National Aeronautics and
Space Administration
Mary W. Jackson NASA Headquarters

May 15, 2023

ESO Day Documentation

NASA's Earth Science Division hosted an Earth System Observatory (ESO) Day on April 11, 2023. The purpose of this event was to provide updates on ESO mission status, expected acquisition timelines, industry partnerships, data sharing approach, and applications of ESO data.

The Agenda from the ESO Day event included the following presentations and discussions:

- ESO Introduction
- Atmosphere Observing System (AOS) Overview
- Surface Biology and Geology (SBG) Overview
- Mass Change (MC) Overview
- Open Source Science
- Applications Overview
- Q&A

The presentations from this event, and written responses to questions addressed in the Q&A session have been consolidated into this document.

The ESO team plans to host semi-annual status updates, and looks forward to future engagements.

EARTH SYSTEM OBSERVATORY

The Earth System Observatory will deliver a holistic, 4D view of our planet's climate systems- the Earth's land, ice, atmosphere and oceans- to vastly improve our nation's response to evolving natural hazards, changing agricultural conditions, and severe weather challenges, including droughts, tropicalstorms, and wildfires.

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National Aeronautics and Space Administration

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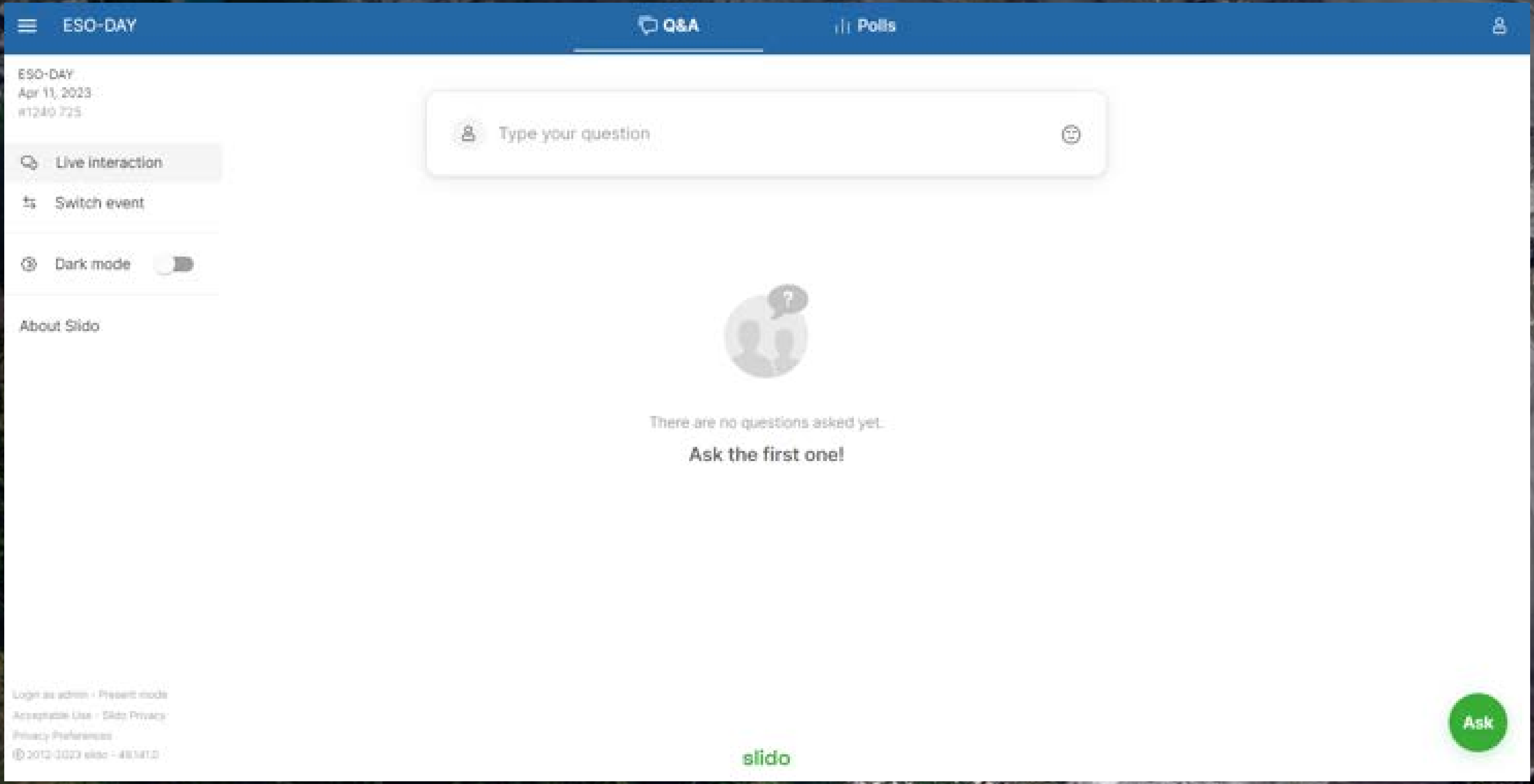
Earth System Observatory Industry Day Agenda

- ESO Introduction
- AOS Overview
- SBG Overview
- MC Overview
- Open Source Science
- Applications Overview
- Q&A

Q&A Portal

Participants can join at **slido.com** with **#1240725**



EARTH SYSTEM OBSERVATORY

NASA’s Earth System Observatory (ESO)

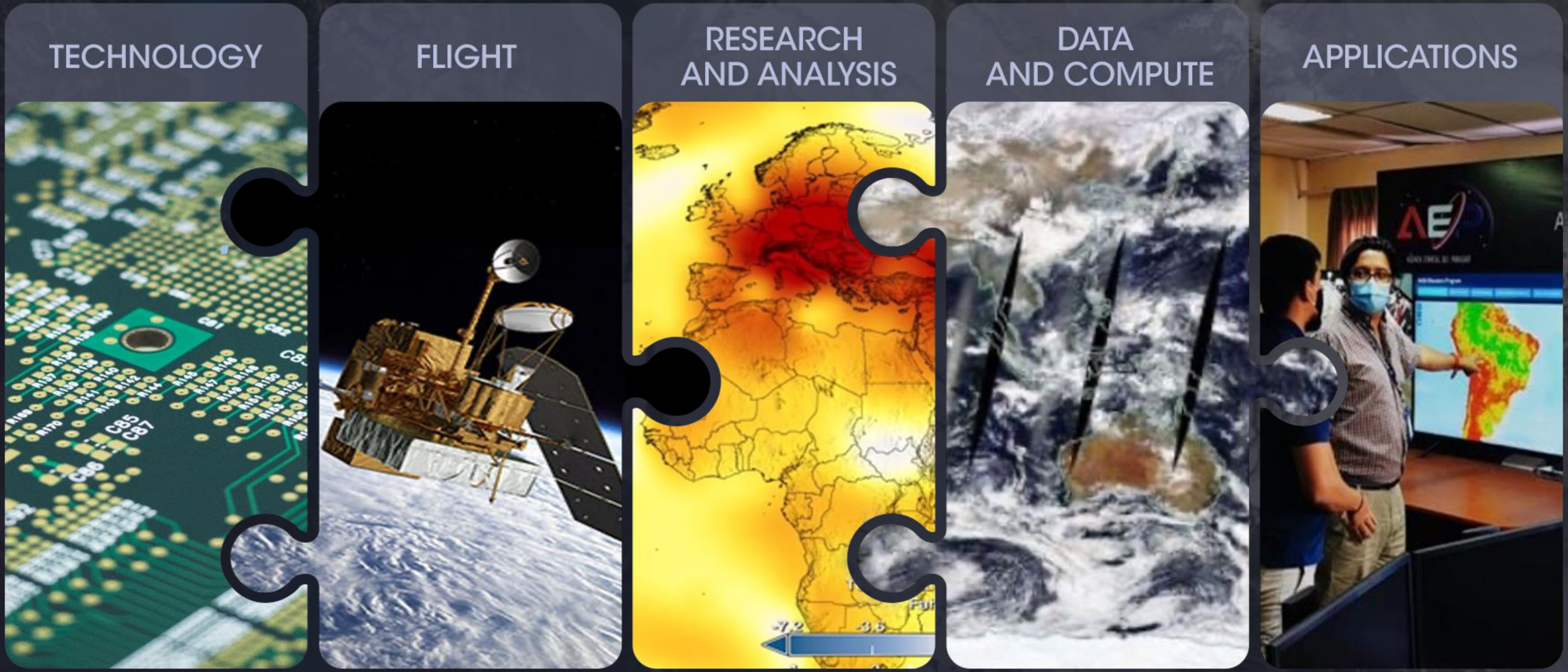
Formulation Overview

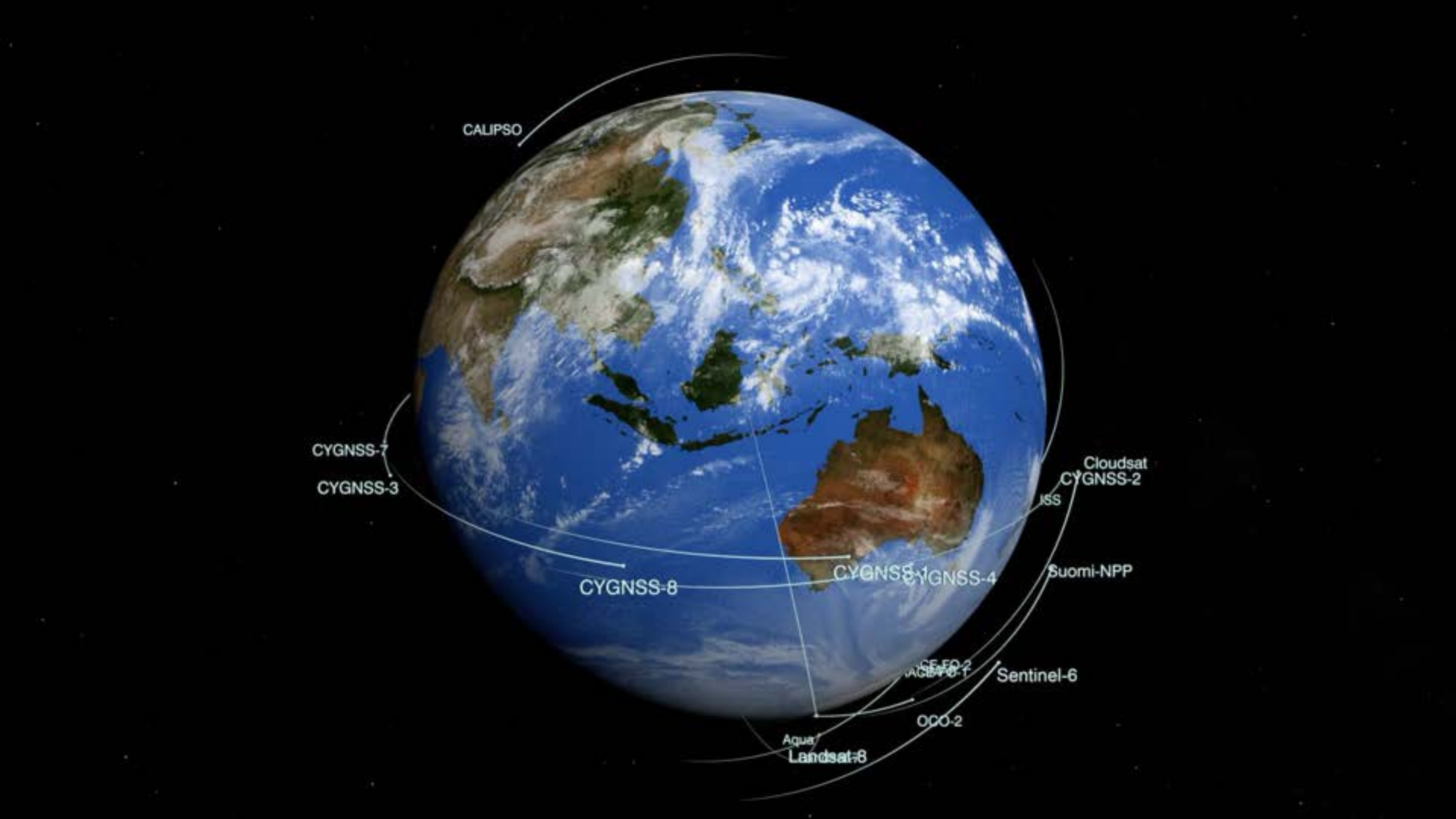
Dr. Karen St. Germain

Director, Earth Science Division

Science Mission Directorate, NASA

Advancing Earth System Science End-to-End

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CYGNSS-3
CYGNSS-8
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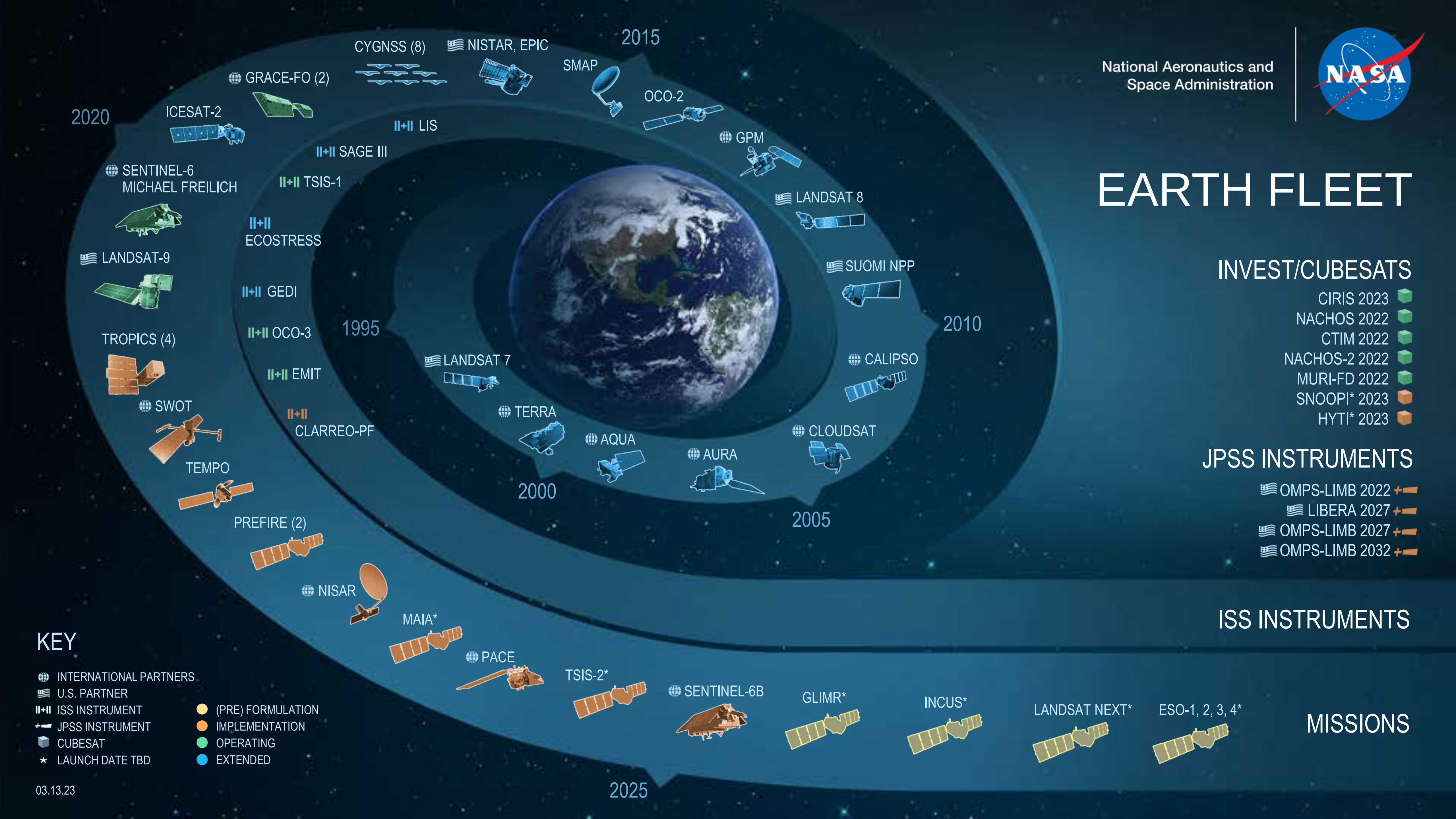
Suomi-NPP
Sentinel-6
OCO-2
Aqua
Landsat-8


National Aeronautics and Space Administration
NASA
EARTH FLEET
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CLOUDSAT
CALIPSO
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OCO-2
SMAP
NISTAR, EPIC
CYGNSS (8)
GRACE-FO (2)
ICESAT-2
SENTINEL-6 MICHAEL FREILICH
LANDSAT-9
TROPICS (4)
SWOT
TEMPO
PREFIRE (2)
NISAR
MAIA*
PACE
TSIS-2*
SENTINEL-6B
GLIMR*
INCUS*
LANDSAT NEXT*
ESO-1, 2, 3, 4*
LIS
SAGE III
TSIS-1
ECOSTRESS
GEDI
OCO-3
EMIT
CLARREO-PF
INVEST/CUBESATS
CIRIS 2023
NACHOS 2022
CTIM 2022
NACHOS-2 2022
MURI-FD 2022
SNOOPI* 2023
HYTI* 2023
JPSS INSTRUMENTS
OMPS-LIMB 2022
LIBERA 2027
OMPS-LIMB 2027
OMPS-LIMB 2032
ISS INSTRUMENTS
MISSIONS
KEY
INTERNATIONAL PARTNERS
U.S. PARTNER
ISS INSTRUMENT
JPSS INSTRUMENT
CUBESAT
LAUNCH DATE TBD
(PRE) FORMULATION
IMPLEMENTATION
OPERATING
EXTENDED
03.13.23

EARTH SYSTEM
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INTERCONNECTED CORE MISSIONS

CLOUDS, CONVECTION AND PRECIPITATION
Water and Energy in the Atmosphere

SURFACE BIOLOGY AND GEOLOGY
Earth Surface & Ecosystems

AEROSOLS
Particles in the Atmosphere

SURFACE DEFORMATION AND CHANGE
Earth Surface Dynamics

MASS CHANGE
Large-scale Mass Redistribution

AOS

MCR: May 2022
KDP-A: Jan 2023

SBG

MCR: Jun 2022
KDP-A: Nov 2022

MC

MCR: Jun 2022
KDP-A: March 2023

SDC

Remaining in extended Study Phase

ESO Core Missions

- Successfully completed Mission Concept Reviews in summer 2022
- Missions passed KDP-A and now in Formulation
- SDC will remain in extended study phase to take advantage of NISAR mission lessons learned
- ESO Independent Review Board, July - October 2022
  - IRB report and NASA response posted at nasa.gov/reports

Earth System Explorers (ESE)

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- Draft Announcement of Opportunity (AO) released on Dec 6, 2022
- Final AO expected to be released Spring 2023
- PI-Managed Mission Cost (PIMMC) cap of $310M (FY24 $)
- NASA will provide launch vehicle services
- Two-step selection process

- New Earth System Explorers Program Office in process of being stood up at GSFC; undergoing SRR/SDR in March 2023

ESO by the Numbers

$3.5B total investment for first four ESO missions

½ will be competed

5 international partners

Up to **8** competed instruments

3 competed spacecraft

4 competed launch vehicles

Integration of Earth System Observatory Data

New **Open-Source Science Policy:**

- All **mission data, metadata, software, databases, publications, and documentation** shall be available on a full, free, open, and unrestricted basis **starting in Phase B** with no period of exclusive access.
- **Science workshops and meetings** shall be **open** to broad participation and documented in public repositories.

Collaborative, accessible, inclusive, transparent, and reproducible from the beginning.

Exploring **common data approaches** for the ESO:

- A **data processing study** to examine data system efficiencies and promote Open Science principles, including co-location of mission data to enable Earth system science and applications.
- A **latency study** to evaluate flight hardware and ground system architectures to **minimize product latency** and support cross-ESO science product generation.

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EARTH SYSTEM OBSERVATORY

Atmosphere Observing System (AOS) Overview and Status

Carla Procaccino

Program Executive

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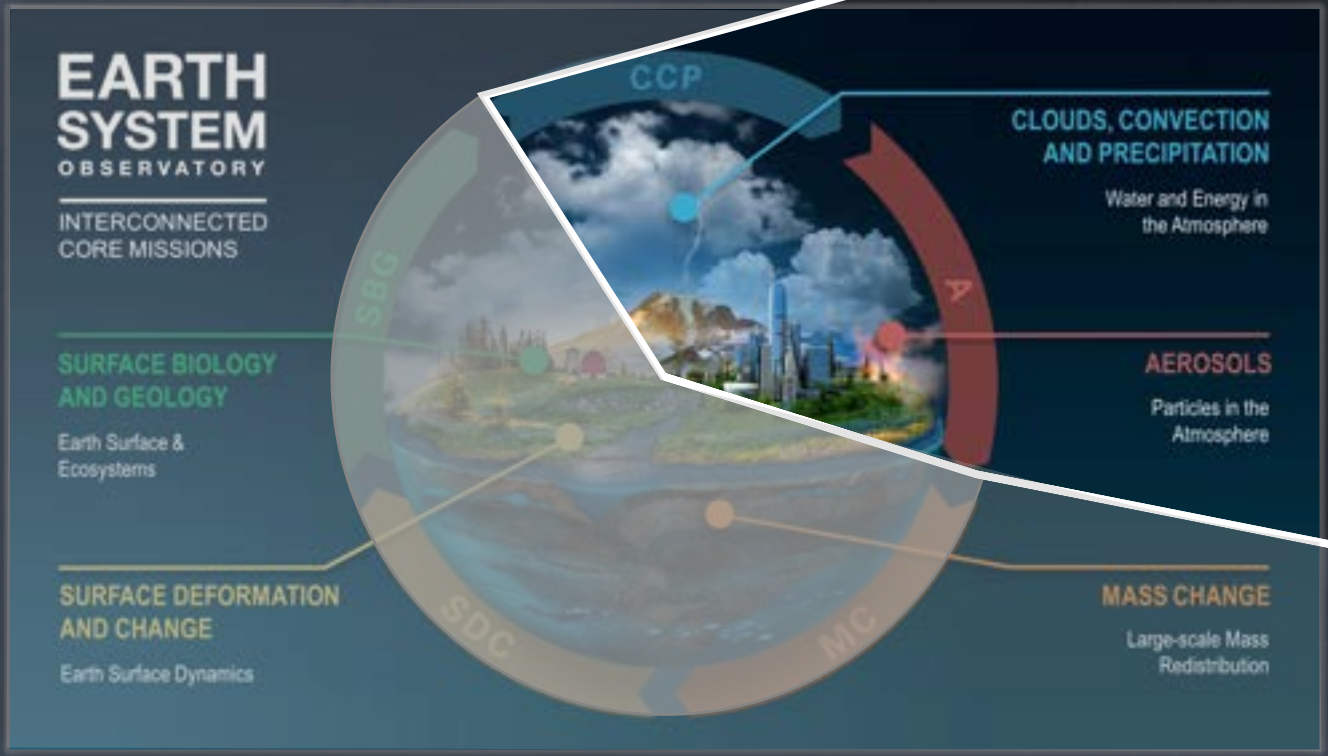
EARTH SYSTEM OBSERVATORY

Content

- AOS Goals
- Science Priorities
- AOS Mission History
- AOS Mission Overview
  - AOS-Storm
  - AOS-Sky
- AOS Architecture
- AOS Formulation Status
- Next Steps

EARTH SYSTEM OBSERVATORY

AOS Designated Observables: Goals



1. **Cloud Feedbacks**
   - Low Cloud and High Clouds
2. **Storm Dynamics**
3. **Cold Cloud & Precipitation Processes**

4. **Aerosol Processes**
   - Aerosol Attribution and Air Quality
   - Aerosol Removal & Redistribution
5. **Aerosol Impacts on Radiation**
   - Aerosol Direct Effect and Absorption
   - Aerosol Indirect Effect

Precipitation and aerosols are the key connections to other Designated Observables

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Major Science Priorities & Questions for AOS

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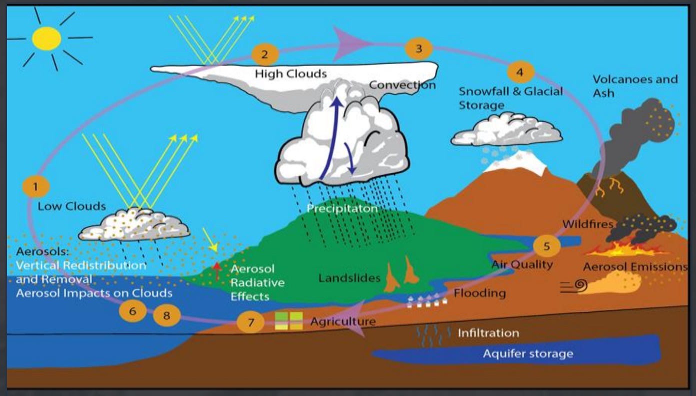
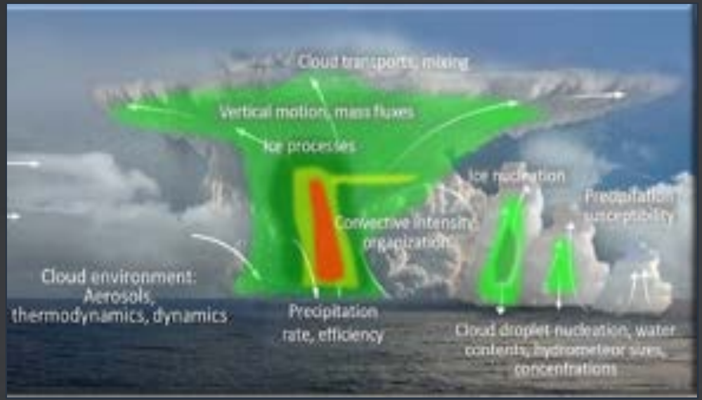


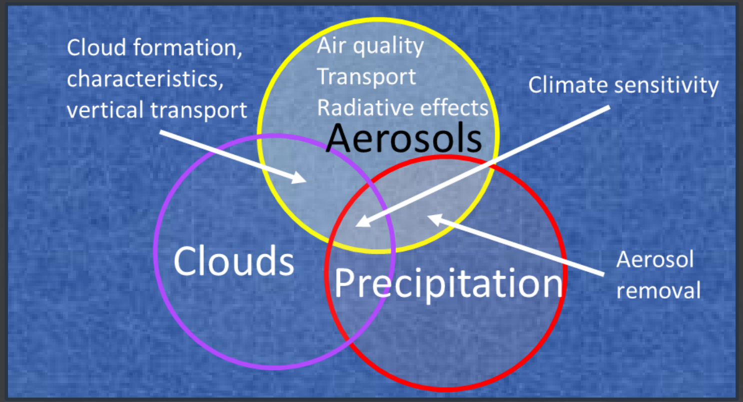
1. CLIMATE: How can we improve our ability to predict local and regional climate response to natural and anthropogenic forcings and reduce the uncertainty in global climate sensitivity?

