Briefing to the Committee on Earth Science and Applications from Space (CESAS)

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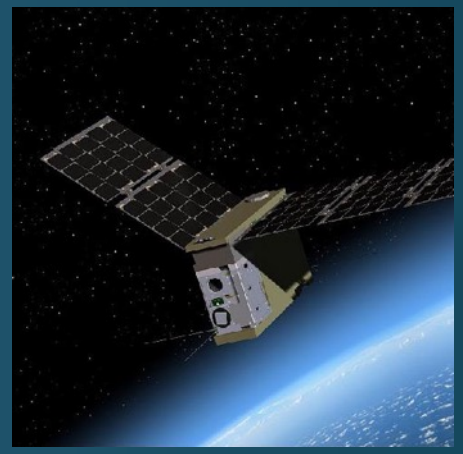
March 2021

Earth Science Overview



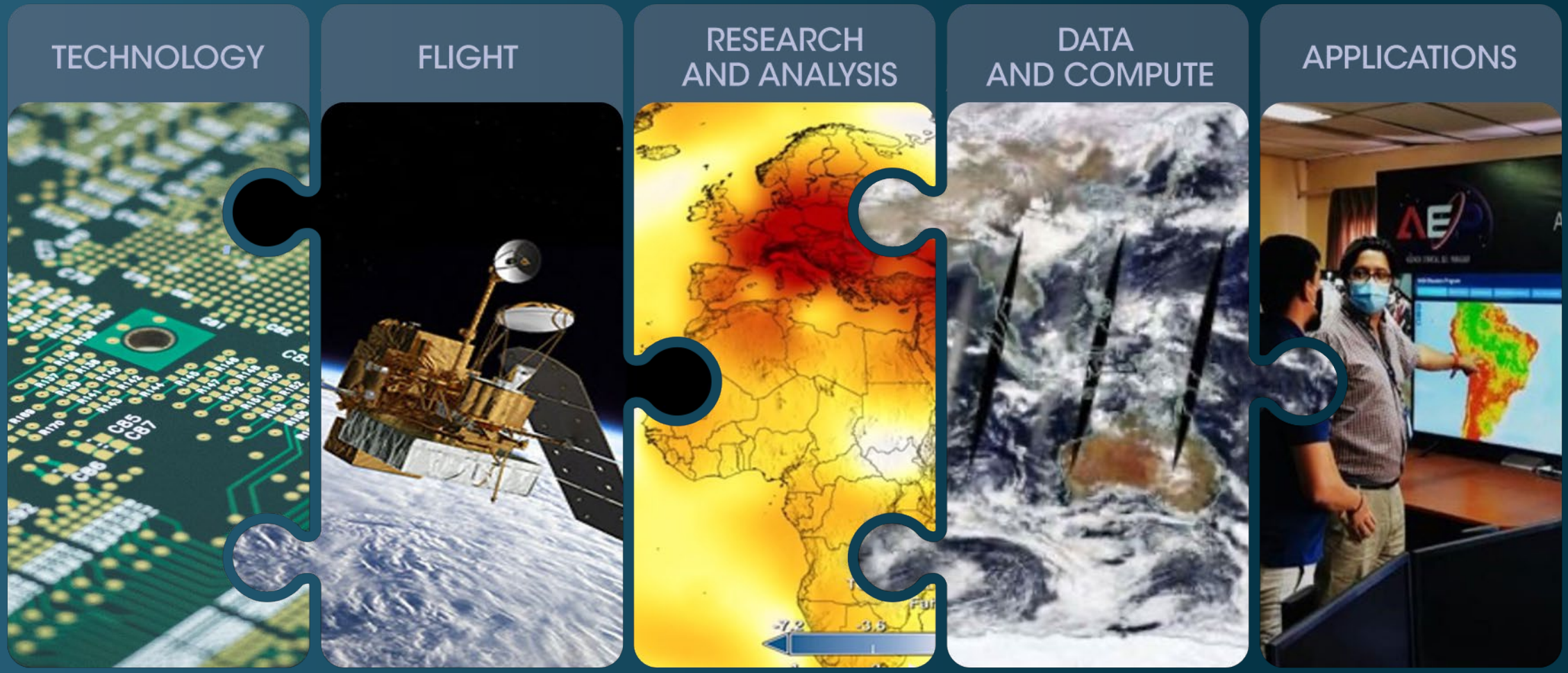
Strategic Objective

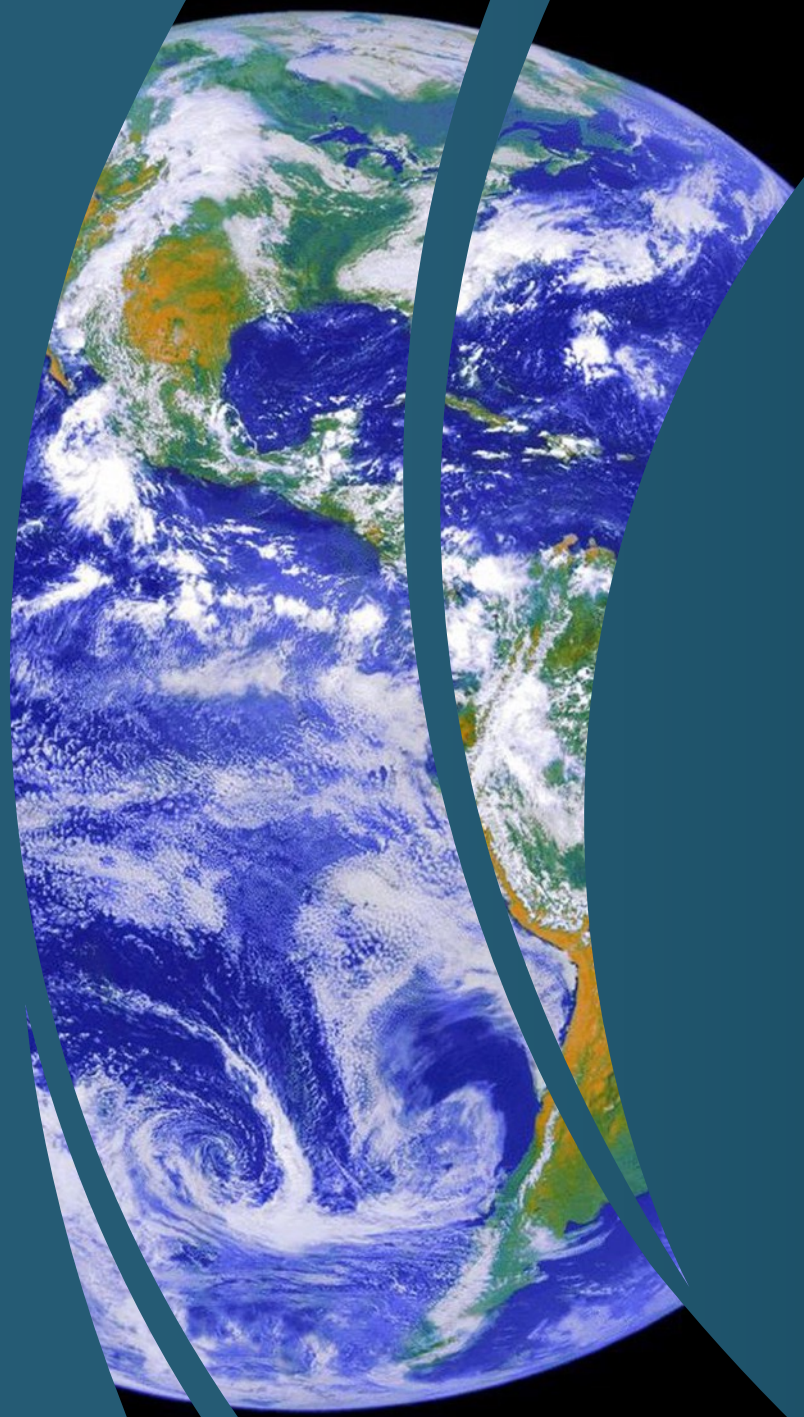
- Advance knowledge and prediction of the whole Earth system to meet the urgent demands of climate change

Major Activities

- Build and operate Earth observing satellite missions, many with international and interagency partners (e.g., ESA, NOAA, USGS)
- Conduct and sponsor cutting-edge, interdisciplinary research
  - Field campaigns and airborne missions to complement and validate satellite measurements
  - Analyses of NASA and non-NASA mission data
  - Modeling & Informatics to advance our understanding and prediction of the Earth System
- Build partnerships with public sector, private sector, NGOs, and international organizations to accelerate the uptake of scientific understanding and deliver societal benefit
- Invest in Earth observation technologies, including intelligent systems and development and demonstration of CubeSat/SmallSat instruments

