQ

Community Involvement

- ACCP Community Summer Forum 22 June 2020
- ACCP Community Fall Forum 29 September 2020
- ACCP Website: https://vac.gsfc.nasa.gov
- Science Community Committee recommendations (include radiation measurements, inclined orbit, Δ-t observations)
- Potential International partners (JAXA, DLR, CSA, CNES) involved
- Modeling Workshops Fall and Spring 2021
- Sub-Orbital Workshop Spring 2021

Mass Change (MC)

Mass Change (MC) Study Update

- Near-finalization of **Value Framework** results to assess the cost effectiveness of 50+ architectures along with science value metrics (performance), and risk, cost, and schedule. The analysis included 2 SmallSat architectures from a dedicated Team X study and an atomic interferometer gravity gradiometer (AIGG) studied in a dedicated Instrument Design Lab (IDL) session. The following conclusions have been reached as the study team works to narrow the trade space:
  - **SST architectures, consisting of either one or two pairs of satellites in either an in-line or pendulum formation, remain in the trade space.**
  - Constellations of **SmallSats** utilizing Satellite-Satellite Tracking (SST) are not a cost-effective solution due to stringent requirements on the flight system.
  - The **AIGG** has a high science performance ceiling but a long and uncertain path to achieving TRL 6.
  - Constellations of satellites using **Precise Orbit Determination (POD)** have a low science value, unable to fulfill the MC Baseline Science Objectives.
  - **LEO-MEO** SST architectures are not recommended to due a combination of low science value and technological challenges.
- **Continuity** considerations of observations with GRACE-FO. Stochastic analysis provides a range of dates for GFO lifetime based on variation in solar flux predictions and operations with a GFO accelerometer transplant (decreased altitude). GRACE-FO system reliability assessed via comparison with historical analogies.

Variants of Satellite-to-Satellite Tracking Architectures

The GRACE and GRACE-FO satellites implement the same basic architectural concept: A single pair of satellites in a polar orbit at ~500 km altitude.

The quality of gravity fields derived from GRACE and GRACE-FO are largely equivalent

The following **three primary methods** may be implemented to improve the quality of gravity fields relative to GRACE and GRACE-FO, which leads to **interest** in specific SST architecture variants:

Flying at a lower altitude: Increases sensitivity to mass change by being closer to the source

- Options: Must implement drag compensation system so lifetime of satellites can be extended beyond a few months

Adding directionality to the observable: The GRACE and GRACE-FO architectures make measurements in the North-South direction. Because of this, there is little East-West sensitivity to mass changes. The gravity solution is thus susceptible to errors entering in a North-South striping pattern, which is prevalent in GRACE/GRACE-FO solutions.

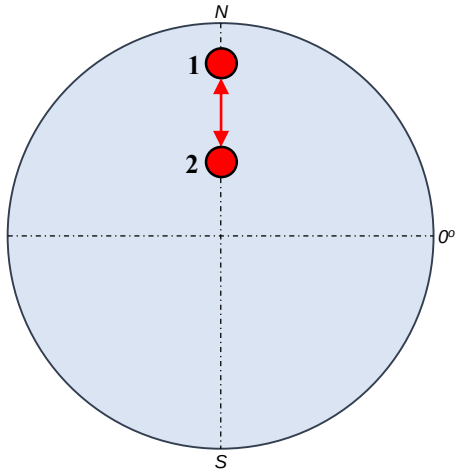
- Options: Pendulum and/or Bender

Increased temporal sampling: The largest error source for mass change missions is temporal aliasing error due to under-sampling high frequency mass variations. Since we do not sample quickly enough to measure these high frequency mass variations with a single satellite pair, we rely on models of them in the data processing. Additional pairs of satellites allow us to more directly estimate high frequency mass variations, and decrease reliance upon models.

- Options: Bender

SST Variant Architecture Concept Summary

Architecture 1
Single In-line Pair



Satellites 1 and 2 track each other in a polar orbit. They optionally carry additional payload.

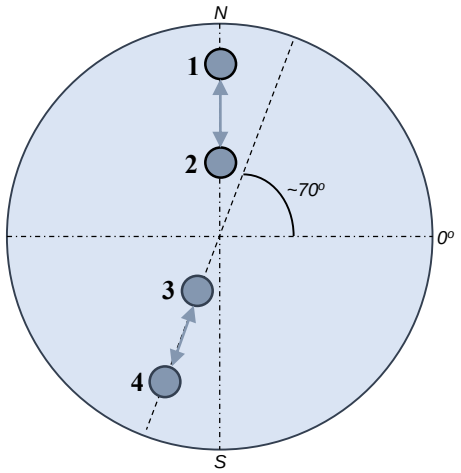
Why? ***Spatial Resolution* = (430)² km²***

- Provides North-South information
- Lowest cost option to satisfy Baseline Science Objectives
- Low Risk, high heritage, building on lessons learned from GRACE and GRACE-FO

Technical Considerations/Risk:

- Engineering modifications to LRI upgrading the instrument from Class D to Class C

Architecture 2
Two In-line Pairs



Satellites 1 and 2 track each other in a polar orbit. Satellites 3 and 4 track each other in a moderately inclined orbit (~70°). Both pairs fly at lower altitude with drag compensation technology

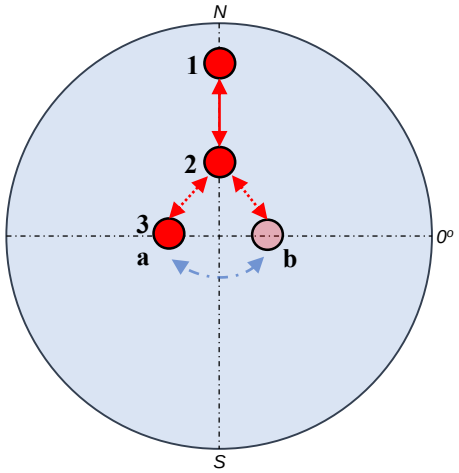
Why? ***Spatial Resolution* = (195)² km²***

- Provides both North-South information (pair 1-2 and pair 3-4) and East-West information (pair 3-4), improving science
- Increased temporal sampling reduces temporal aliasing error, and enables certain applications, improving science
- Bender formation flying all satellites at a low altitude will improve science

Technical Considerations/Risk:

- Requires development of a drag compensation system, increasing the complexity of the flight system, and a more precise accelerometer

Architecture 3
In-line Pair + Pendulum



Satellites 1 and 2 track each other in a polar orbit. Satellite 3 "swings" back and forth from position a to position b while it tracks satellite 2 (or 1 if if satellite 2 fails). This motion is referred to as a "Pendulum" motion.

Why? ***Spatial Resolution* = (235)² km²***

- Provides both North-South information (pair 1-2 and pair 2-3) and East-West information (pair 2-3), improving science
- 3-satellite architecture increases system redundancy allowing failure of any single element

Technical Considerations/Risk:

- The rate of change in distance between satellite 2 and 3 is significantly greater than between satellite 1 and 2, requiring a more complex ranging instrument
- Requires development of an accelerometer that is sensitive in all three axes
- Satellite pointing and control is not well understood between the three-satellite constellation

*spatial resolution corresponds to 15 mm equivalent water height at monthly timescales

Partner Engagement

- **ESA:** Phase 0 study on the Next Generation Gravity Mission (NGGM) concept is complete and phase A study approved and will be initiated. Baseline concept is a version of the IGSWG-recommended “Bender” architecture consisting of two pairs of in-line satellites: one polar and one lower inclined, both at a lower altitude requiring drag compensation technology, leveraging GOCE mission technology.

- **Germany (HGF/GFZ, DLR, MPI, AEI):** Brief GRACE-I initial study completed in spring 2020. Baseline mission concept is similar to GRACE-FO, but with a fully redundant laser ranging interferometer (LRI) as the primary payload. Possible add-on of the ICARUS (animal tracking) payload. Phase 0 study expected to begin in fall 2020.

- **CNES:** Initiated a phase 0 study on MARVEL concept in January 2020, where the baseline mission concept was LEO/MEO pair. After internal review in September 2020, continuation of Phase 0 study will focus on the detailed design and implementation of a hybrid in-line/pendulum architecture using a laser chronometer as the inter-satellite ranging payload to enable the pendulum formation.

NASA / ESA Ad hoc Joint Science Study Team (AJSST)

NASA & ESA formed an Ad-Hoc Joint Study Science Team (AJSST) to consolidate all MC relevant science objectives, user requirements, organize traceability and develop mission measurement requirements.

- Membership includes MC DO team science leads from and members from the European science community. AJSST meetings held April 2020 – July 2020

The task of the AJSST was the collection and consolidation of relevant user information originating from the ESA NASA Interagency Gravity Science Working Group (IGSWG) Report (*), the 2017 National Academies of Science Earth Science Decadal Survey, IUGG report, proposals to the Agencies and other relevant sources of user needs also in view of potential future contributions to EC Copernicus services

The compatibility between objectives, targets, requirements and expected performance

Mission Requirements Document (MRD), intended as a living document, serves as an input to the European Space Agency (ESA) for the Phase-A/B1 initiated in 2020.

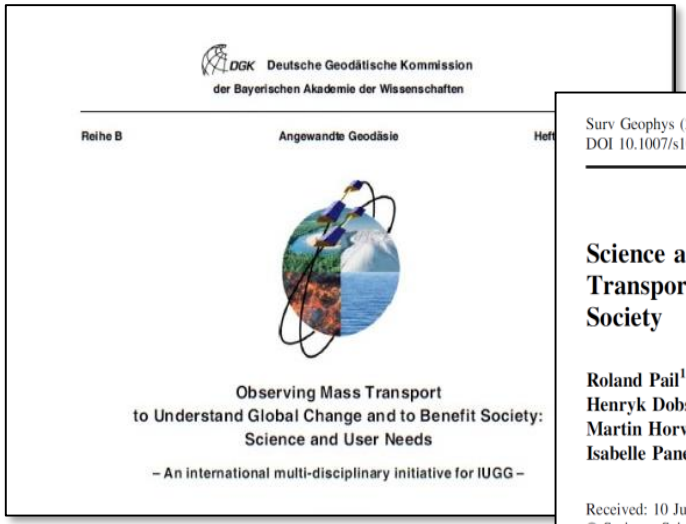
* NASA and ESA Joint Programme Planning Group (JPPG) for cooperation in the field of Earth Observation established the International Gravity Science Working Group (IGSWG) - 12/2013 until 5/2016.