- The two largest sources of future warming prediction uncertainty are (IPCC AR6 Report):
  - radiative forcing by aerosol
  - cloud feedbacks



2. CONVECTION: Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do? How do microphysical properties relate to storm dynamics?

- Convective storms deliver much of the fresh water for society and are a principal source of life-threatening severe weather.



3. AEROSOLS: What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impacts on human health, agriculture, and ecosystems?

- Aerosol profile and amounts are key to near-surface air quality, transport & vertical redistribution, and aerosol-cloud interactions
- Aerosol extinction is critical in determining the radiative effects of aerosols

AOS Mission History

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National Academies of Sciences, Engineering, and Medicine "Decadal Survey for Earth Science and Applications from Space 2017–2027" (ESAS 2017)

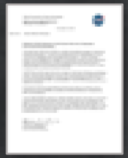
- Aerosols (A) and Clouds, Convection, and Precipitation (CCP) identified as two of the five Designated Observables

National Academies of Sciences, Engineering, and Medicine 2018

ACCP Study was completed, and recommended a dual orbit plane constellation and sub-orbital components for the AOS architecture

✓ **AOS completed Mission Concept Review (MCR)**

SMD commissioned ESO IRB. Recommendations included AOS descopes



2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

NASA ESD solicited a multi-Center study to develop mission concepts that combined the A and CCP observables due to their significant synergy

The NASA Science Mission Directorate (SMD) issued a Project Authorization Letter establishing two projects at GSFC:

- AOS Inclined (AOS-I)
- AOS Polar (AOS-P)

AOS

✓ **AOS successfully passed Key Decision Point-A and entered formulation**

- Project Names updated to AOS-Storm and AOS-Sky

AOS Mission Overview

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MCR design* included a four-satellite constellation, with complementary instruments, operating in two orbit planes

- Delivers globally distributed measurements on range of temporal scales

International contributions expand capabilities

NASA's two spacecrafts and their instruments are enhanced by observatories and instruments provided by JAXA, CSA, and CNES

KDP-A Cost Target set at $1.80-1.99B

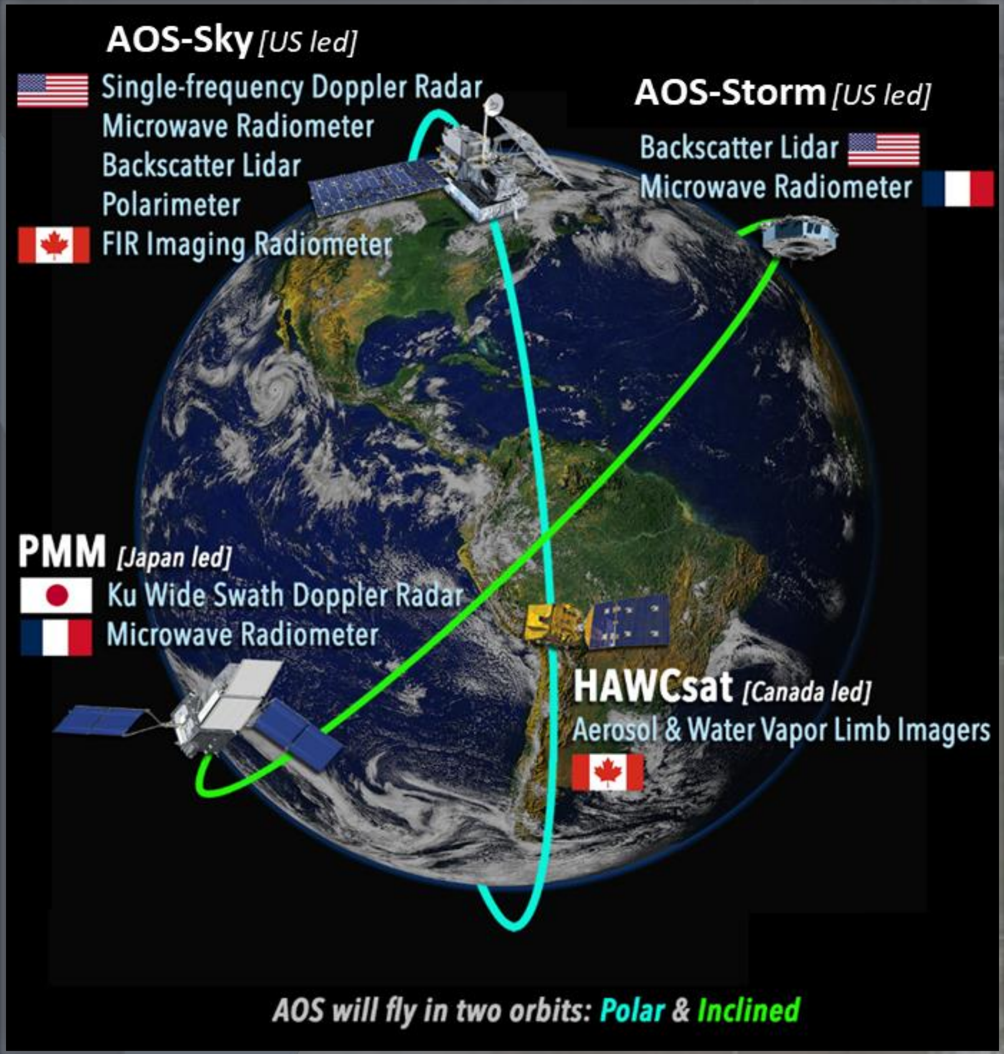
NASA Provided Spacecraft and Launches

AOS-Storm

- NET July 2028 Launch
- Co-Manifested launch with JAXA Precipitation Measurement Mission (PMM)

AOS-Sky

- NET December 2030 Launch
- Co-Manifested launch with CSA High-altitude Aerosols, Water vapor, and Clouds Satellite (HAWCsat)



*AOS is currently conducting architecture trades. The mission design and requirements may change during phase A.

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AOS: A Distributed Science Mission

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AOS-Storm

Cat II, Risk Class C
Orbit: 407 km, 55° inclination
Design Life: 2 yr (3 yr consumables)

- Offers diurnal sampling of convective storm dynamics
- Provides diurnal measurements of the structures of dust and smoke aerosols
- Enables more accurate predictions of convective rainfall and severe weather, and can support fresh-water resource management

AOS-Sky

Cat II, Risk Class C
Orbit: 450 km, sun-sync, 13:30 LTAN
Design Life: 3 yr (5 yr consumables)

- Provides aerosol, cloud and climate processes observations from the tropics to the poles through sensor synergy
- Contributes key insight into the vertical structure of earth's atmosphere
- Enables enhancements to disaster monitoring, and can inform air quality health policy

AOS is a distributed science mission with products dependent on observations provided by multiple platforms. By leveraging multiple orbits, sub-orbital components and complementary instrumentation, key measurements are optimized, and new discoveries of Earth's climate systems are enabled.

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AOS Architecture Overview

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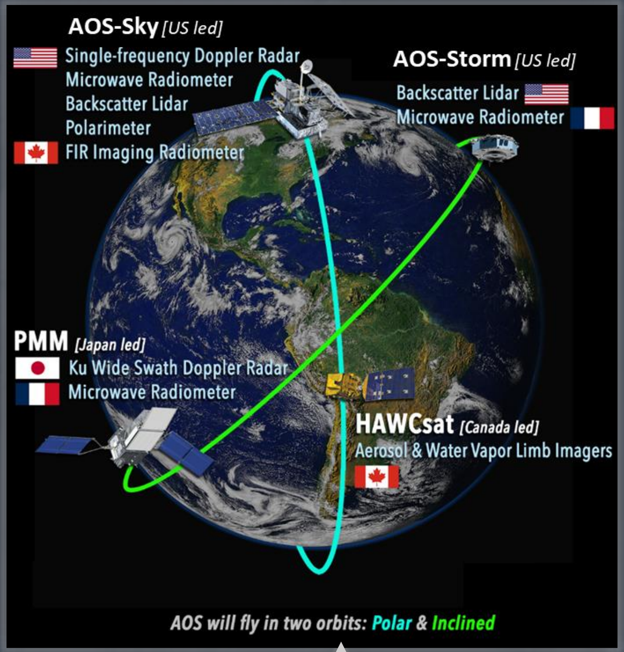
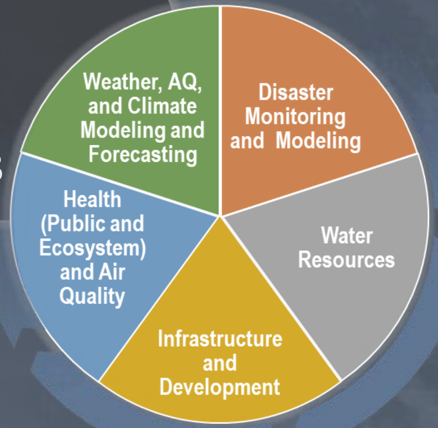
Space Segment



Launch Segment

AOS will provide key information to support decision making at timescales from hours to decades



Science and Applications

- Operations
- Data Processing
- Calibrations
- Validations

Sub-Orbital Segment

Ground Segment

- Telecommunications
- Mission Operating Center

Instrument Ops Terminals

Partner MOC / SDS

Science Data System

- Open Science

Partner Science Data

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AOS Applications

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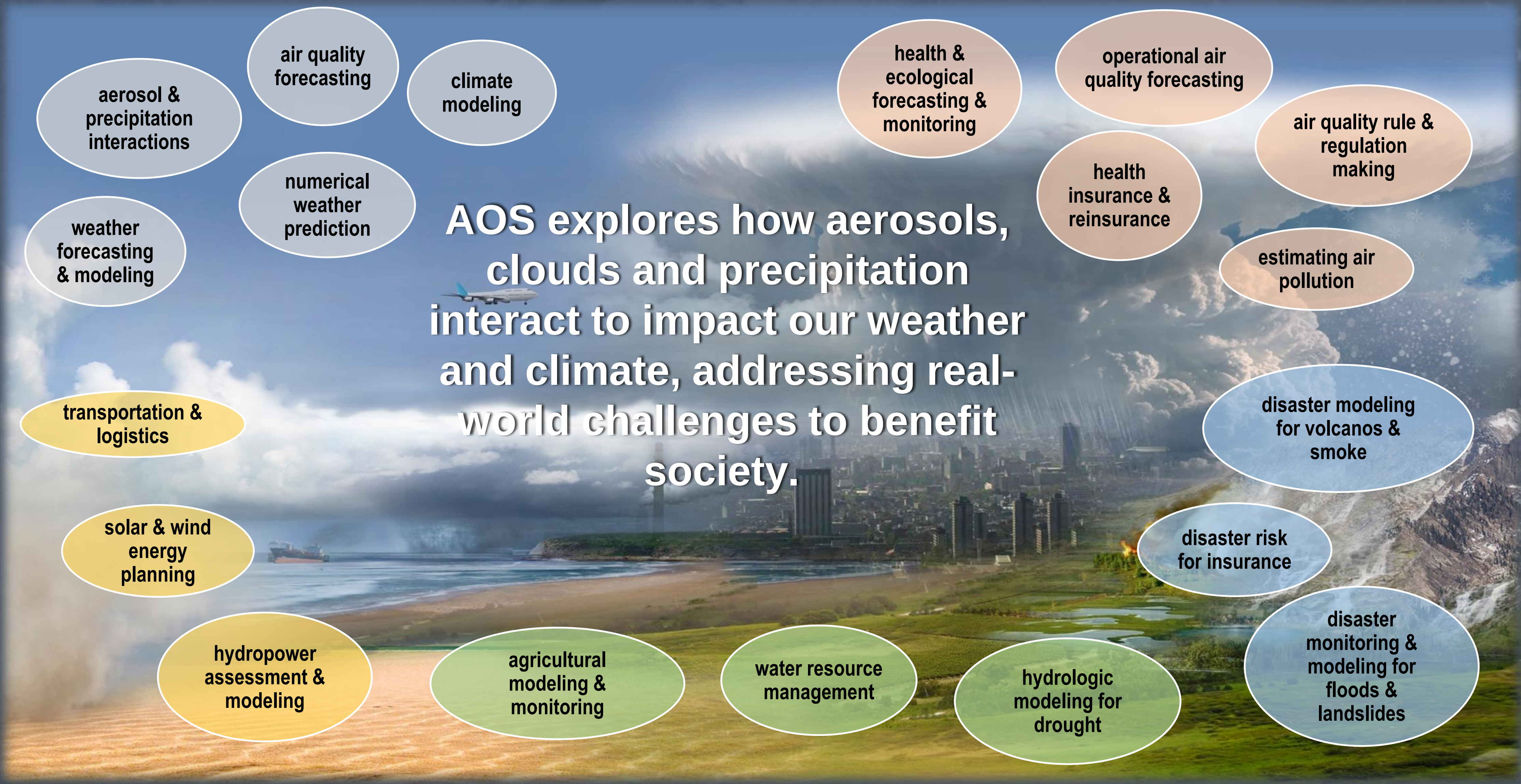

AOS explores how aerosols, clouds and precipitation interact to impact our weather and climate, addressing real-world challenges to benefit society.

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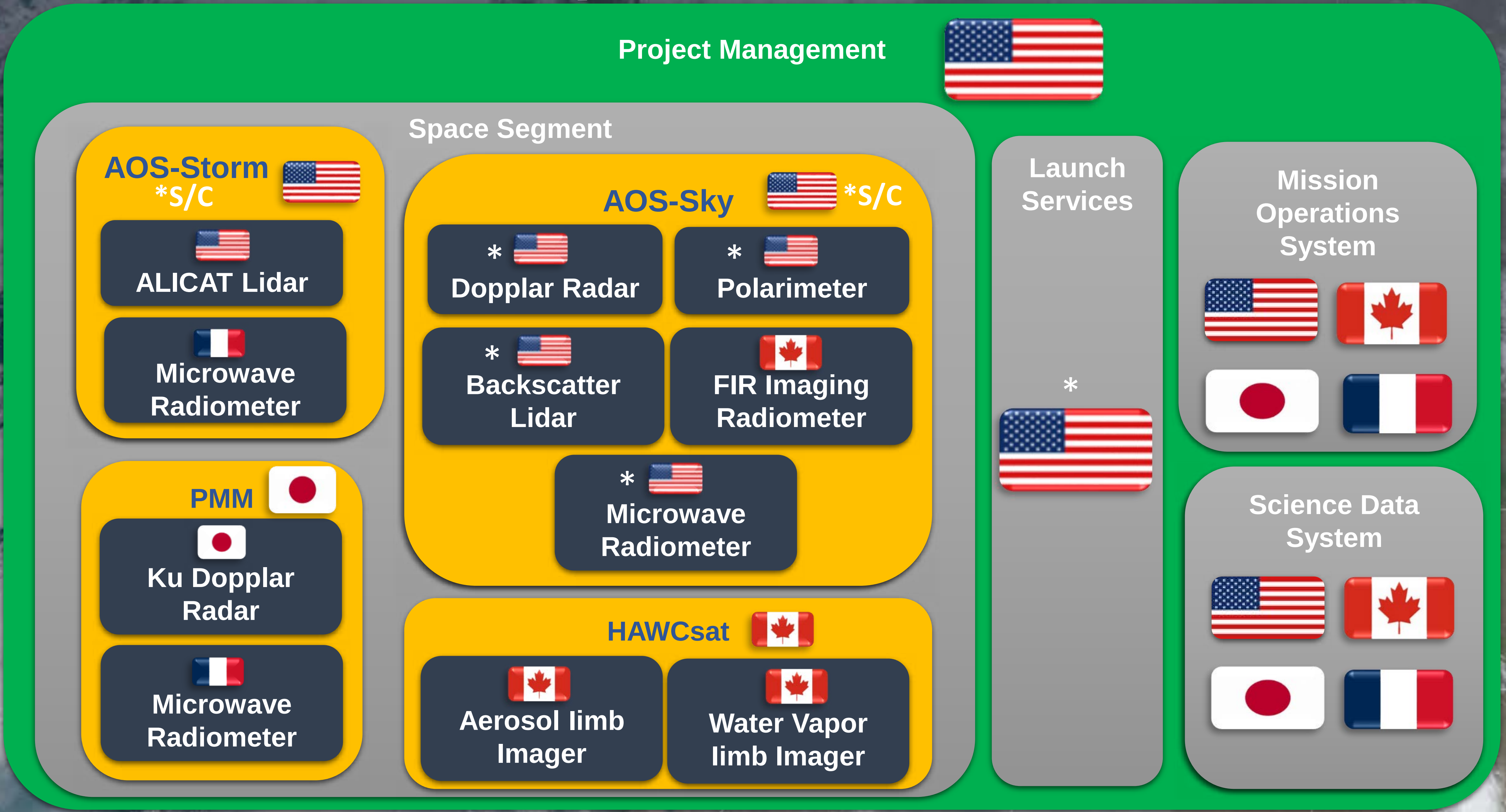
AOS Partnerships

* Components Procured from US Industry



Anticipated Acquisition Approach

Acquisition Milestone	Source	Acquisition Timeline
Instrument Concept Study RFP Release • Doppler Radar • Lidar • Radiometer • Polarimeter	US Industry	Q2CY2023
Instrument Development Final RFP Release	US Industry	Q4CY2024
Spacecraft Concept Study RFO through RSDO	US Industry	Q2CY2023
Spacecraft Development Final RFOs through RSDO	US Industry	Q3CY2025

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- [x] **KDP-A:** 13 Jan 2023
- [ ] **SRR/MDR:** June 2024
- [ ] **KDP-B:** July 2024
- [ ] **PDR:** June 2026
- [ ] **KDP-C:** July 2026

AOS Formulation Status

- AOS was granted approval to proceed into Phase A on 13 Jan 2023
- AOS was assigned several actions to study and implement architecture content adjustments, that were directed in response to the ESO IRB Findings.
  - The AOS team is conducting trade studies and market research for the AOS-Sky Radar and Lidar
  - AOS is studying science capability adjustments and other efficiencies to reduce costs
  - AOS is studying options for a management structure to manage AOS as a distributed science mission
  - The AOS science teams will update the draft science requirements in coordination with the trade studies above
- Trade study completion and architecture decision expected in June 2023

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- [x] **KDP-A:** 13 Jan 2023
- [ ] **SRR/MDR:** June 2024
- [ ] **KDP-B:** July 2024
- [ ] **PDR:** June 2026
- [ ] **KDP-C:** July 2026

AOS: Next Steps

- Complete trade studies to identify cost-saving opportunities
- Continue engagements with science and application communities
- Perform Phase A activities on the path to SRR/MDR and KDP-B
  - Baseline Level 1 and Level 2 requirements, flow down and complete development of lower-level requirements
  - Continue to mature plans for international partnerships
  - Generate Project Applications Plan to define Early Adopter engagement and activities
  - Update Launch schedule estimates
  - Release RFPs for Spacecraft and Instruments

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For more information

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AOS Website: https://aos.gsfc.nasa.gov

ACCP Science Narrative:

https://aos.gsfc.nasa.gov/docs/ACCP_Science_Narrative-2021.07.19.pdf

AOS Community Assessment Report

https://aos.gsfc.nasa.gov/docs/AOS_Community_Assessment_Report.pdf

ESO IRB Report

https://www.nasa.gov/sites/default/files/atoms/files/eso_irb_documents.pdf

SURFACE BIOLOGY AND GEOLOGY

EARTH SYSTEM OBSERVATORY

Surface Biology and Geology (SBG) Overview and Status

Michael Egan
Program Executive

EARTH SYSTEM OBSERVATORY

Content

- SBG Purpose
- SBG Mission Description
- SBG Architecture Overview
  - Thermal Infrared (TIR)
  - VSWIR Hyperspectral
- SBG Programmatic Timeline

Surface Biology and Geology (SBG) - Purpose

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SBG is key to understanding in five Decadal Survey research and applications (R&A) focus areas:

- Terrestrial and aquatic ecosystems
- Hydrology
- Weather
- Climate
- Solid Earth

The Decadal Survey (DS) defines the implementation as two sensors "*Hyperspectral imagery in the visible and shortwave infrared; multi- or hyperspectral imagery in the thermal IR*":

1. "….a moderate spatial resolution (30-45 m GSD), hyperspectral resolution (10 nm; 400-2500 nm), high fidelity (SNR = 400:1 VNIR/250:1 SWIR) imaging spectrometer is needed for characterizing land, inland aquatic, coastal zone, and shallow coral reef ecosystems"
2. "….30-60 m TIR observations in the 10.5-11.5 µm and 11.5-12.5 µm spectral regions are needed with a 2-4 day revisit frequency"

SBG Applications Themes

Precursor efforts
HyspIRI, ECOSTRESS, EMIT

SBG applications working group
225+ members

SBG RTI Studies
560+ respondents | 90+ interviews

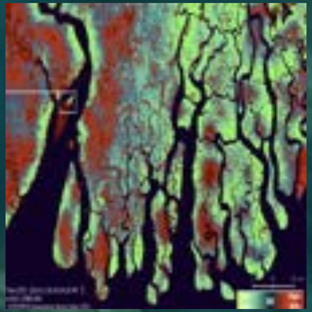
wildfires risk and recovery | **public health and heat waves** | **food security** | **strategic minerals** | **water quality** | **forest management** | **coral reefs** | **water resources** | **aquaculture** | **conservation** | **greenhouse gas emissions**

