National Aeronautics and Space Administration

EXPLORE EARTH

NASA Earth Science: A Personal View*

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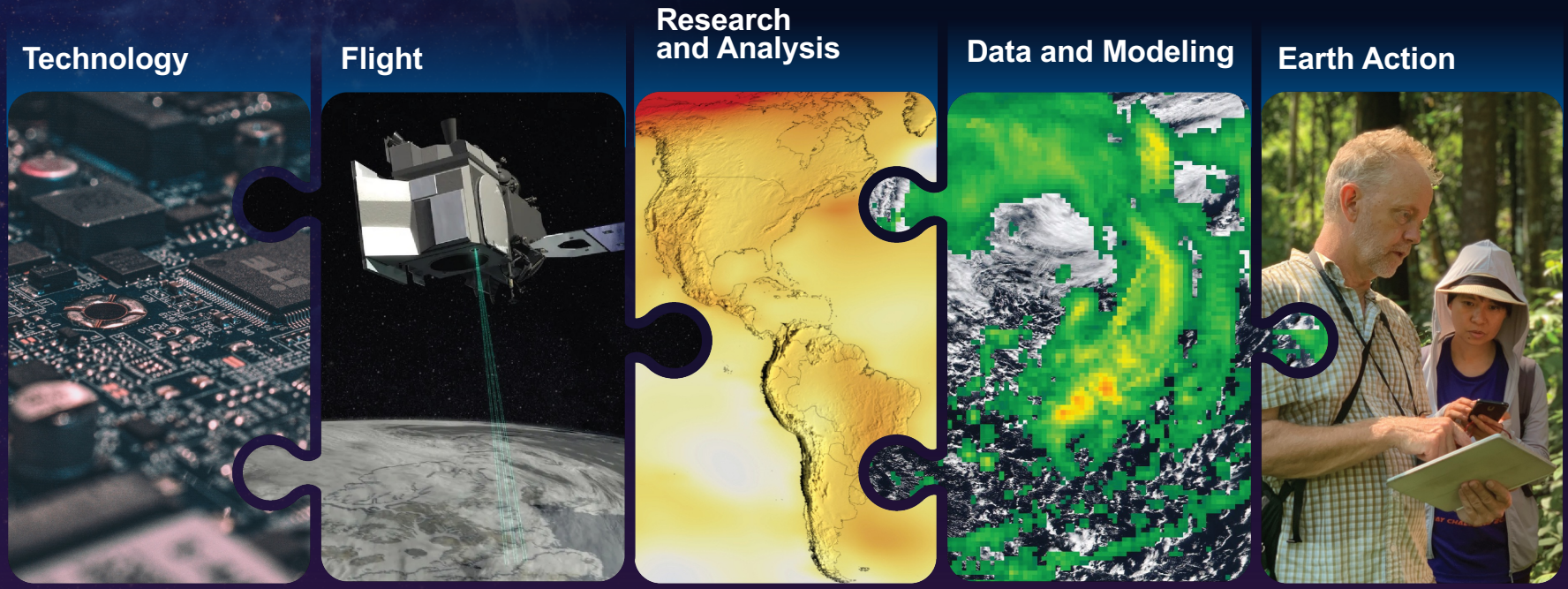
Associate Director for Research
NASA Earth Science Division

July 7, 2024

** Prepared with inputs from numerous colleagues from NASA HQ, centers, and the ESD investigator community*

Advancing Earth System Science End-to-end



NASA earth

Earth Science to Action Strategy

Virtuous Cycle
- User needs inform next iteration of programs, missions and initiatives

Public Understanding & Exchange
- Put more scientific understanding into public sphere
- Deliver applied science to users
- Participate in multi-way info exchange
- Use input to inform subsequent work

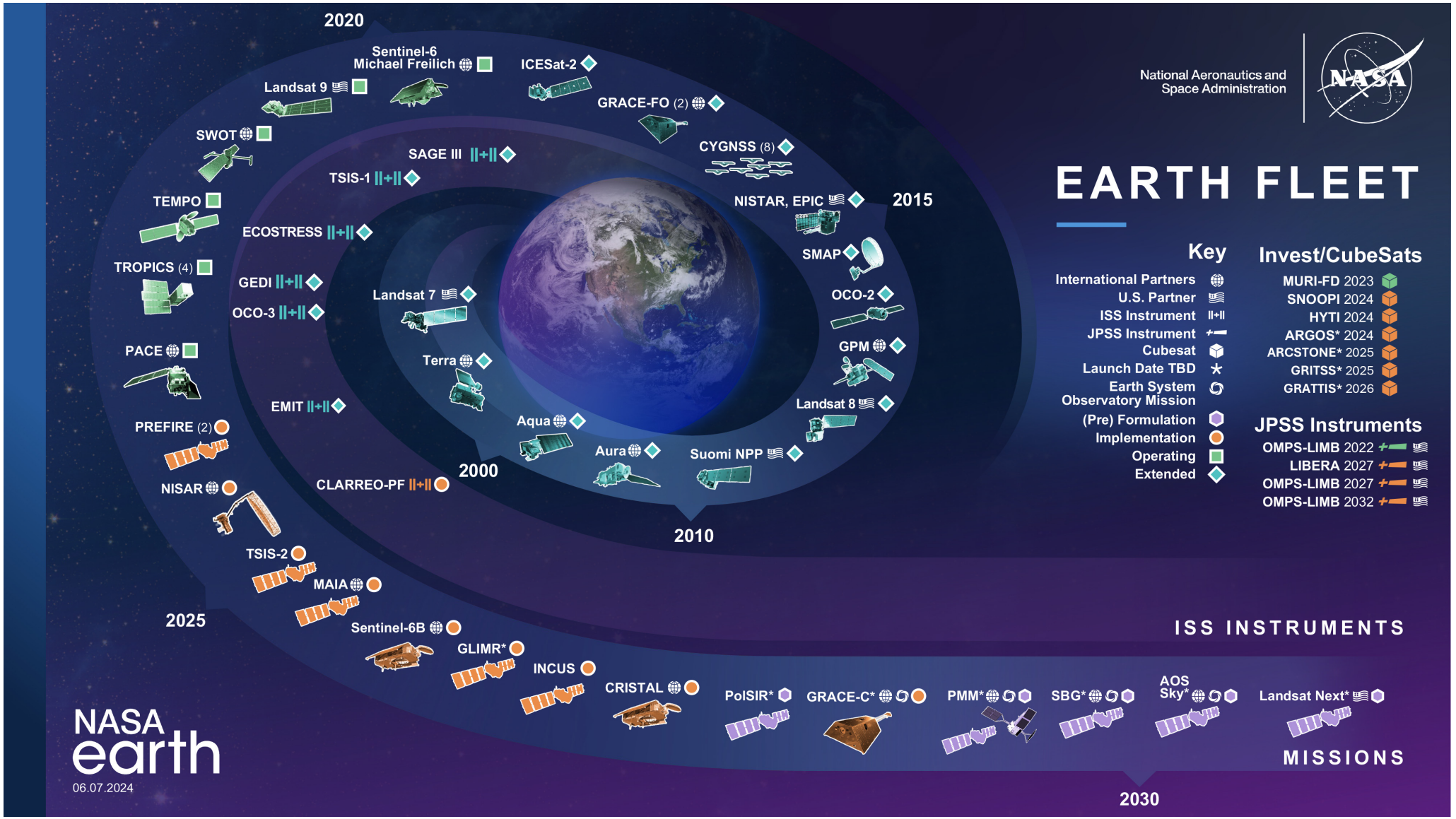
Solutions & Societal Value
- Offer models, scientific findings and info through Open-Source Science principles
- Support climate services
- Provide science applications and tools to inform decisions