Advancing Earth System Science End-to-end





Excellence in Earth Science

Deliver on current commitments

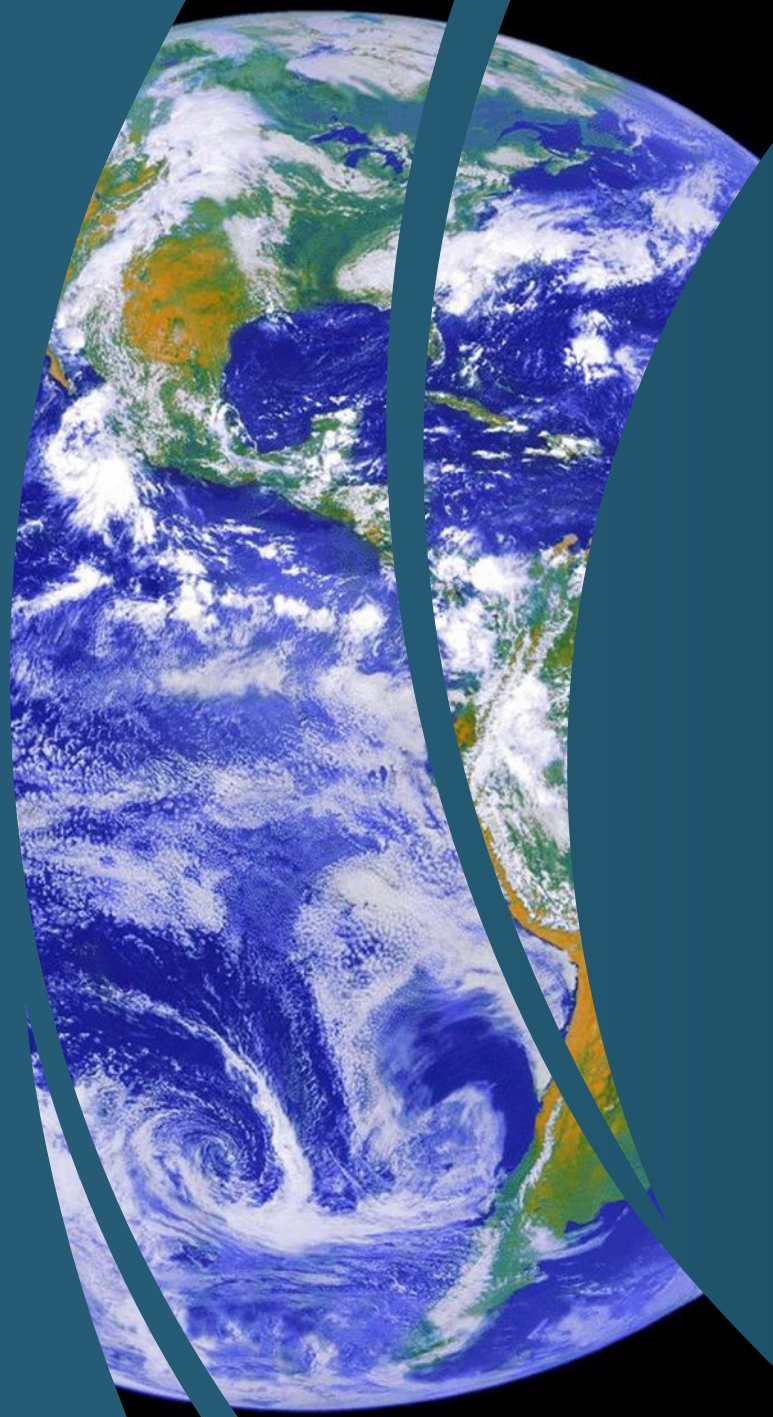
- Maintain portfolio balance
- Manage COVID-19 impacts

Execute Decadal with focus on innovation

- Decadal Survey progress & planning
- Innovation & industry engagement throughout the value chain

Achieve excellence through teamwork, diversity, and inclusivity

- Active inclusion and removal of barriers
- Accelerate discovery and use through Open Science
- National & International leadership and partnership



Deliver on Current Commitments

- Maintain portfolio balance
- Manage COVID-19 impacts
- Research and Applied Science highlights

Mission Execution

- Maintain rigor on mission implementation:
  - Develop and maintain clear, quantitative, and verifiable Level-1 science requirements and mission success criteria
  - Manage projects within agreed budgets and schedules

- For missions in operation:
  - Continue to operate safely and efficiently
  - Ensure maximum return from measurements and data products
  - Ensure the long-term integrity of the data records

- Maintain a balanced program across measurements and across mission generations

COVID-19 continues to be a challenge

NASA EARTH FLEET

OPERATING & FUTURE THROUGH 2023

SWOT (CNES)
LANDSAT-9 (USGS)
SENTINEL-6 Michael Freilich/B (ESA, EUMETSAT, NOAA)
TROPICS (6)
GEOCARB
NISAR (ISRO)
MAIA
PREFIRE (2)
TEMPO
TSIS-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
OCO-3
TSIS-1
ECOSTRESS
LIS
SAGE III

JPSS-2, 3 & 4 INSTRUMENTS

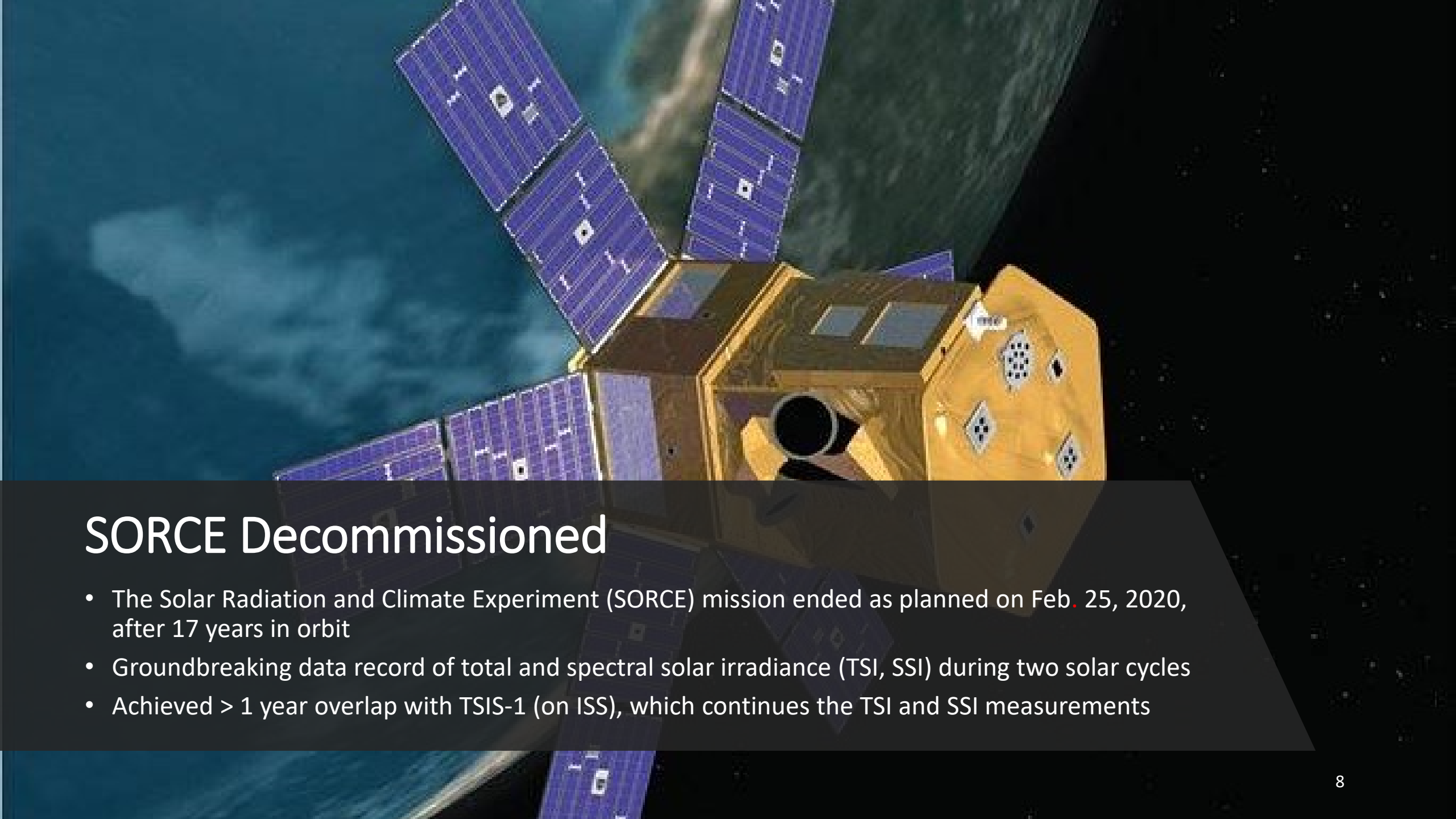
OMPS-Limb
LIBERA

11.02.20

INVEST/CUBESATS

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

(PRE) FORMULATION
IMPLEMENTATON
PRIMARY OPS
EXTENDED OPS
2020 Senior Review

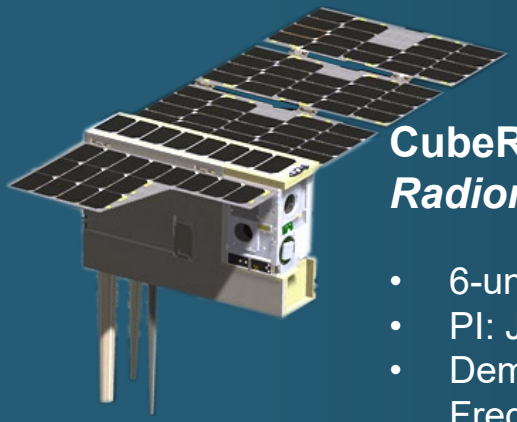


SORCE Decommissioned

- The Solar Radiation and Climate Experiment (SORCE) mission ended as planned on Feb. 25, 2020, after 17 years in orbit
- Groundbreaking data record of total and spectral solar irradiance (TSI, SSI) during two solar cycles
- Achieved > 1 year overlap with TSIS-1 (on ISS), which continues the TSI and SSI measurements