Mission Architecture
synergize research and applications

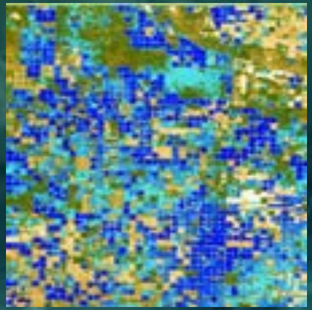
Mission Requirements
research and applications informed

Community Engagement
application ready products and data systems

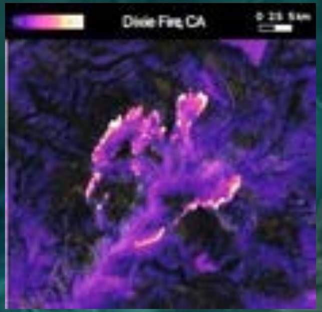
SBG community will build on and expand the ECOSTRESS and EMIT applications activities, comprised of a community of practice with 500+ members



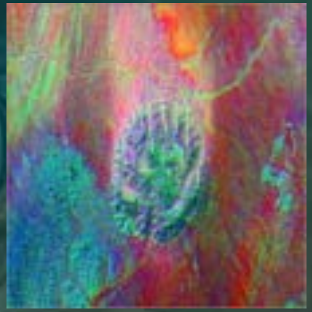
Ecosystem management



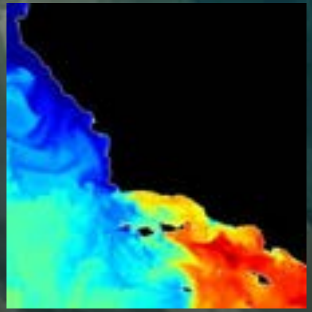
Agricultural water use and management



Wildfire behavior

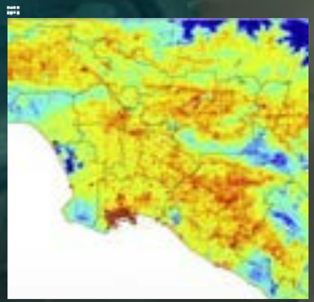


Strategic minerals

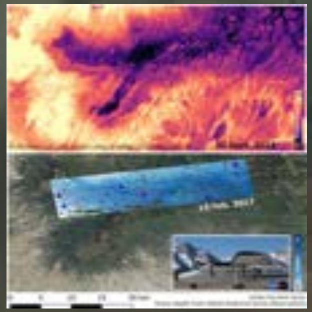


Water temperature and aquatic health

Volcano risk and hazards

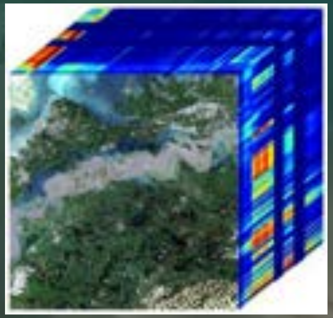


Urban Heat and Public Health

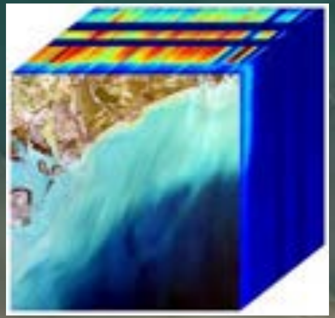


Mountain snowmelt and water resources (snow temperature)

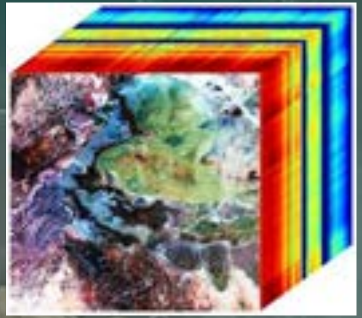
ECOSTRESS Thermal



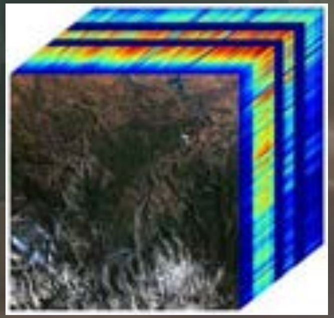
Natural Hazards



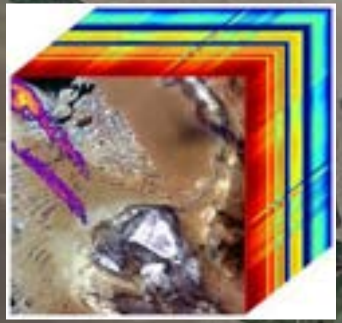
Water quality, harmful algal blooms



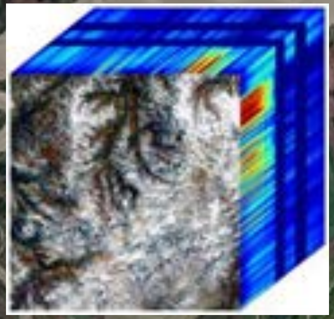
Strategic minerals



Fire risk and management



Greenhouse Gas Emissions, point sources



Mountain snowmelt and Water Resources (Snow albedo)

EMIT Spectroscopic

SBG Mission Description

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- Surface Biology and Geology (SBG) will help answer climate, ecosystems and natural resources, hydrology, solid Earth, and weather-related questions
- Category 2 mission per NPR 7120.5F
- Risk Classification C per NPR 8705.4A
- Wide-swath Thermal Infrared (TIR) Imager platform, launch in 2027
- Wide-Swath Visible and Short-Wave Infrared (VSWIR) Spectrometer platform, launch in 2028
- Three-year prime mission for each
- Lead and other NASA Centers: JPL with ARC, GSFC, KSC LaRC, and MSFC
- Partnership with the Agenzia Spaziale Italiana (ASI) for TIR

SBG System Requirements

	Mission & Instrument Parameters	Threshold (11/28 observables fully met)	Baseline (16/28 observables fully met)
VSWIR	Spatial Resolution (@ Nadir)	≤ 45 m	≤ 35 m
	Temporal Resolution	≤ 22 days	≤ 16 days
	Spectral Resolution	≤ 20 nm	≤ 10 nm
	Wavelength Range	440-2450	380-2500
	Sensitivity (SNR)	≥ 350 (VNIR) / ≥ 200 (SWIR)	≥ 400 (VNIR) / ≥ 250 (SWIR)
	On-Orbit Overlap of VSWIR and TIR	≥ 1 Year	≥ 2 Years
TIR	Spatial Resolution (@ Nadir)	≤ 120 m	≤ 60 m
	Temporal Resolution	≤ 5 days	≤ 3 days
	Spectral Range	≥ 3 TIR Bands + MWIR	≥ 5 TIR Bands + MWIR
	Sensitivity (NeDT)	≤ 0.4 K	≤ 0.3 K

SBG-TIR Architecture and Workshare

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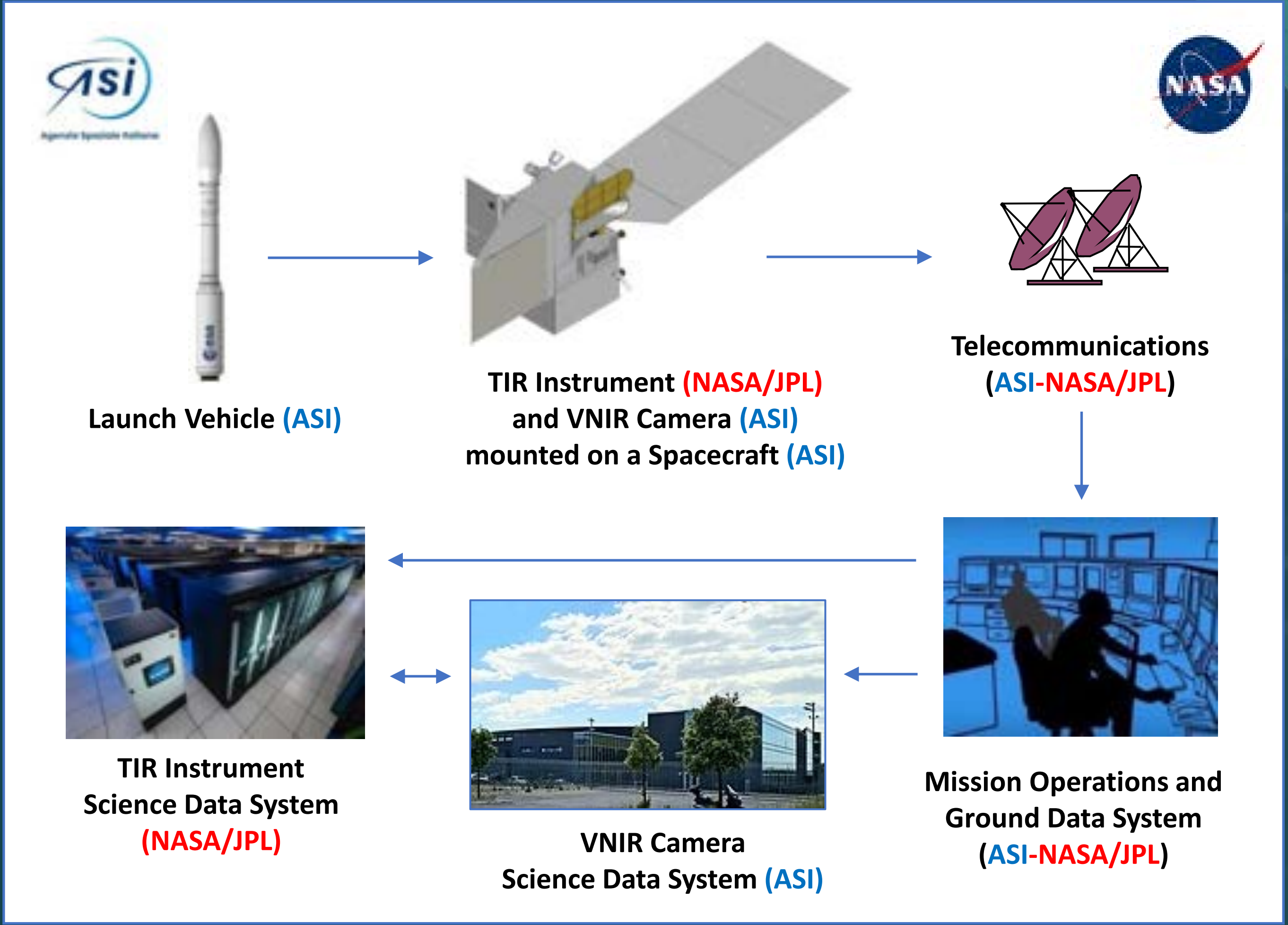

Legend: NASA/JPL ASI

Responsibilities/Contributions

- NASA/JPL
  - TIR Instrument
  - Mission System Elements, as appropriate
- ASI
  - Visible and Near-Infrared (VNIR) Camera
  - Spacecraft
  - Launch Vehicle
  - Mission System Elements, as appropriate

SBG-VSWIR Architecture

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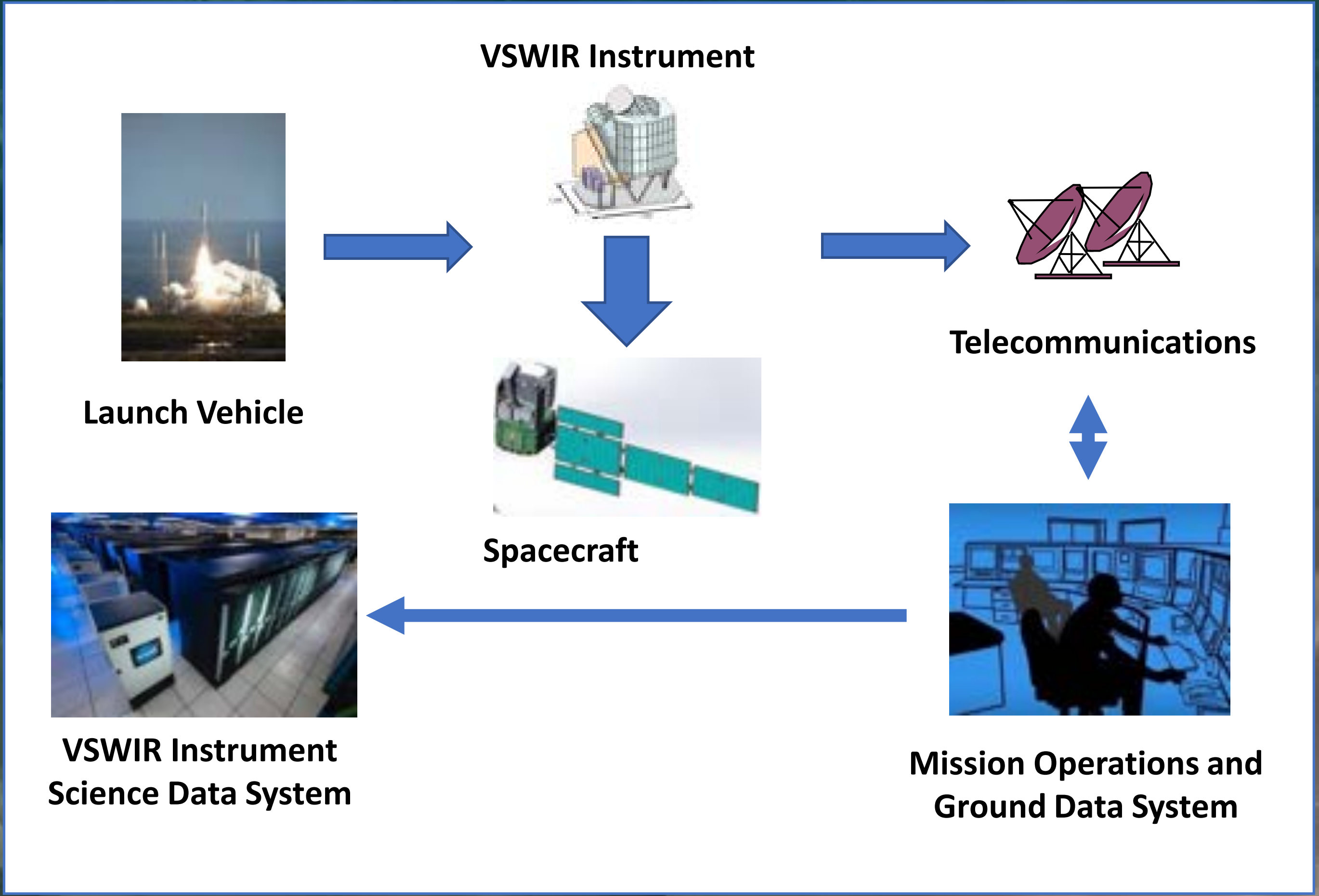

SBG-VSWIR will be an all-domestic endeavor

Preliminary Acquisition Strategy

	Architecture Component	Provider(s)	Notes
TIR	Spacecraft	ASI	
	VNIR Camera	ASI	
	TIR Instrument	JPL, Industry	JPL Lead, competitively procured subsystems
	Launch Vehicle	ASI	
VSWIR	Spacecraft	Industry	Competitively sourced
	VSWIR Instrument	JPL, Industry	JPL Lead, competitively procured subsystems
	Launch Vehicle	US Launch Provider	via LSP

Release of RFPs for competed components expected after KDP-B

Responsibilities of other NASA Centers

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- **Ames Research Center (ARC)** supports activities related to Research & Applications (RA), Ground & Science Data System (GDS/SDS), and system engineering
- **Goddard Space Flight Center (GSFC)** focuses on defining calibration/validation objectives and requirements, RA formulation efforts, and GDS study support
- **Kennedy Space Center (KSC)** provides launch service needs for the VSWIR platform
- **Langley Research Center (LaRC)** focuses on calibration/validation and provides system engineering support, as needed (e.g., mission design and navigation)
- **Marshall Space Flight Center (MSFC)** supports activities related to SBG Applications Working Group, RTI Community Survey, Community Assessment Report (CAR), and Thermal IR Synergies-International Applications Working group

SURFACE BIOLOGY AND GEOLOGY

SBG Project Status

Key Formulation Activities

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✓	Project Authorization Letter (PAL)	May 23, 2021
✓	Mission Concept Review (MCR)	June 22-24, 2022
✓	Key Decision Point A	November 8, 2022
	Acquisition Strategy Meeting (ASM)	Q1 2023
	Systems Requirements Review (SRR)/Mission Definition Review (MDR)	September 2023
	Key Decision Point B	November 2023
	Preliminary Design Review (PDR)	July 2024
	Key Decision Point C	September 2024

SBG Project Future Milestones

Implementation

	Critical Design Review (CDR)	September 2025
	System Integration Review (SIR)	January 2027
	TIR Delivery to ASI	February 2027
	Key Decision Point D	March 2027
	TIR Launch Readiness Date	Late 2027
	VSWIR Launch Readiness Date	Mid 2028

MASS CHANGE


EARTH
SYSTEM
OBSERVATORY
National Aeronautics and
Space Administration
NASA

Content

- **Mission Overview**
- **Science Goals and Data Record**
- **Mission Architecture**
- **Partnerships and Acquisition Approach**
- **Data Acquisition**
- **Key Milestone Status**

Content

- Mission Overview
- Science Goals and Data Record
- Mission Architecture
- Partnerships and Acquisition Approach
- Data Acquisition
- Key Milestone Status

EARTH SYSTEM OBSERVATORY

Mass Change

Nicole Herrmann
Program Executive, Earth Science Division
Science Mission Directorate
NASA Headquarters

Mass Change (MC)

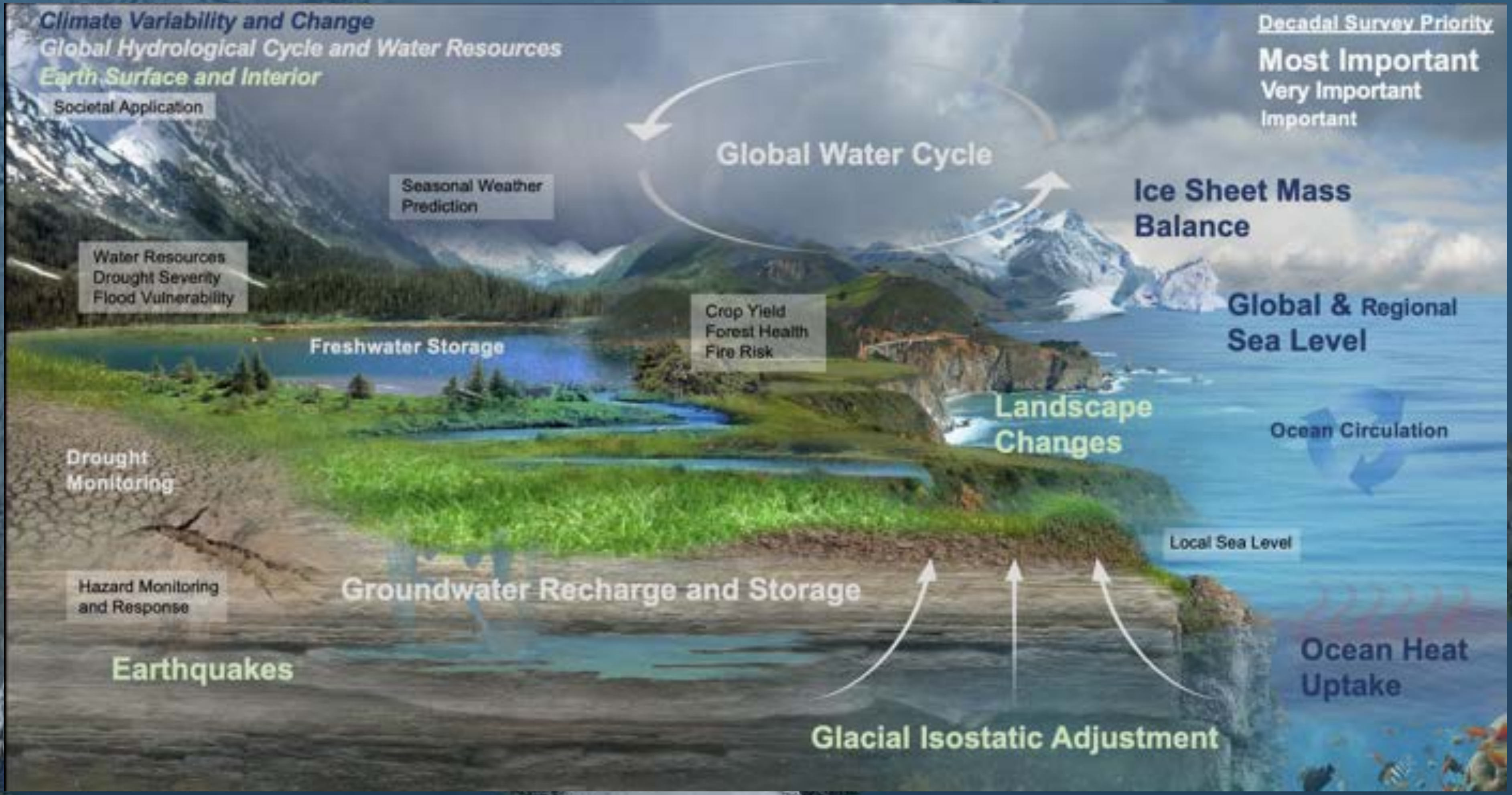
The MC mission will continue the more than two decades of large-scale mass change observations (ice, water cycle, earth dynamics) through gravimetric measurements.

This valuable data is currently used for drought assessment and forecasting, associated planning for water use by agriculture, understanding the drivers of sea level rise, Earth’s energy imbalance, and ice mass loss from the world’s ice sheets.

Mass Change Science and Applications at a Glance

"Measuring the global movement of water and changes in water resources is critical to understand how Earth's climate system works, to inform predictions of the future trends in our climate and to assess food and water security, which are key elements impacting economic and political stability."

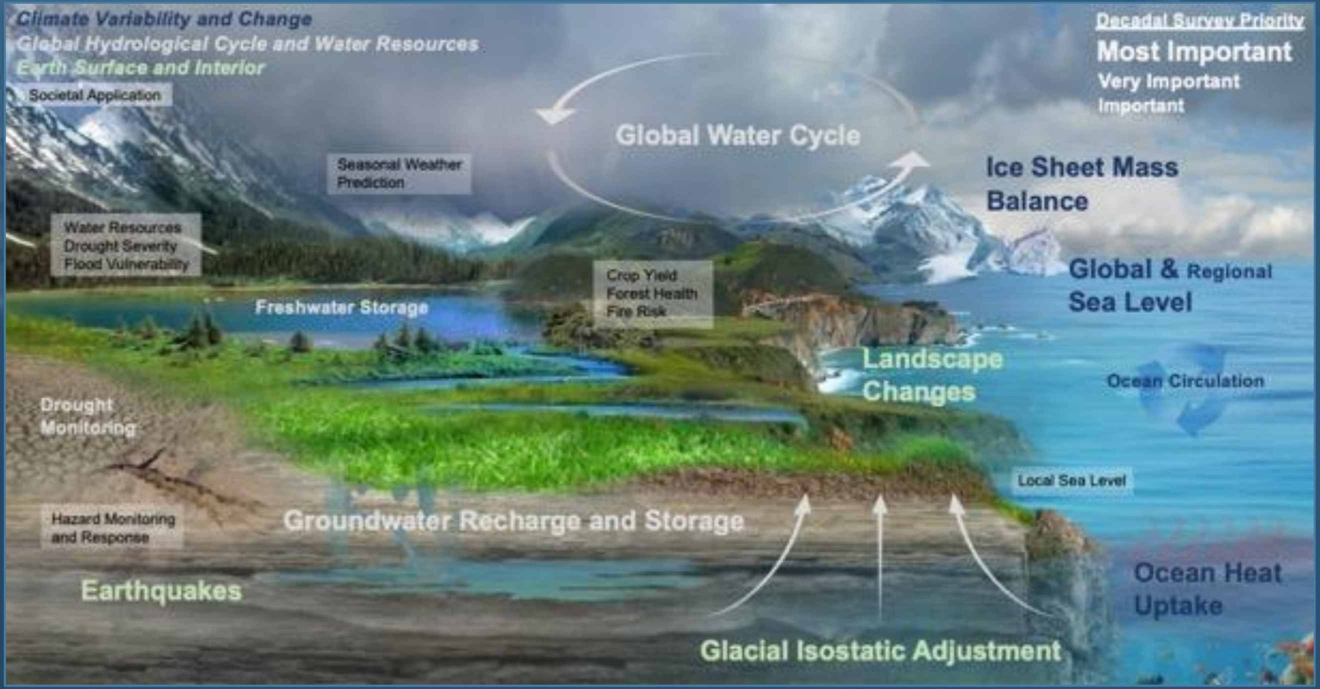
T. Zurbuchen, at GRACE 20th anniversary



Mass Change Mission Overview

Technical Overview

- Partnership between NASA & DLR
- Two identical Spacecraft separated by 100-300 km
- Launch Date: May 2028
- Launch Vehicle: Provided by DLR
- Spacecraft Bus: Airbus; GRACE-FO Heritage
- Baseline design life: 5 years (7 years consumables)
- Orbit: 500 km altitude, 89º Inclination
- Project: Cat II
- Risk Class: C



Measurement System

Satellite to Satellite Tracking:

- Laser Ranging Interferometer
- Accelerometer
- GNSS Receiver
- Star Camera Attitude determination

Mass Change provides

- A global view of **underlying physical processes and interconnections** between Earth system components to distinguish between **trends, accelerations, and variability**.
- Quantitative measurements of **terrestrial water storage** that allow for a look beyond the surface, which helps **decision-making**.
- Constraints to the **water and energy budget**, which helps to bound trends and variability in other variables.
- Continuation of current **operational uses** and a potential for **expanding applications** for water resource management and coastal planning.