IUGG 1st resolution in 2011 and letter to Space Agencies in 2012

Global User Community Science Team (IUGG, IAG, GGOS)

ESA-NASA - JPPG Interagency Gravity Science Working Group

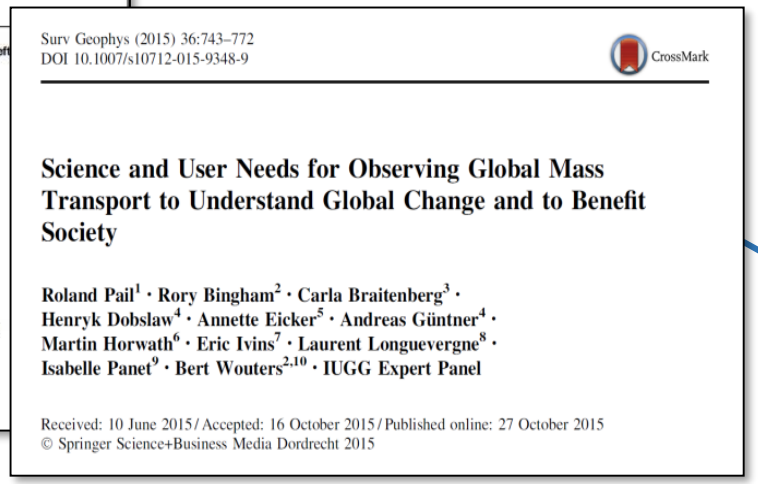
Decadal Survey for Earth Science 2017 NAS


DGK Deutsche Geodätische Kommission
der Bayerischen Akademie der Wissenschaften

Reihe B Angewandte Geodäsie Heft

Observing Mass Transport
to Understand Global Change and to Benefit Society:
Science and User Needs

– An international multi-disciplinary initiative for IUGG –


Surv Geophys (2015) 36:743–772
DOI 10.1007/s10712-015-9348-9

CrossMark

Science and User Needs for Observing Global Mass Transport to Understand Global Change and to Benefit Society

Roland Pail[1] · Rory Bingham[2] · Carla Braitenberg[3] · Henryk Dobslaw[4] · Annette Eicker[5] · Andreas Güntner[4] · Martin Horwath[6] · Eric Ivins[7] · Laurent Longuevergne[8] · Isabelle Panet[9] · Bert Wouters[2,10] · IUGG Expert Panel

Received: 10 June 2015 / Accepted: 16 October 2015 / Published online: 27 October 2015


Towards a sustained observing system for mass transport to understand global change and to benefit society

NASA/ESA Interagency Gravity Science Working Group (IGSWG)

12 May 2016

Doc. nr.: TUD-IGSWG-2016-01


CONSENSUS STUDY REPORT

THRIVING ON OUR CHANGING PLANET

A Decadal Strategy for Earth Observation from Space

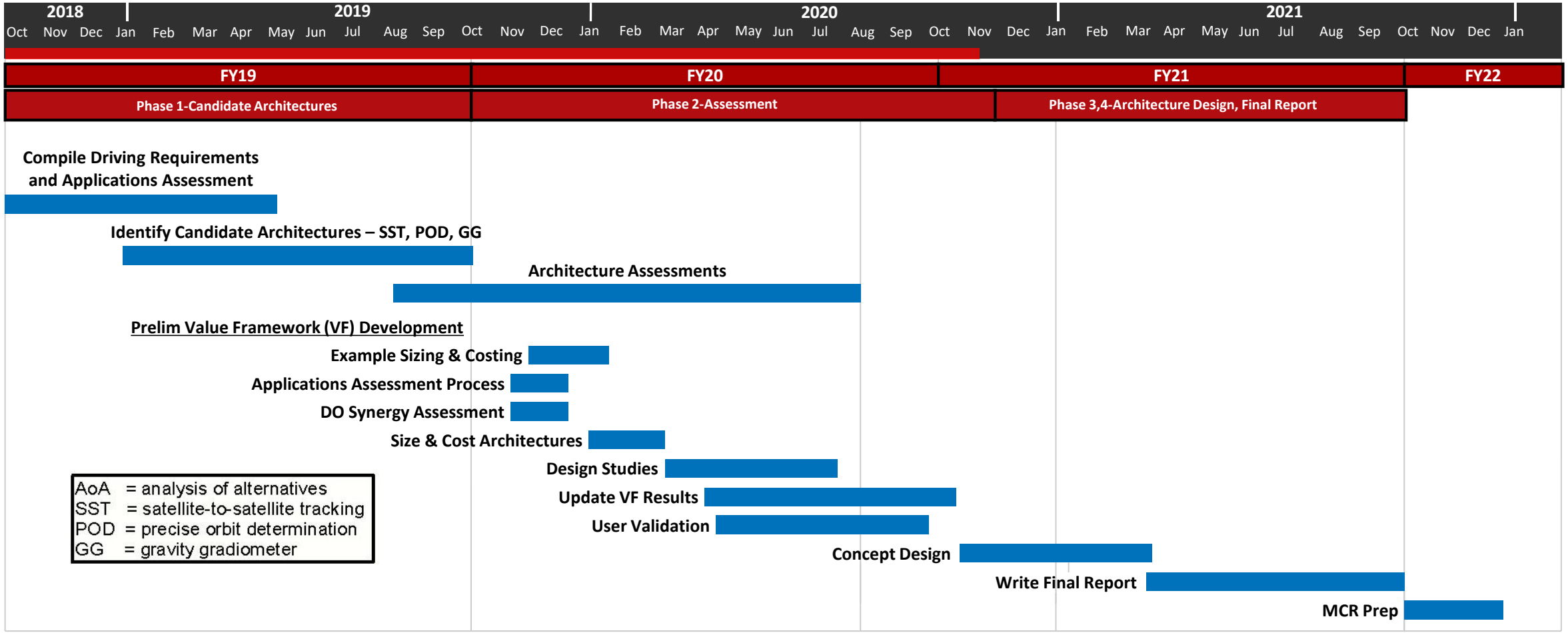
NASA - Mass Change DO Study SATM

Science Value Highlights

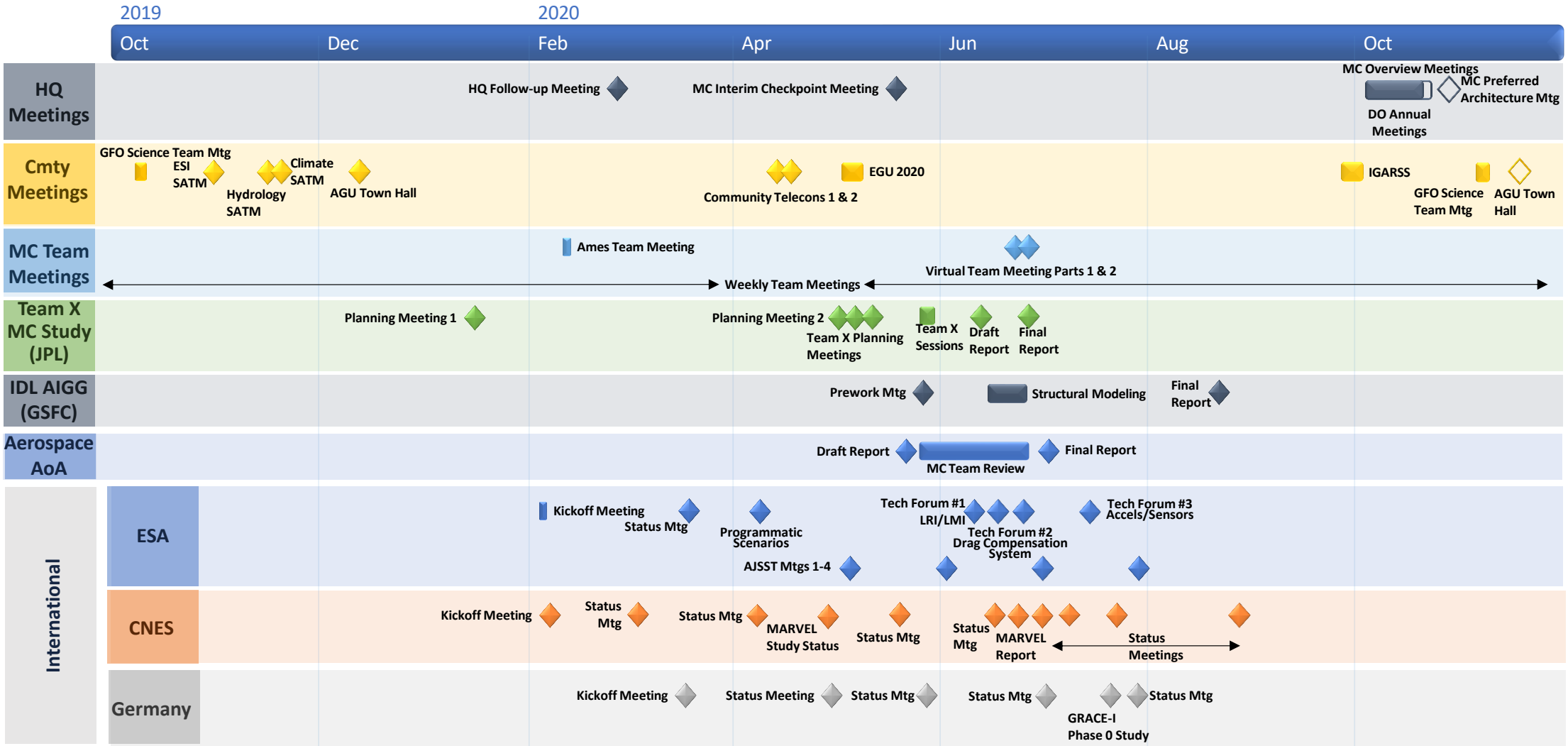
	Architecture 1 capabilities	Architecture 2 capabilities (in addition to Architecture 1)
Baseline science objectives	**Meets** (roughly corresponds to quality of program of record)	**Exceeds by factor of 4**
Global spatial resolution	**(430)^2 km^2** for monthly solutions at 15 mm equiv. water height	**(195)^2 km^2** for monthly solutions at 15 mm equiv. water height
Global temporal resolution	**Nominally Monthly**	**Nominally Bi-Weekly**
Cryosphere	• **Mass balance of largest ice sheet drainage basins in Greenland and Antarctica** and of large glacier clusters	• **Mass balance of individual ice sheet drainage basins and mountain glacier systems**, supporting their modeling and prediction
Hydrology	• **20% of global hydrological basins observed** • Closure of water budget at large scales: (430)^2 km^2 • Understanding climate change and human impacts on the water cycle at large scales	• **85% of global hydrological basins observed** • Closure of water budget at smaller scales: (195)^2 km^2 • Improved data assimilation into hydrology models • Improved estimates of groundwater changes
Oceanography	• **Separation of mass and steric contributions to total sea level** • Improved determination of ocean bottom pressure and deep ocean flow, e.g. the Atlantic meridional overturning circulation (AMOC)	• **Separation of mass and steric sea level at regional scales**; improves understanding of ocean-atmosphere heat fluxes • Measurement of the Antarctic Circumpolar Current (ACC)
Solid Earth	• **Monitoring of earthquakes of Magnitude > 8.0 (~1 event/year)** • Monitoring of large tectonic movements and underground anthropogenically driven mass variations	• **Monitoring of earthquakes of Magnitude > 7.0 (~12 events/year)** • Separation of tectonic, GIA, hydrological, and cryospheric signals • Deep interior properties and dynamics
Applications	• **Spatial resolution and ~50-day latency limits applications** • Water management and groundwater monitoring at large scales • Monitoring and forecasting of floods and droughts • Impact of melting ice sheets on local sea level rise	• **Improved latency and spatial resolution benefits all applications** • Significant contributions to water management on smaller scales • Operational forecasting/early-warning of flood events and droughts • Hazard mitigation: weather services; fire risk; earthquake assessment

Relevant citations: *IUGG Report, Observing Mass Transport to Understand Global Change and to Benefit Society, 2015*
IGSWG Final Report, Towards a sustained observing system for mass transport to understand global change and to benefit society, 2016
ESA/NASA MRD, Next Generation Gravity Mission as a Mass-change and Geosciences International Constellation (MAGIC), 2020