2020 Holidays Mark End for Two CubeSat Missions

- Thanksgiving 2020 - CubeRRT (CubeSat Radio Frequency Interference Radiometer Technology)
- Christmas 2020 – RainCube (Radar in a CubeSat)
- Both
  - Launched on May 21, 2018, from NASA's Wallops Flight Facility
  - Deployed from the ISS on July 13, 2018
  - Re-entered Earth's atmosphere after achieving their objectives to test and validate new technologies in space
  - Far exceeded estimates of endurance, stretching months of planned missions into over two years of operations

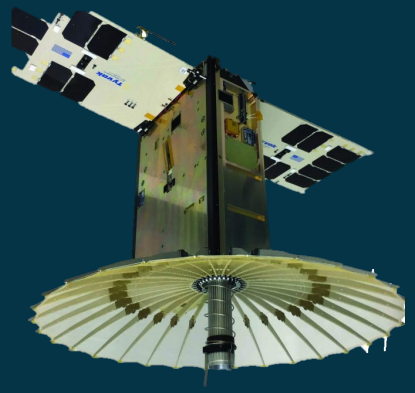


CubeRRT – *Removing Interference in Radiometric Signals*

- 6-unit CubeRRT CubeSat mission
- PI: Joel Johnson, Ohio State
- Demonstrated on-board, real-time Radio Frequency Interference (RFI) processing from space
- Response to passive microwave observations seeing increase in man-made interference, which corrupts geophysical retrievals in a variety of crucial science products
- Demonstrated these artificial signals could be effectively filtered out on board the spacecraft

RainCube – *Vertical Profiling of Precipitation*

- 6-unit RainCube CubeSat mission
- PI: Eva Peral, JPL
- Demonstrated the first radar instrument on a CubeSat
- Validated a new architecture for Ka-band precipitation radars & a new, ultra-compact, deployable antenna
- A constellation of RainCubes could provide the temporal resolution – minutes rather than hours – needed to model rapidly-evolving weather phenomena



Next Launch: Landsat 9

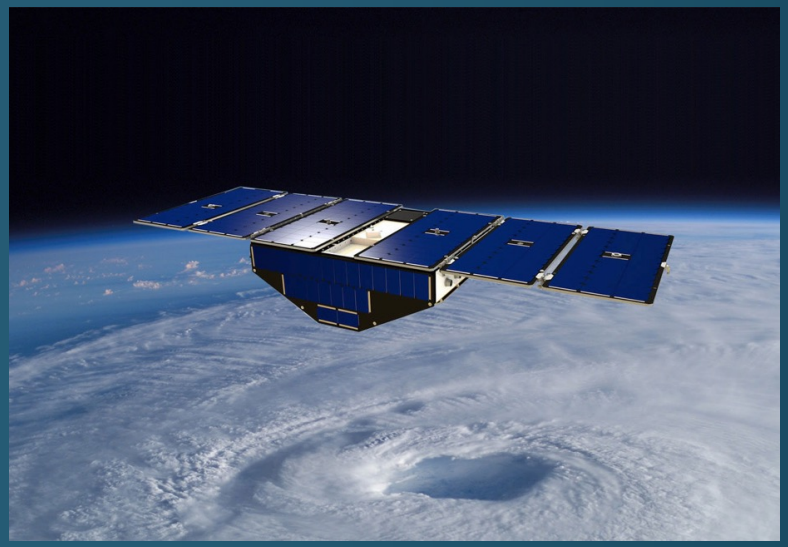
Designed and operated to repeatedly observe the global land surface at a moderate scale that shows both natural and human-induced change

USGS Partnership

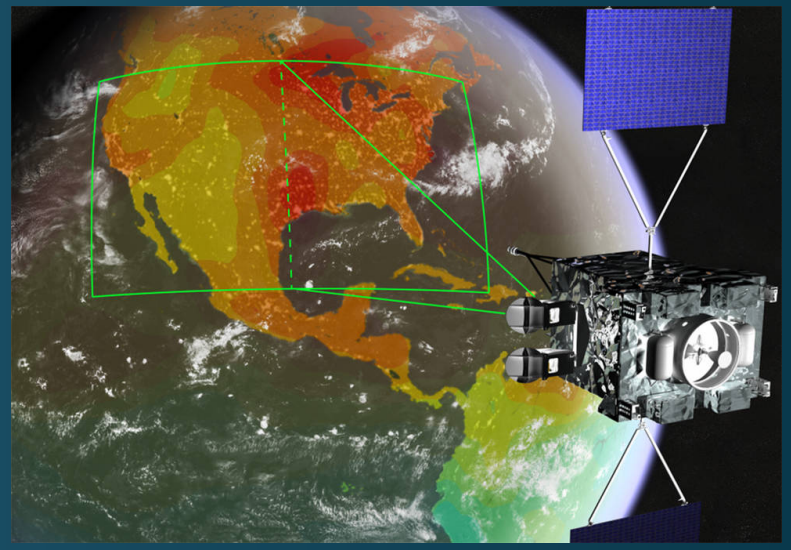
Launch in November 2021

Phytoplankton blooms in the Chukchi Sea, off the coast of Alaska, as seen by Landsat 8. (Image credit: NASA-USGS)

EVM-3 Announcement of Opportunity (AO)
Released Nov 18, 2020; proposals due *Mar 25, 2021*



EVM-1 (CYGNSS)



EVM-2 (GeoCarb)

?

EVM-3
&
NOAA
Operational Enhancement
Opportunity

Earth Venture Suborbital-3 Selections

Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE)
Identify how aerosol particles change cloud properties in ways that affect Earth's climate system.

- Initial deployment completed in 2020, remaining deployments delayed to FY 2022/23 due to COVID-19

Dynamics and Chemistry of the Summer Stratosphere (DCOTSS)
Investigate how strong summertime convective storms over North America can change the chemistry of the stratosphere.

- Initial deployment completed in 2020, remaining deployments delayed to FY 2021/22 due to COVID-19

Delta-X
Improve understanding of the natural processes that maintain and build land in major river deltas threatened by rising seas, with a focus on the Mississippi delta.

- Initial deployments delayed to FY 2021 due to COVID-19

Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS)
Improve understanding of the mechanisms of snow band formation and the factors that influence the location of the most intense snowfall with flights over the northeastern United States.

- Initial deployments delayed to FY 2021 due to COVID-19

Submesoscale Ocean Dynamics Experiment (S-MODE)
Explore the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere, with measurements collected by aircraft and shipborne instruments off the coast of San Francisco.

- Initial deployments delayed to FY 2021 due to COVID-19

Earth Venture Opportunities & Challenges

Mission	Mission Type	Release Date	Selection Date	Major Milestone
EVS-1 (EV-1) (AirMoss, ATTREX, CARVE, DISCOVER-AQ, HS3)	5 Suborbital Airborne Campaigns	2009	2010	Completed KDP-F
EVM-1 (CYGNSS)	Class D SmallSat Constellation	2011	2012	Launched Dec. 2016
EVI-1 (TEMPO)	Class C Geostationary Hosted Instrument	2012	2012	Delivered to storage Dec. 2018
EVI-2 (ECOSTRESS & GEDI)	Class C & Class D ISS-hosted Instruments	2013	2014	Launched June & Dec. 2018
EVS-2 (ACT-America, ATOM, NAAMES, ORACLES, OMG, CORAL)	6 Suborbital Airborne Campaigns	2013	2014	CORAL, NAAMES, ORACLES completed KDP-F
EVI-3 (MAIA & TROPICS)	Class C LEO Hosted Instrument & Class D CubeSat Constellation	2015	2016	Delivery NLT 2021
EVM-2 (GeoCarb)	Class D Geostationary Hosted Instrument	2015	2016	Launch ~2022
EVI-4 (EMIT & PREFIRE)	Class C ISS-hosted Instrument & Class D Twin CubeSats	2016	2018	Delivery NLT 2021
EVS-3 (ACTIVATE, DCOTTS, IMPACTS, Delta-X, SMODE)	5 Suborbital Airborne Campaigns	2017	2018	Passed Initial Confirmation Review, 2 began deployments
EVI-5 (GLIMR)	Class C Geostationary Hosted Instrument	2018	2019	Delivery NLT 2024
EVC-1 (Libera**)**	Class C JPSS-Hosted Radiation Budget Instrument	2018	2020	Delivery NLT 2025
EVM-3	Full Orbital	2020	2021	Launch ~2026
EVI-6	Instrument Only	2021	2022	Delivery NLT 2027
EVC-2	Continuity Measurements	2022	2023	Delivery NLT 2028
EVS-4	Suborbital Airborne Campaigns	2023	2024	N/A
EVI-7	Instrument Only	2024	2025	Delivery NLT 2030
EVM-4	Full Orbital	2024	2025	Launch ~2030
EVC-3	Continuity Measurements	2025	2026	Delivery NLT 2031
EVS-5	Suborbital Airborne Campaigns	2027	2028	N/A

EVS
Sustained sub-orbital investigations
(~4 years)