Mass Change Data Record: An established climate variable

2022: GCOS establishes Terrestrial Water Storage as an Essential Climate Variable; recommends urgent action to ensure continuity of gravity measurements

2000

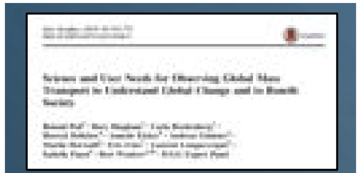
2010

2020

1997: Gravity Recovery and Climate Experiment (GRACE) selected under the NASA Earth System Science Pathfinder Program.

2007: Decadal Survey recommends a higher capability GRACE-II as a Tier-3 mission to continue observations from GRACE

2010: NASA Climate-Centric Architecture report recommends GRACE Follow-On as a gap-filler to continue observations between GRACE and GRACE-II



2015: IUGG Report on science and user needs for mass change to improve upon POR

2016: NASA/ESA IGSWG Report provides roadmap for 2-pair implementation to satisfy needs in IUGG report

2017: Decadal Survey recommends Mass Change as a Designated Observable to continue observations from GRACE-FO

2002: Launch of GRACE

Continuity has been called for in three community reports: DS-2007, CCA-2010, DS-2017

Advances the goals of a broad community of the most important climate science and applications

2017: GRACE End of Life

2018: Launch of GRACE-FO

2002-2017, 2018 – present: GRACE and GRACE-FO Establish a Mass Change Climate Data Record

How does it work?

Unlike other Earth-observing satellites, which carry instruments that observe some part of the electromagnetic spectrum — for example, visible light or infrared energy — the two MC satellites themselves act as the observational system.

MC, like GRACE and GRACE-FO, continuously measures distance changes between the satellites and is accurate to within a few microns/sec.

MASS CHANGE

MC Mission Concept is Near Identical to GRACE-FO

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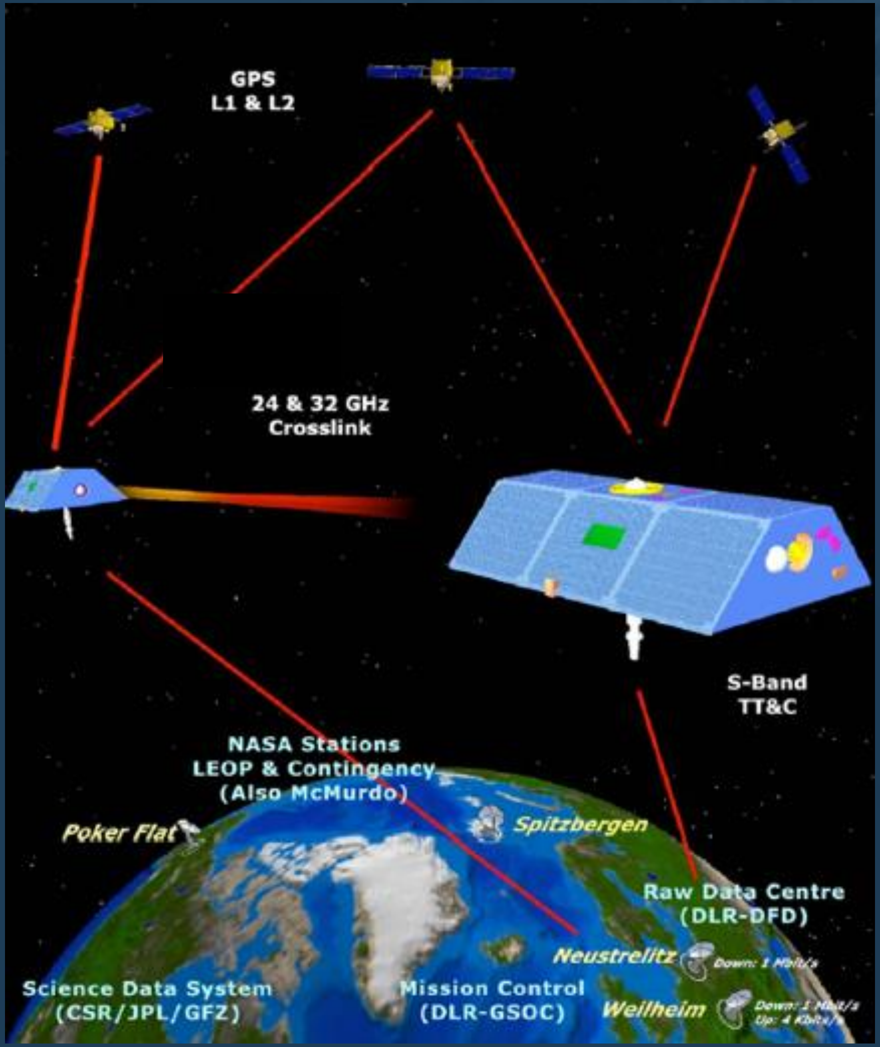

- The “twin satellite” observatory will fly in a polar mapping orbit with a No Early Than (NET) launch of 2028
- Mission Management is provided by JPL (Cat 2, Class C)
- Mission Operations provided by DLR/German Space Operations Center (GSOC)
  - Ground tracking is provided through Weilheim and Neustrelitz contributed by DLR/Germany.
  - Plus NSN through a cooperative agreement.
- Launch Vehicle: Provided by DLR/Germany
- Science Data System (SDS) processes ranging data to produce Earth gravity field every 30 days and delivers them to the NASA Archive

MASS CHANGE

Science Goals

From Table 3.5 of Decadal Survey, Basis for MC Being Foundational

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Ensures continuity of measurements of

- Terrestrial Water Storage (TWS) change, including groundwater
  - Essential Climate Variable
  - Required for closing the water budget
- Land ice contributions to sea-level rise
- Ocean mass change
- Ocean heat content (when combined with altimetry),
- Glacial isostatic adjustment
- Earthquake mass movement

Also important for operational applications

- Drought assessment and forecasting
- Water Management

Potential data integration with SBG (evapotranspiration and land use), AOS (precipitation), NISAR (soil moisture), and SWOT (surface water and runoff)

Addresses various "Most Important" objectives of

- Climate
- Hydrology
- Solid Earth

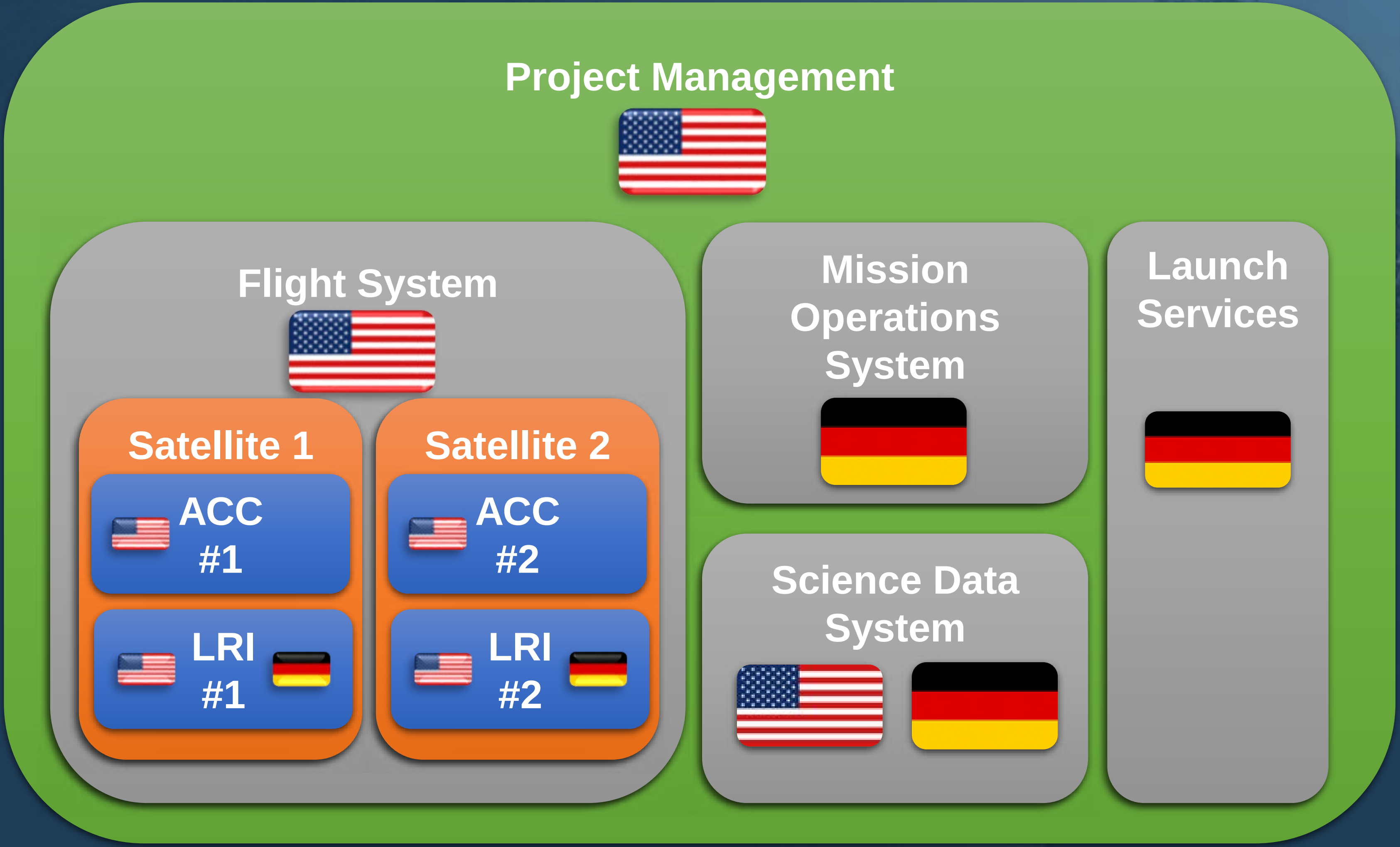
Addresses key components of

- Water and Energy Cycle integrating theme

Driving science and applications requirements support these goals by providing continuity in the record of Earth system mass change

US – German Partnership

EARTH SYSTEM OBSERVATORY



Top Level Acquisition Approach

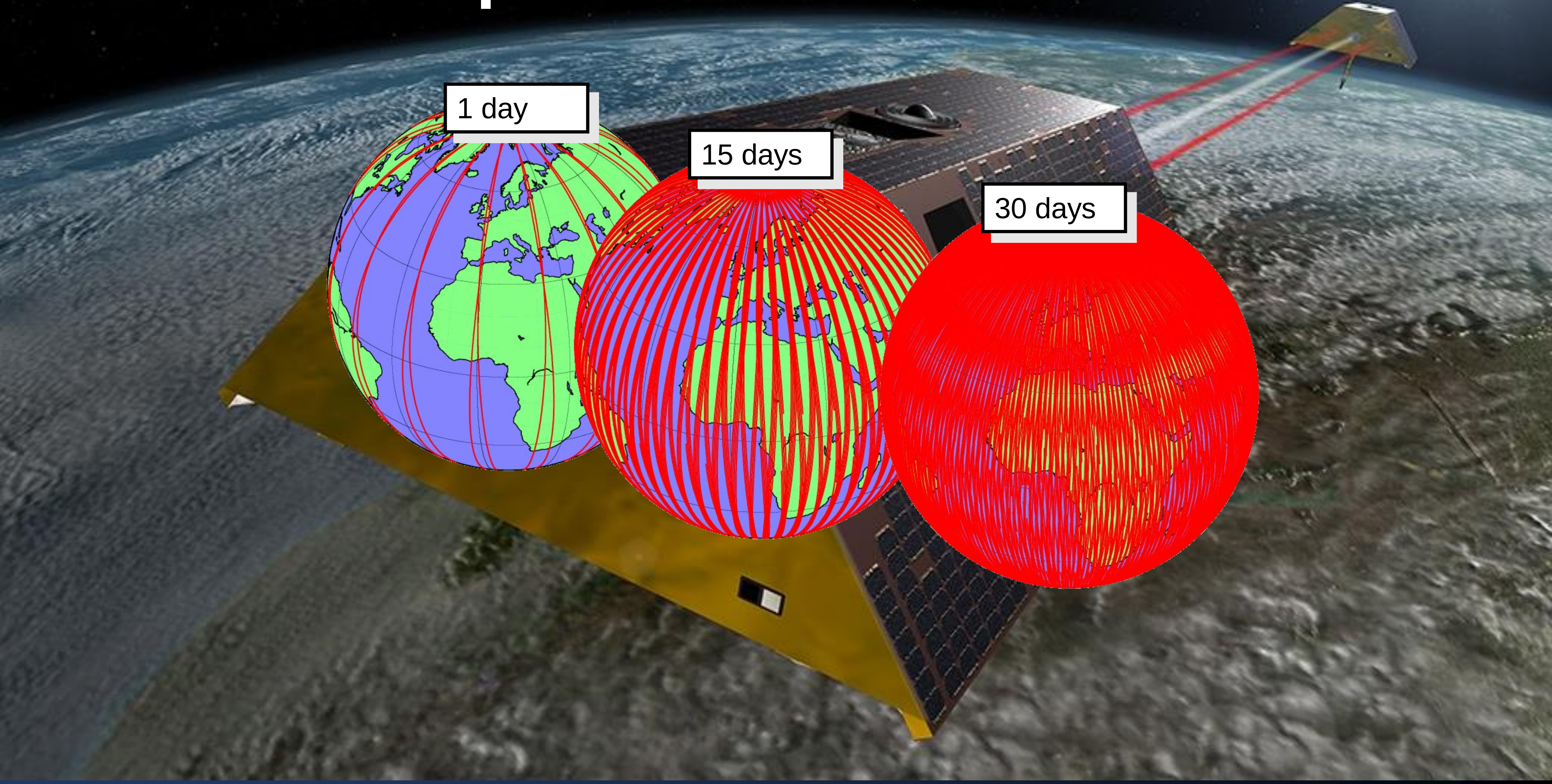
EARTH SYSTEM OBSERVATORY

Acquisition approach maximizes GRACE-FO heritage to reduce cost, schedule, and performance risk

Component	Source
Launch Services	DLR Contributed*
Mission Operations	DLR Contributed*
Spacecraft	Airbus**
Measurement System	Hybrid
Laser Ranging Instrument	
Optics	DLR Contributed*
Electronics Laser and Cavity	JPL, Tesat**, Ball Aerospace**
Accelerometer	GRACE-FO Flight Spares

*Anticipated international agreement
**JPL subcontracts

MC: Data Acquisition

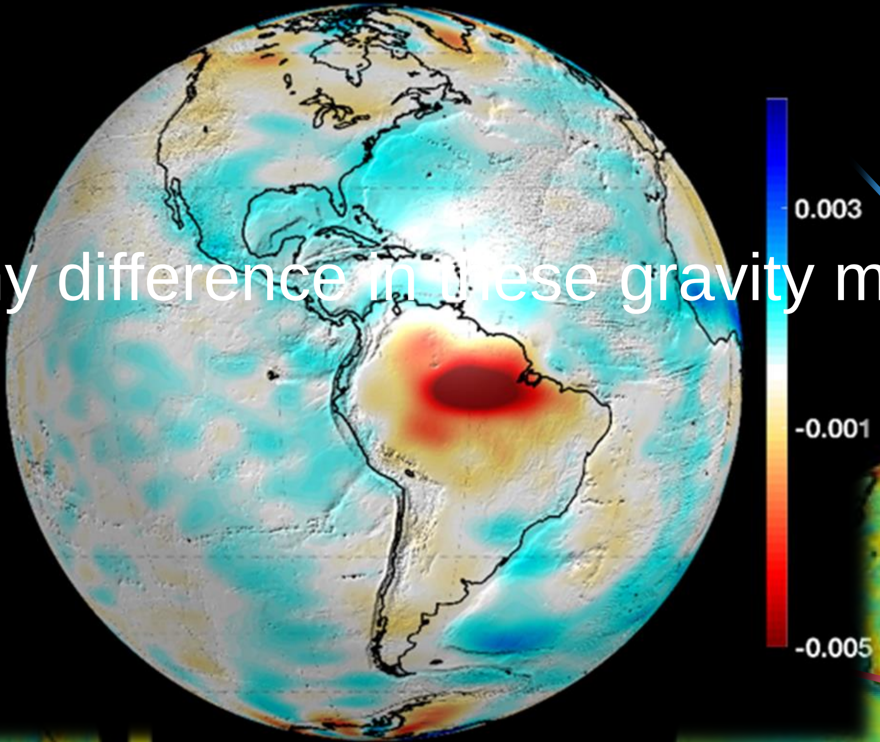


MC: ‘seeing’ surface mass

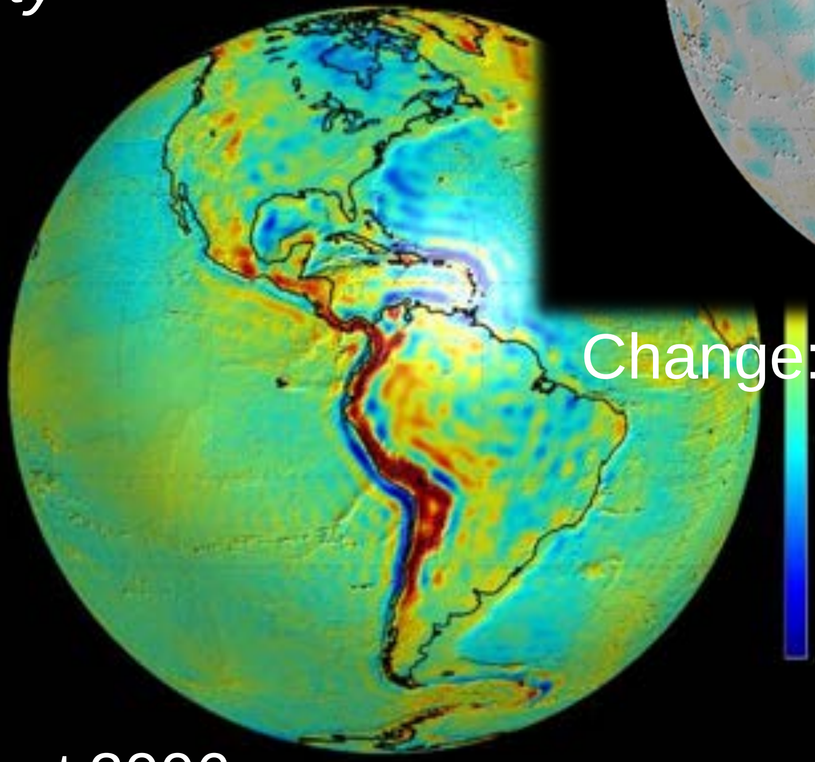
Jet Propulsion Laboratory
California Institute of Technology

Changes between the two maps are more noticeable at a scale of 1 part per million in gravity

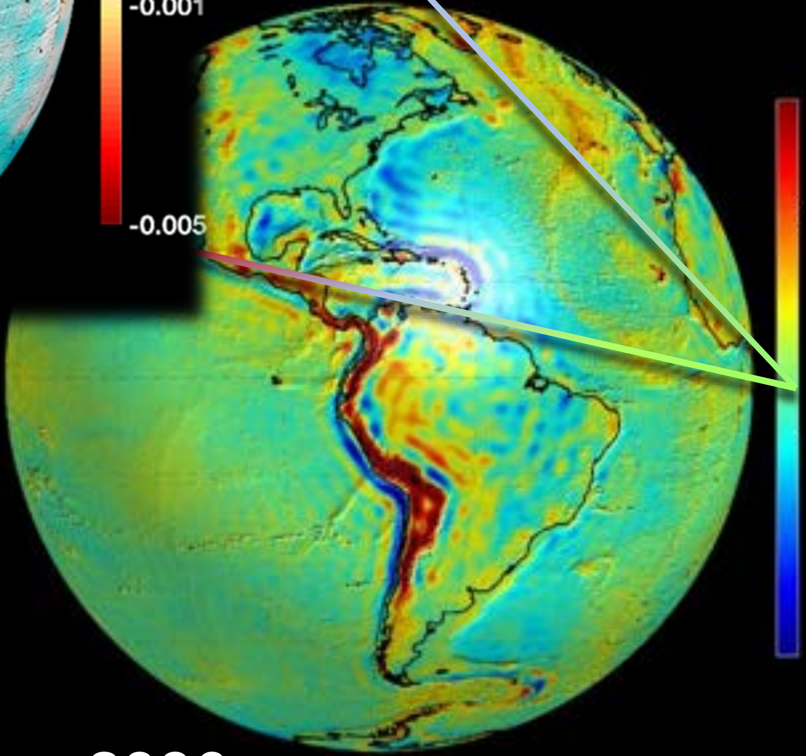
See any difference in these gravity maps?



Change: Aug to Sep 2006

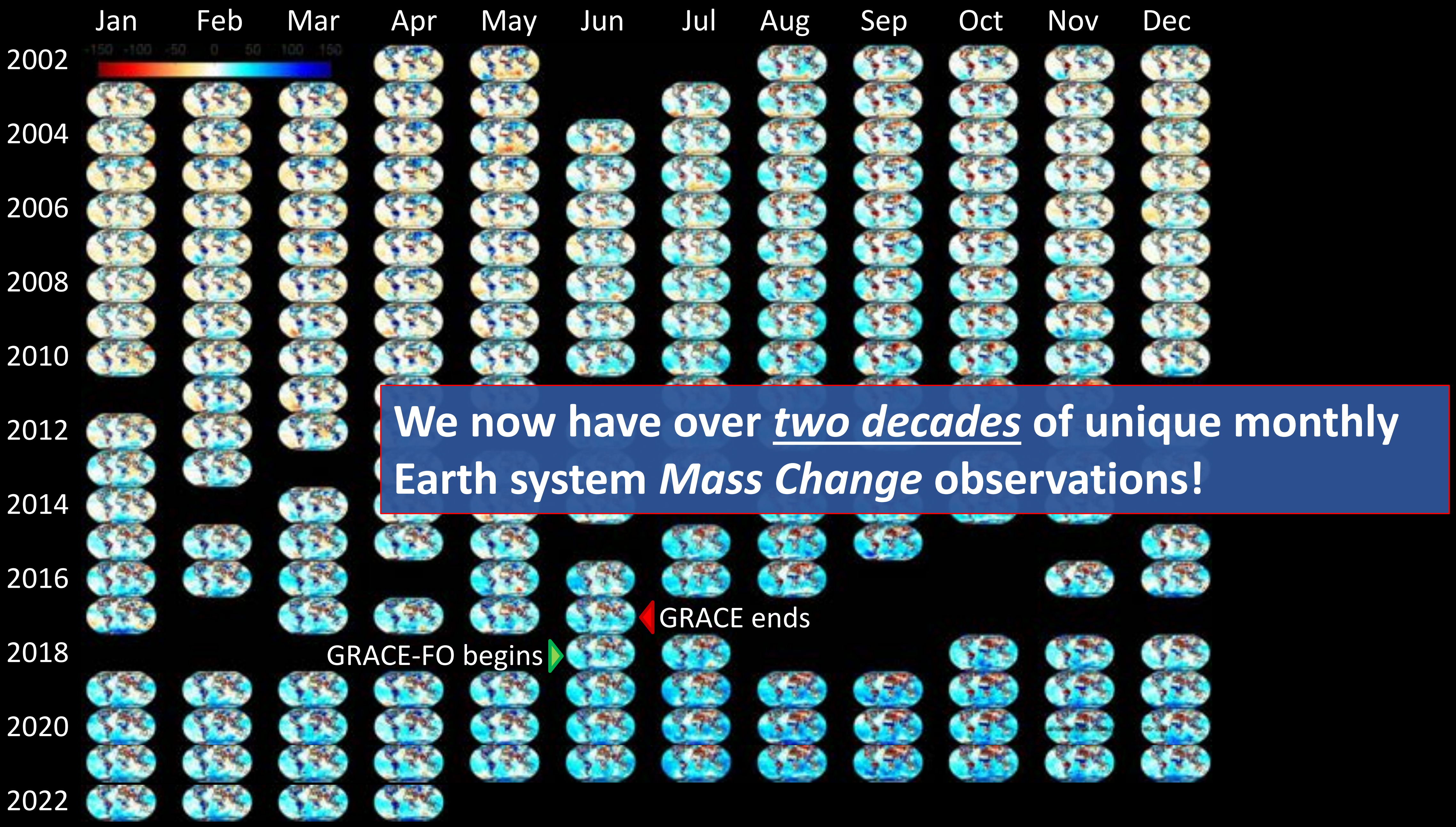


August 2006



September 2006

Units:
Gravity anomaly [micro-gal]


Jan
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2022
-150 -100 -50 0 50 100 150
GRACE ends
GRACE-FO begins
We now have over *two decades* of unique monthly Earth system *Mass Change* observations!