Mass Change Overall Schedule

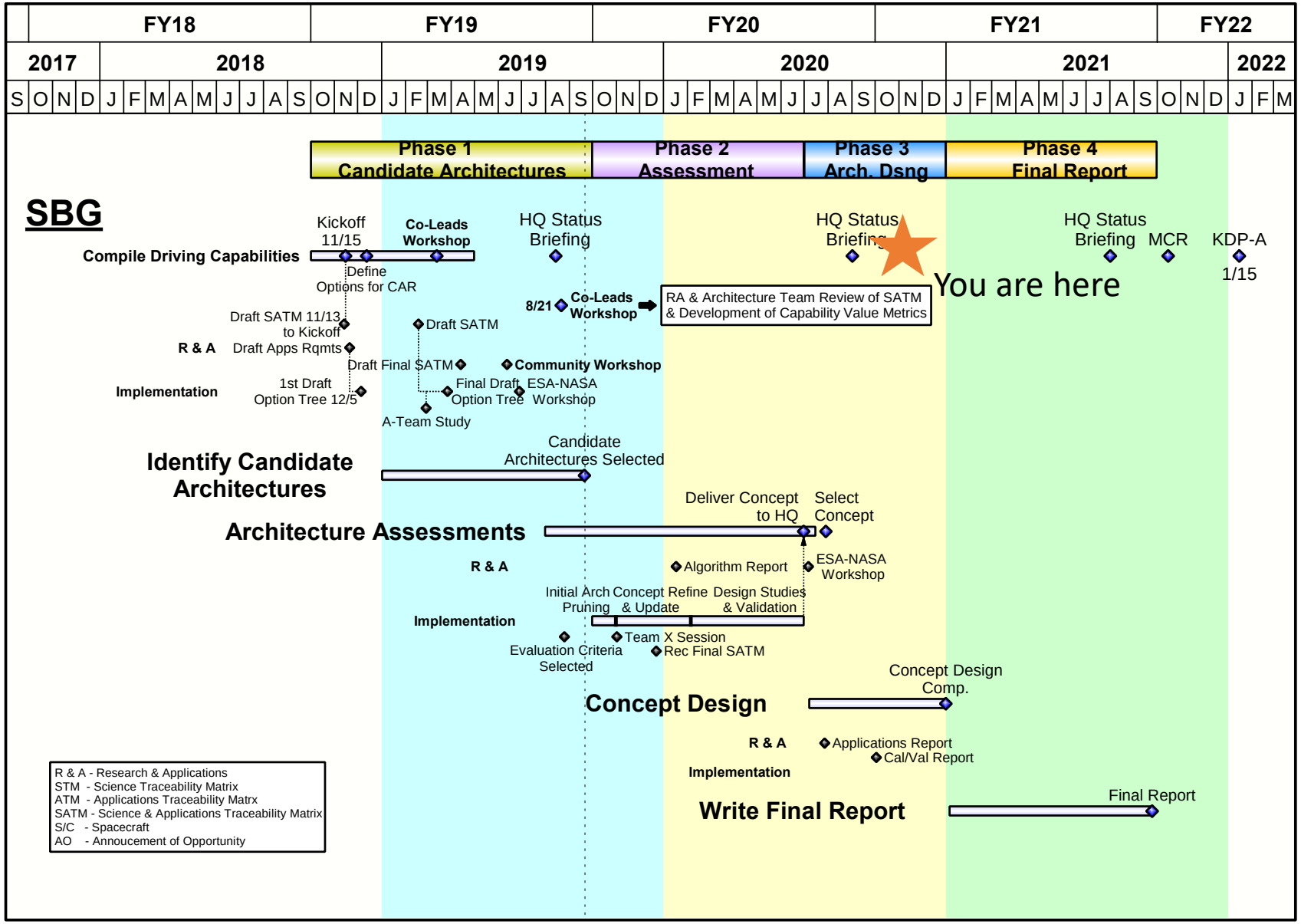


Mass Change Phase 2 Schedule



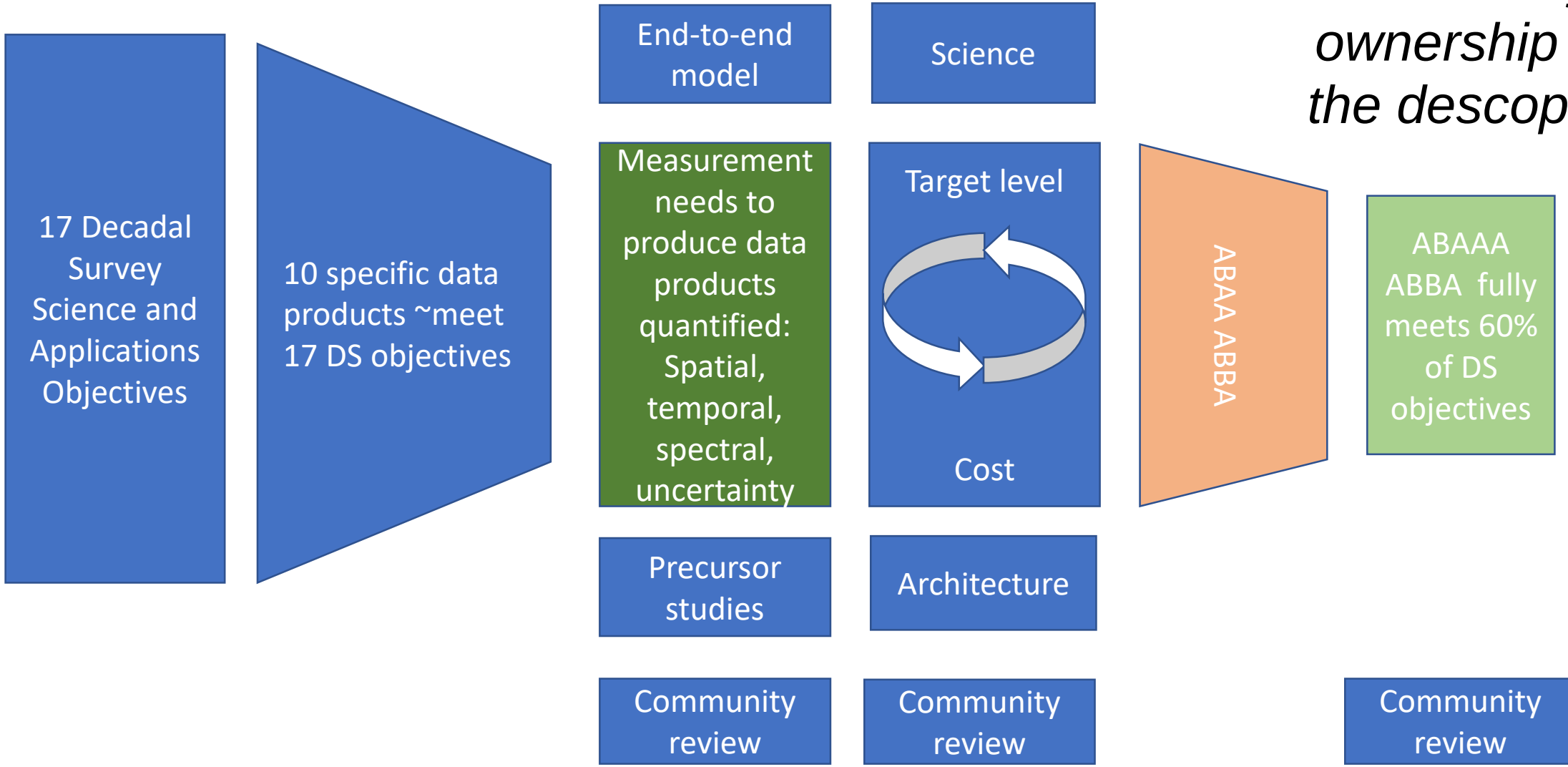
Surface Biology and Geology (SBG)

SBG Study Schedule



Measurement Target Development Process

giving the community ownership of the descopes



SBG Update

Phase 2 Assessment of Architectures

- 6 Design Sessions at multiple centers
- Accomplished Virtually

Phase 2 of the SBG architecture study

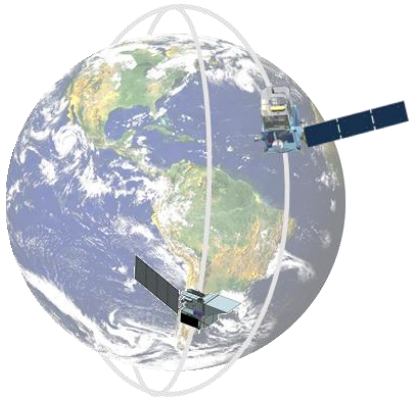
- Identified three high science value options near the $650 FY18$M cost target (from ~61 Architectures):
  - Single large satellite with both VSWIR and TIR
  - Constellation of one VSWIR medium-sat and one TIR smallsat
  - Constellation of five VSWIR smallsats and one TIR smallsat

Further analysis/work on Phase 2

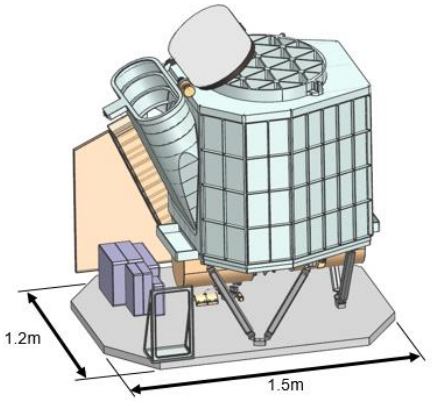
- No longer carrying single-satellite architecture
- Examining lower-cost, lower-science value options
- Exploring international dependencies
- Collected new information on launch options and cost
- Assessed mission design performance for constellations

Two Architectures

Alternative 1: Two Platforms - 1 wide swath VSWIR + TIR

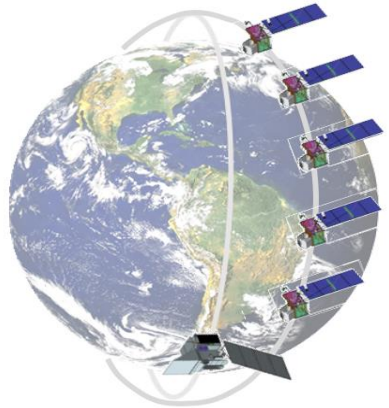


- Wide swath instrument uses two spectrometers
- Observation swath of 185 km
- 6000 cross-track samples

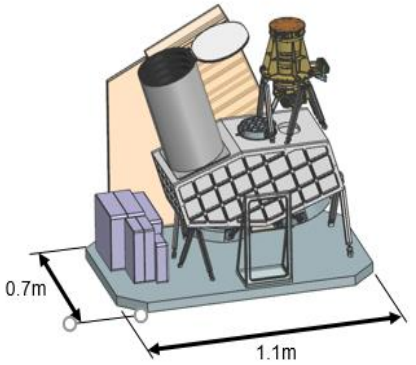


- VSWIR-1
  - 139* kg, 251* W (peak)
  - FoV: 25.5°
  - Spatial Res: 30 m
  - Swath: 185 km
  - Spectral Res: 10 nm
  - Range: 0.38 – 2.5 µm
  - Bands: 220

Alternative 2: Six-Platform Constellation - 5x narrow swath VSWIR + TIR



- Narrow swath instrument uses a single spectrometer (similar to EMIT)
- Observation swath of 38 km
- 1280 cross-track samples
- Constellation based on narrow swath instrument requires 5 copies for an approximately equivalent swath width



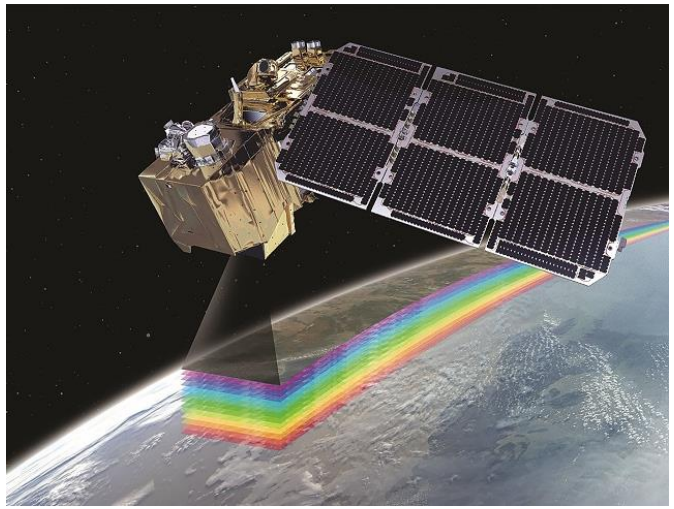
- VSWIR-3
  - 86* kg, 127* W (peak)
  - FoV: 3.4°
  - Spatial Res: 30 m
  - Swath: 38 km
  - Spectral Res: 10 nm
  - Range: 0.38 – 2.5 µm
  - Bands: 220