Earth System Science & Applied Research
- Grow scientific understanding of Earth's systems
- Develop predictive modeling for science applications and tools to mitigate, adapt and respond to climate change

Foundational Knowledge, Technology, Missions & Data
- Technology innovation
- Earth observations missions
- Data collected from space, air and ground

NASA earth

05.01.2024



National Aeronautics and Space Administration

EARTH FLEET

Key

- International Partners
- U.S. Partner
- ISS Instrument
- JPSS Instrument
- Cubesat
- Launch Date TBD
- Earth System Observatory Mission
- (Pre) Formulation
- Implementation
- Operating
- Extended

Invest/CubeSats

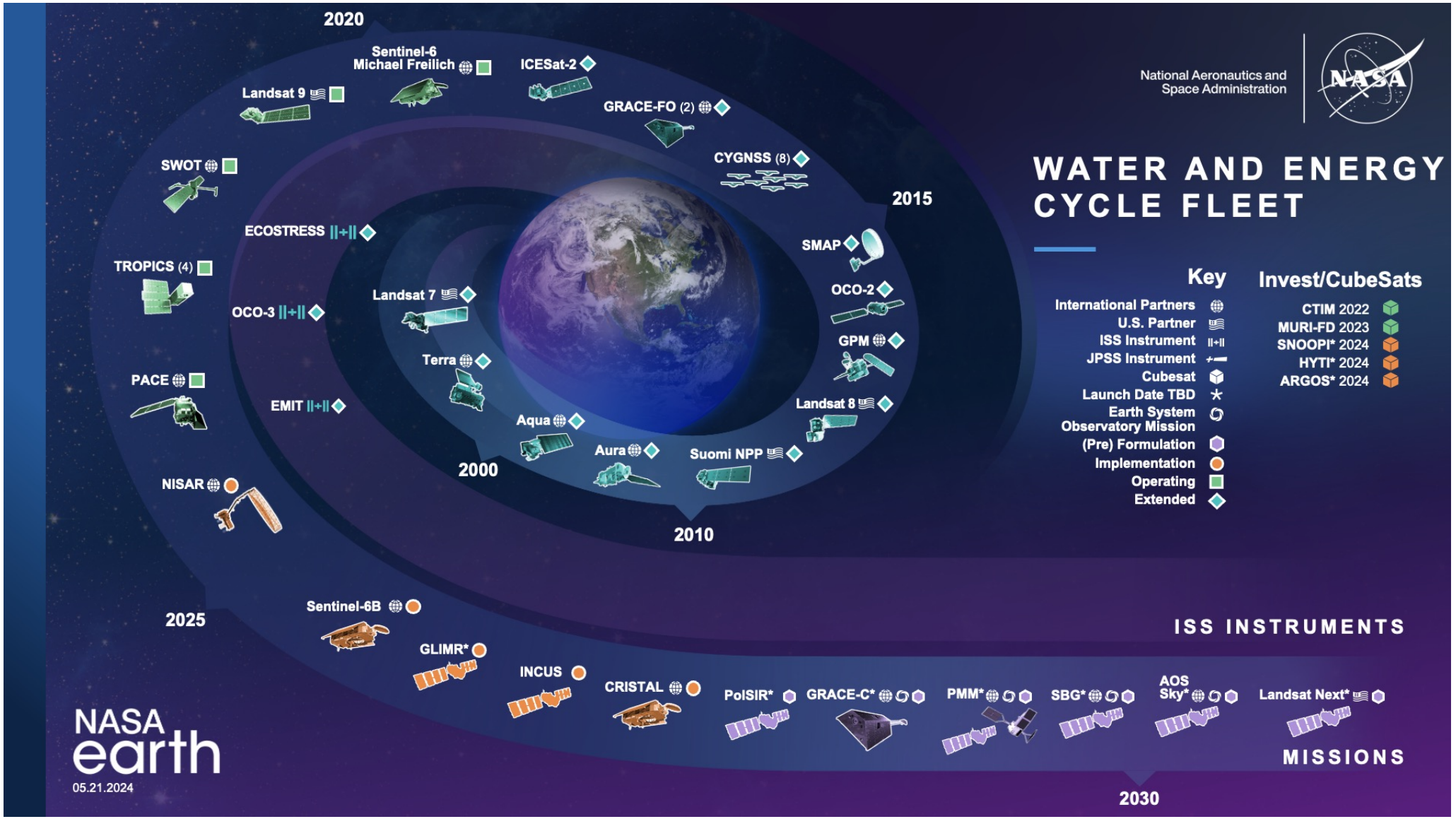
- MURI-FD 2023
- SNOOPI 2024
- HYTI 2024
- ARGOS* 2024
- ARCSTONE* 2025
- GRITSS* 2025
- GRATTIS* 2026