Status and Key Milestones

- October 2018: Began Mass Change Designated Observable (MCDO) study and continued through May 2021, producing a comprehensive final report in July 2021
- June 2022: Mission Concept Review Complete
- March 2023: Key Decision Point – A passed and Phase A start
- April 2023: System Requirements Review
- Summer 2023: Mission Definition Review
- Fall 2023: Phase B start
- NLT Summer 2024: PDR
- Launch Readiness Date: mid-2028

CHIEF SCIENCE DATA OFFICE

EARTH SYSTEM OBSERVATORY

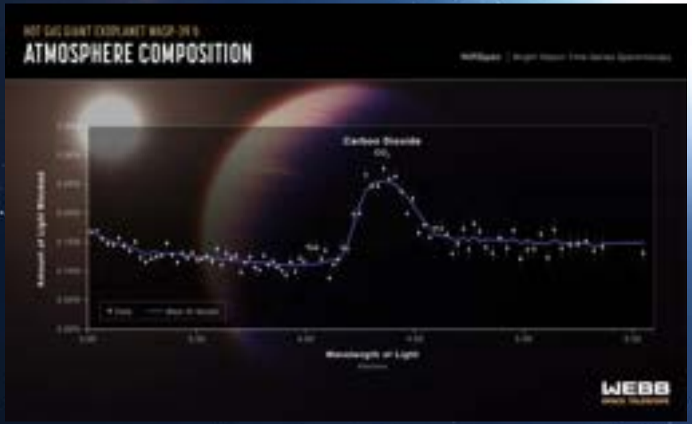
Open-Source Science and Data & Compute for the Earth System Observatory

Joel Scott, Program Executive
Earth Science Data Systems

Content

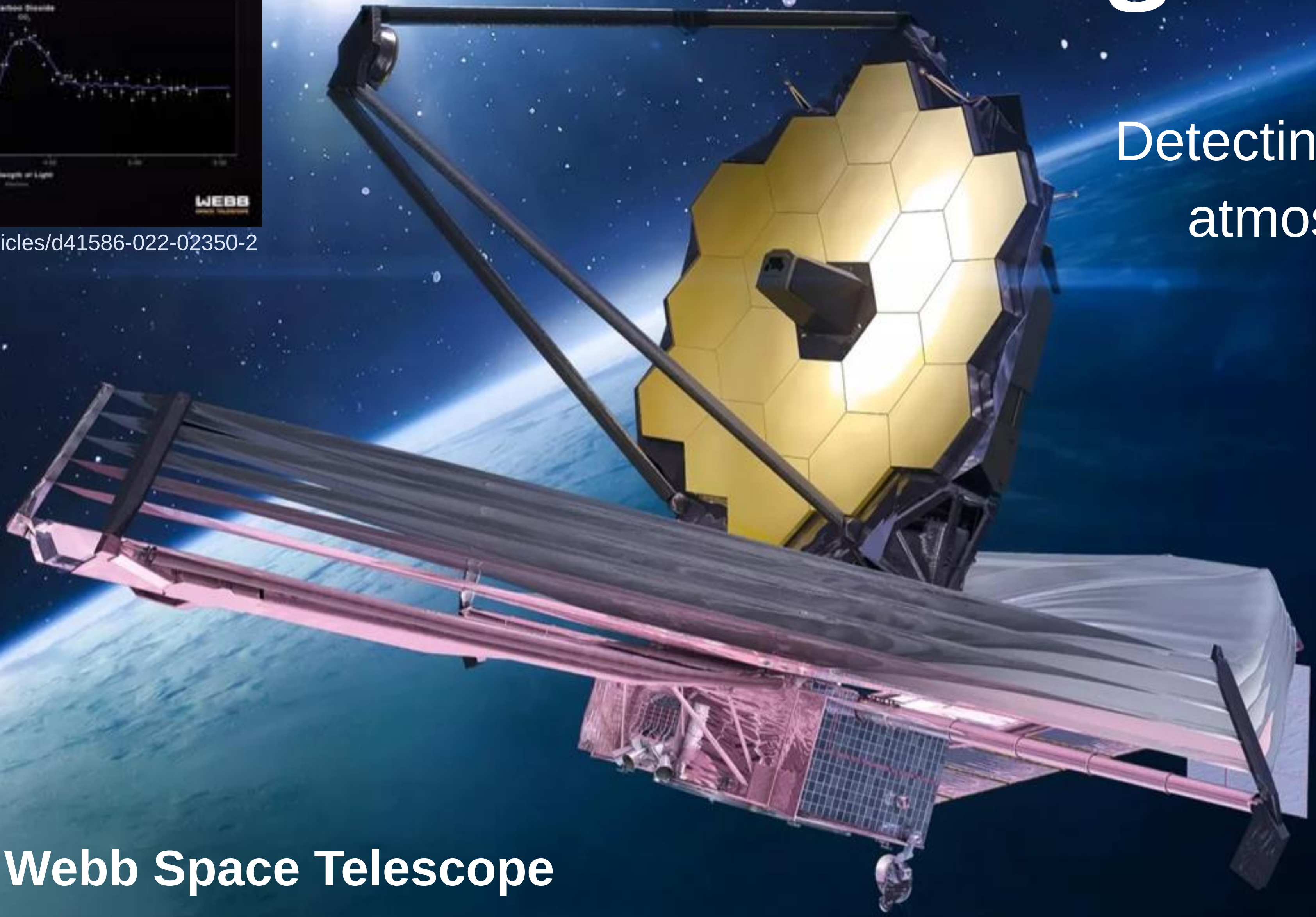
- NASA’s Open-Source Science Initiative
- 2023: Year of Open Science
- NASA policy (SPD-41a)
- ESO Processing Study
- VEDA: Cloud-based, Open Source, Earth Science Analytics Platform

Accelerating Science



https://www.nature.com/articles/d41586-022-02350-2

Detecting CO_2 in the atmosphere of an exoplanet



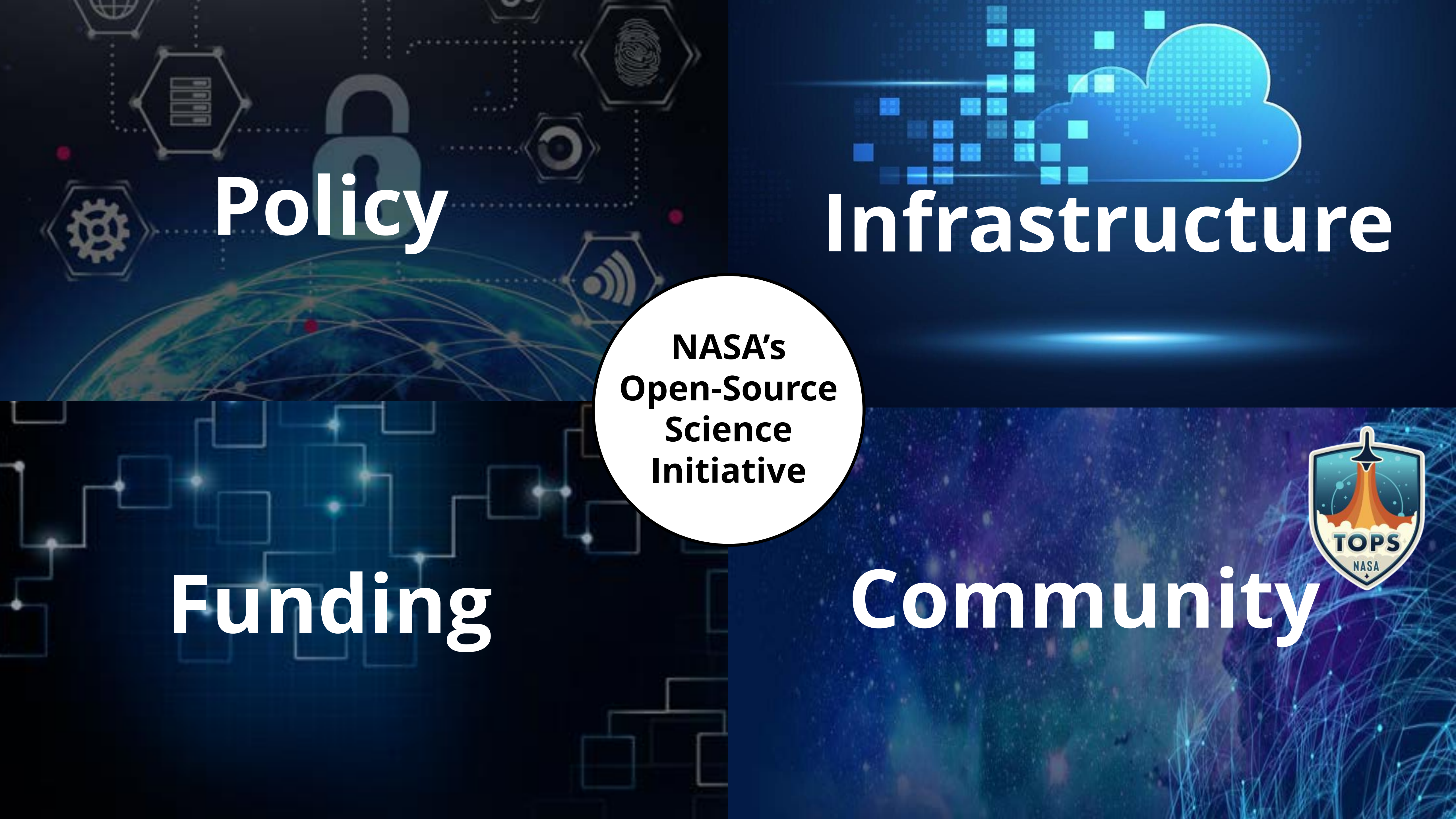
James Webb Space Telescope
Early Release Science Program

Can we build on and extend results?

In 2011, AAAS Science Journal policy changed to require the sharing of data and software upon request.

A 2018 study tested 204 scientific papers after policy implemented:

Stodden et al. (2018; https://doi.org/10.1073/pnas.1708290115/)


Policy
Infrastructure
NASA’s Open-Source Science Initiative
Funding
Community
TOPS
NASA

The White House announces

A Year of Open Science

NASA ✦ NSF ✦ NOAA ✦ DOE ✦ GSA ✦ NEH ✦ NIH ✦ USDA ✦ USGS (and more)

Learn more at:
https://open.science.gov/

Along with other organizations and a coalition of 88 universities

A multi-agency initiative across the federal government to spark change and inspire open science engagement through events and activities that will advance adoption of open science.

SPD-41a is SMD's updated Scientific Information Policy.

- SPD-41a updates the previously released SPD-41, which consolidated existing Federal and NASA policy on sharing scientific information.

- Policy updates were developed with:
    - Science Mission Directorate (SMD) community input via workshops and RFIs
    - Office of General Counsel, Office of Procurement, and establishing an office around data and computing services across NASA Data Archives in alignment with software release processes
    - National Academies studies
    - OSTP Memo on Ensuring Free, Immediate, and Equitable Access to Federally Funded Research

- One component of NASA's broader Open-Source Science Initiative (OSSI)

Scientific Information Policy Website

The Role of Open Science in Earth System Observatory

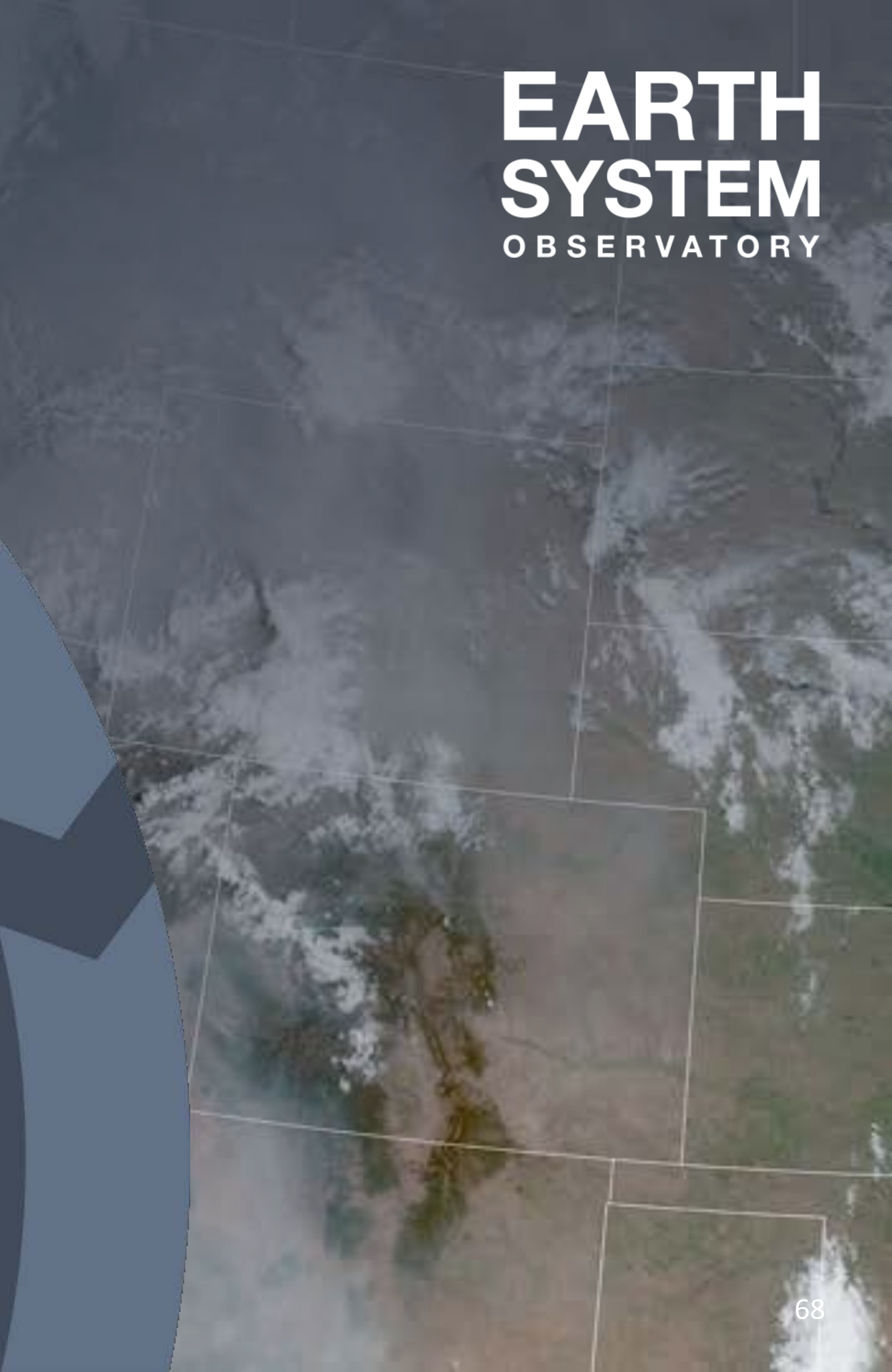
Open-Source Science Policy for Earth System Observatory

A. **All mission data, metadata, software, databases, publications, and documentation shall be available on a full, free, open, and unrestricted basis starting in Phase B** with no period of exclusive access.
B. **Science workshops and meetings** shall be **open** to broad participation and documented in public repositories.

1	**Software shall be developed openly** in a publicly accessible, version-controlled platform using a **permissive software license allowing for community use and contributions.**
2	**Manuscripts shall be published with open access licenses**; versions of as-accepted manuscripts shall be made available as open preprints and deposited in a NASA or [Partner] **repository upon publication.**
3	All mission **data, calibration information, and simulated products supporting development and validation of algorithms shall be made available without any conditions to use.**
4	Scientific data, metadata, software, publications and documentation **shall be archived and made available by NASA and/or [Partner] starting in Phase B.**
5	**NASA and [Partner]** software, documentation and data **shall be properly marked, cited, and/or attributed**. Metrics to measure and acknowledge open-source science contributions will be developed.
6	**NASA and [Partner] will mutually develop an Open-Source Science Plan** that specifies details of collaboration.

Collaborative, accessible, inclusive, transparent, and reproducible from the beginning.

EARTH SYSTEM OBSERVATORY



Earth System Observatory Science Data Processing Infrastructure

ESO Processing Study: Driving Principles

- Evolvable architecture, specifically between analysis and processing environments
- No disruption to the existing cost basis for missions' processing plans
- Any solution must support open-source science principles and policies

Broad Architectural Types Considered

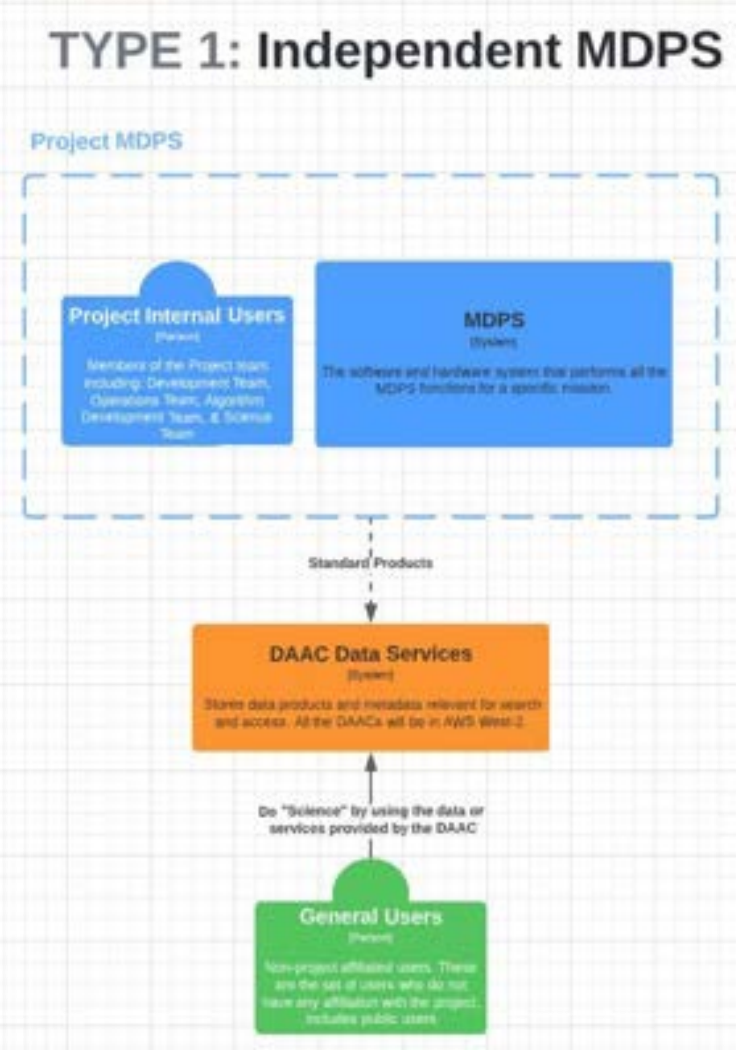
- **Type 1: Fully Independent Data Processing System (Business as Usual)**
  - Mission maintains fully autonomy
  - Flexible, but reduces opportunity for re-use and open-science
  - Limited evolvability

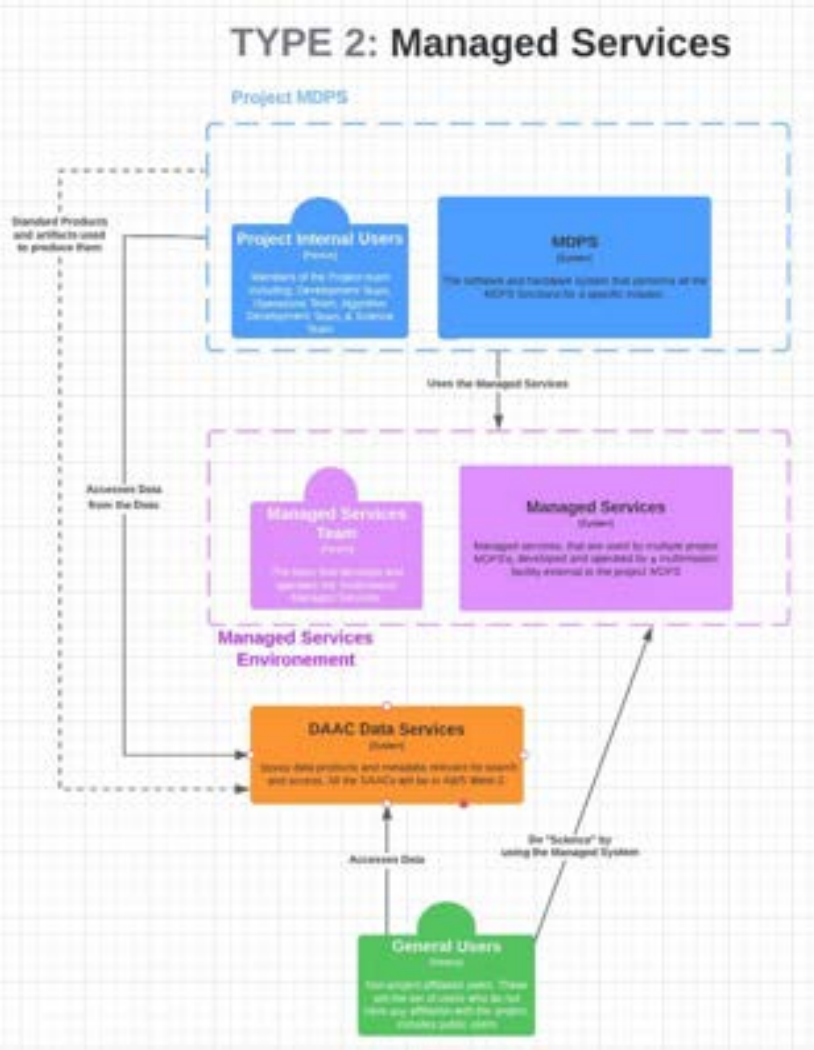
- **Type 2: Multi-Mission Organization (MMO) Providing Some Managed Services for Mission Processing**
  - Some shared resources among missions
  - Largely Maintains Mission Autonomy
  - Provides path for evolution