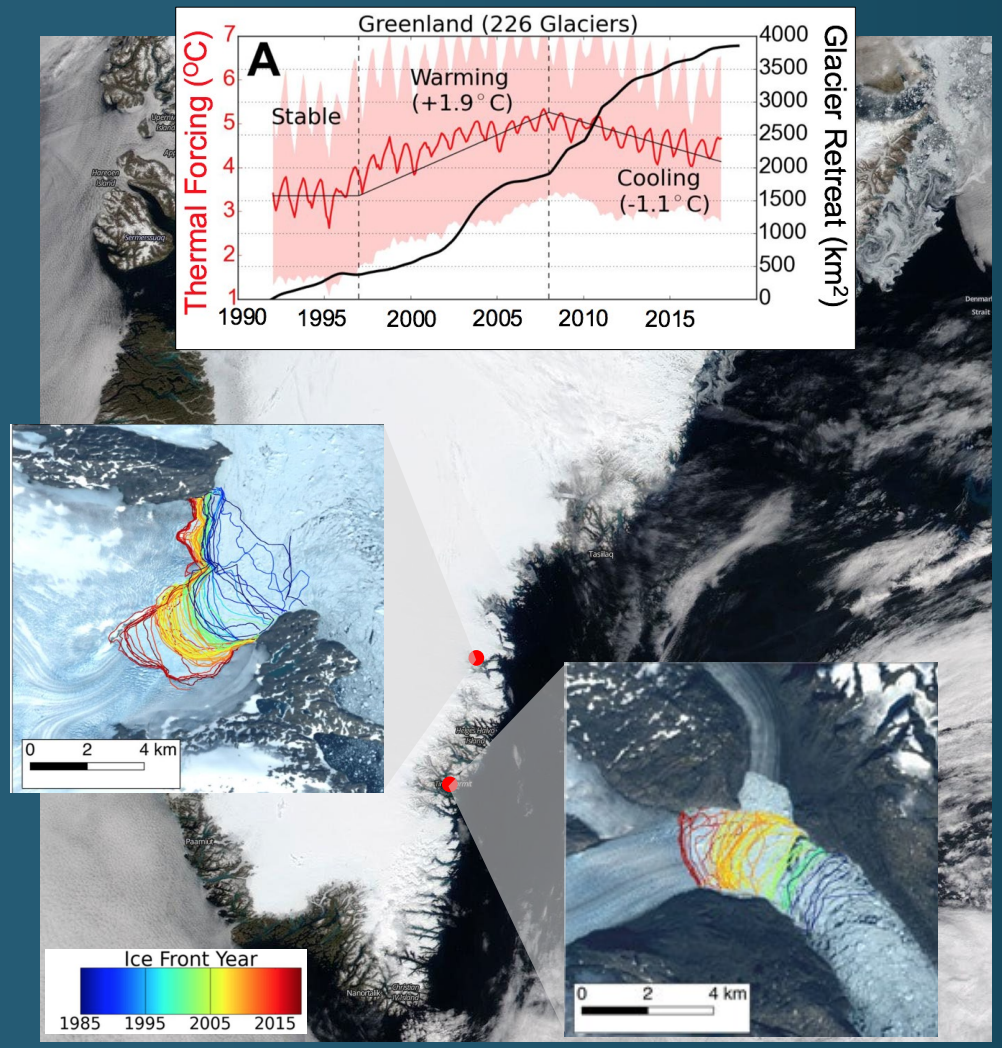
EVM
Complete, self-contained, small missions
(~4 years)

EVI
Facility-class instruments flown as Missions of Opportunity (MoOs)
(~3 years)

EVC
Complete missions or hosted instruments targeting "continuity" measurements
(~3 years)

Major market shift in GEO hosting has left two missions, TEMPO and GeoCarb, facing significant increased cost

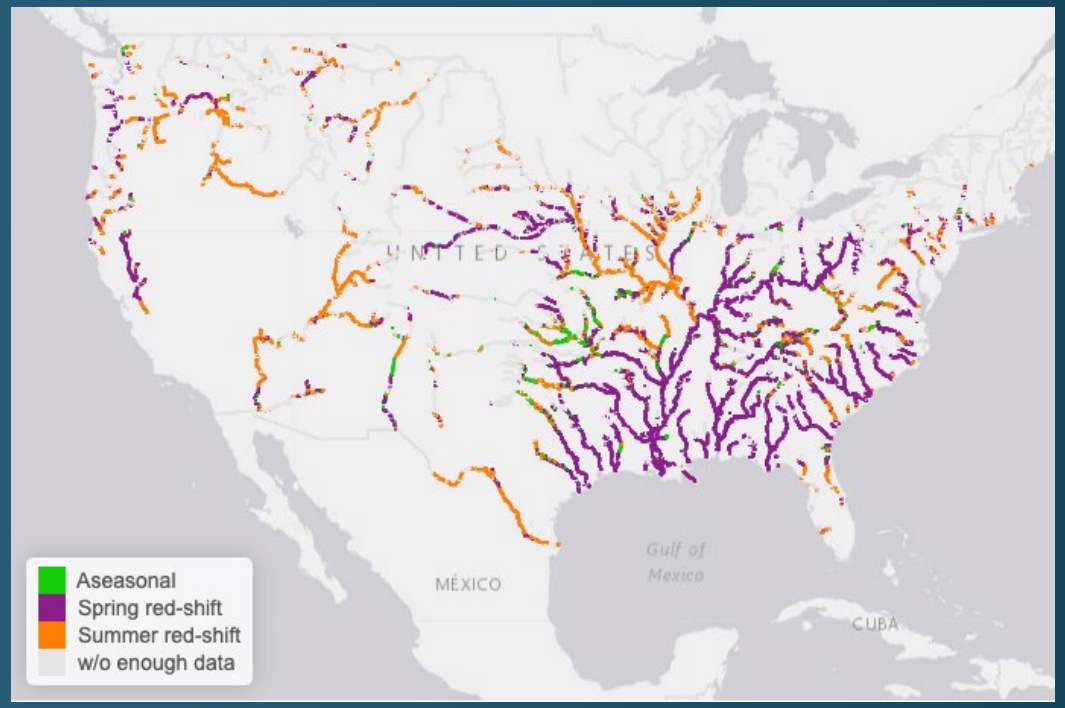
OMG: Ocean Warming Drives Greenland Glacier Retreat



- Multi-year measurements from Oceans Melting Greenland (OMG)
- Role of ocean warming in ice sheet dynamics below the surface
  - Warming indicated by average ocean temperature below 200m
- Ice sheet loss linked from “undercutting”
  - Warm, salty water at bottom of fjords melts the base of a glacier, causing ice above to break apart
  - Changes loss estimates by at least a factor of 2
  - Most significant in deep fjords
- “Memory” in the system
  - Ocean warming paused in 2008–2017, but the net ice discharge from Greenland glaciers kept increasing, ice fronts kept retreating, and rate of undercutting remained higher than in the previous decade

Wood, M., et al. (2021). Ocean forcing drives glacier retreat in Greenland. *Science Advances*, *7*(1), https://doi.org/10.1126/sciadv.aba7282