JPSS Instruments

- OMPS-LIMB 2022
- LIBERA 2027
- OMPS-LIMB 2027
- OMPS-LIMB 2032

NASA earth

06.07.2024


2020
Sentinel-6 Michael Freilich
ICESat-2
Landsat 9
GRACE-FO (2)
SWOT
CYGNSS (8)
2015
ECOSTRESS
SMAP
TROPICS (4)
OCO-2
Landsat 7
OCO-3
GPM
Terra
PACE
Landsat 8
EMIT
Aqua
Aura
Suomi NPP
2000
NISAR
2010
2025
Sentinel-6B
GLIMR*
INCUS
CRISTAL
PolSIR*
GRACE-C*
PMM*
SBG*
AOS Sky*
Landsat Next*
ISS INSTRUMENTS
MISSIONS
2030
NASA earth
05.21.2024
National Aeronautics and Space Administration
NASA
WATER AND ENERGY CYCLE FLEET
Key
International Partners
U.S. Partner
ISS Instrument
JPSS Instrument
Cubesat
Launch Date TBD
Earth System Observatory Mission
(Pre) Formulation
Implementation
Operating
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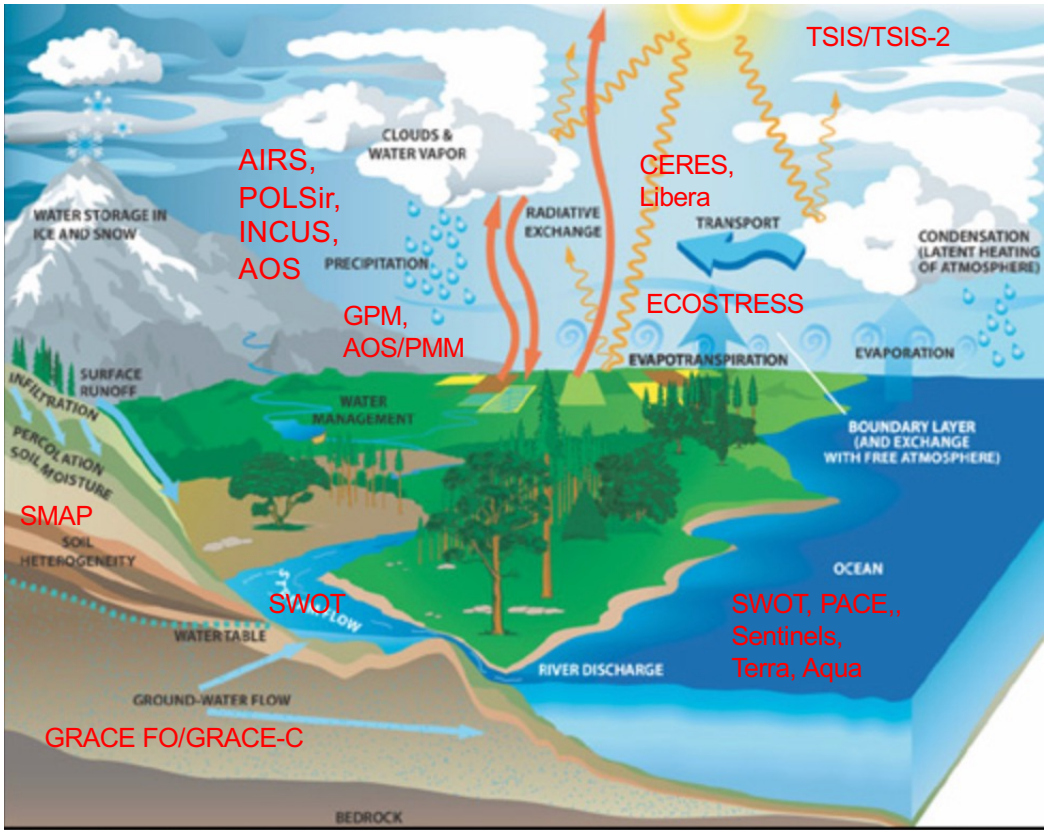
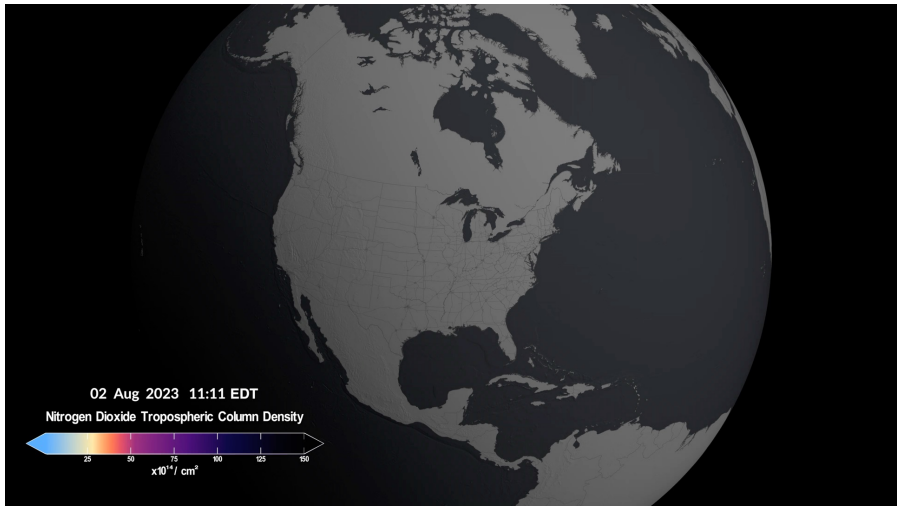
Invest/CubeSats
CTIM 2022
MURI-FD 2023
SNOOPI* 2024
HYTI* 2024
ARGOS* 2024

A “NASA View” of the Global Water and Energy Cycle*

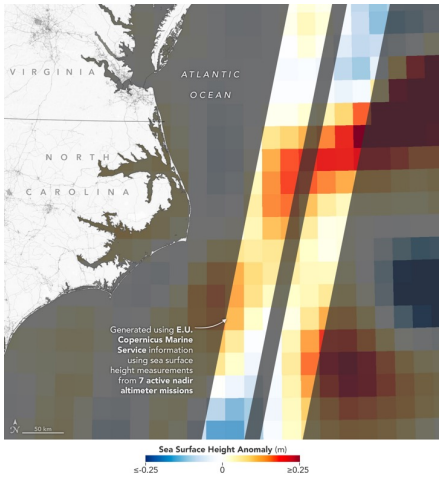


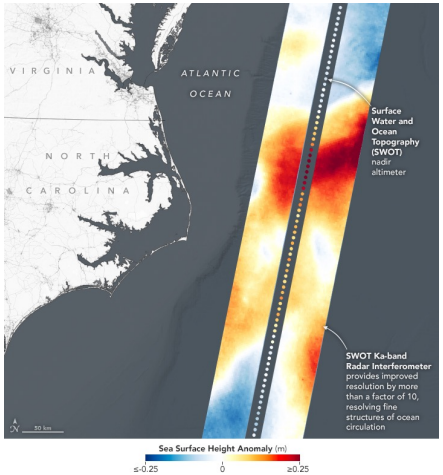
* This is a SIMPLIFED view!

Early Results from Some of our Newer Satellites

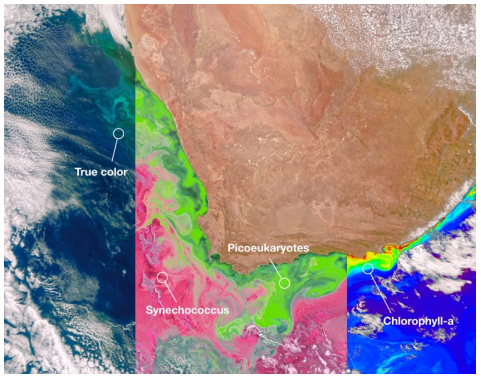


TEMPO





SWOT (compared to Precursor Missions)



PACE

PREFIRE

PREFIRE launches were accomplished on May 25 and June 5, 2024 by Rocketlab from their launch facility in Mahia, New Zealand!

https://prefire.ssec.wisc.edu/

Earth Venture Mission-3: INCUS

PI: Susan van den Heever, Colorado State University

Addressing why convective storms, heavy precipitation and clouds occur exactly when and where they do

Three SmallSats

- JPL Ka-band radar with 5 beams (RainCube heritage)
- JPL cross-track scanning microwave radiometer (TEMPEST-D heritage)
- Tendeg deployable 1.6m Ka-band antenna
- Blue Canyon Technologies X-SAT Venus commercial bus

Colorado State University

BLUE CANYON TECHNOLOGIES

JPL

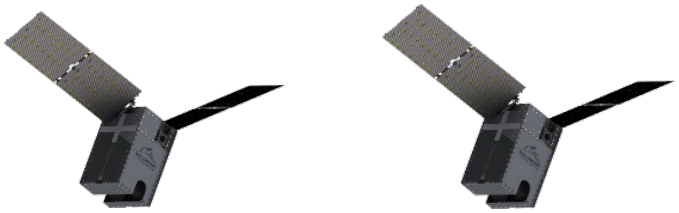
TENDEG
Space Antennas And Deployables

Polarized Submillimeter Ice-cloud Radiometer (PolSIR)

On May 22, 2023, NASA announced the selection of PolSIR as the sixth Earth Venture Instrument (EVI-6) investigation aimed at study of ice clouds to determine how and why they change throughout the day, which will provide crucial information about how to accurately simulate these high-altitude clouds in global climate models.