Surface Biology and Geology (SBG) Update

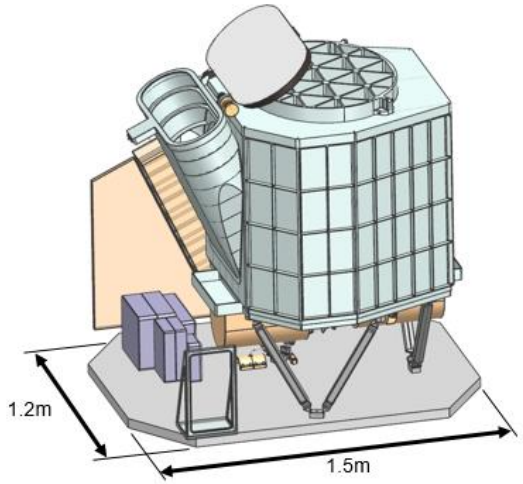
- Goal: study final report, MCR, and Phase A (Mission Formulation) by Fall 2021
- July 29 Preferred Architecture Briefing to NASA HQ
- Two Architectures under HQ consideration
  - HQ and SBG Study Team iterating permutations of these two general options
  - Includes deeper dives on architecture costs and implementation challenges
- NASA HQ Balancing Many Factors before Making Architecture Decision(s)
- Applications: RTI user needs and valuation study complete; on SBG website
- SISTER Pathfinder and MEET-SBG OSSE precursor activities underway

Enhancing Revisit with Seamless International Data from 16-Day VSWIR and 3-Day TIR

ESA CHIME (2028)

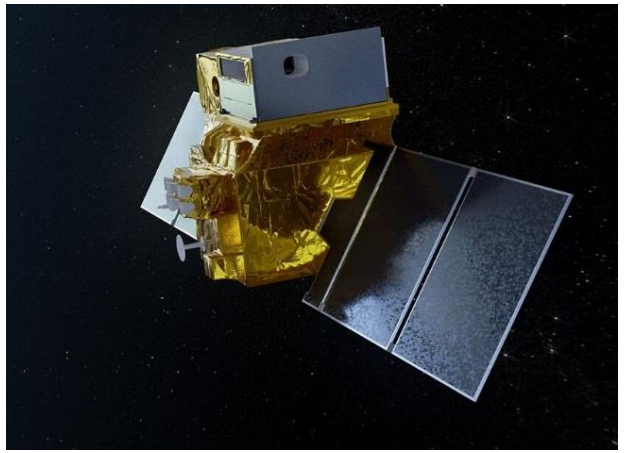


SBG VSWIR concept

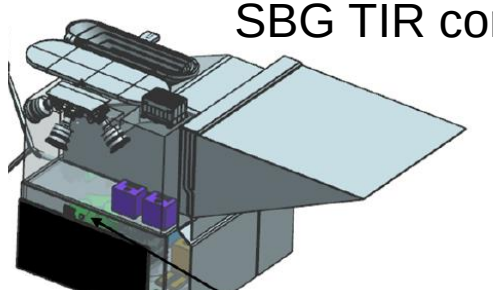


SBG VSWIR + CHIME could achieve 8 to 11 day revisit.

TRISHNA



SBG TIR concept

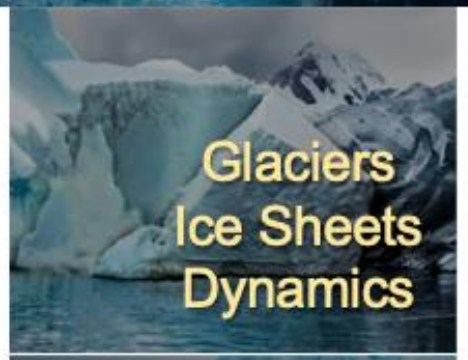


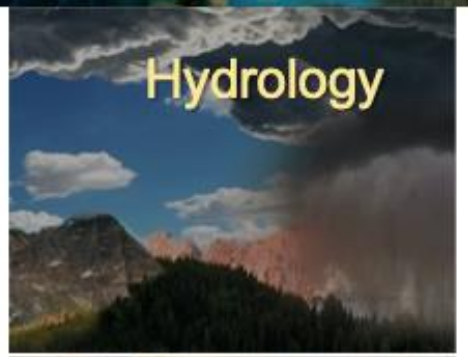
SBG-TIR + Trishna could achieve 1 to 1.5 day revisit.

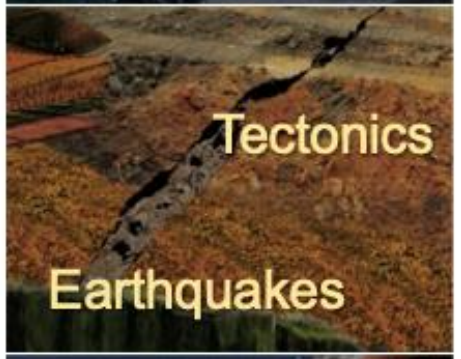
Surface Deformation and Change (SDC)

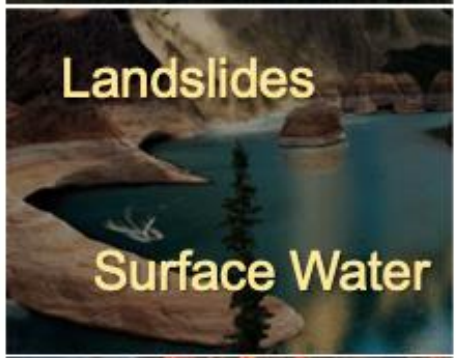
Surface Deformation and Change Observables

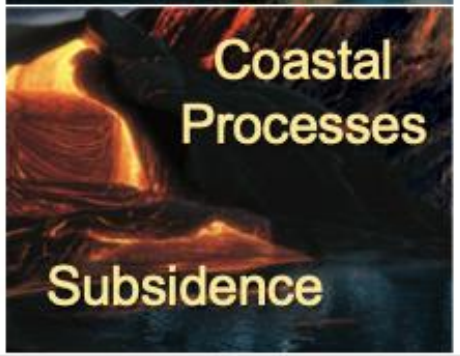
SDC Science Objectives

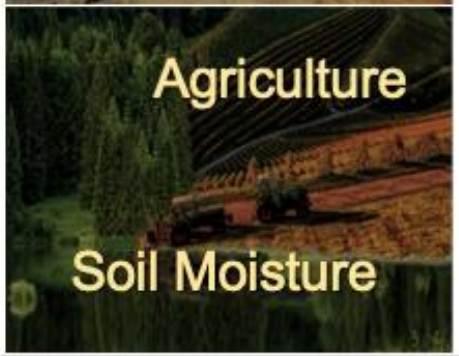








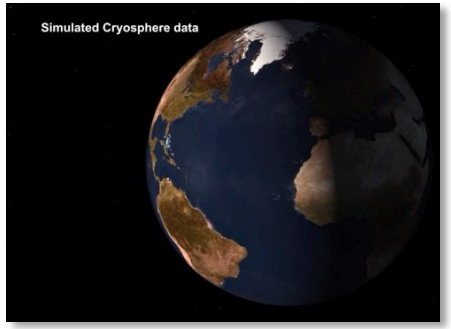


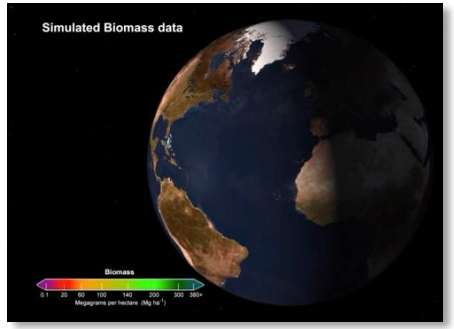


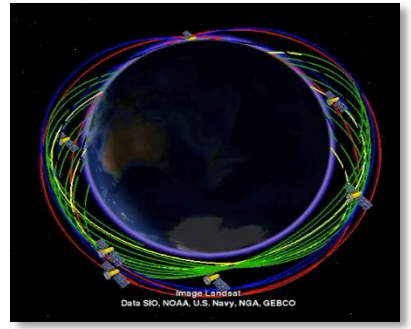
Unique Aspects of Surface Deformation and Change (SDC) Designated Observable Study

- **Primary observable:** An affordable synthetic aperture radar-based system(s) that would meet the Decadal Survey recommendations – *geodetic measurements (SAR phase)*
- ***Added study observables****: Assess non-geodetic measurements (radiometry/SAR backscatter) and downstream sciences in the trade space (i.e. ecosystems, soil moisture, hydrology), though not emphasized in Decadal Survey*
  - *Requires additional exploration of SATM*
- **Study Duration:** *5 Years*
  - *Complicates engagement with commercial and international partners*
  - *Still 1-2 years away from down-selection*
- **Engagement:** There are literally dozens of potential *partnerships*, data sources, alliances, domestic and *international*

SDC Team Evaluating the Landscape in 2030







NISAR, BIOMASS will have completed their primary missions; NISAR in Senior Review

Sentinel-1, COSMO-SkyMed continuing

ROSE-L, if it goes forward

Commercial SAR will supplement civil capability

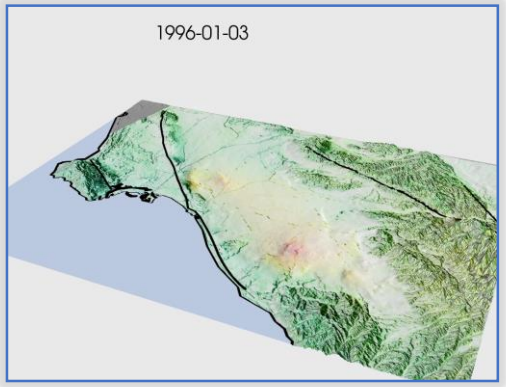
➔ Spectacular Scientific Results

➔ Outstanding Applications

➔ Petabytes of data

What next?