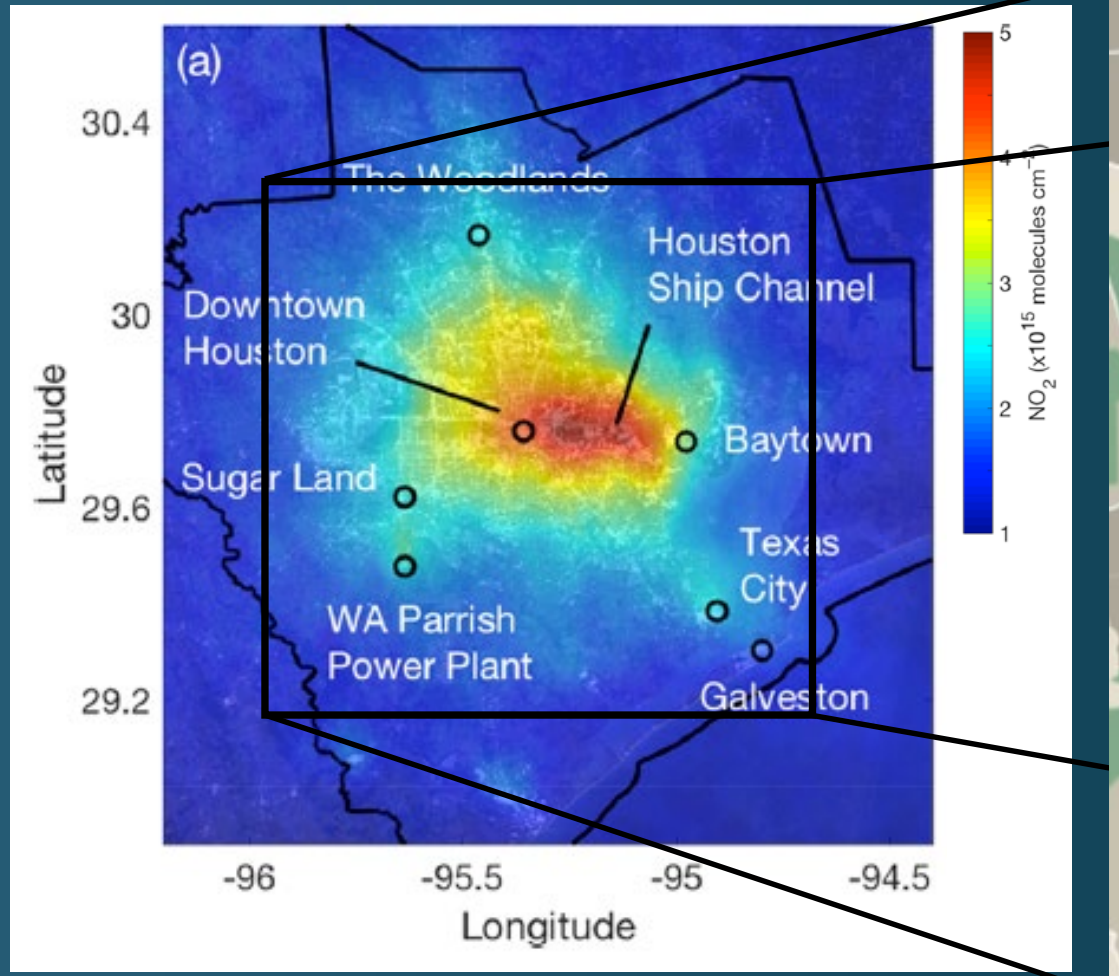
Color of U.S. Rivers is Changing

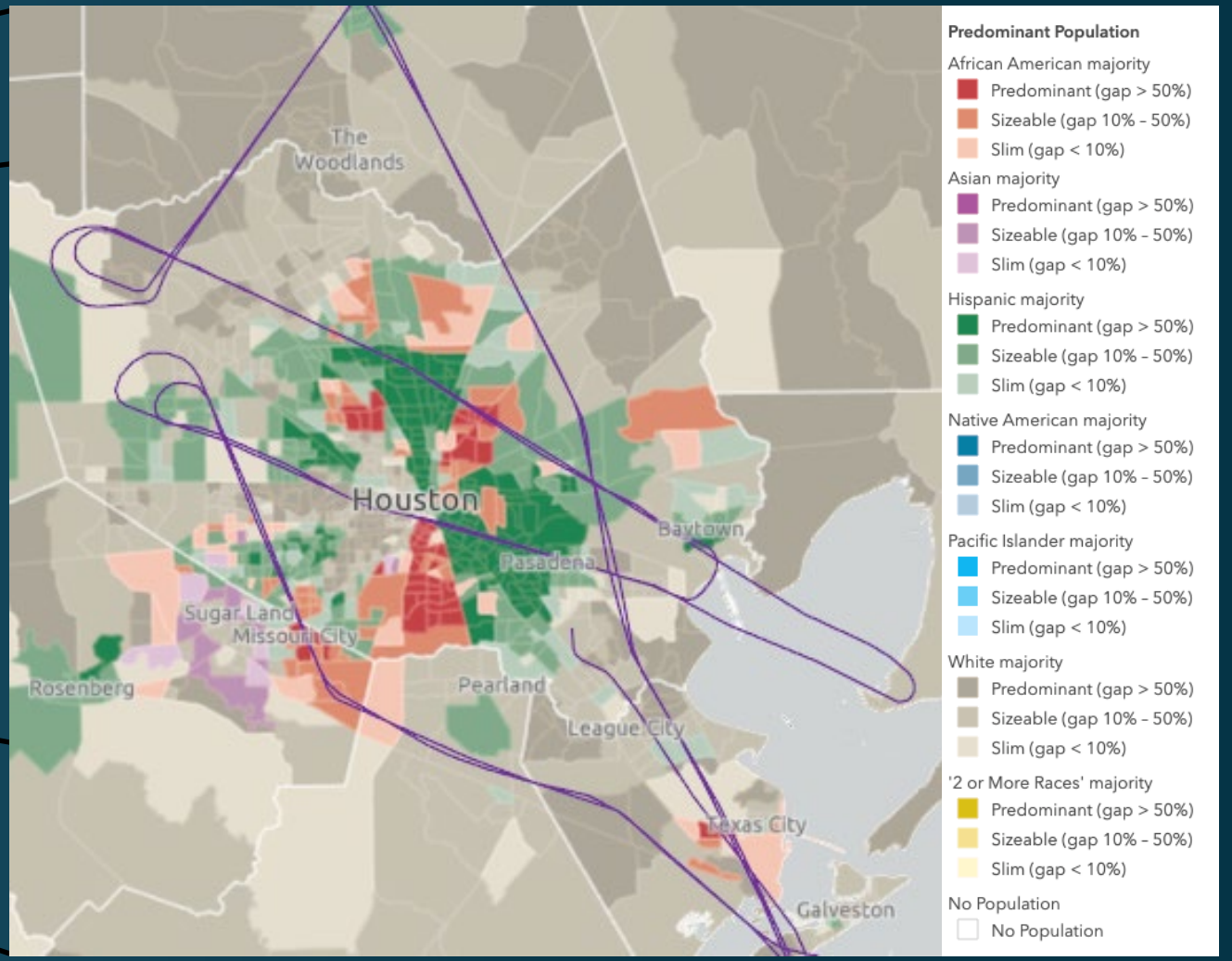


- First map of U.S. river color from river surface reflectance between 1984-2018 from Landsat imagery
- Colors such as blues, greens, browns, and yellows, linked to water quality
  - Related to the amount of sediment, algae, and dissolved organic carbon in water
  - Three seasonal patterns identified
- River color can indicate rivers and drain basin land-areas are undergoing rapid environmental change
  - River flow
  - Land use
  - Watershed management
- **One third** of U.S. rivers had significant color shifts over the last 35 years
  - Hotspots often located near dams and urban areas

Gardner, J. R., Yang, X., Topp*, S. N., Ross, M. R. V., Altenau, E. H., & Pavelsky, T. M. (2021). The color of rivers. *GRL*, *48*(1), https://doi.org/10.1029/2020GL088946
*funded via NESSF (now FINESST)

Pollution Disproportionately Impacts Low-Income, Non-White, and Hispanic Neighborhoods in Houston, TX





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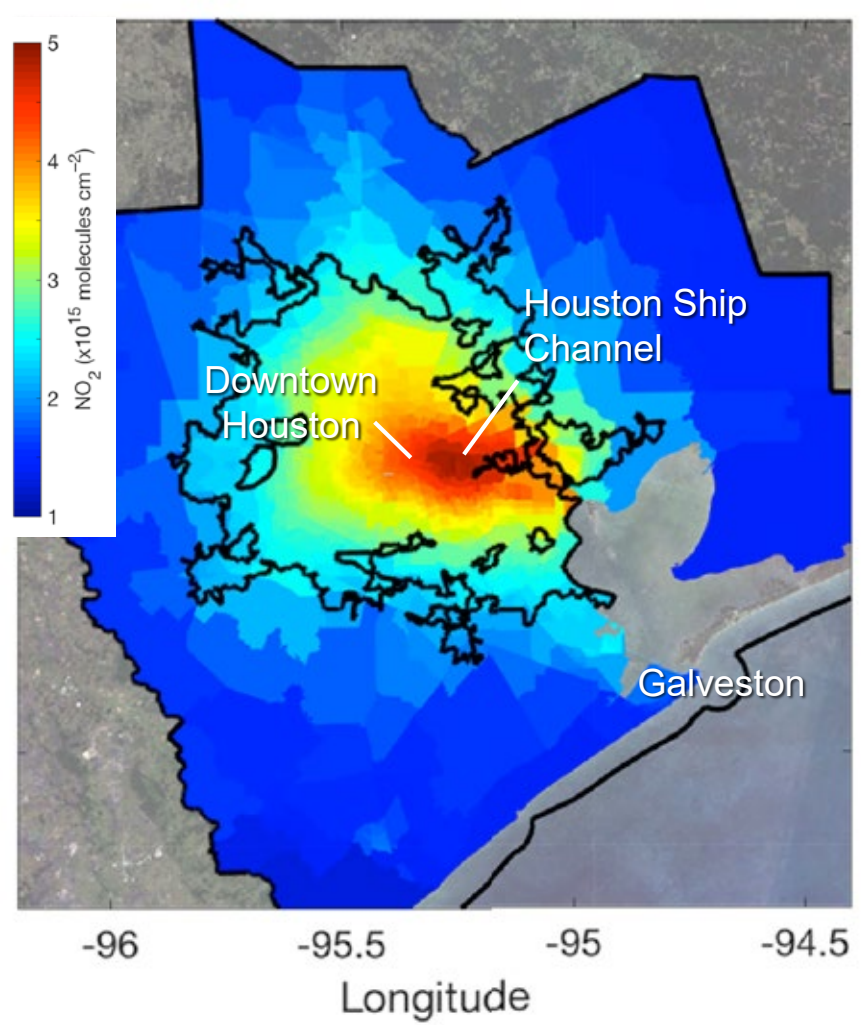
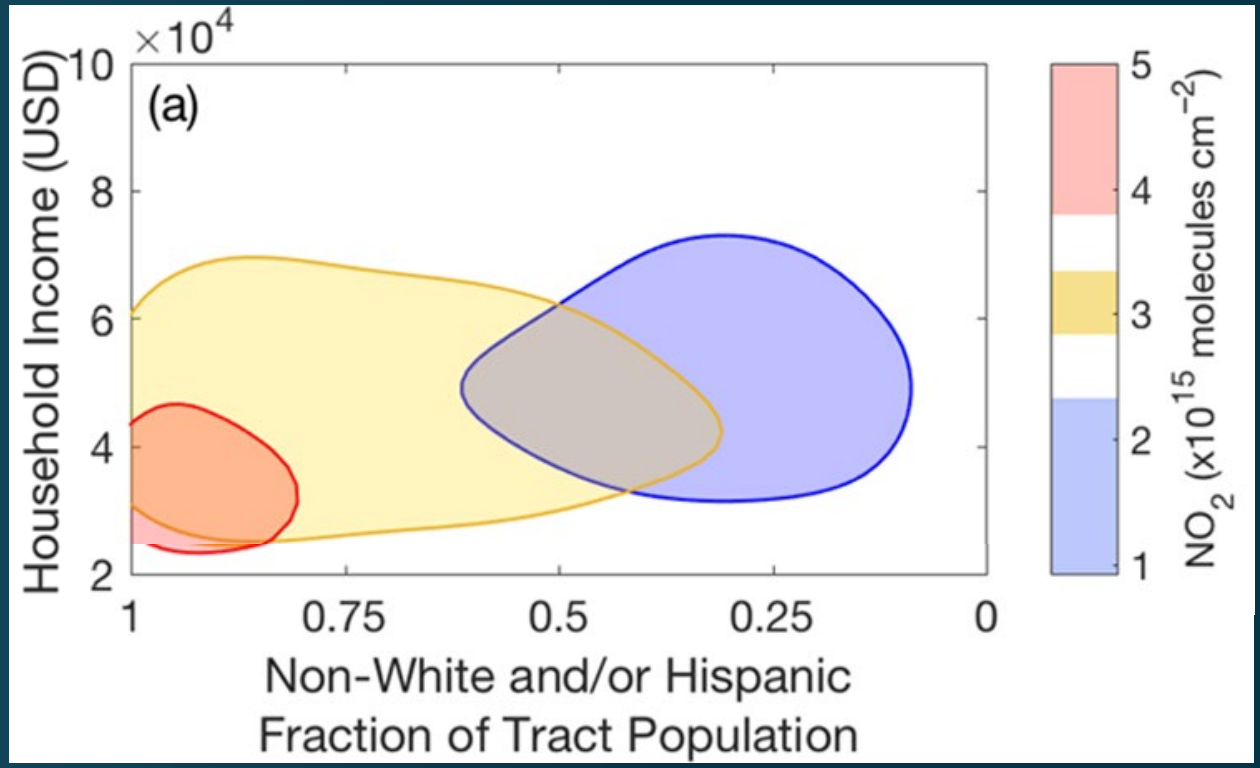
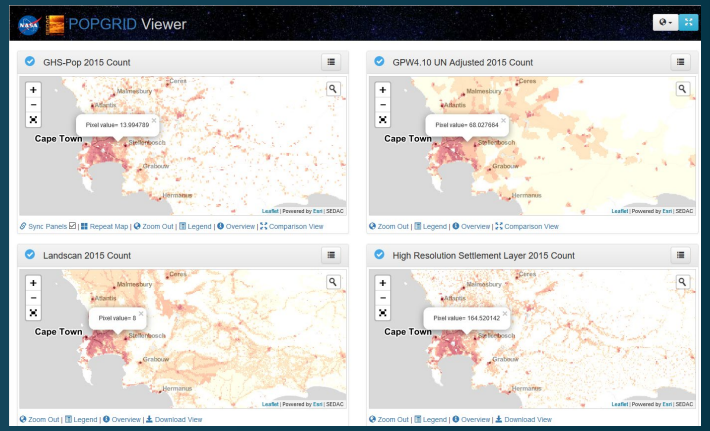