Mission Overview

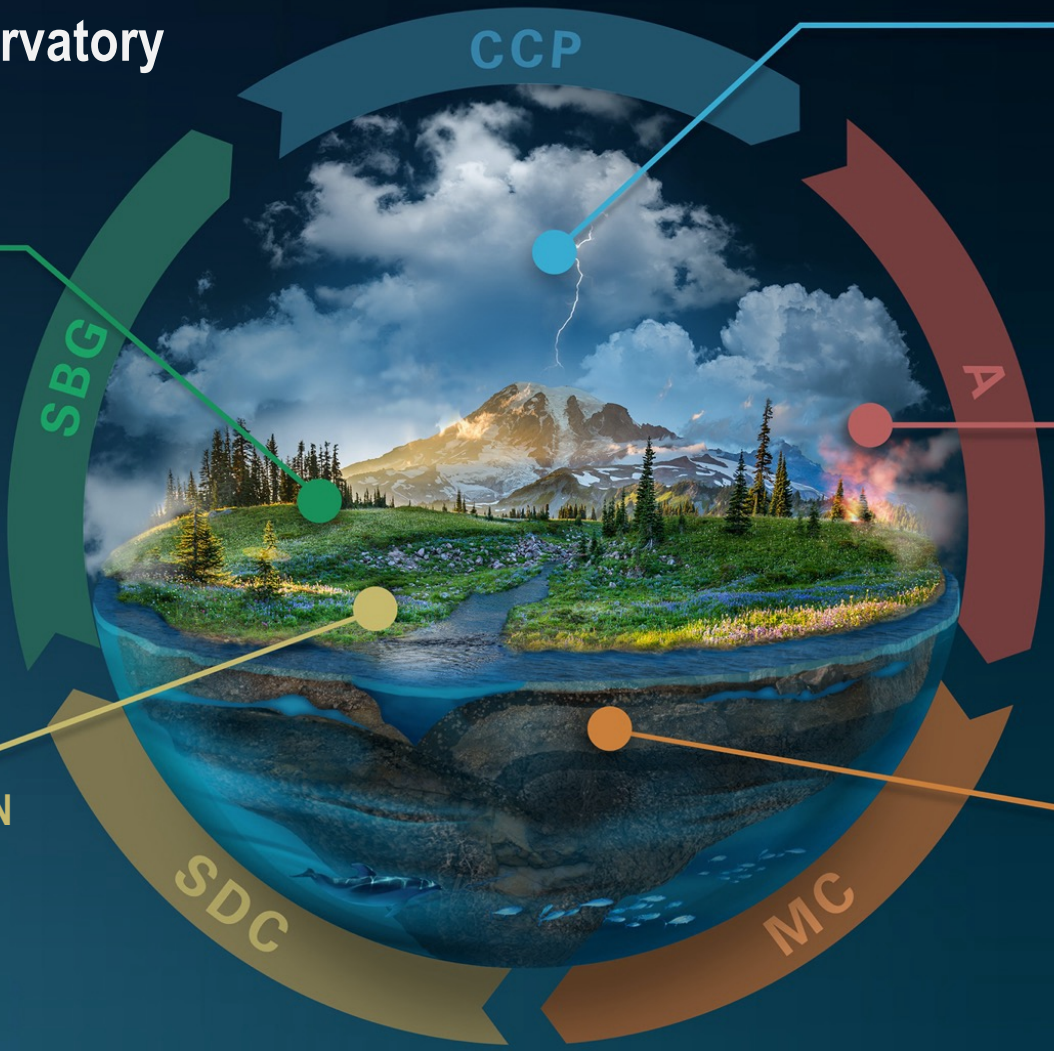
- The 2-year investigation will comprise of two identical 12 U CubeSats, each with dual-band radiometers: 683-GHz (QV & QH), 325/1.5-GHz (QV), 325/3.5-GHz (QV), 325/9.5-GHz (QV & QH)
- Low earth orbit between 35°and 51°inclination separated by 3-8 hours
- **Cost**: $37M (FY24) Class-D mission with Launch provided by NASA Launch Services Program outside cost cap
- **Team**: Vanderbilt University, NASA/GSFC, University of Wisconsin, Wisconsin: Blue Canyon Technologies, Virginia Diodes Inc., NOAA, Université Paris-Saclay
- **Expected launch**: Not earlier than 2027



Science Objectives

- Constrain seasonally influenced diurnal cycle of tropical ice water path (IWP) and particle diameter
- Determine the diurnal variability of ice clouds in the convective outflow areas
- Determine the relationship between shortwave and longwave radiative fluxes and the diurnal variability of ice clouds