Urban Infrastructure

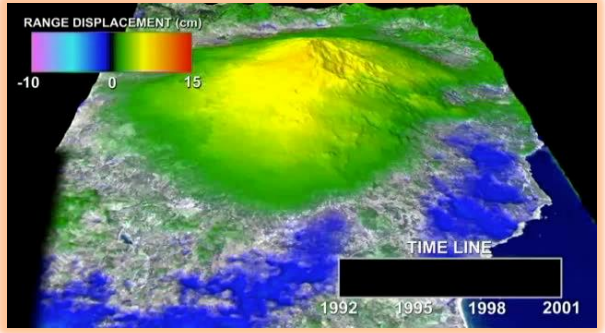


Ice Caps and Sheets

Oil & Gas

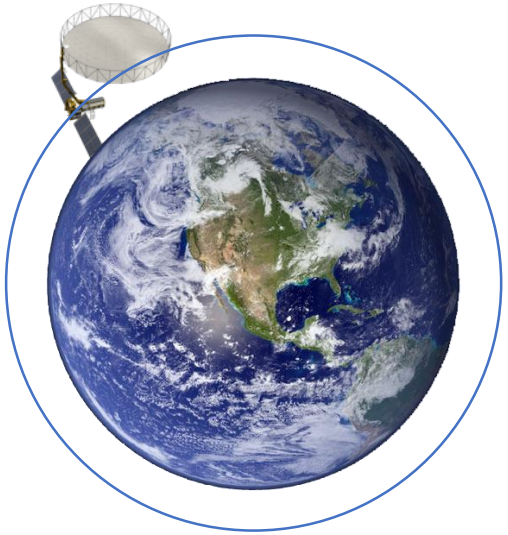
Aquifers

Volcanoes



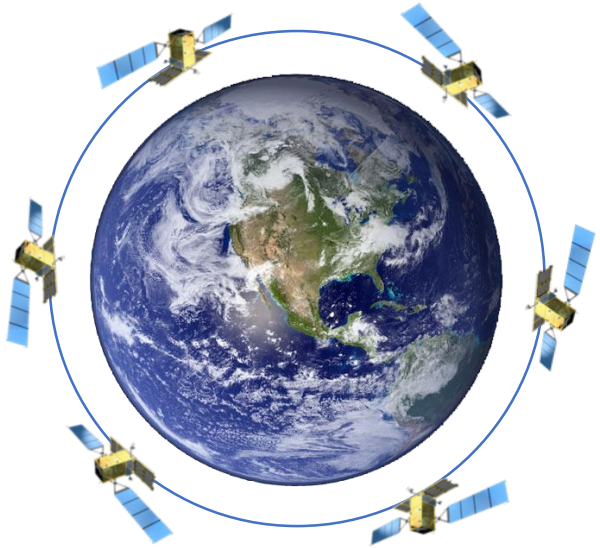
Note: Graphic of ESA Sentinel-1 (C-band) used to represent ROSE-L
Note: Graphic of ASI's CSK used to represent (relatively) small SAT SAR systems

Architectures Under Study Trade Cost, Risk, and Innovation



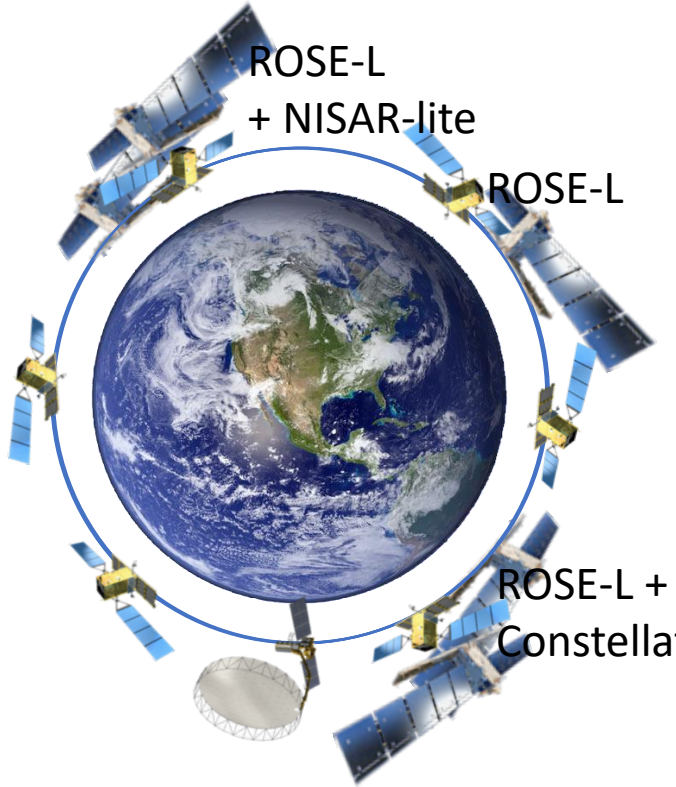
NISAR-lite

Capability	Effectiveness*
Continuity	
Coverage	
Error Reduction	
Look Diversity	



NISAR-lite equivalent
Small SAT constellation

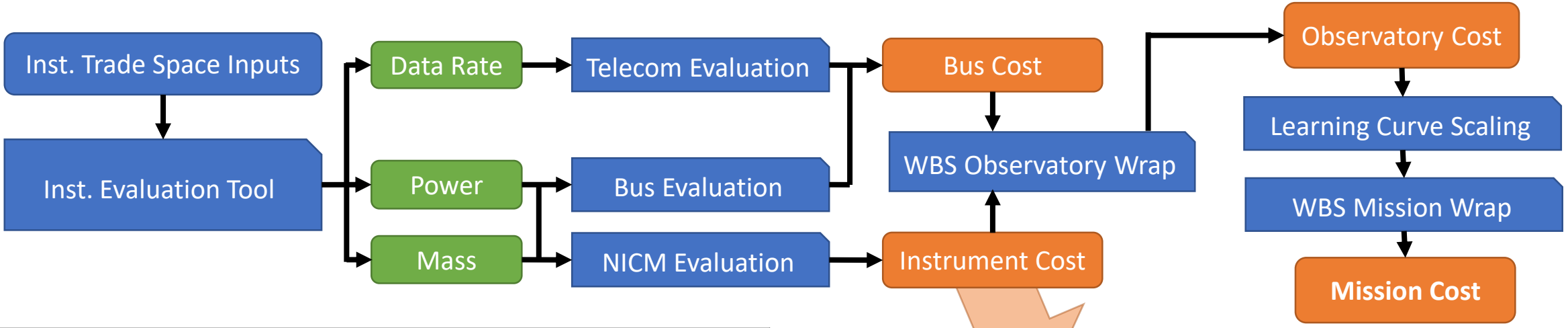
Capability	Effectiveness*
Continuity	
Coverage	
Error Reduction	
Look Diversity	



Capability	Effectiveness*
Continuity	
Coverage	**Or better!**
Error Reduction	
Look Diversity	

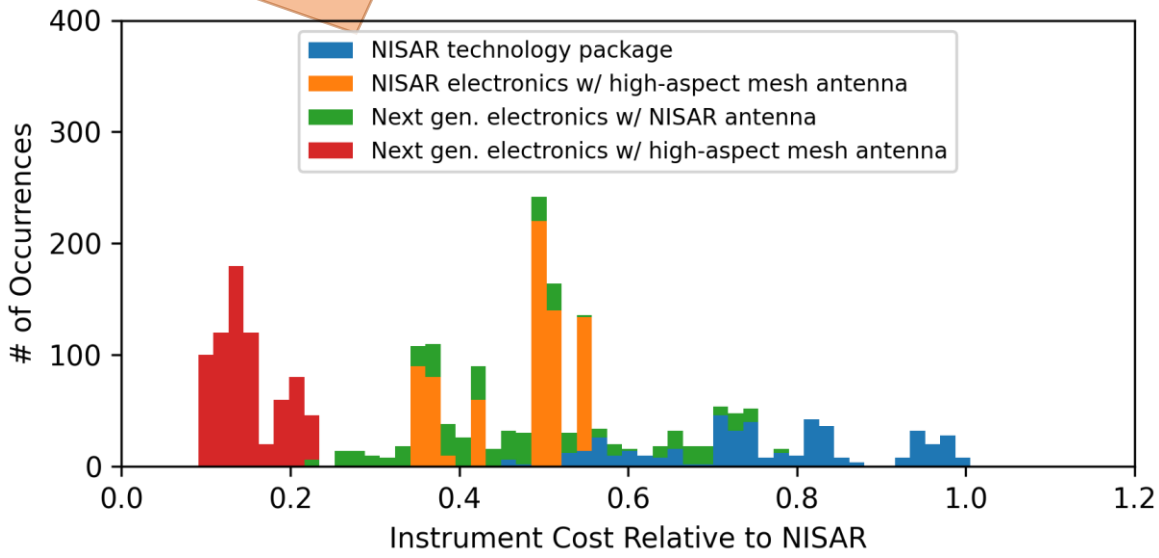
* Notional, still to be vetted and quantified

Phase 1 Cost Modeling Process



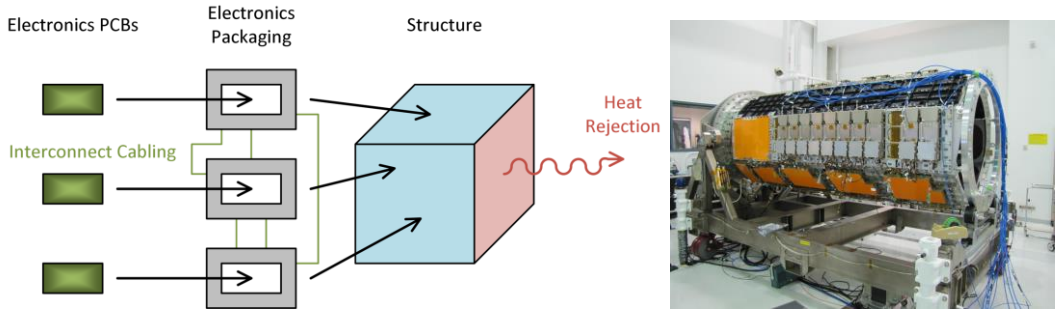
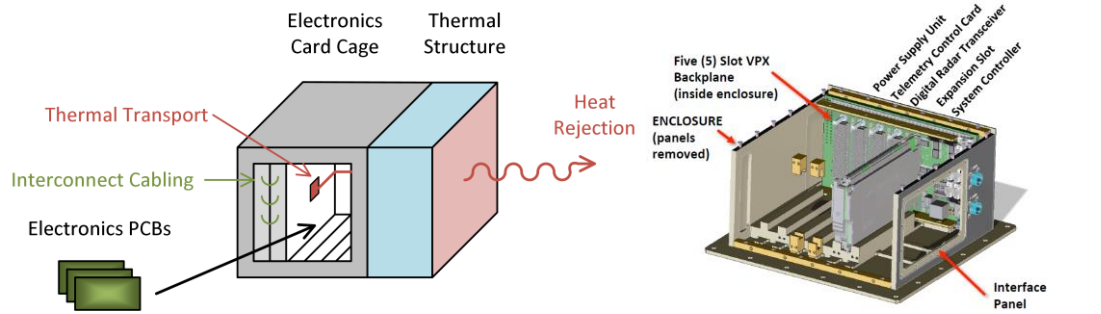
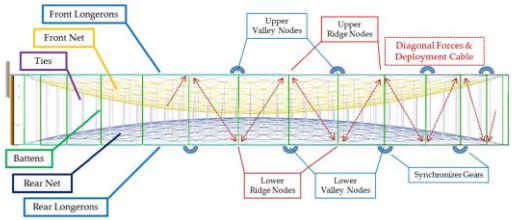
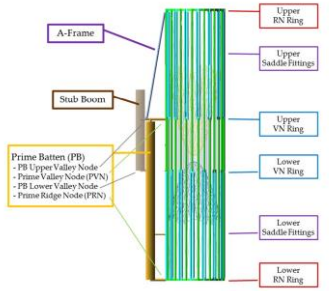
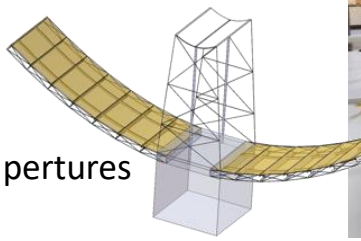
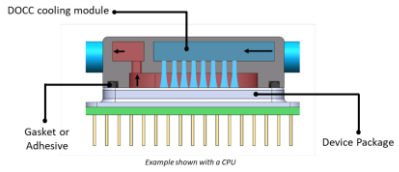
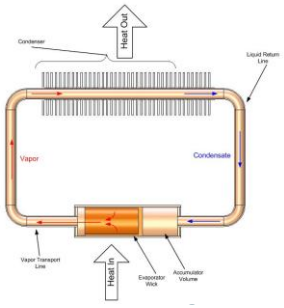
Tag	Architecture Short Name	Mission Cost ($FY19)
L1A	NISAR-Lite Quick Turn	
L1B	NISAR-Lite w/ Miniaturization	
L6A	6 Subswath Small-sats	
L6B	2 Multi-squint groups	