Demetillo**, M. A. G., Navarro, A., Knowles, K. K., Fields, K. P., Geddes, J. A., et al (2020). Observing nitrogen dioxide air pollution inequality using high-spatial-resolution remote sensing measurements in Houston, Texas. *Environmental Science & Technology, 54*(16), 9882–9895. https://doi.org/10.1021/acs.est.0c01864 **FINESST proposal

LAUNCH OF THE

Earth Observations Toolkit for SUSTAINABLE CITIES AND HUMAN SETTLEMENTS



POPGRID VIEWER

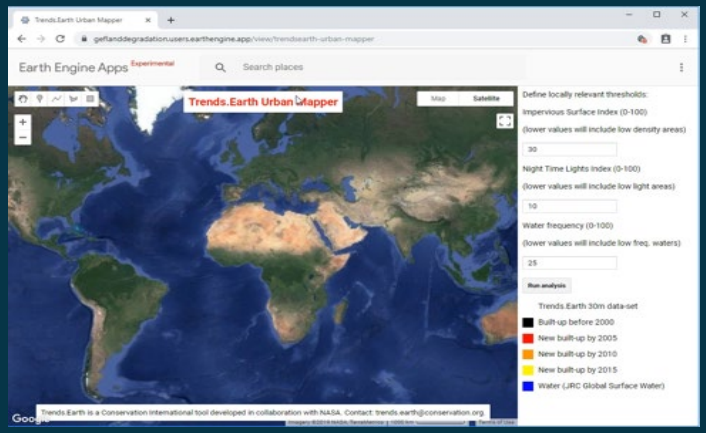
Enables direct comparison of different population datasets for user-defined areas of interest

PURPOSE

- Make urban-related EO data and tools easy to find and use
- Put EO data and tools into context for analysts and decision makers
- Facilitate knowledge sharing, skill-building, and collaboration among local communities, cities, countries, and EO experts

TRENDS.EARTH

Allows users to track changes in urban extent and estimate the ratio of land consumption rate to population growth rate



- ✓ More than 25 data sets
- ✓ More than 10 interactive tools
- ✓ Over 10 uses cases
- ✓ Directory of EO experts, city and country POCs
- ✓ Contribute and feedback forms

LAUNCHED AT A SIDE EVENT AT THE UNITED NATIONS STATISTICAL COMMISSION ON FEBRUARY 25, 2021
https://2o4.short.gy/SDGgeospatial