Earth System Observatory



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in the Atmosphere

AEROSOLS

Particles in the Atmosphere

MASS CHANGE

Large-scale Mass Redistribution

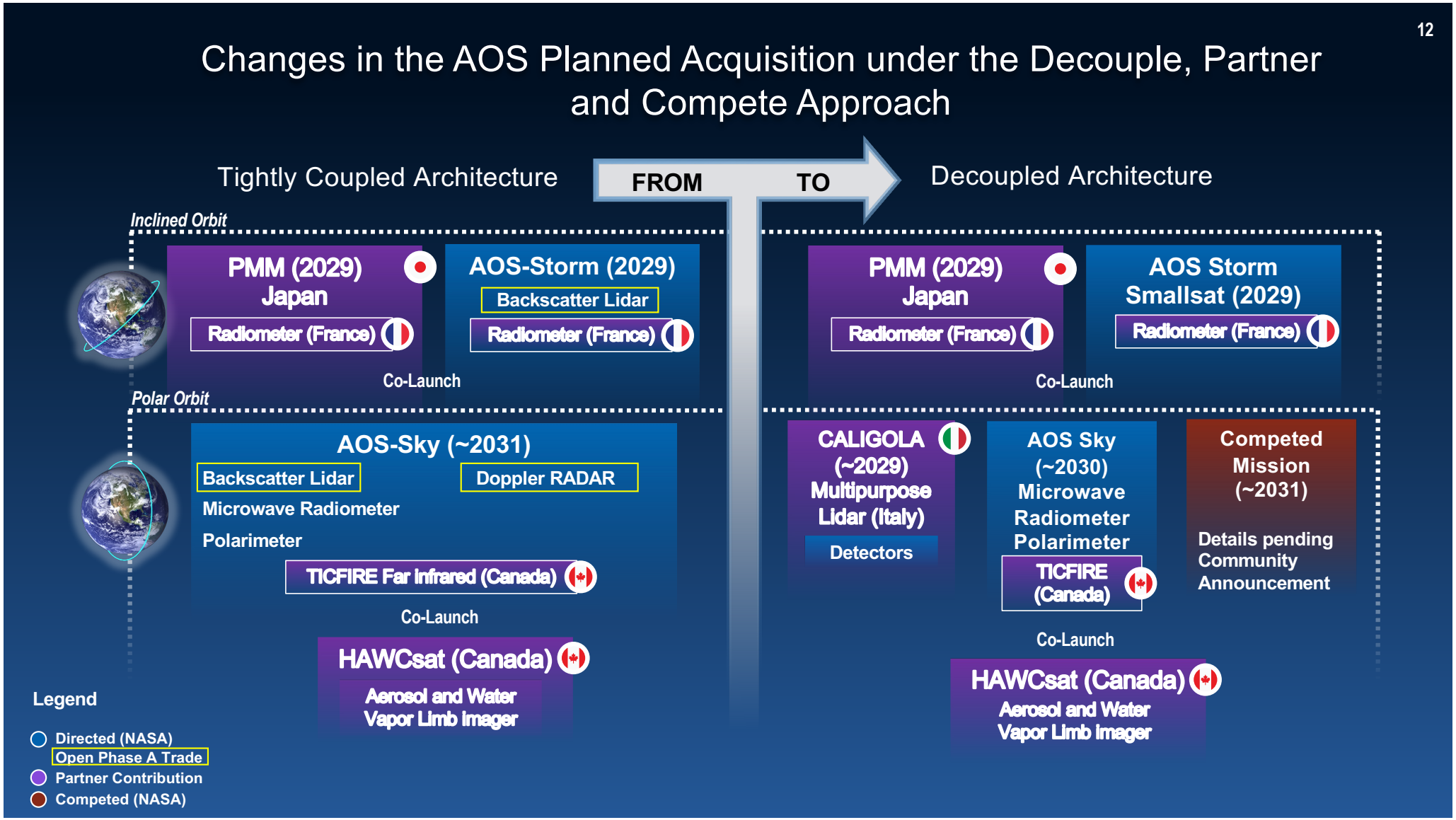
SURFACE BIOLOGY AND GEOLOGY

Earth Surface & Ecosystems

SURFACE DEFORMATION AND CHANGE

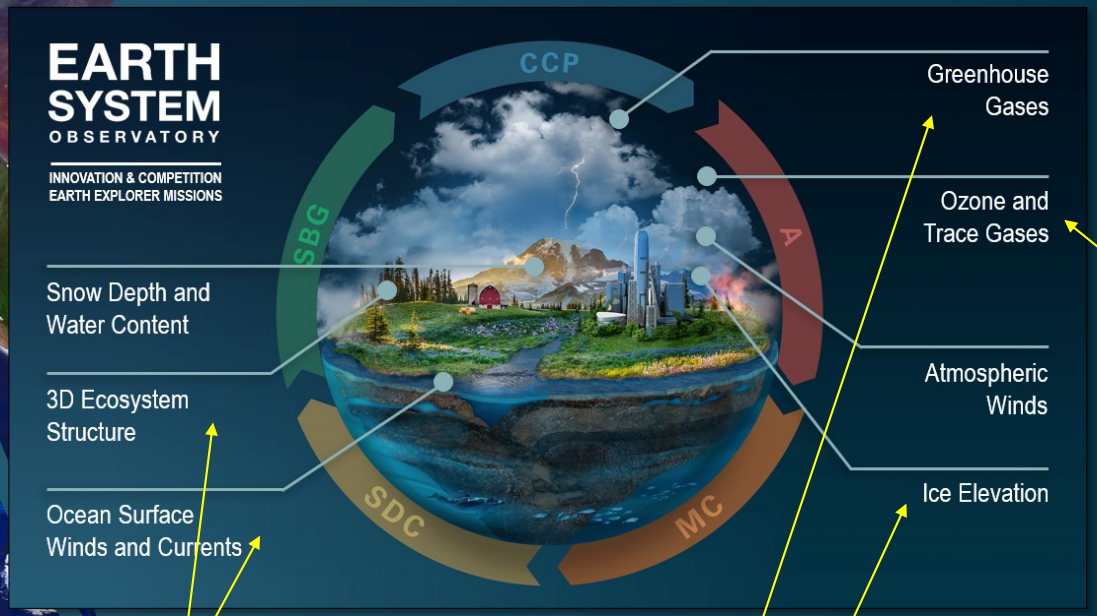
Earth Surface Dynamics

Changes in the AOS Planned Acquisition under the Decouple, Partner and Compete Approach



Earth System Explorers (ESE)

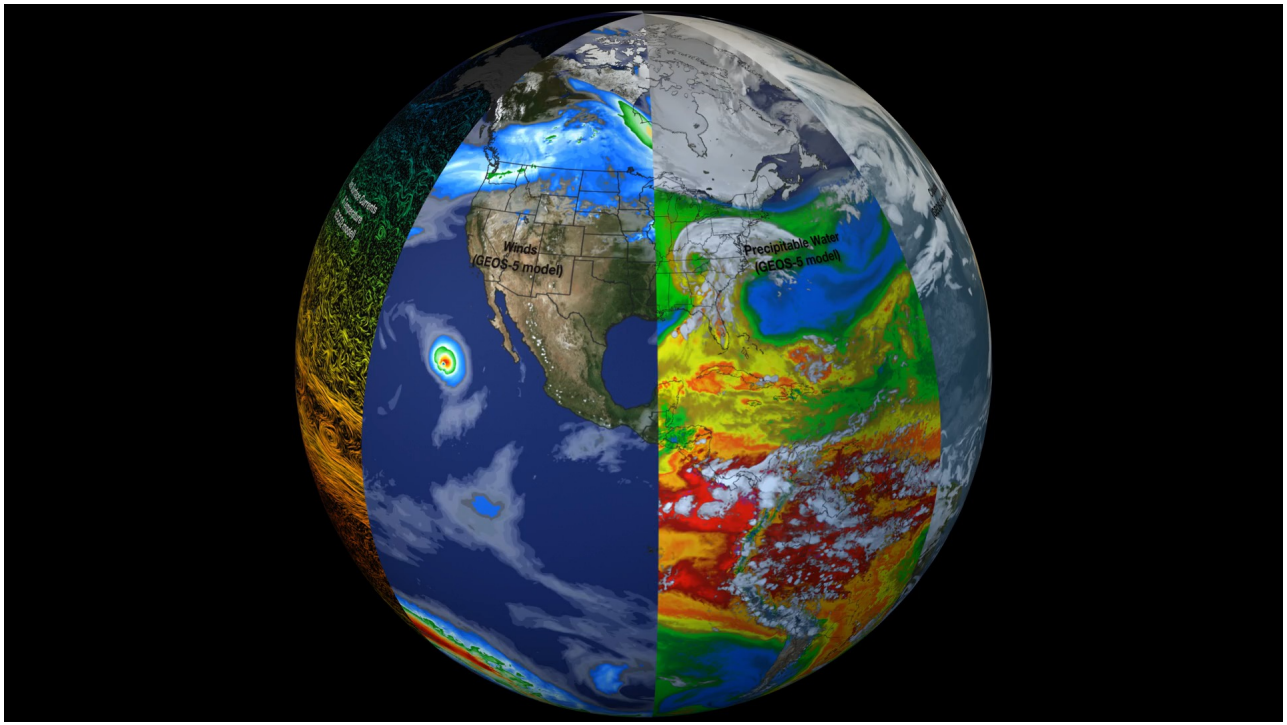
EARTH SYSTEM OBSERVATORY



- Draft Announcement of Opportunity (AO) released on Dec 6, 2022
- Final AO was released May 2, 2023
- PI-Managed Mission Cost (PIMMC) cap of $310M (FY24 $)
- NASA will provide launch vehicle services
- Two-step selection process
- Initial selection announced May 7, 2024:

The Stratosphere Troposphere Response using Infrared Vertically-Resolved Light Explorer (STRIVE)
The Ocean Dynamics and Surface Exchange with the Atmosphere (ODYSEA)
Earth Dynamics Geodetic Explorer (EDGE)
The Carbon Investigation (Carbon-I)

NASA Earth System Science



Atmospheric Composition
Water and Energy Cycle
Carbon Cycle and Ecosystems

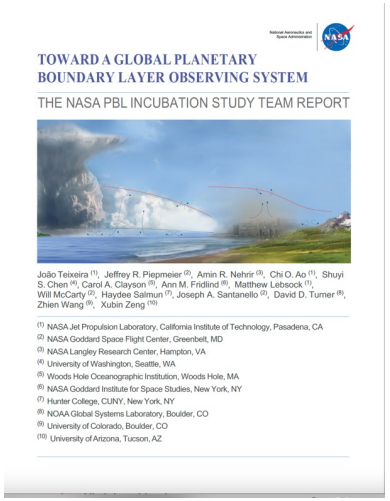
Earth Surface and Interior
Weather and Atmospheric Dynamics
Climate Variability and Change

NASA Scientific Visualization Studio svs.gsfc.nasa.gov/30701

Research Opportunities for GEWEX-Related Activity at NASA*

- Research and Analysis – Disciplinary Programs (only a few listed here!)
  - Terrestrial Hydrology
  - Radiation Sciences
  - Weather and Atmospheric Dynamics
  - Modeling, Analysis, and Prediction
- Research and Analysis – Interdisciplinary/Cross-Disciplinary Programs
  - Interdisciplinary Science
  - Remote Sensing Theory
  - Earth Venture Suborbital (Budget is in flight program but R&A runs solicitation)
- Competed Science Teams for Operating Missions
  - SMAP
  - CYGNSS
  - S-NPP/JPSS (including CERES)
  - SWOT/Other Altimetry
  - GRACE FO
  - GPM
- Earth Action (formerly Applied Sciences) (e.g., Water Resources)
- Technology (Instruments, Components, Information Systems, Cubesats)
- Decadal Survey Incubation (joint R&A/ESTO) – Planetary Boundary Layer

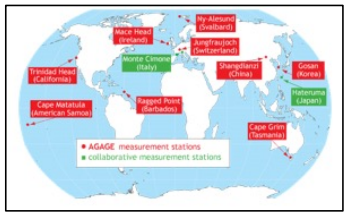
* This is a simplified view – it doesn't include everything!