*Last remaining work is to apply the process to all candidate architectures before the end of phase I (April 2021)



Major SDC Developments Since Last Community Forum

Technology Theme: Deliver needed capability in a smaller, lighter package

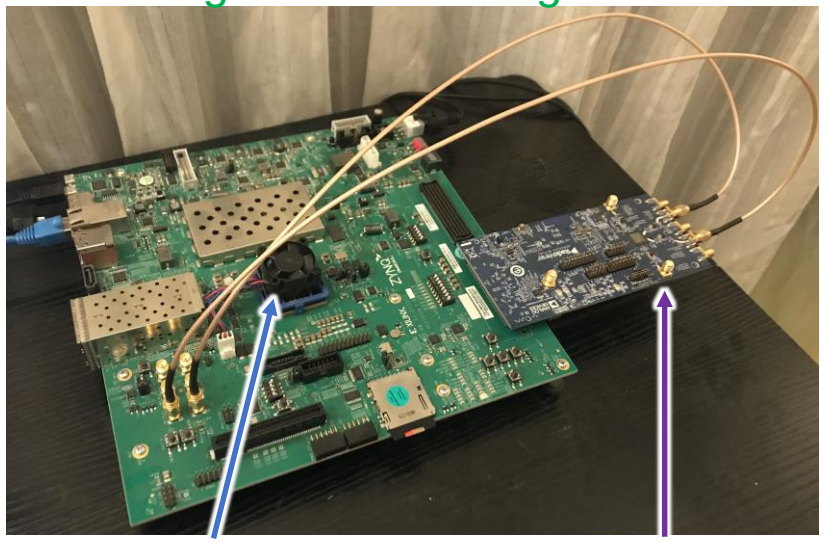
	Current Approach	New Approach
Electronics Integration		
Antenna Apertures	• Deployable Mesh • Circular Aperture for SweepSAR  	• Deployable Mesh w/ tailored shape - or - • Reflectarrays - or - • Slotted Waveguide - or - • Low mass steerable apertures   
Thermal Technologies	• Mylar Blanketing • Silver Teflon Radiators • Heaters 	• Passive Heat Loops • Reductions in thermal resistance • Controlled heat rejection  

Major SDC Developments Since Last Community Forum

New Technology development

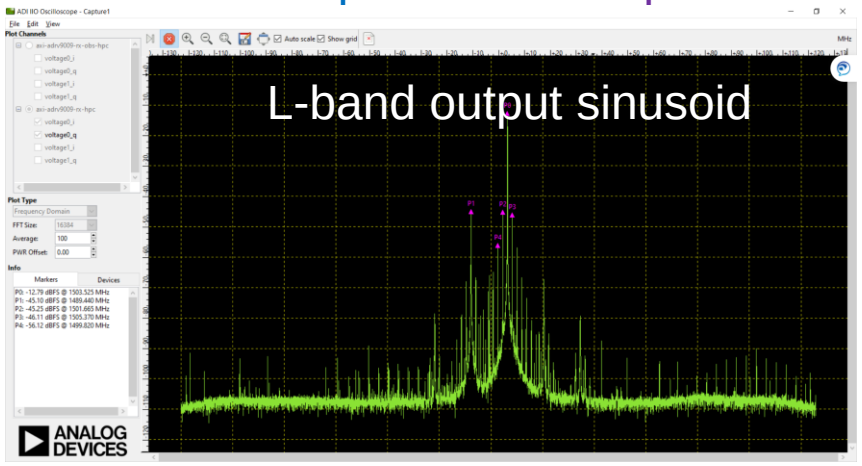
- Use transceiver built-in to next gen FPGA to provide radar chirp
  - 12.5 Gbps transceiver can be used as a 1-bit DAC
- ***Would eliminate two different boxes typically used***:
  - Waveform generator
  - Upconverter
- This funding intended to advance from TRL 2 to TRL 3
- Accomplishments since July start:
  - Zynq Development Environment working;
    - Xilinx FPGA design tools, software design tools, PetaLinux build
    - Analog Devices github projects, and communications tools
  - ADRV9009 characterized for sinusoids and chirps
- Future work
  - Non-linear FM chirps for frequency domain apodization
  - Phase-coded/orthogonal waveforms (for constellation applications)
  - Hardware testing with Class-D (saturation) amplifiers

Working at home during COVID-19



UltraScale Transceiver Transmitter Outputs

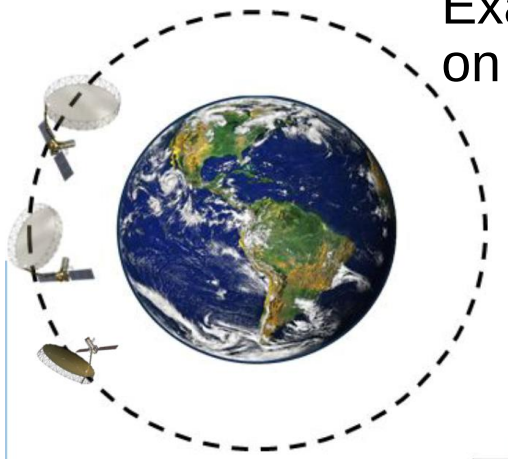
ADRV9009 ADC Inputs



Major SDC Developments Since Last Community Forum

Time Transfer Study

Examine effects of timing errors on SAR constellations



Orbital Plane Spacing

Model Constellation
Orbital Mechanics

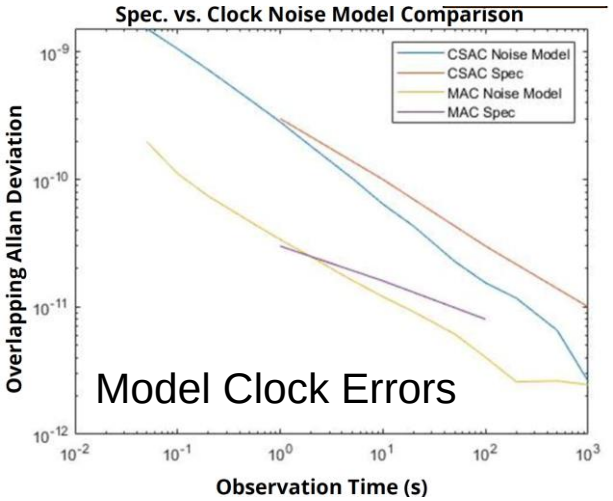
SAINTS
(Synthetic Aperture radar INterferometry Timing Study)

Project Update: 8/25/2020

Massachusetts Institute of Technology
University of Florida
NASA

University PIs:
Kerri Cahoy: kcahoy@mit.edu
John Conklin: jwconklin@ufl.edu

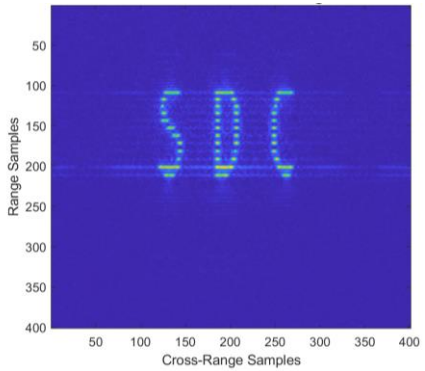
Nick Belsten: nbelsten@mit.edu
Dani Coogan: dcoogan@ufl.edu



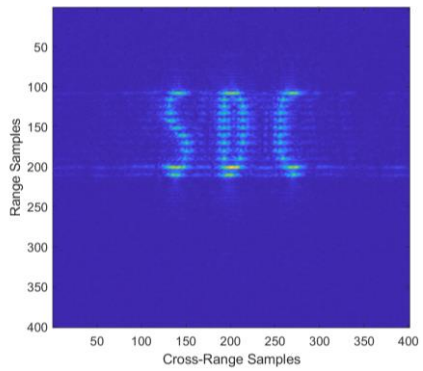
Model Clock Errors

Model Multi-static Imaging/InSAR Performance with Clock Errors

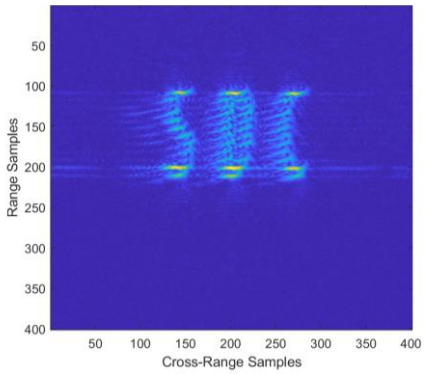
No Error



CSAC 0.1 µs Error



0.1 µs/s Error

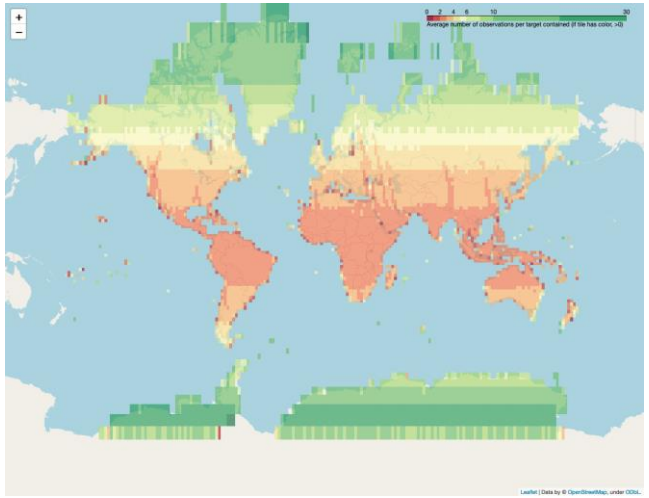


Assessment of Coverage with Performance Tool

Scheduling for Global Coverage with Constellation of Small Swath SARs

Example: Six 40 km swath spacecraft

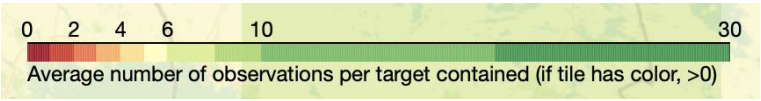
Each can point to collectively cover the full 240 km swath like Sentinel-1 or NISAR

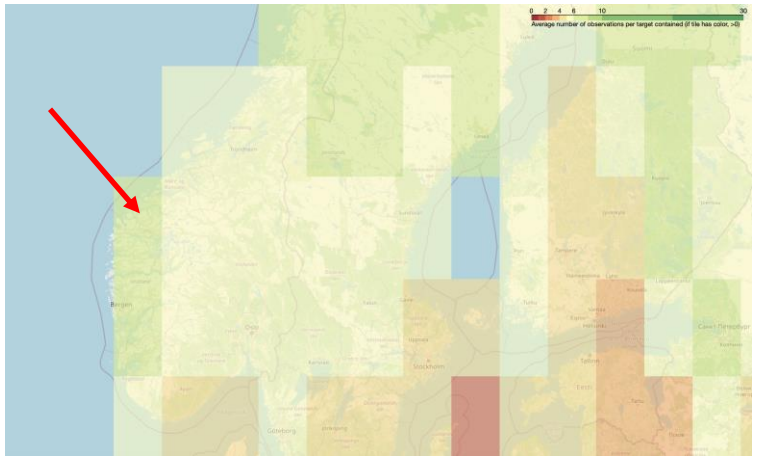


Divert spacecraft from global mapping to observe disaster areas where they occur

More frequent observations of areas of interest (big cities)

Repoint swaths that would otherwise be over water to get more frequent land coverage





Performance Tool when complete will enable assessments of complex constellation configurations