VISIT: https://eo-toolkit-guo-un-habitat.opendata.arcgis.com

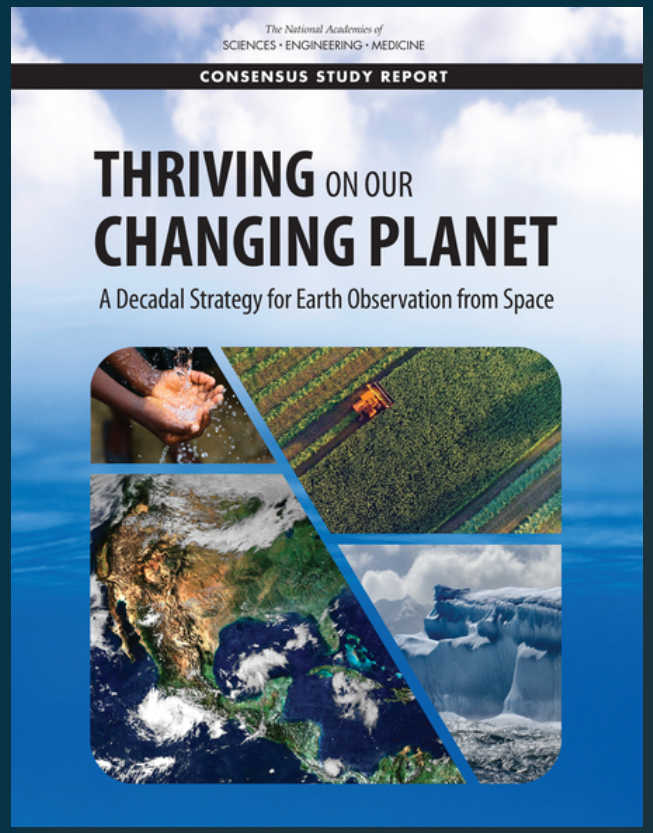
Decadal Execution & Innovation

Decadal Survey progress & planning

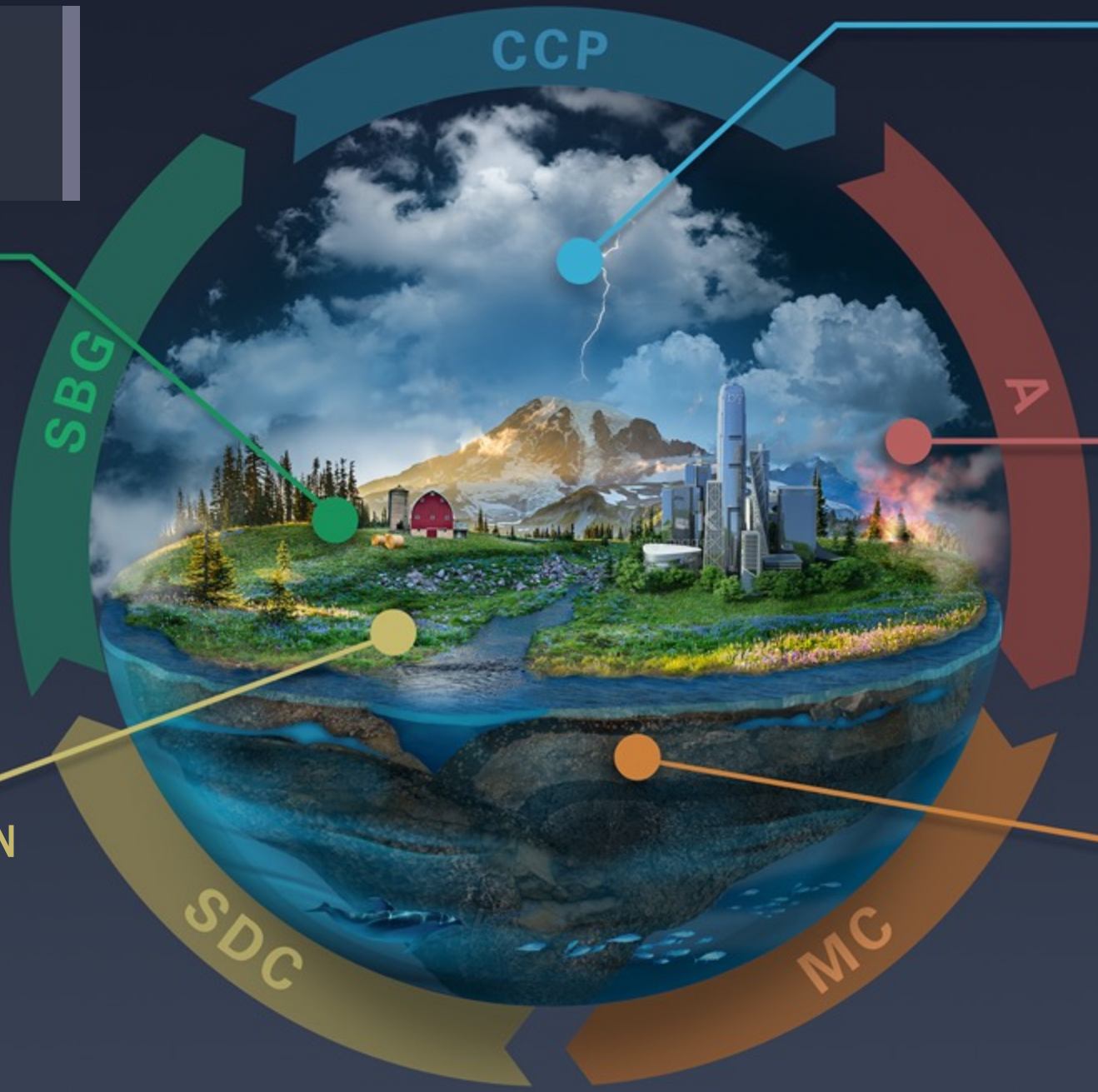
Innovation & industry engagement

2017 Decadal Survey – An Ambitious Vision

- Key recommendations
  - Innovate and amplify cross-benefits of science & applications
  - Leverage partnerships
  - Institute programmatic agility & balance
  - Expand competition
- Implement and innovative observing program
  - Designated Observables – *Essential*
  - Earth System Explorer – *Priority; competitive*
  - Earth Venture – *Innovation; expand for affordable Continuity*
  - Incubation – *Plant seeds for the future*



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

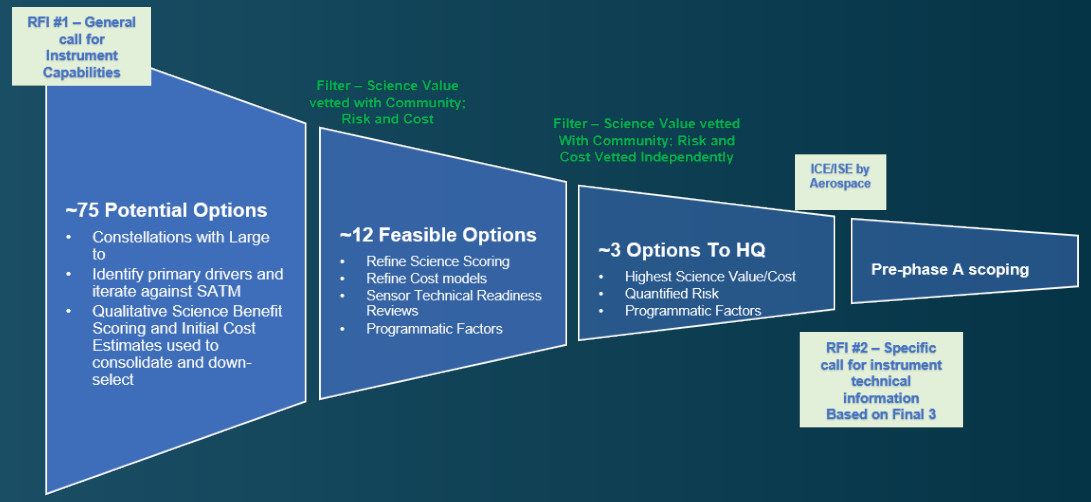
Earth Surface & Ecosystems

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics

Designated Observables Progress

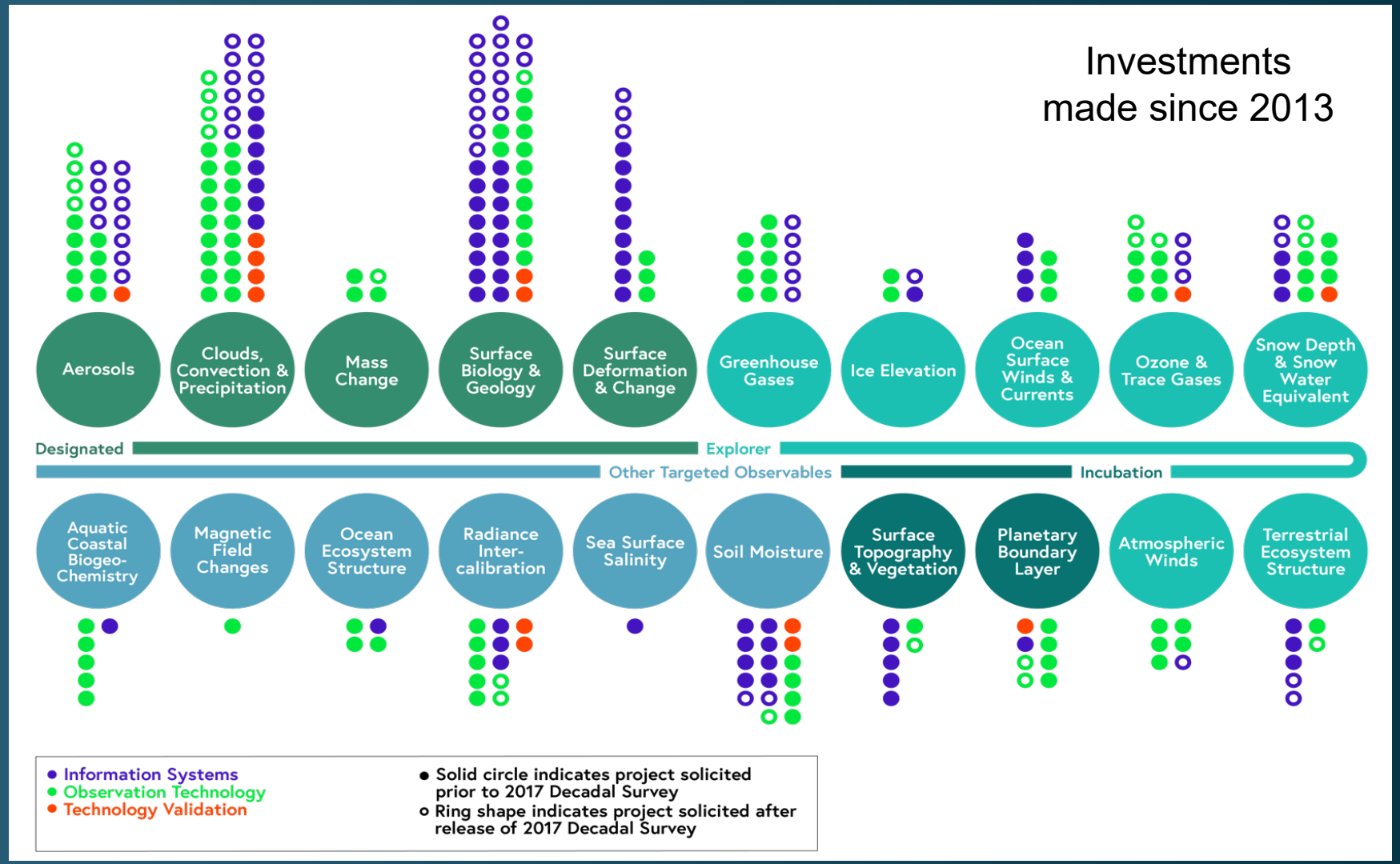
- Development of mission options and analyses by strong, multi-center teams
- Industry engagement, RFIs, and funded studies
- Community engagement
- Exploring range of international partnerships
- Preliminary cost analysis for U.S. elements
- Cross-cutting Data and Open Science strategy



NASA Principles to Initiate Decadal Observables Programs

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

Technology Investments Position NASA for Success



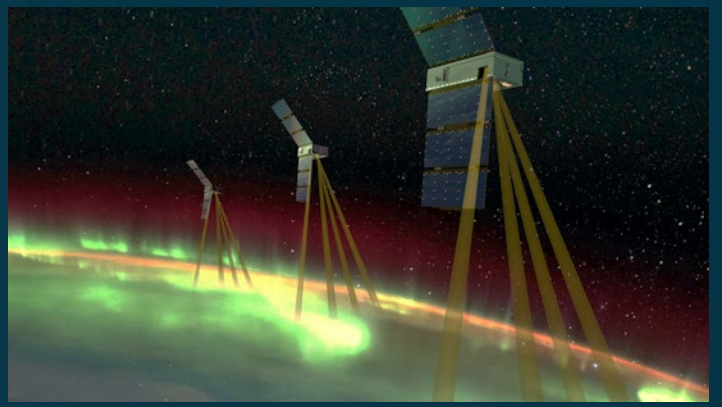
NOAA engagement:

- Quarterly discussions
- ~150 projects reviewed
- ~25 of interest to NOAA
- 4 direct discussions for augmentation by NOAA

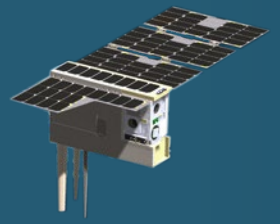
Earth Science Technology Heritage in New Heliophysics Mission!!!