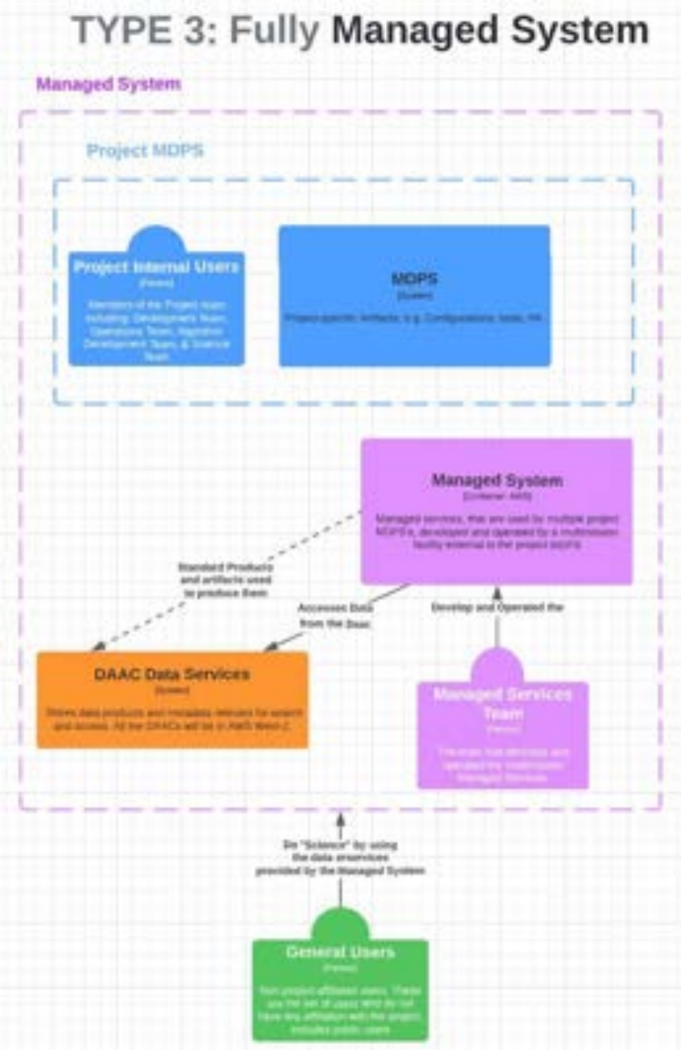
- **Type 3: Fully MMO Managed System for Mission Processing and Archiving**
  - Fully shared resources among DAACs and Missions
  - Reduced autonomy for current ESO Missions
  - Provides path for evolution
  - Highly complex both technically and programmatically

Note: Each of the above architecture Types has associated Variants, which were each evaluated individually. Each variant represents a change in some specific responsibilities and internal components, while largely maintaining overall architecture
(e.g. T2V3 = “Architecture Type 2, Variant 3”)

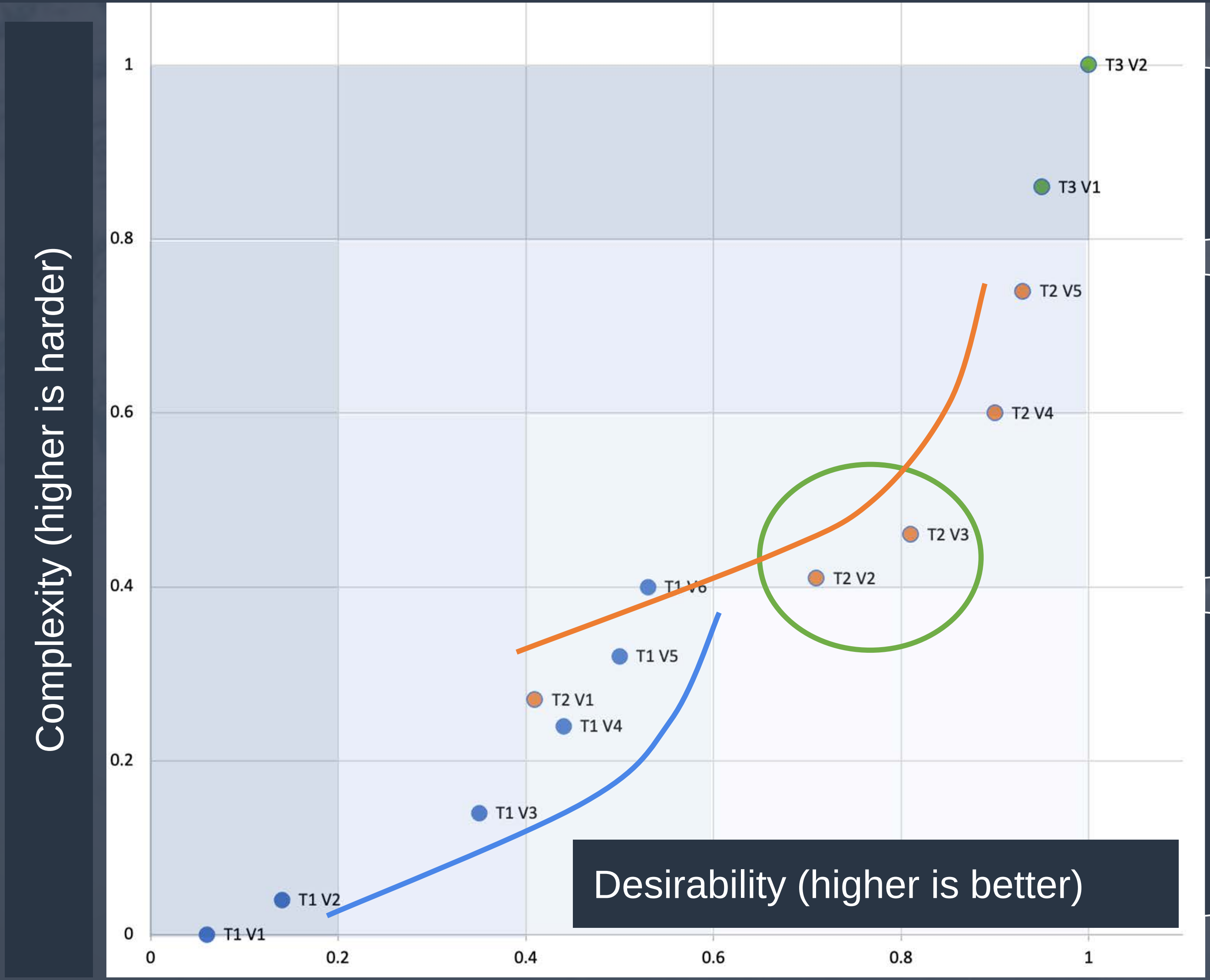
Broad Architectural Types







Balancing Complexity with Desirability



T3: Highly desirable but very complex

T2, the sweet spot: Complexity is manageable with room to evolve

T1: Manageable complexity but limited our evolutionary pathways

VEDA

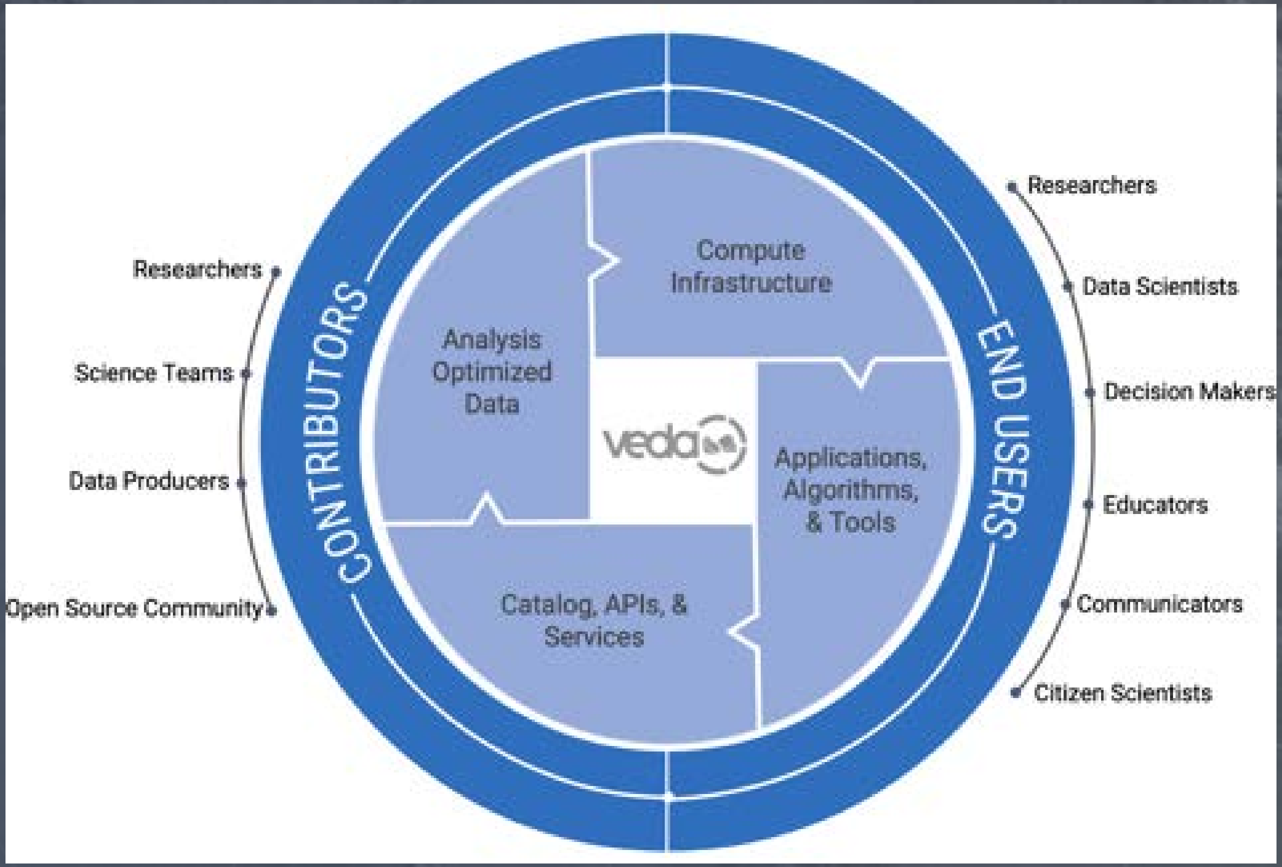
(Visualization, Exploration, and Data Analysis) Cloud-based, Open-Source, Earth Science analytics platform

EARTH SYSTEM OBSERVATORY

What is VEDA?

Why?

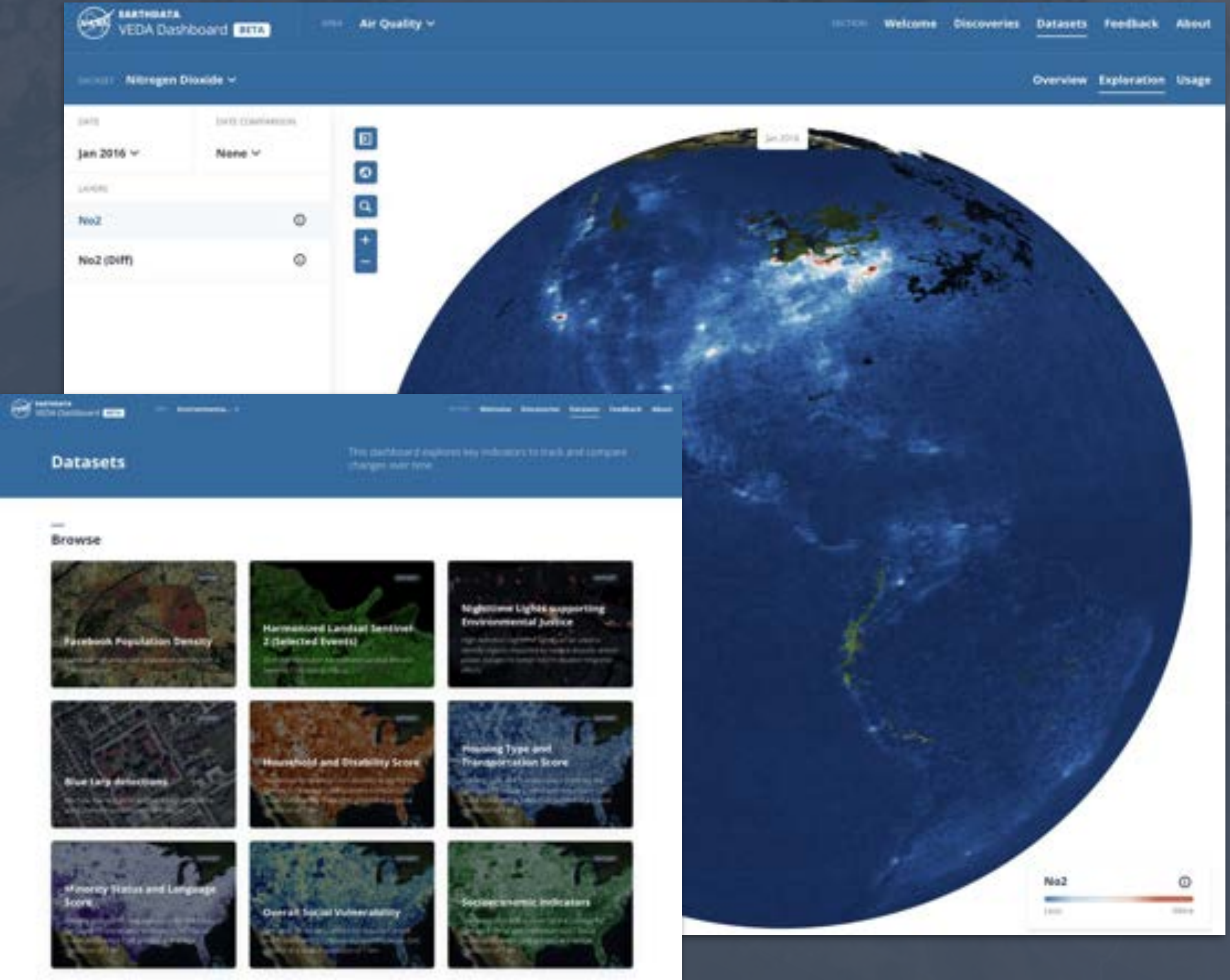
- Interdisciplinary science depends on large amount of Earth science data and access to advanced computational resources
- Working with these datasets is non-trivial
- Big data science requires advanced distributed computing knowledge



What?

VEDA is an open-source science cyberinfrastructure that streamlines data processing, analysis, visualization, and exploration, with cloud-based, optimized Earth science datasets for in-place use, via accessible computation to produce user-friendly scientific results, while leveraging existing NASA tools and services, promoting interoperability.

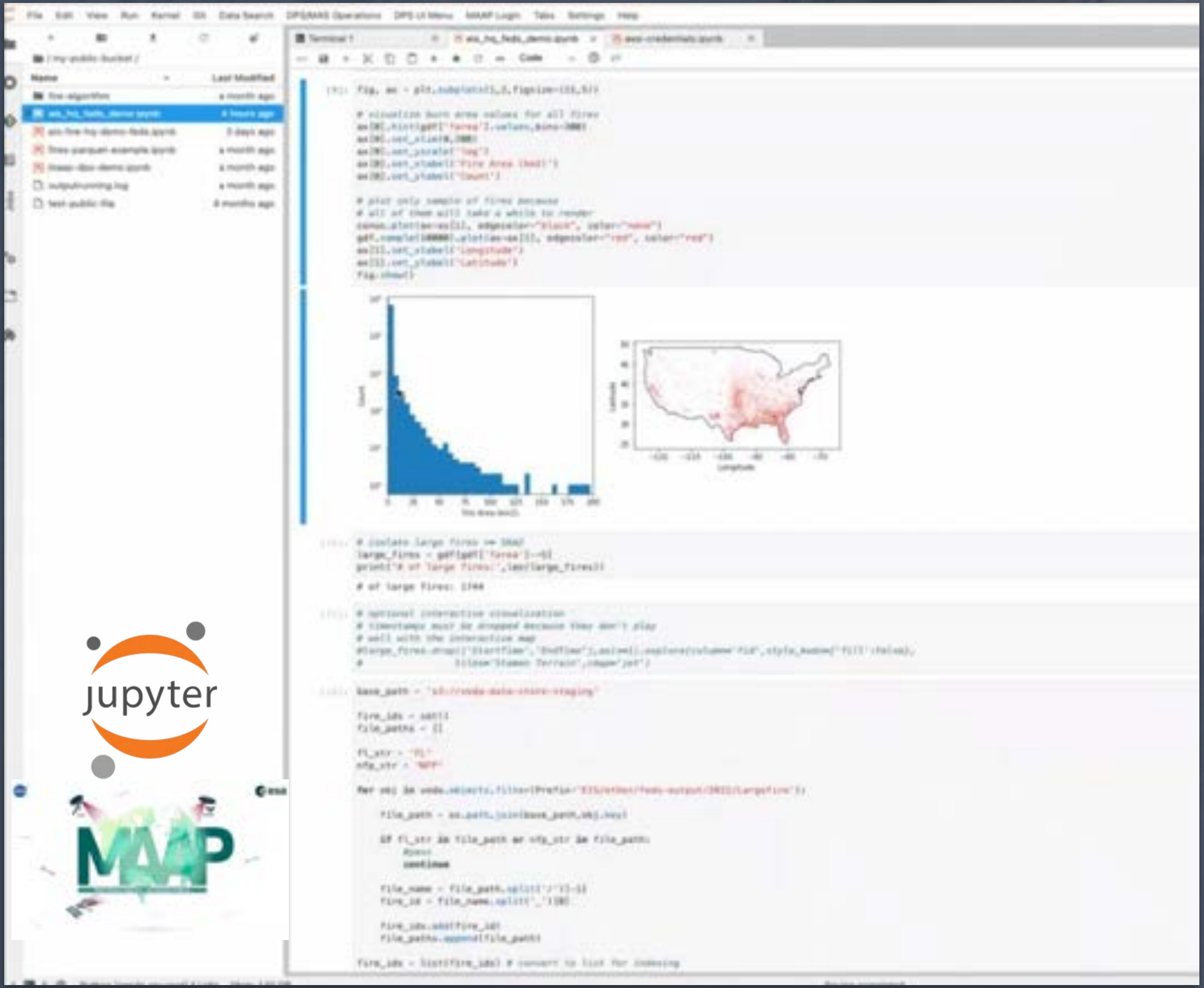
Explore | Analyze | Publish | Communicate



- Finding relevant data products
- Exploring data to identify interesting features

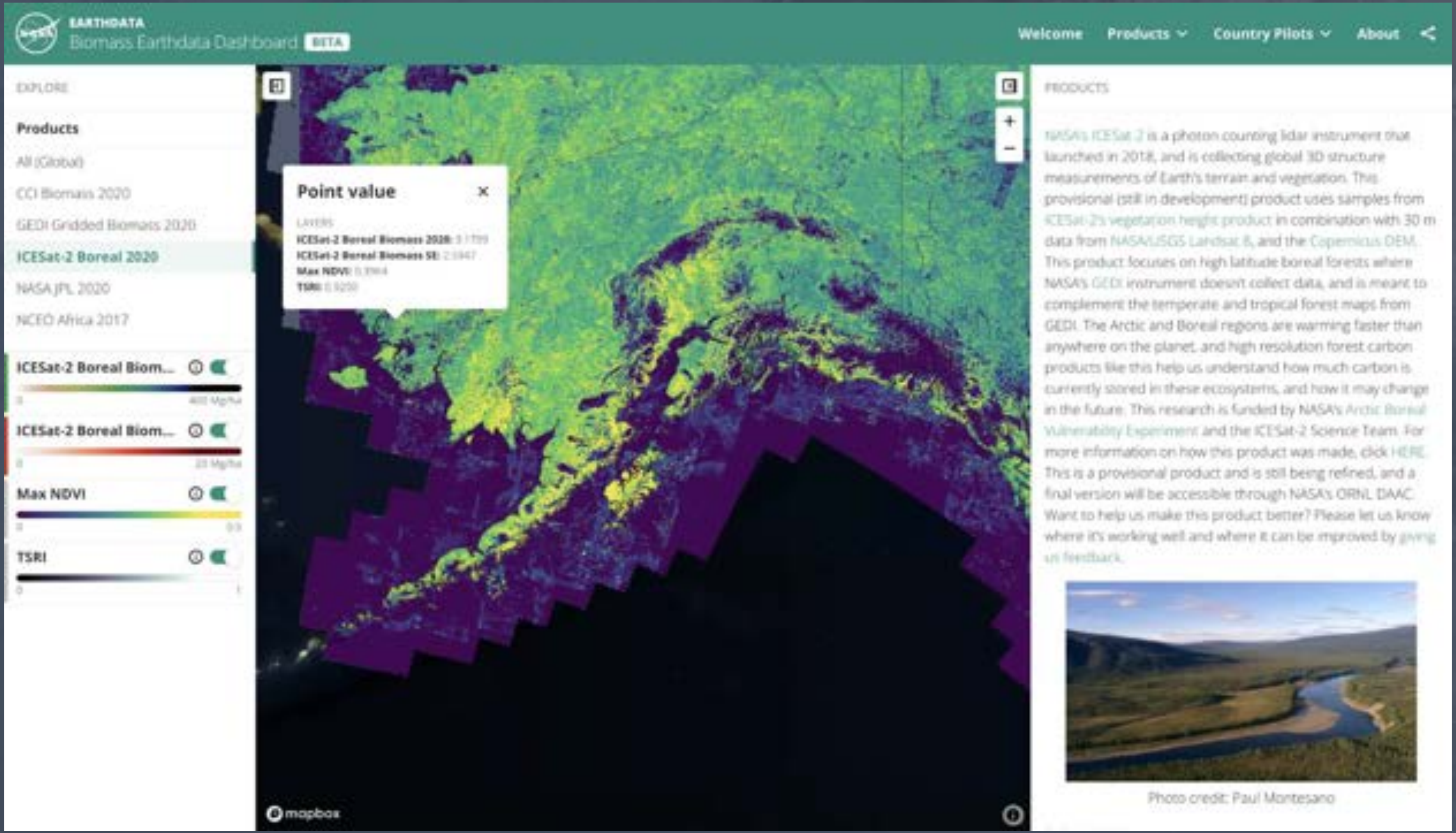
[VEDA Dashboard on NASA Earthdata]

Explore | **Analyze** | Publish | Communicate



- Developing advanced data products and analysis
- Carrying out calculations "in place" without the need to download data
- Dynamically allocating resources for computationally demanding processing

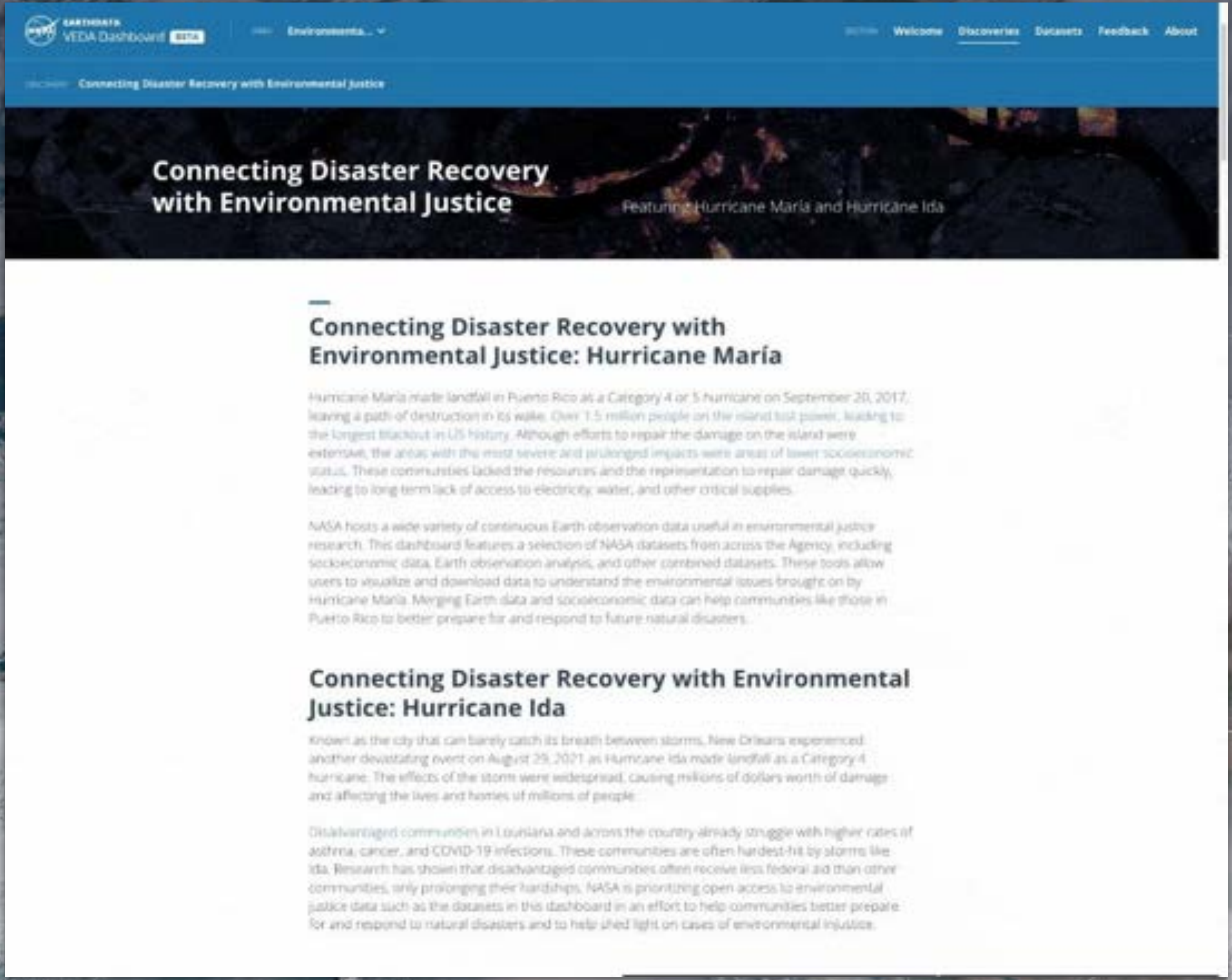
Explore | Analyze | **Publish** | Communicate



- Conveniently delivering data through existing interfaces
- Providing automatic access to interactive visualization capabilities
- Allowing users to analyze your products within the environment

veda

Explore | Analyze | Publish | **Communicate**



- User friendly and more engaging data-driven storytelling
- Enrich science and applications narratives with interactive exploration

National Aeronautics and
Space Administration

We need YOU!