TOWARD A GLOBAL PLANETARY BOUNDARY LAYER OBSERVING SYSTEM

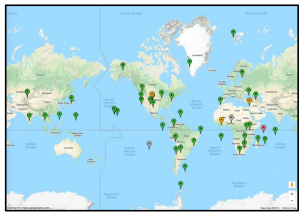
THE NASA PBL INCUBATION STUDY TEAM REPORT

Examples of NASA-Supported Ground Networks

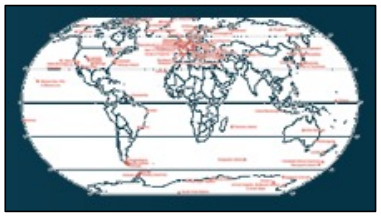
AGAGE



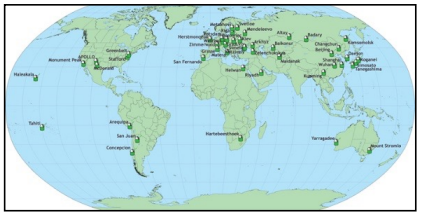
GGN



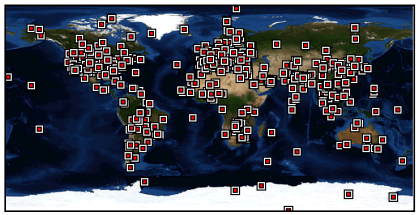
NDACC



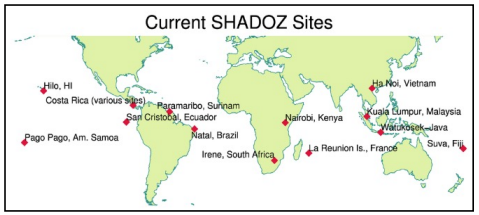
NSGN



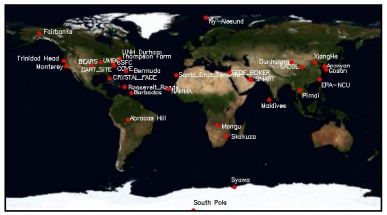
AERONET



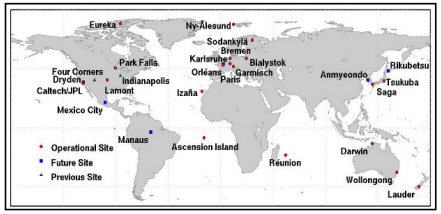
SHADOZ



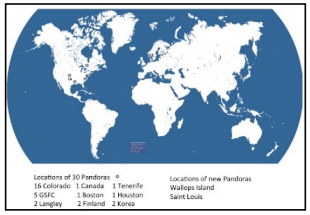
MPLNet



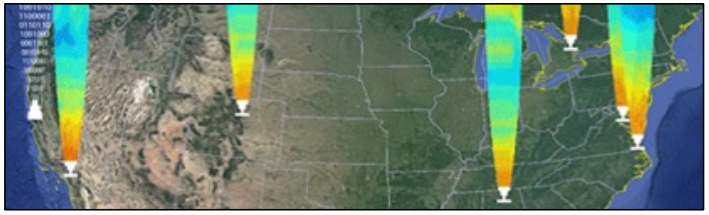
TCCON



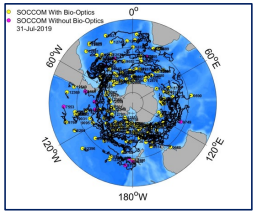
PANDORA



TOLNet



SOCCOM



NASA Earth Science Division Airborne Fleet

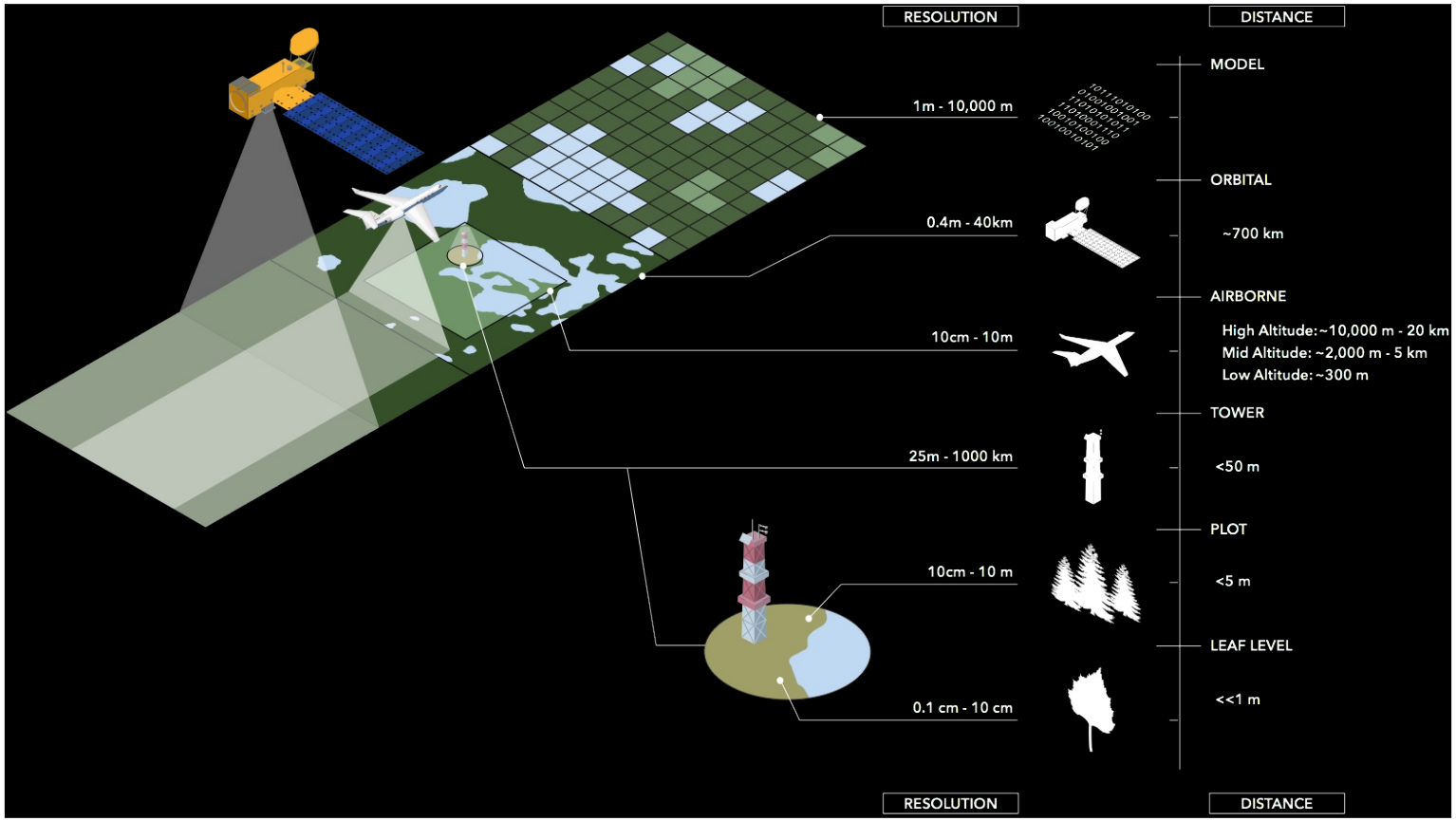
DC-8's Final Return to AFRC – 4/1/24 after ASIA AQ

Newest Addition to Fleet – B-777 (at LaRC) – will replace DC-8 now that it's been retired!