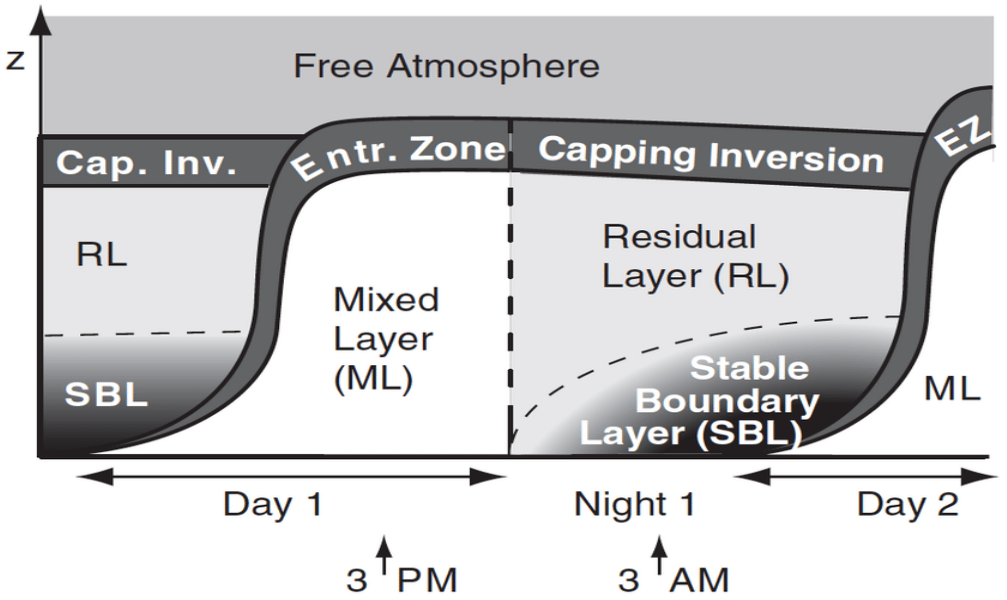
Major SDC Developments Since Last Community Forum

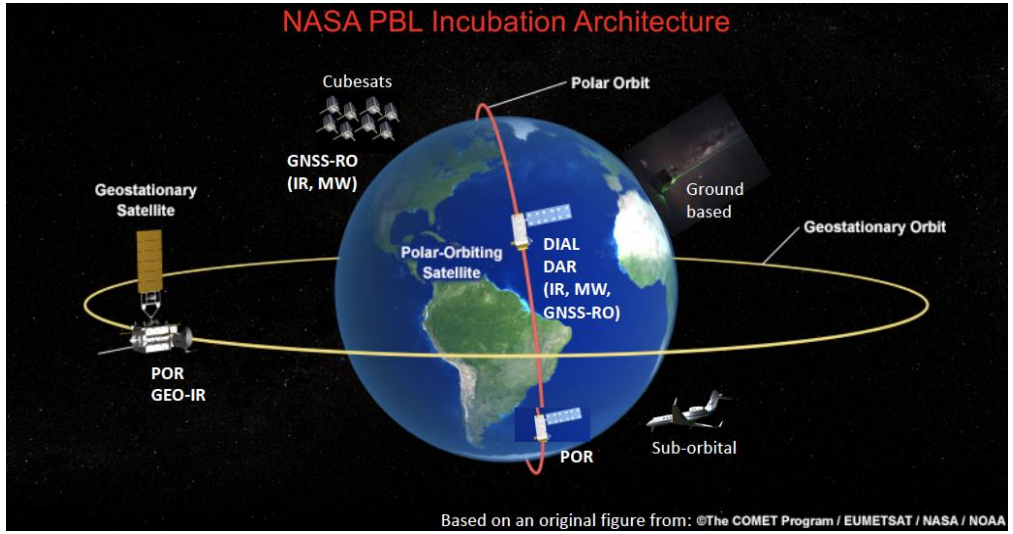
- Science and Applications Traceability Matrix Near Final
  - Added Hydrology and Ecosystems leads in FY20
- Architecture Definition and Cost Modeling Tool completed
- Constellation Time-transfer Modeling Tool nearly complete
- Mission Planning Tool for SAR/InSAR Constellation completed and exercised
- Constellation Performance Tool Enhancements on-going
- Commercial SAR Evaluation Methodology devised
- RTI Technology and Philanthropies interactions kicked off
- First results from integrated waveform generator on a chip
- Selected contractor for generating Global Coherence Map at C-band using Sentinel-1

Incubation Program Updates

PBL Study Update

- Community Engagement
  - **Community Workshop, May 19, 20, 25, 26, 2020;** average 200 attendees each session
    - High-latitude PBL & PBL and Deep Convection,
    - Land and Surface Interaction & Ocean and Sea Interaction,
    - Applications & Weather, Climate Models, and Data Assim.
    - Passive & Active PBL sensing, & In-situ and Suborbital
  - **October 13, 2020: PBL Technology Survey released**
    - ~50 responses so far
    - Submit entries ASAP to pbl-study-input@lists.nasa.gov
- Schedule
  - **September 11, 2020:** Draft Study Team white paper delivered to NASA HQ (50 pages)
  - **November 2020:** White paper revision incorporating HQ feedback due
  - **NLT January 2021:** Final white paper due
  - **Ongoing:** PBL augmentation activities
  - **PBL Activity Proposal Solicitation(s):** 3-9 months after white paper released to the public
- Key Preliminary Findings
  - Architecture of multiple platforms and sensors on orbital and suborbital assets would best address PBL needs

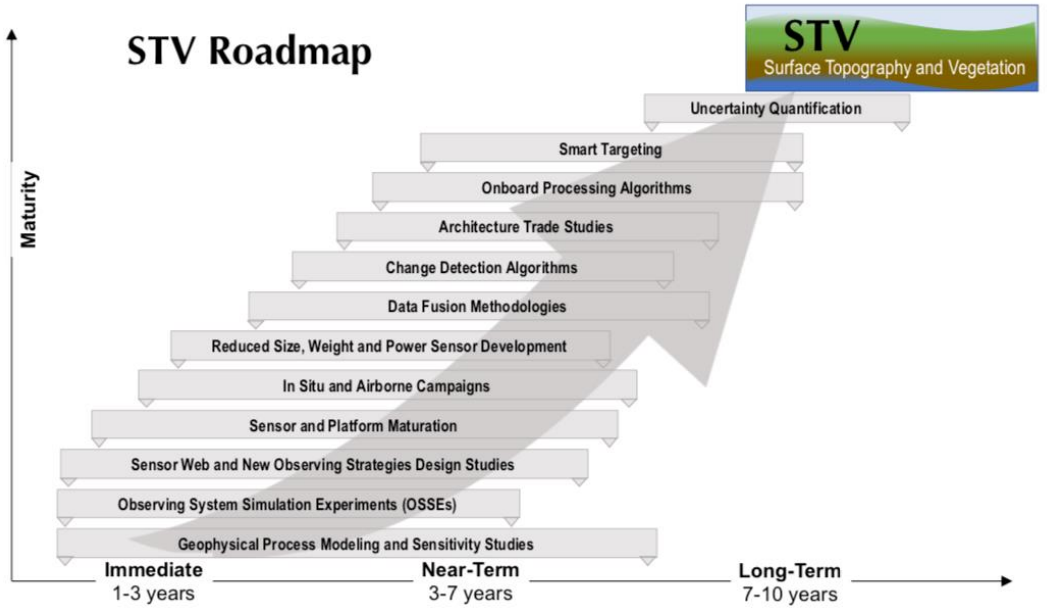


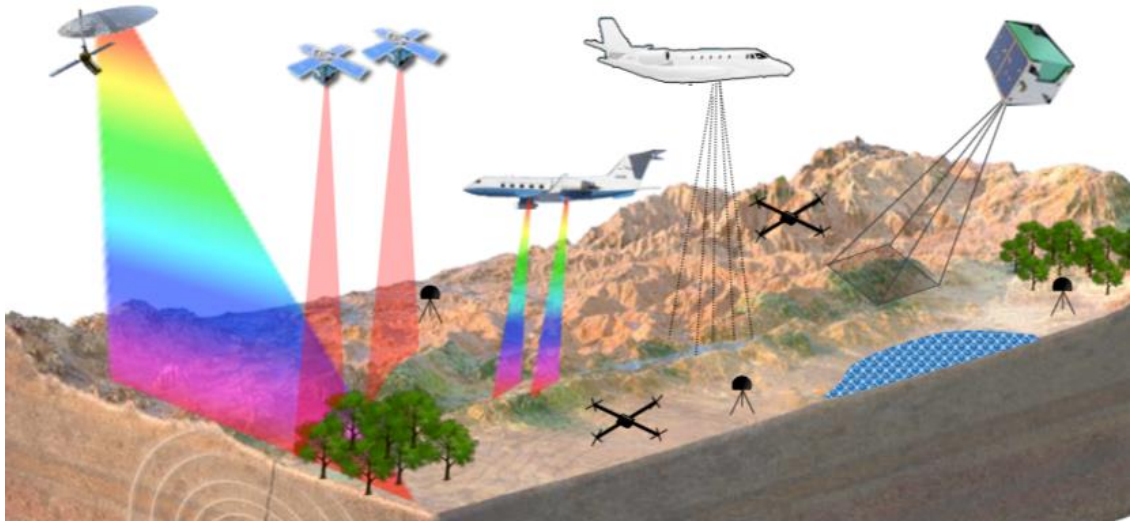


PBL Website: https://science.nasa.gov/earth-science/decadal-pbl

STV Study Update

- Community Engagement
  - **Kick-off Plenary, July 9, 2020, 300 attendees**
  - **July: Science & Application Breakouts, averaging 51 attendees**
    Solid Earth, Vegetation, Cryosphere, Hydrology, Bathymetry
  - **August: Objectives and Product Needs Questionnaire**
    149 responses
  - **September: Technology Breakouts, averaging 49 attendees**
    Lidar, Radar, Stereo Photogrammetry, Information Systems
  - **September: Current and Emerging Technology Quad Charts**
    60 responses
- White Paper Schedule
  - **October 29:** Draft delivered to HASA HQ
  - **Late November:** Revision incorporating HQ feedback
  - **December 3: AGU STV Townhall:** Release of draft to community and solicit comments
  - **Dec - Jan:** Revision based on comments
  - **End of February:** Delivery of final white paper
- Key Preliminary Findings
  - Need global baseline mapping and targeting for change
  - Architecture of multiple platforms and sensors on orbital and suborbital assets would best address STV needs