Applied Sciences

Dr. Emily Sylak-Glassman
Program Manager, Applied Sciences Program
Earth Science Division
Science Mission Directorate, NASA

EARTH SYSTEM OBSERVATORY

APPLIED SCIENCES PROGRAM

Mission

Enable people & organizations to apply insights from Earth science to benefit the economy, health, quality of life, and environment.

What We Do

Financial and programmatic investments to:

- Generate creative solutions with organizations to improve their decisions and actions
- Lower the technical and institutional barriers to using Earth science information
- Use connections across sectors for multiplier effects and bring insights back to ESD

APPLICATIONS PROGRAM AREAS

Our program areas help tackle challenges on our home planet. Each covers a different area in which Earth science information can serve society in responding to the urgent challenges of our time.

What are Earth science applications?

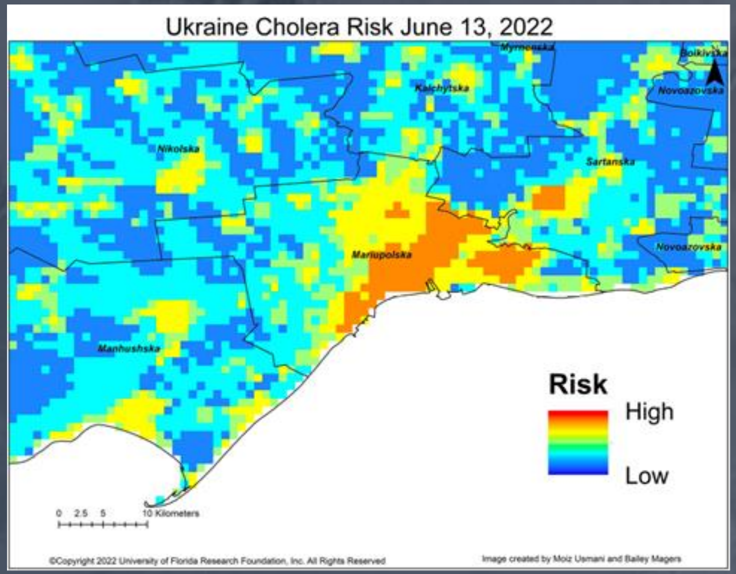
Applications refer to uses of Earth science data, models, and information products to inform organizations' decisions and actions on management, policy, and business activities.

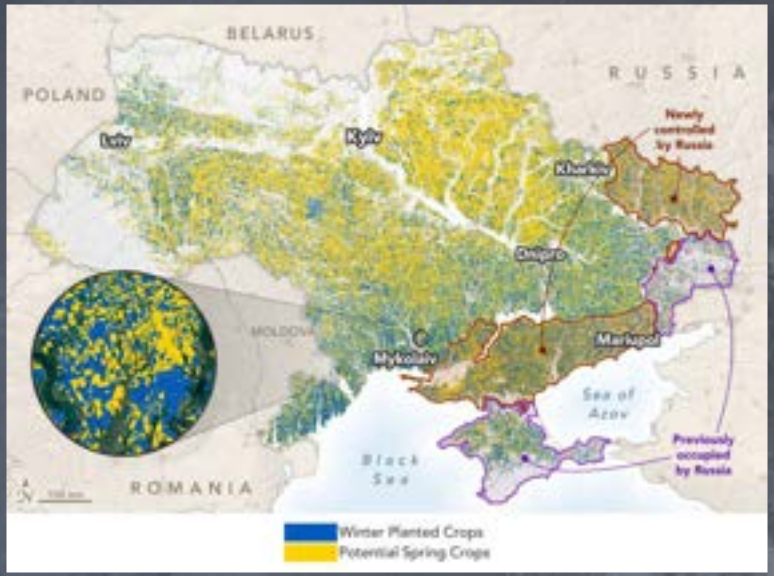
- Agriculture
- Disasters
- Ecological Conservation
- Health and Air Quality
- Water Resources
- Capacity Building
- Mission Engagement
- Climate & Resilience
- Energy
- Wildland Fires

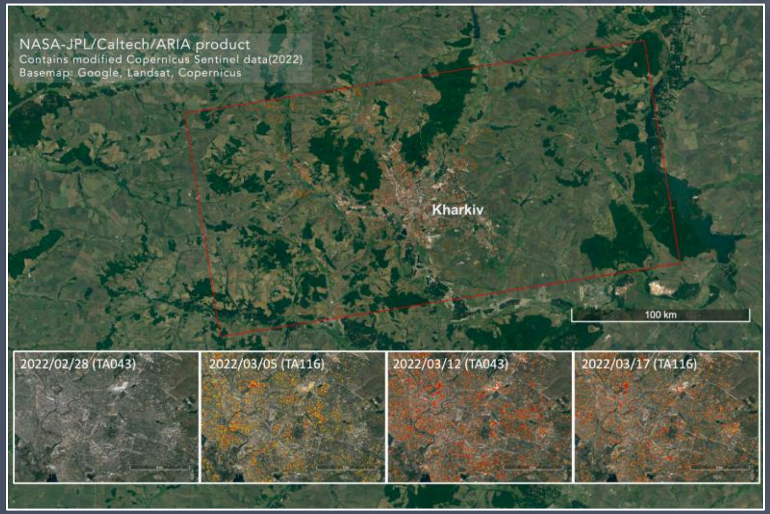

Mark Owens
Alfalfa Farmer and State Rep, District 60
OREGON

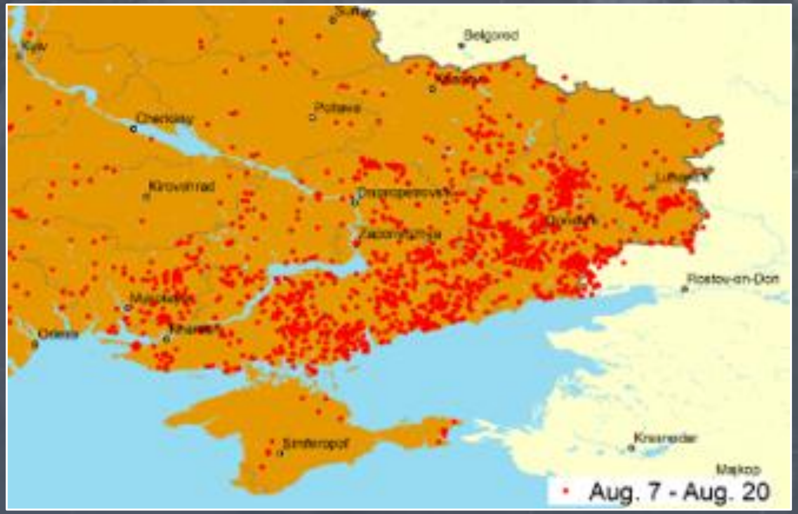
UKRAINE

The Applied Sciences Program continues to provide support for the humanitarian crisis caused by the war in Ukraine on issues related to agriculture and food security, damaged infrastructure, and the risk of cholera outbreaks.









EARTH SYSTEM OBSERVATORY

INTERCONNECTED CORE MISSIONS

CLOUDS, CONVECTION AND PRECIPITATION
Water and Energy in the Atmosphere

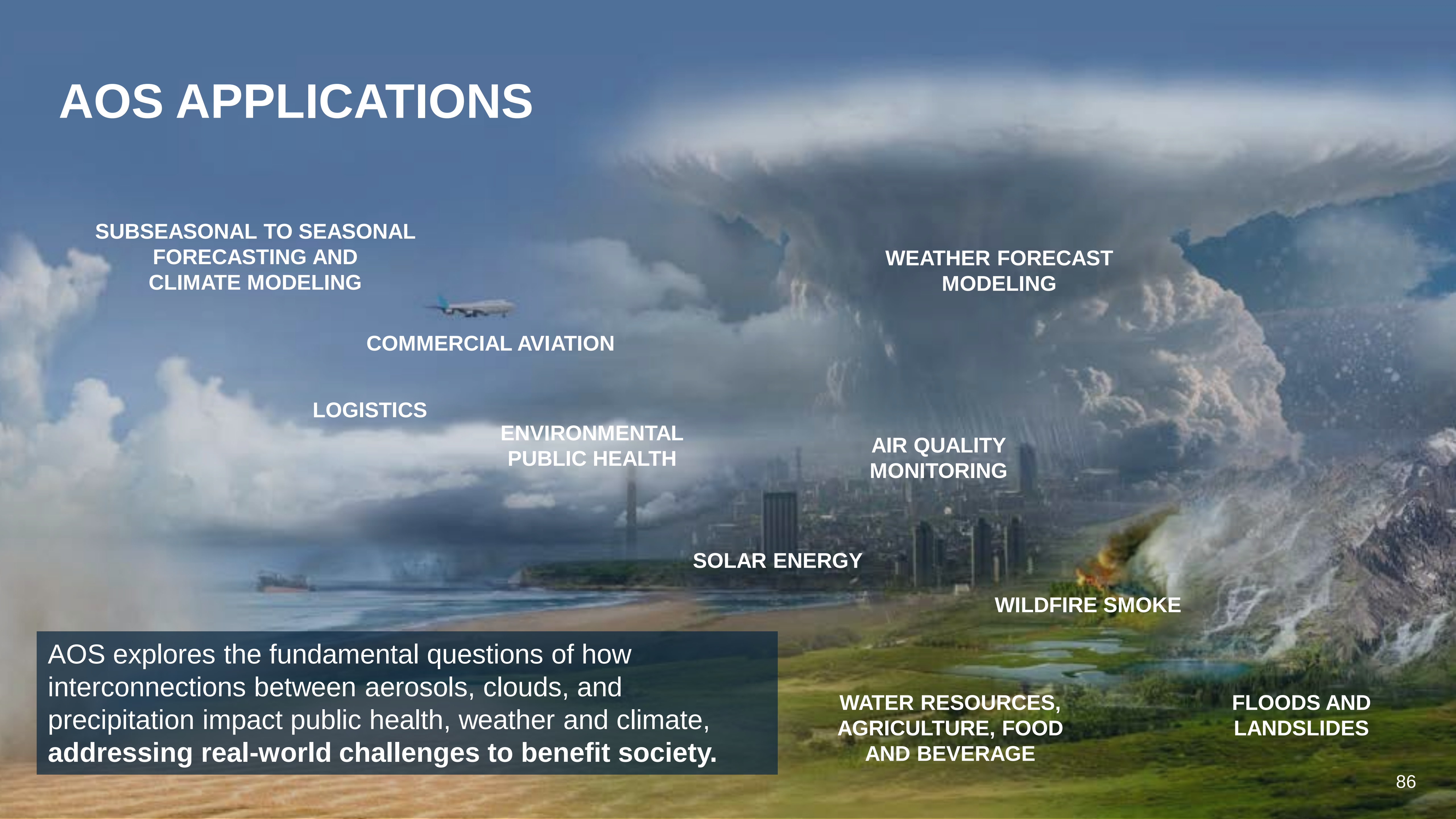
SURFACE BIOLOGY AND GEOLOGY
Earth Surface & Ecosystems

AEROSOLS
Particles in the Atmosphere

SURFACE DEFORMATION AND CHANGE
Earth Surface Dynamics

MASS CHANGE
Large-scale Mass Redistribution

AOS APPLICATIONS



AOS explores the fundamental questions of how interconnections between aerosols, clouds, and precipitation impact public health, weather and climate, **addressing real-world challenges to benefit society.**

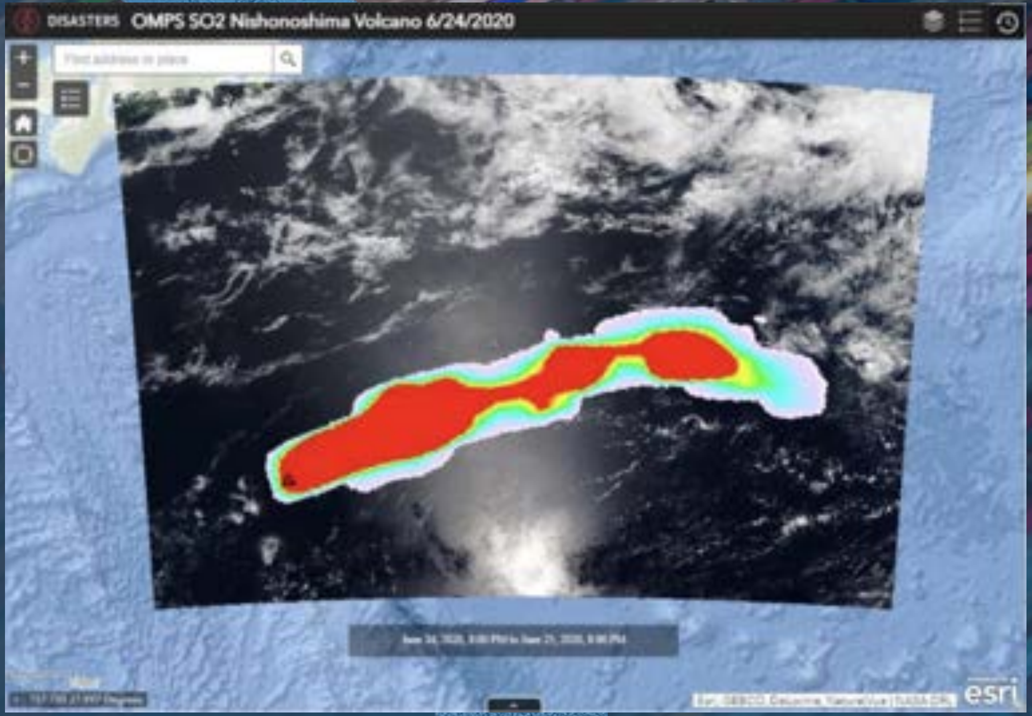
Enhancing Logistics Capabilities with AOS

Global parcel business exceeded $300 billion in 2018 alone. Delays to operations can disrupt the supply chain resulting in significant financial losses.

Timely and accurate depiction and prediction of weather affecting this industry's transportation modes are vital to their success.

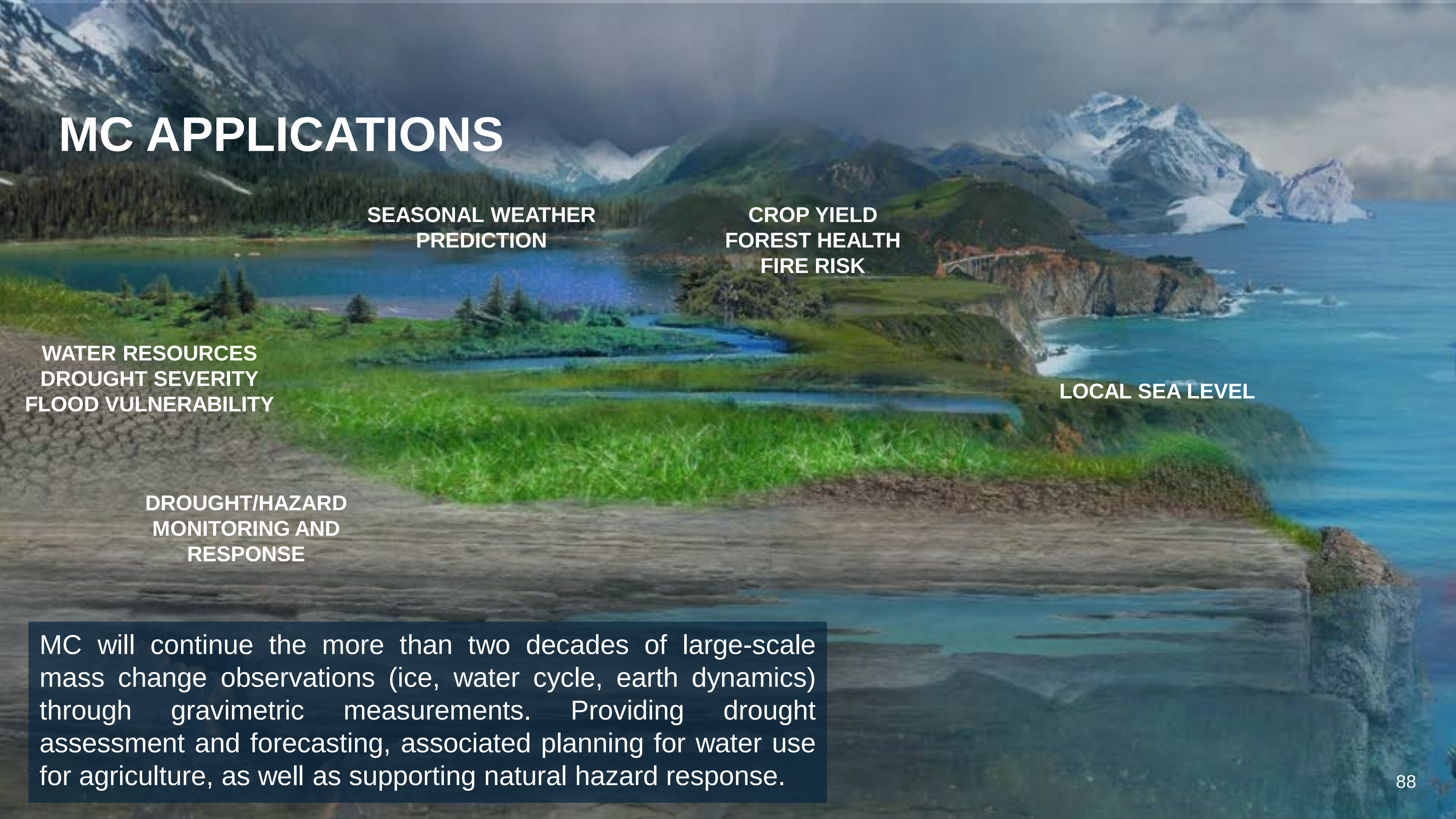
Data from a mission like AOS may reduce delays from fog and volcanic ash and enable users to work around environmental challenges to ultimately deliver parcels on time.

Data may also enable new markets, such as UAV delivery, to expand.



NASA's Disasters program works with partners to provide real time satellite observations that provide crucial information for re-routing air traffic around the hazardous volcanic clouds.

MC APPLICATIONS



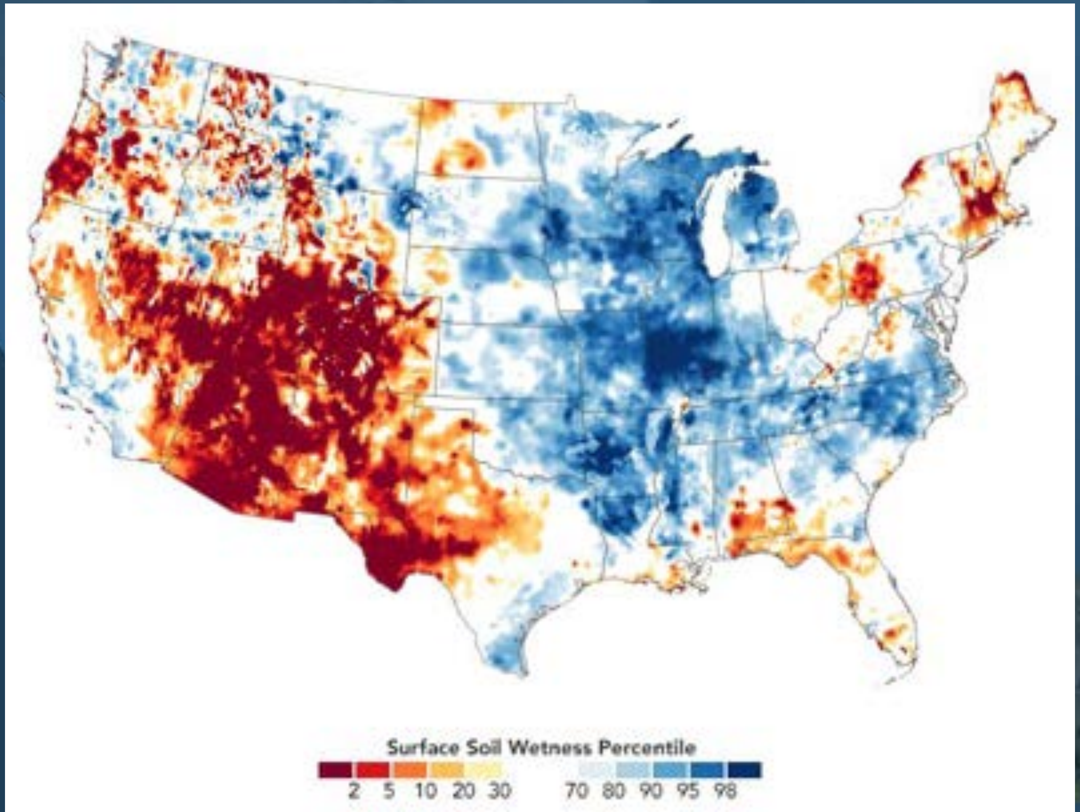
MC will continue the more than two decades of large-scale mass change observations (ice, water cycle, earth dynamics) through gravimetric measurements. Providing drought assessment and forecasting, associated planning for water use for agriculture, as well as supporting natural hazard response.

Managing Droughts with Mass Change

Droughts in the U.S. between 1980 and 2022 have collectively cost $327.7B.