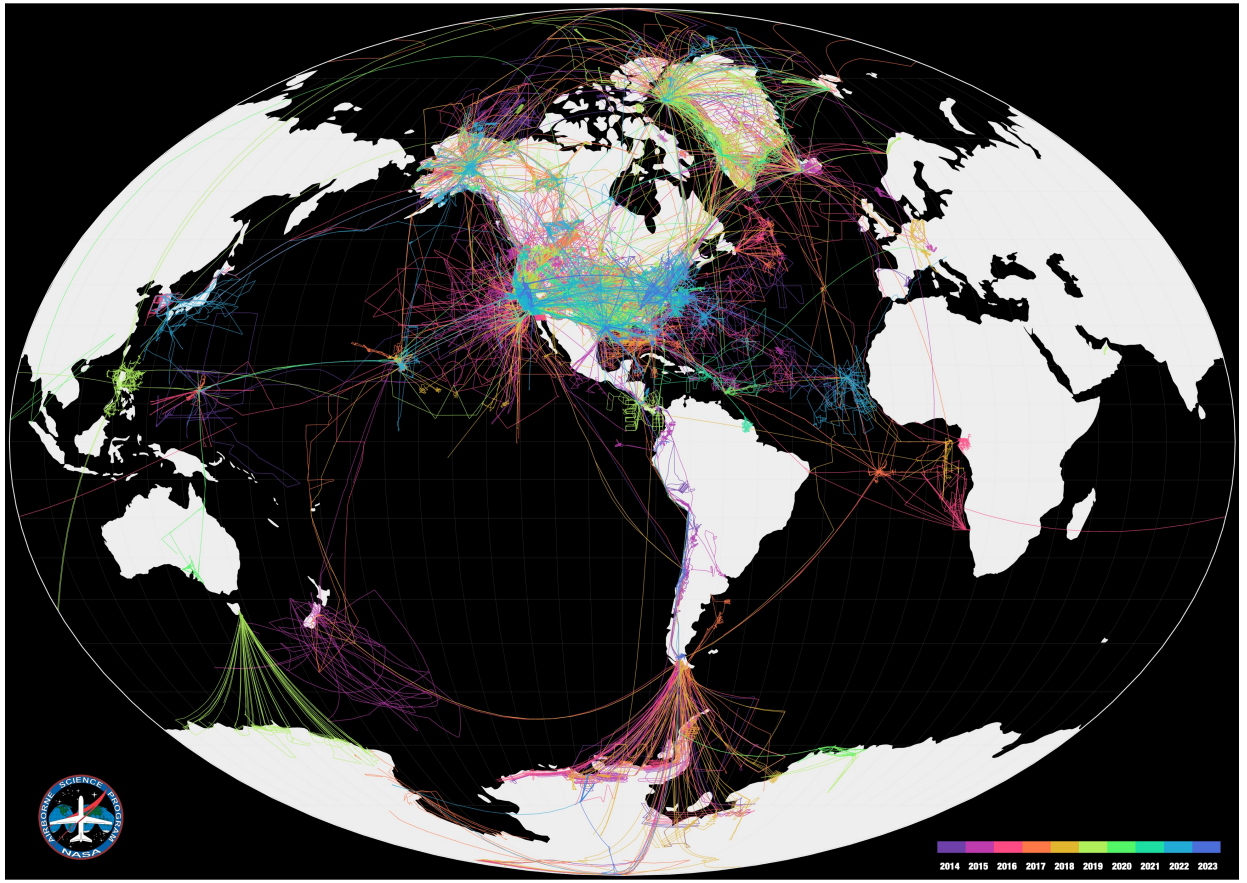
What Airborne Science Means at NASA

- Airborne Science at NASA integrates unique capabilities in the following areas:
  - **Platforms:** airborne platforms that can fly instrument packages (from a single instrument to several dozen) to locations needed for the desired observations
  - **Sensors:** remote sensing and/or *in situ* sensors that can work individually or collectively to address science and/or technology questions and opportunities
  - **Systems:** data, information, and operational systems that enable data to be acquired, transmitted, shared, and to allow investigator interactions with crew to optimize flight trajectories
  - **People:** the human capital that allows airborne missions to be carried out safely and effectively in remote locations, frequently under harsh conditions with little indigenous local support; also the ability to design experiments/campaigns and turn acquired data into knowledge
  - **Opportunities:** program-directed and competitive solicitations for mission/campaign development and also instrument development/evolution; well-defined flight request approach for use of platforms/facility sensors
- The linkage among these is critical — especially the "marriage" between platforms and sensors (pods/viewing ports for remote sensing instruments, well-characterized inlets for *in situ* sensors)
- Airborne Science is fully integrated with space-based measurements, surface-based measurements and modeling into an "integrated whole" with involvement of all components included in planning/design

Scaling Strategy for Field Campaigns



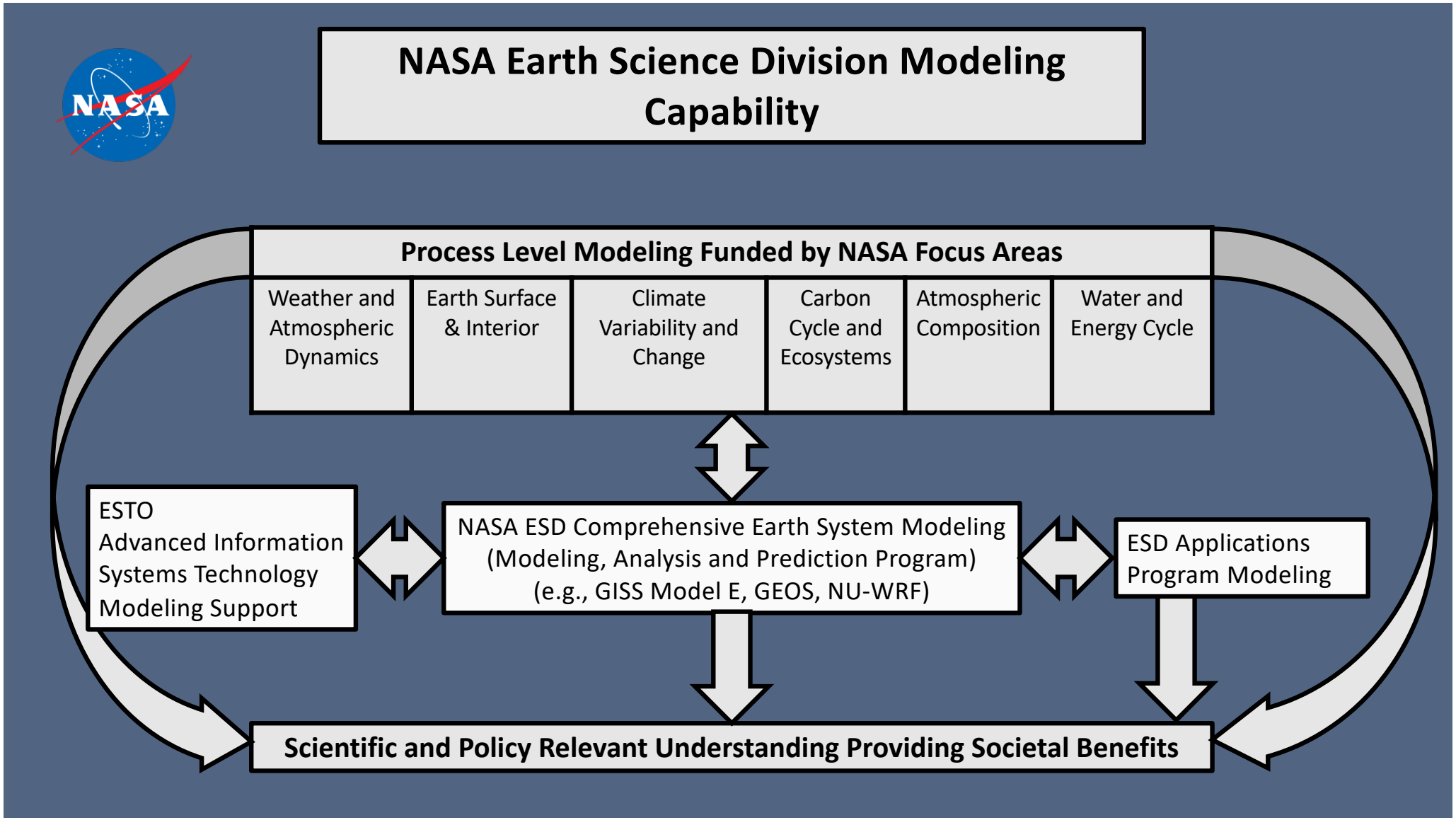
NASA Airborne Science Flights – 2014-2023