STV Website: https://science.nasa.gov/earth-science/decadal-stv

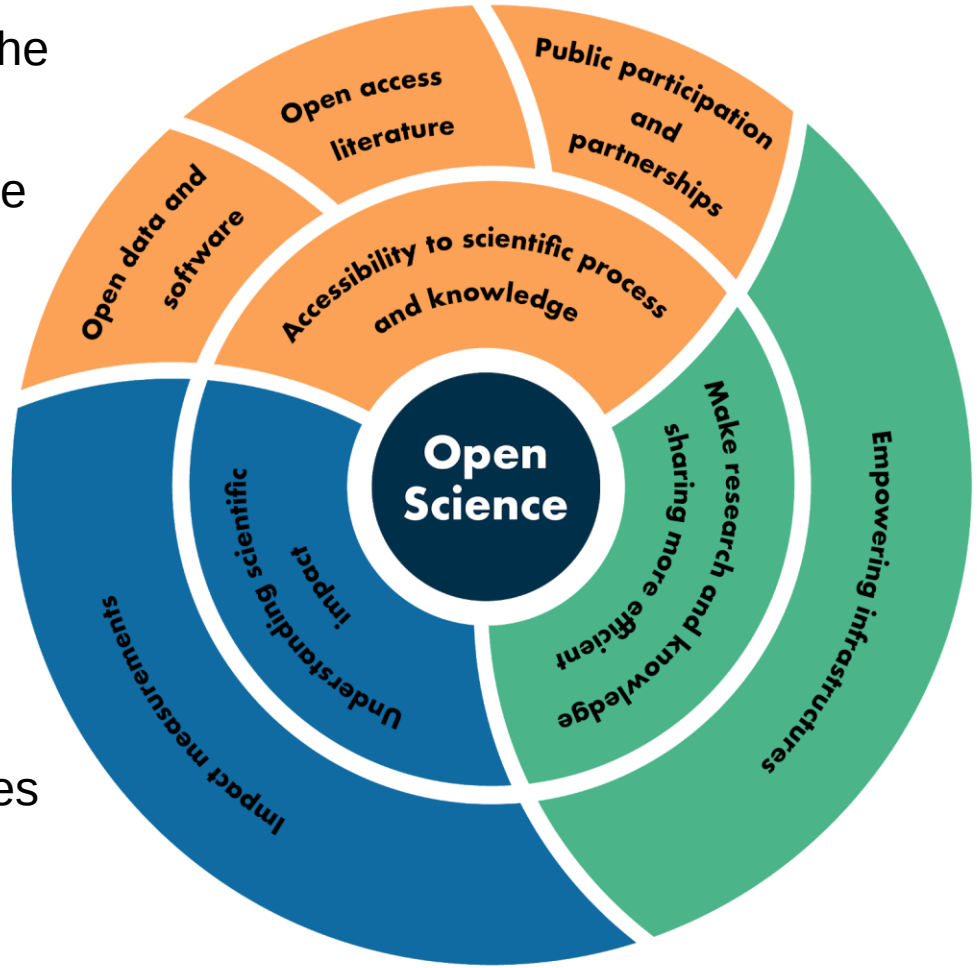
Open Science

Open Science for Decadal Observables

Co-develop an Open Science Ecosystem to dramatically increase the speed of scientific discovery for DOs.

- Open access, availability and discoverability of data – shorten the time it takes for a new user (research and applied) to find and learn how to use data
- Open access to and advancement of modeling and simulation code – increase the community of hands-on contributions to improving models, assimilation, and prediction tools
- Share knowledge and use current informatics and data science tools, in the same ecosystem as the data – explore data in new ways
- Incentivize and energize innovation through prizes and challenges

ESD is leading the development of an open science ecosystem for SMD's Strategy for Data Management and Computing for Groundbreaking Science



Cross-Benefits of Applications and Research

ESD & Cross-Benefit

[Programs] with both science and applications elements need to explicitly identify the connection, and define opportunities to amplify the cross-benefit … *Decadal Survey, p. 61*

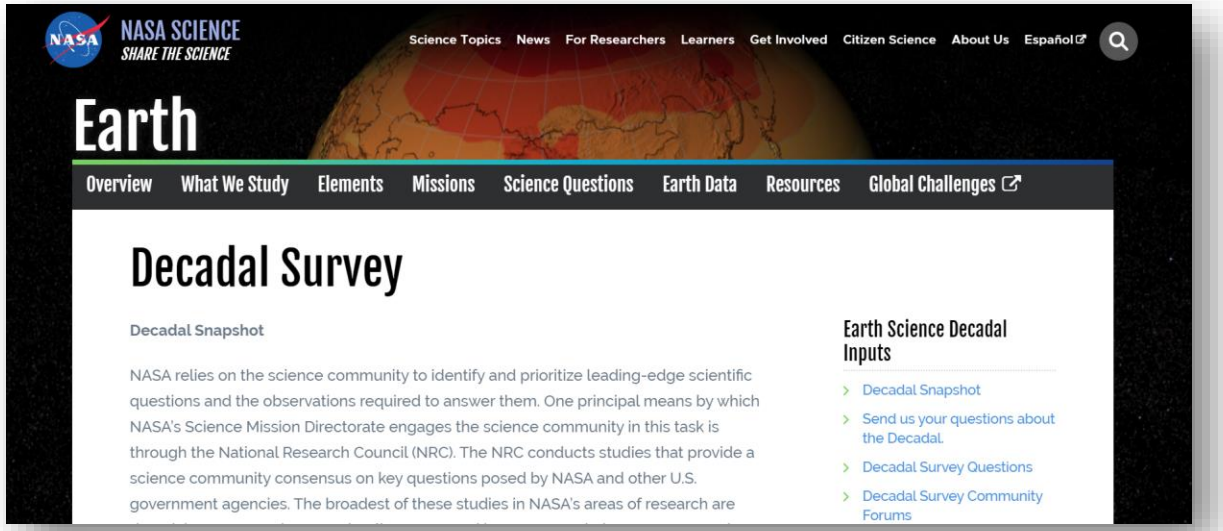
- Continuation of activities previously highlighted
- Next Health & Air Quality Applied Sciences Team will include financial support from R&A's Tropospheric Composition program
- DO Discussion topic: *Accelerating Science & Applications Return*
  - Data: How can the plan and schedule for precursor data, data product development, and calibration/validation support acceleration of research and applications?
  - Engagement: How can we inclusively broaden engagement and support of communities to stimulate additional and timely research and applications? for diverse feedback on data quality and usefulness and innovative uses?
  - Practices: What fundamental methodological advances might be shared (e.g., analysis capabilities, uncertainty quantification, modeling, assimilation techniques)

What’s Next?

What's Next?

ESD Decadal Survey Web Page:
https://science.nasa.gov/earth-science/decadal-surveys

- ESD Leadership Team continues to address additional DS topics
- Check the ESD Decadal Survey web page to:
  - Find meeting schedules and details
  - Ask questions and see answers as they become available
  - Review information in previous sets of charts
- Community Forums
  - 2021 Community Forums
    - March 18, 2021; 1-3 p.m. EST
    - July 15, 2021; 1-3 p.m. EST
    - November 18, 2021; 1-3 p.m. EST
  - WebEx and telecon information, in addition to other updates, will be posted on the NASA ESD Decadal Survey website
  - For information about future Decadal Survey Community Forums, please send an email to Amy Treat at Amy.A.Treat@nasa.gov



Questions Process

- Please type your question directly in the Q&A panel
- Or you can email questions to Amy Treat at Amy.A.Treat@nasa.gov
- Answers to relevant questions will be posted on our website: https://science.nasa.gov/earth-science/decadal-surveys

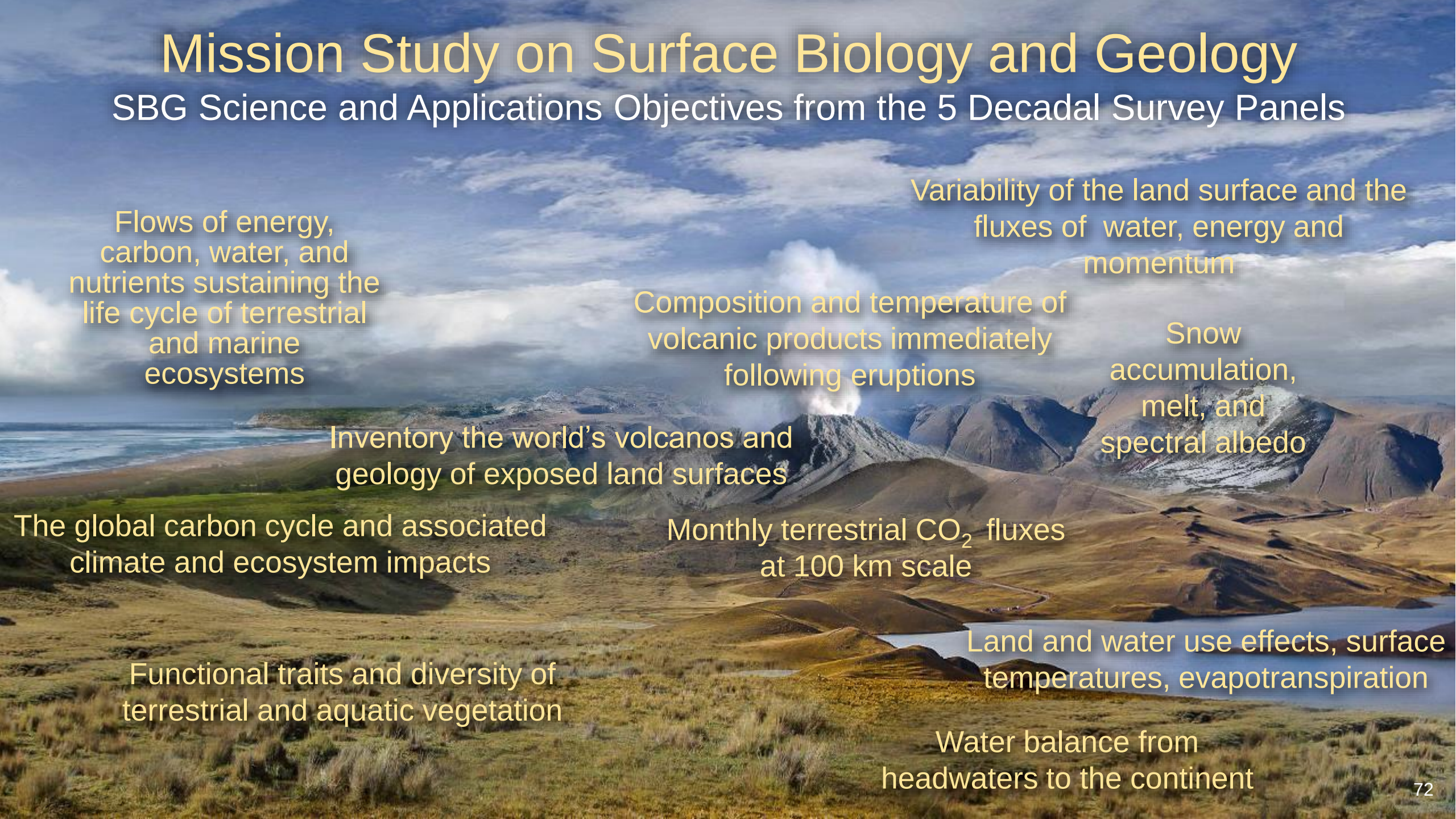
How to Get Involved!

- To join a working group or sign up for updates, send an email to:
  - **ACCP:** a-ccp-comments@lists.nasa.gov
  - **MC:** masschange@jpl.nasa.gov
  - **SBG:** sbg@jpl.nasa.gov
  - **SDC:** sdc-study@lists.nasa.gov
- General updates can be found on our website: https://science.nasa.gov/earth-science/decadal-surveys/

Backup

Mission Study on Surface Biology and Geology

SBG Science and Applications Objectives from the 5 Decadal Survey Panels



Targeted Observables 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 and 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 Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	Earth surface geology and biology, ground/water temperature, snow reflectivity, active geological 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 and Change	Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperature Radar (InSAR) with ionospheric correction	X		
Greenhouse Gases	CO2 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 and Currents	Coincident high-accuracy currents and vector winder to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift	Radar scatterometer		X	

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

Targeted Observables Priorities

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Ozone and Trace Gases	Vertical profiles of ozone and trace gases (including water vapor, CO, NO2, methane, and N20) globally and with high spatial resolution	UV/IR/microwave limb/nadir sounding and UV/IR solar/stellar occultation		X	
Snow Depth and 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 and 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 and DIAL lidar; and lidar** for PBL height			X
Surface Topography and 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, Magnetic Field Changes, Ocean Ecosystem Structure, Radiance Intercallibration, Sea Surface Salinity, Soil Moisture

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

ESD has decided to treat Atmospheric Winds as Explorer