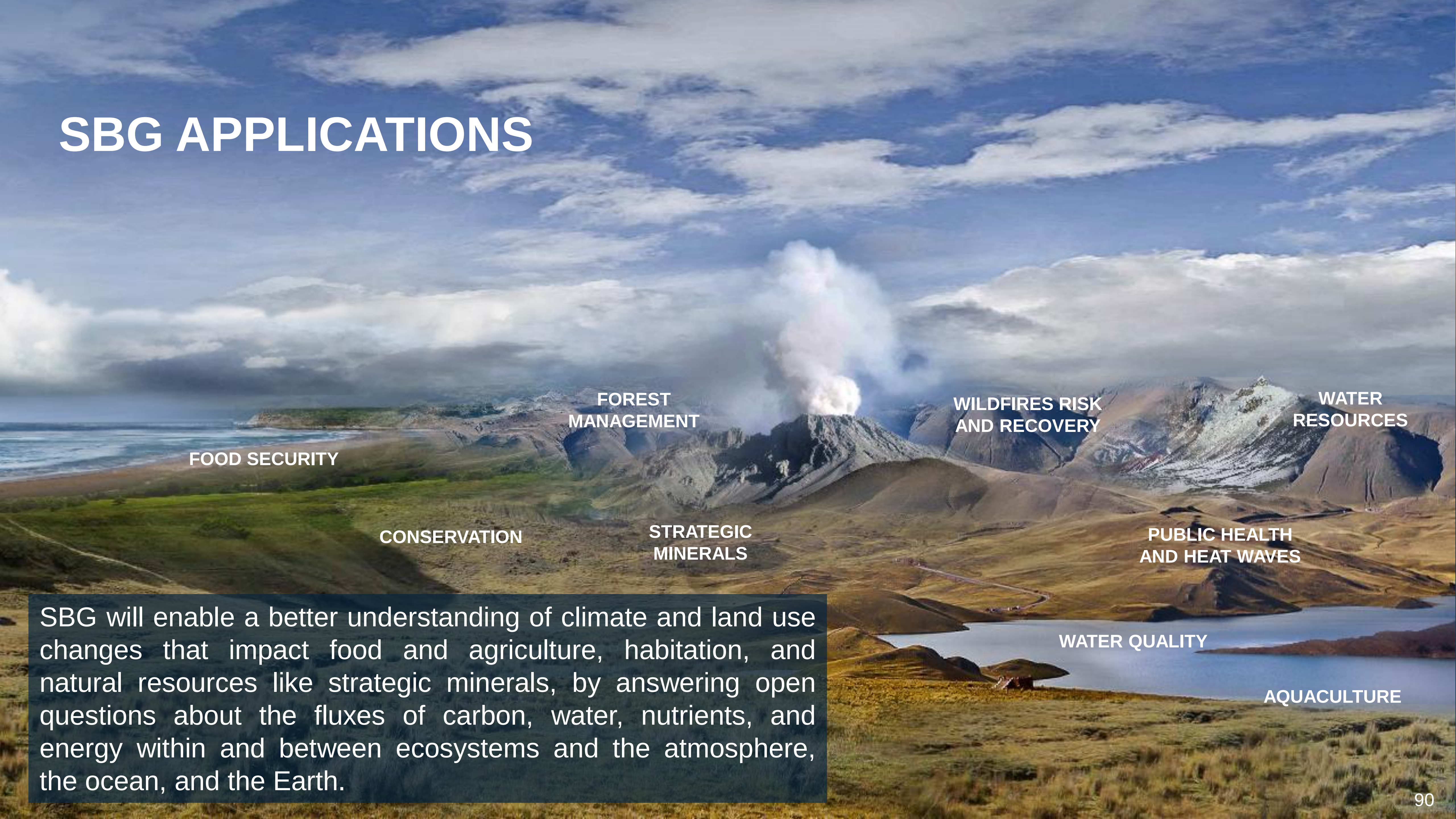
State, local, and regional water managers need information about groundwater for water conservation planning and to assess the need for state drought emergency declarations.

Timely information from Mass Change can inform water extraction, replenishment, and drought contingency plans.



GRACE-FO data, which is similar to what Mass Change will provide, were used to show how the levels of soil moisture on August 10 2020 compare to long-term records for the month.

SBG APPLICATIONS



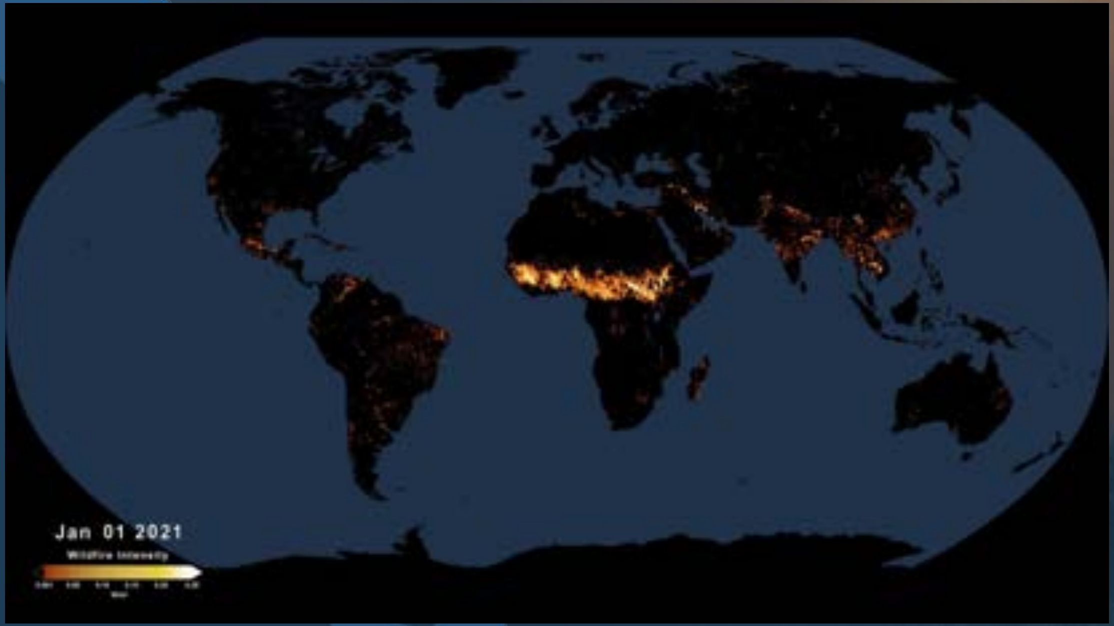
SBG will enable a better understanding of climate and land use changes that impact food and agriculture, habitation, and natural resources like strategic minerals, by answering open questions about the fluxes of carbon, water, nutrients, and energy within and between ecosystems and the atmosphere, the ocean, and the Earth.

Addressing the Urgent and Growing Concern of Fires with SBG

Climate change has led to longer fire seasons. Average annual federal spending on fire suppression totaled $2.5 billion (in 2020 dollars) between 2016 and 2020.

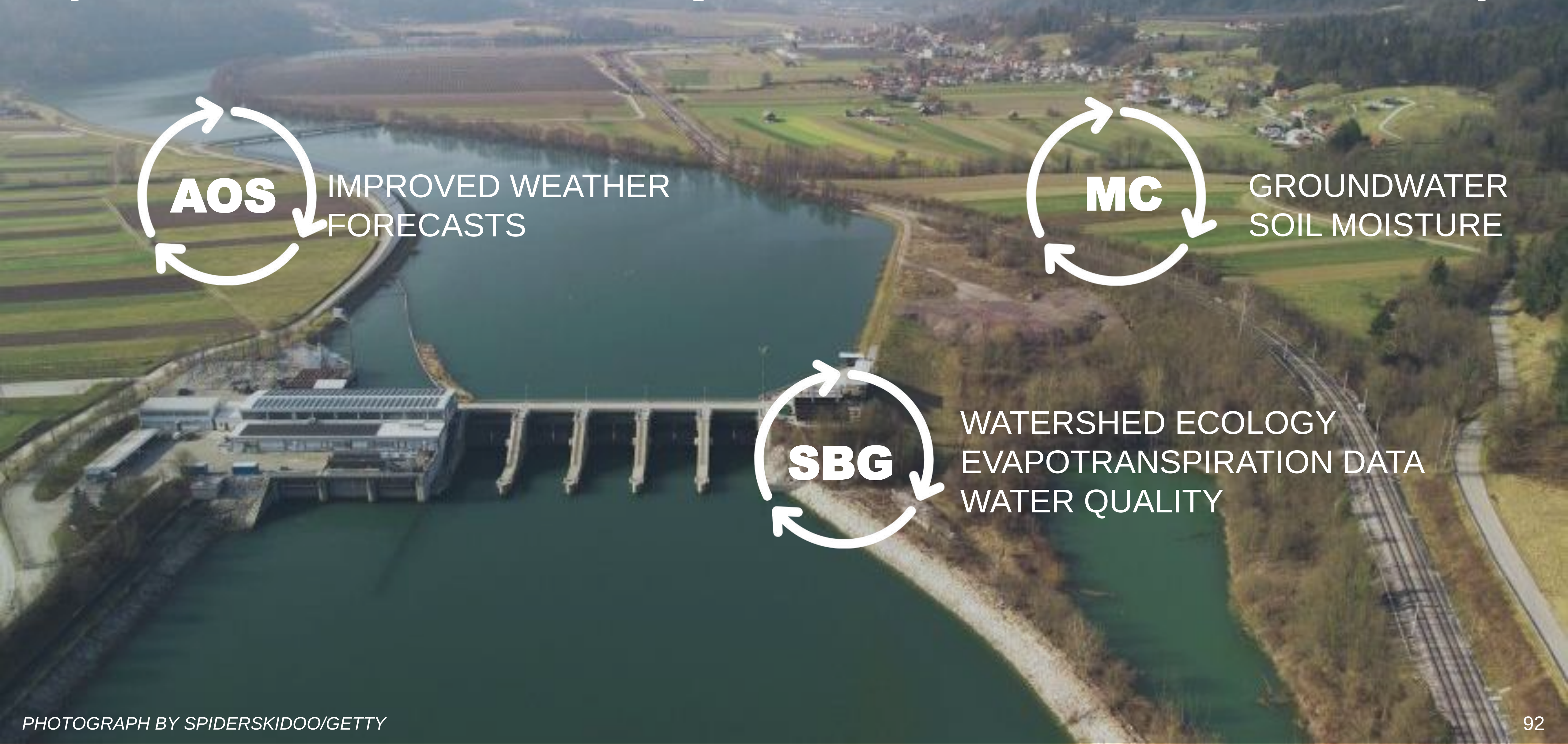
SBG will be able to provide detailed fuel mapping to improve risk severity maps, thermal data to track prescribed burns, and ecological data to monitor landscape recovery.

By improving remote sensing accuracy, SBG may have a value of >$30M to large utilities in fire-prone states alone.



This animated visualization uses a moving three-day average of summed VIIRS measurements of fire radiative power (FRP), to present a view of fire intensities around the globe.

Hydroelectric Power Management – it takes an Observatory



PHOTOGRAPH BY SPIDERSKIDOO/GETTY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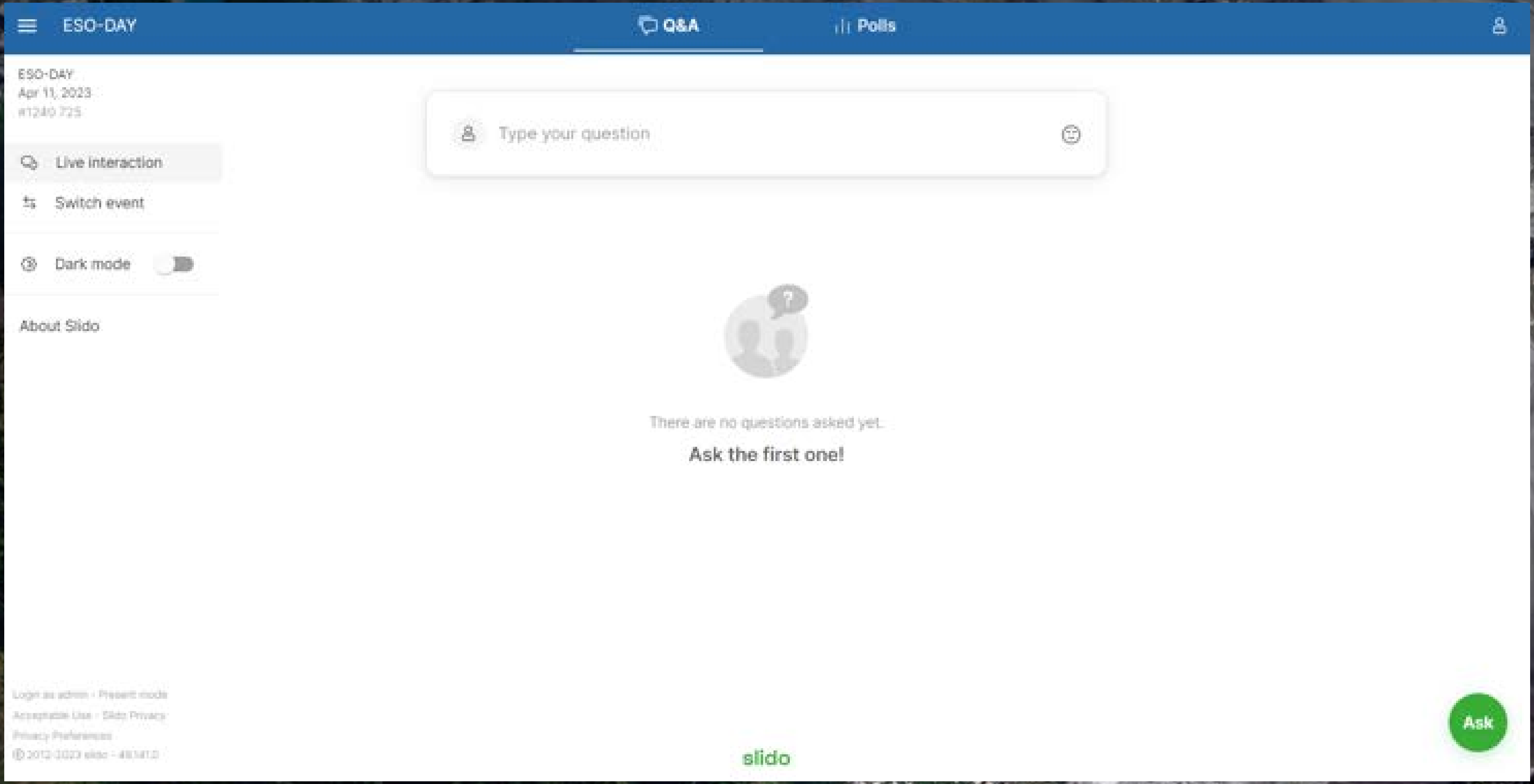

ESO DAY Written Q&A

Content: This document provides answers to the questions asked on Slido and in the room on April 11, 2023, during the ESO Day event. The questions are listed in the order they were ranked via Slido, and asked in the room.

Seems like JPL has a lot to do on SBG and MC - why aren't more program elements available for industry competition, given the conclusions from the Pysche IRB?

The Earth System Observatory (ESO) represents a balanced acquisition approach that achieves its cost goals through contributions from international partners, NASA Centers, and industry partners. Each mission's acquisition strategy is driven by cost constraints, instrument development risks, and the ability to leverage heritage solutions.

The core missions also have different objectives:

- Mass Change (MC) will provide continuity measurements as an evolution of GRACE and GRACE-FO
- Surface Biology and Geology (SBG) will provide instrument advancements to build upon the science enabled by HyspIRI, ECOSTRESS, and EMIT
- Atmosphere Observing System (AOS) will provide scientific advancements through synergy of measurements rather than the advancement of any instrument in particular

While the acquisition strategy is not finalized for SBG, it is expected that the Visible to ShortWave InfraRed (VSWIR) system will competitively procure >50% of the mission from industry. The current mix includes 100% competed spacecraft bus/system integration and launch vehicle. For the instrument, the current expectation is that JPL will contract out for an instrument prime contractor, and provide some spectrometer components as Government-Furnished Equipment (GFE). For the Thermal InfraRed (TIR) instrument, the launch and satellite bus and the Visible and Near-InfraRed (VNIR) instrument will be provided by the international partner, and JPL will be the TIR instrument integrator, and will contract TIR subsystems to industry. In the cases of the TIR instrument and the VSWIR GFE components, the acquisition is structured to take advantage of heritage from the JPL ECOSTRESS and EMIT missions and meet the most important Decadal Survey objectives with the least risk.

The MC mission architecture has evolved from GRACE and GRACE-FO and as a continuity mission, MC is leveraging the heritage acquisition strategy of GRACE-FO to reduce cost, schedule, and performance risk.

With respect to the findings of the Psyche IRB, the staffing plan at JPL to support the SBG and MC missions was examined during development of the acquisition strategy, and contributed in part to decisions on the acquisition approach and how industry support would be leveraged.

What are the ESO mission cost caps?

A lifecycle cost estimate target range was established for each of the ESO core missions at their Key Decision Point-A. These cost targets capture phase A-F efforts and include Headquarters' Unallocated Future Expenses (UFE). The targets are depicted in Table 1 below.

Mission	Lifecycle Cost Estimate Target Range (Phases A-F)
AOS	$1800 - $1990M FY22$
MC	$425 - $653M FY22$
SBG	$786M - $877M FY22$

Table 1: ESO Core Mission Cost Target Ranges

What are the plans for procurement and integration of Commercial Data that are complementary to ESO?

Commercial data is and continues to be an important resource for NASA Earth science and discovery. The NASA Earth Science Division (ESD) established the Commercial Smallsat Data Acquisition (CSDA) program to identify, evaluate, and acquire commercial small-satellite (smallsat) data that support NASA's Earth science research and application goals. These commercial smallsat data provide a cost-effective way to augment and complement the suite of Earth observations acquired by NASA, other U.S. Government agencies, and international partners. ESD recognizes the potential impact commercial smallsat constellations may have in encouraging and enabling efficient approaches to advancing Earth System Science and applications development for societal benefit. To facilitate standard scientific collaborations, NASA requires end user license agreements (EULAs) associated with commercial smallsat data to enable broad levels of dissemination and shareability of the commercial data with U.S. government agencies and partners. There are a set of license tiers (i.e., EULA tiers) associated with contracted data providers for an initial purchase to allow evaluation and/or subsequent purchases. NASA requires the ability to uplift from more restrictive licenses to less restrictive licenses without renegotiation of awards. The scientific community may use commercial datasets that are acquired by NASA for scientific purposes in adherence to vendor-specific terms and conditions. Commercial data sets that are currently available through the CSDA program are listed here, alongside EULA information: https://www.earthdata.nasa.gov/esds/csda/commercial-datasets

NASA ESD will consider hosting a Commercial Data Day, similar to this ESO Day, in the near future.

The schedule slide for the AOS spacecraft acquisition approach did not differentiate between Sky and Storm are the dates the same?

The anticipated acquisition approach on slide 24 represents the expected dates for AOS acquisition milestones. Solicitations for Sky and Storm spacecraft will likely occur in the same timeframe. The AOS project team is currently conducting architecture trades to evaluate cost-saving opportunities to stay within the cost target. Spacecraft and instrument requirements, and their development timelines, may change based on the results of these trades. Please refer to SAM.gov for the latest information on AOS solicitations.

Given the evolution of hyperspectral and thermal imaging since the 2017 Decadal, how is SBG evolving to make the best use of industry solutions and products?

During the SBG Architecture studies, which began in 2018 and culminated in the Mission Concept Review in 2022, the SBG project released Requests for Information (RFIs) on both the TIR and VSWIR components of the mission. This informed the project of the current state of the art and state of the practice in academic, government, international and industry solutions and products, and formed the basis for the SBG acquisition strategy. A mid-2020 RFI for instrument technical information revealed industry interest and capability in the hyperspectral instrumentation that could meet SBG requirements, and led to the current acquisition approach. Forthcoming RFPs to select an industry prime contractor for the VSWIR instrument will further ensure the best use of current solutions.

Will there be study contracts for all the competed AOS-Sky instruments, including the microwave radiometer and the polarimeter? What is the timeline for the release of the AOS-Sky instrument studies? What is the duration of the studies?

The AOS project team is currently preparing to release RFPs for each of the competed AOS-Sky instruments. Final expectations for study contract need and their associated requirements will be determined once the current AOS architecture trades conclude.

The AOS-Sky instrument study RFPs are expected to be posted to SAM.gov starting in May 2023. The period of performance for the studies will be specified in the solicitations.

The ESO budgets all "went up"; in contrast the new ESE budget was actually reduced - why is that?

ESO mission budgets were derived from the 2017 Decadal Survey cost targets. The Decadal Survey cost targets for the designated observables represented development costs for the missions, and the current NASA cost targets reflect the life cycle costs (LCC) for these missions. With adjustments, as defined by the NASA New Start Inflation Index, AOS and SBG remain in family with the recommended targets. The budget for MC was adjusted following the IRB recommendation to increase redundancy to support long-term continuity of measurements. Earth Science budget constraints, and efforts to balance science priorities led to the decrease in the Earth System Explorers (ESE) cost target. Unfortunately, ESD had to absorb ~$300M of COVID impacts as well as other cost impacts associated with technical issues encountered in the existing program of record. In addition, the ESD had to adjust its budget due to appropriations reductions of approximately $200M in both FY2022 and FY2023. The ESE cost cap of $310M FY24$ is intended to support achievement of the decadal goal of holding three ESE competitions within the decade and is in family with the caps for MIDEX missions offered in other NASA Science divisions. Table 2 below depicts the cost targets from the Decadal Survey and current NASA cost targets.

Mission	2017 Decadal Survey Development Cost Targets	Current Cost Targets
AOS	$1600M FY18$	$1800 - $1990M FY22$ LCC Target
MC	$300M FY18$	$425 - $653M FY22$ LCC Target
SBG	650M FY18$	$786M - $877M FY22$ LCC Target
ESE	$350M FY18$	$310M FY24$ (not including the cost of AO-provided access to space or any contributions)

Table 2: Cost Targets of DS vs Current Budget

How will AOS data and products be shared with the National Weather Service?

The National Weather Service, and other civil forecasting users are highly proficient at using existing datasets, acquiring them from NASA's near-space network including direct broadcast sites or the global telecommunications system and integrating familiar data from new sources into their processes. AOS and NASA's open science principles will continue to enable accessibility of lower latency data and archives to operational users. Observational datasets from AOS can be used by this community to forecast severe weather, hydrology, aviation weather, etc.

How does the recent NRO hyperspectral award to Planet dovetail with NASA's ESO particularly SBG?

Insofar as the National Reconnaissance Office (NRO) award to Planet is designed to study how Planet's future hyperspectral system aligns with the national security space architecture, the opportunities are likely limited, depending on the scope of the NRO initial data license. NASA will be interested in seeing how the Planet hyperspectral offering may augment the ability to improve the ESO ability to meet the Designated Observables of the Decadal Survey.

Why is JPL procuring the Mass Change spacecraft from Airbus? Why not a US provider?

To provide continuity of the mass change measurement and to minimize the gap between GRACE-FO and Mass Change, we are leveraging the heritage spacecraft design from Airbus that was used for GRACE and GRACE-FO. This also allows us to keep costs down and greatly reduce the technical risk to the mission.

Given the desire for an overlap between Storm and Sky, it is odd to plan launch dates 29 months apart when the first spacecraft has a design life of 24 months. What is driving the current AOS LRDs?

Although there is a desire for overlap in the AOS-Storm and AOS-Sky missions, it is not required to meet threshold science requirements. Each AOS mission is expected to provide synergistic measurements across a suite of complementary instruments, and AOS-Storm will focus on Diurnal sampling and AOS-Sky will focus on global measurements. Overlap of inclined and polar measurements would increase the science return by adding some coincident observations.

Some overlap may still occur between the two missions despite the Launch Readiness Date (LRD) separation. The AOS-Storm mission has a design life of 2 years with 3 years of consumables. Historically, many NASA missions have exceeded their planned mission lifespans and have been extended, and this may be the case for AOS-Storm. AOS-Storm will also fly with the JAXA PMM observatory which has a 5-year design life. There is expected to be overlap between PMM and AOS-Sky operations.

The current LRDs are driven by budget profile constraints and expected development timelines.

How does ESO fit into the JEDI data fusion efforts?

The Joint Center for Satellite Data Assimilation (JCSDA) was established in 2001 and is a multi-agency research center of which NASA is a partner. The JCSDA works to improve the use of satellite data for analyzing and predicting the weather, the ocean, the climate, and the environment. Furthermore, the JCSDA develops open-source tools, algorithms, and workflows for satellite data assimilation into environmental forecast models at multiple agencies. The JCSDA has a Joint Effort for Data assimilation Integration (JEDI) project, which aims to exploit the full potential of Earth observations for continuous scientific development, while enabling efficient research work and accelerating the transition from research to operations, acknowledging that observing systems are constantly evolving with ever-increasing data volumes. As NASA executes on the ESO missions with a strong commitment to open-source science, the Earth Science Division is ensuring that ESO mission observations and data will be findable, accessible, interoperable, and reusable across multiple disciplines within the scientific community, including Earth system modelers.

When will the ESE Final AO be released?

The Final Announcement of Opportunity (AO) was released on May 2, 2023.

ONERA is no longer building heritage GRACE-like accelerometers; isn't using flight spares for MC incredibly risky?

The Inheritance Review for the GRACE-FO spare accelerometers was successfully performed earlier this year and NASA has high confidence that the issue from GRACE-FO does not exist with the spare accelerometers.