Earth Venture Suborbital-4 Selected Mission Concepts

Mission	Focus Area	Location(s) Prop.	Platform(s) Prop.	Leadership Team	Size*
PYRocumulonimbus EXperiment (PYREX)	Weather and Atmospheric Dynamics	Palmdale, CA Boise, ID Cold Lake, Alberta	ER-2 WB-57 (or GV) (or perhaps all on B777)	PI: David A. Peterson, Naval Research Laboratory - Monterey, Mid-Career DPI: Neil Lareau, University of Nevada, Reno, Early Career DPI: Olga Kalashnikova, Jet Propulsion Laboratory, Late-Career.	Big
Snow4Flow	Climate Variability and Change	Alaska, Arctic Canada, Greenland and Svalbard	DHC-6 Twin Otter DC3-T Basler DHC-4T Turbo Caribou	PI: John W. Holt, University of Arizona, Late-Career DPI: Lauren C. Andrews, NASA Goddard Space Flight Center, Early-Career DPI: Joseph A. MacGregor, NASA Goddard Space Flight Center, Mid-Career	Big
Landslide Climate Change Experiment	Earth Surface and Interior	California and Alaska	GIII	PI: Alexander Handwerger, Jet Propulsion Laboratory, Early-Career DPI: Noah Finnegan, University of California, Santa Cruz, Mid-Career DPI: Seung-Bum Kim, Jet Propulsion Laboratory, Late-Career	Small
Hemispheric Airborne Measurements of Air Quality (HAMAQ)	Atmospheric Composition	Mexico (Veracruz Ariport) South Korea (Osan Air Base) Italy (Aviano Air Base)	GV P-3B (Y2/3), B777 (Y4)	PI , James H. Crawford, NASA Langley Research Center, Late Career DPI - Laura Judd, NASA Langley Research Center, Early Career DPI - Brian McDonald, NOAA Chemical Sciences Laboratory, Early Career	Small
Nitrogen and Carbon Terrestrial Fluxes: Agriculture, Atmospheric Composition, and Ecosystems (NTERFAACE)	Atmospheric Composition	Palmdale, CA Lincoln, NE	P-3 or B777 B200, C-23 Sherpa, or King Air	PI: Glenn Wolfe, NASA GSFC, Mid-Career DPI: Emily Fischer, Colorado State University, Mid-Career DPI: Jeffrey Geddes, Boston University, Early Career	Small
FORTE: Arctic Coastlines – Frontlines Of Rapidly Transforming Ecosystems	Carbon Cycle and Ecosystems	Fairbanks, AK UAS from Deadhorse, AK	GV GIII (B200, Twin Otter) Drones	PI: Maria Tzortziou, City University of New York, Mid Career DPI: Antonio Mannino, NASA Goddard Space Flight Center, Late Career DPI: J. Blake Clark, NASA GSFC/UMBC, Early Career	Small

* Proposals selected as small will likely not utilize all locations and/or platforms


NASA Earth Science Division Modeling Capability
Process Level Modeling Funded by NASA Focus Areas
Weather and Atmospheric Dynamics
Earth Surface & Interior
Climate Variability and Change
Carbon Cycle and Ecosystems
Atmospheric Composition
Water and Energy Cycle
ESTO Advanced Information Systems Technology Modeling Support
NASA ESD Comprehensive Earth System Modeling (Modeling, Analysis and Prediction Program) (e.g., GISS Model E, GEOS, NU-WRF)
ESD Applications Program Modeling
Scientific and Policy Relevant Understanding Providing Societal Benefits

Key Types of International Engagement

Observations

- Bilateral cooperation in missions and related science
- Multi-lateral organizationally-mediated cooperation
- Field work (airborne, balloon, surface, shipborne)
- Surface-based measurement networks

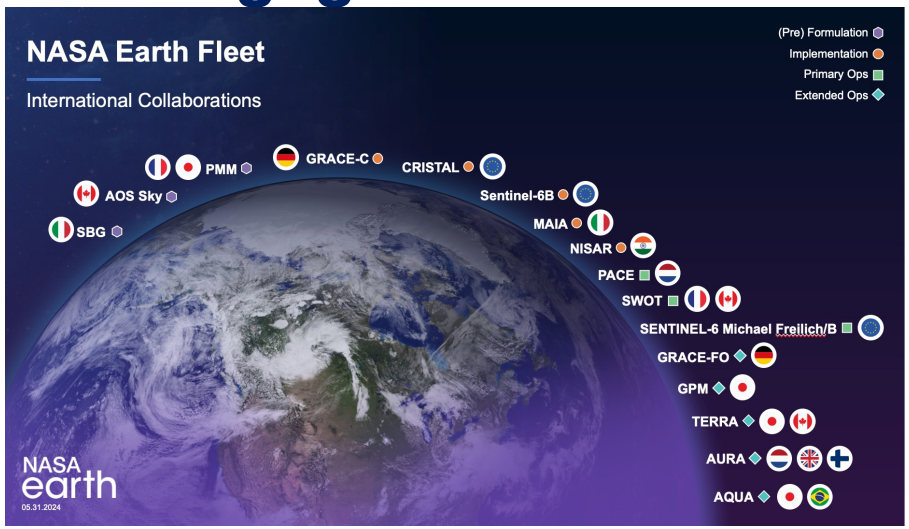
Research, Applications, and Assessment

- Research: WCRP*, Future Earth*
- Applications: UN/SDGs, Disasters
- Assessment: IPCC, WMO/UNEP, IPBES, WOA, AMAP
- Internationally-Focused Opportunities

Education and Capacity Building

- Education: GLOBE
- Capacity Building: SERVIR, ARSET, others

* NASA supports GEWEX IPO, co-supports CliC IPO (with NSF), and AIMES (Future Earth) IPO, and co-supports GLP IPO (Future Earth, with NSF)



GLOBE 2023 Annual Meeting