Heliophysics selected Electrojet Zeeman Imaging Explorer (EZIE) mission

- **E**xploring electric currents in Earth's atmosphere that link the aurora to the magnetosphere
- Led by the Johns Hopkins Applied Physics Lab
- EZIE will comprise three CubeSats flying in formation and carrying payloads containing millimeter radiometers with high-resolution digital spectrometers



Above: Artist's conception the three EZIE CubeSats flying in formation. Below: Artists' impression of an EZIE satellite. (Credit: JHU-APL)



The analog front ends of the EZIE radiometers are derived directly from the **TEMPEST-D** (TEMPoral Experiment for Storms and Tropical systems–Demonstration, PI: Steven Reising, Colorado State) CubeSat, an Earth Venture Instrument launched in May 2018 to demonstrate observations of cloud and precipitation processes.

The digital backends were developed for use on the **CubeRRT** (CubeSat Radio Frequency Interference Radiometer Technology, PI: Joel Johnson, Ohio State) CubeSat, which also launched in May 2018 and demonstrated on-board, real-time Radio Frequency Interference (RFI) processing from space.

The overall digital design is based on early work on an Agile Digital Detector by Chris Ruf at the University of Michigan (who is also serving as the EZIE Deputy Project Scientist), through a 2004 award under the Instrument Incubator Program that has enjoyed widespread infusion, including by the **Hurricane Imaging Radiometer (HIRAD) airborne** instrument.

The EZIE mission also will benefit from the expertise of two other former and current ESTO investigators: Jeng-Hwa (Sam) Yee and Bill Swartz of Johns Hopkins Applied Physics Lab will serve as EZIE Principal Investigator and Mission Implementation Lead, respectively.

Commercial Satellite Data Acquisition

This image of sea ice in the Gulf of Bothnia off the coast of Lulea, Sweden was taken on April 26, 2013 by the Planet Labs Dove 2 satellite.

- Awarded contracts to three companies for pilot activity: Digital Globe (now Maxar), Planet, and Spire
- Pilot extremely successful; transitioned to the Commercial SmallSat Data Acquisition Program
- Released second RFI (October 2019) to onramp qualified vendors; anticipate contracts to be awarded in June 2021.
- Third RFI to on-ramp a third batch of vendors closed January 2, 2021; contract awards anticipated in Fall 2021
- Released Commercial SmallSat Data Analysis solicitation (ROSES A.42)
- Data licensing remains problematic; coordinating with U.S. Government Agencies to develop standardized scientific licenses; discussions are ongoing

Foundations & Philanthropies

Some insights to date:

- Philanthropies are not as aware of current extent of Earth-observing capabilities (most familiar with optical imagery)
- Concerns around privatization of data, ownership, access
- Some are starting to move upstream from applications to technology and missions
- Low awareness of central importance and full capabilities of Earth system science
- Philanthropies interested in complementing ESD with means and approaches available to them
- Philanthropies are curious about key research questions needing added funding to understand Earth as a system

Currently exploring opportunities with

Achieve Excellence Through Teamwork, Diversity & Inclusivity

Active inclusion and removal of barriers

Accelerate discovery and use through Open Science

National & international leadership & partnership

ESD Diversity and Inclusion Task Force

The Goal:

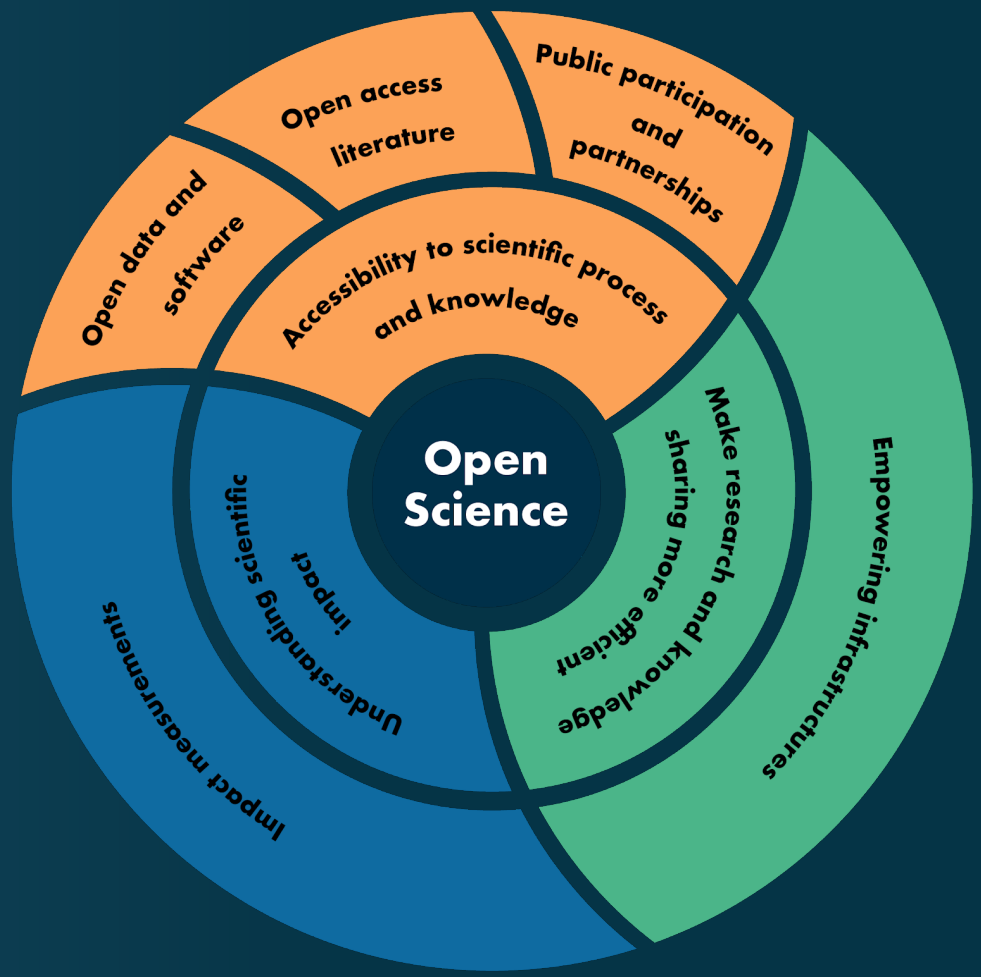
- Build a diverse, equitable, inclusive, and accessible environment for marginalized communities within the Earth science community

The Work:

- Identify the most effective and *impactful actions* that can be directly undertaken within and to 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 the specific actions we can take to grow
- Champion Dual Anonymous Peer Review and other measures to *address any bias* in our panel review process
- Further expand upon current footprint with STEM partnerships and *increase participation* with Historically Black Colleges and Universities (HBCUs) and other Minority Serving Institutions (MSIs)
- *Highlight and amplify* the accomplishments of our diverse NASA scientists and researchers to encourage a more diverse generation of STEM professionals

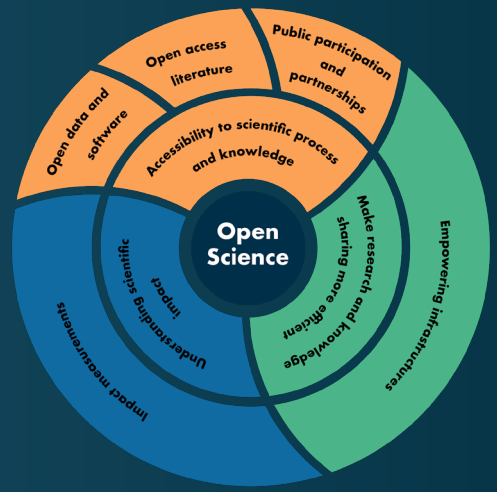
Develop Open Science Ecosystem

- *Shorten the time* it takes for a new user to find and learn how to use data
  - Open access, availability, and discoverability of data
- *Increase the community* of hands-on contributions
  - Open access to and advancement of modeling and simulation code
  - To improve models, assimilation, and prediction tools
- *Explore and exploit data* in new ways
  - Share knowledge and use current informatics and data science tools, in the same ecosystem as the data
- *Incentivize and energize* innovation through prizes and challenges



NASA-NOAA Data & Open Science Collaborations

- Common Metadata Repository Pilot
- Data Expedition Platform
- Google AI partnership via OTA
- Commercial data buys



- Data dissemination
- Direct broadcast

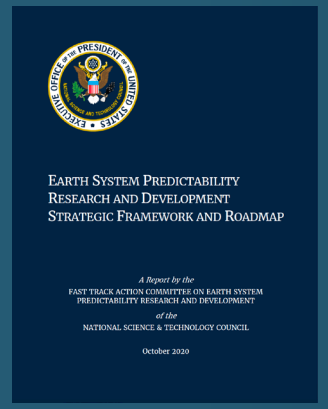
NASA Chairing Committee on Earth Observation Satellites in 2021

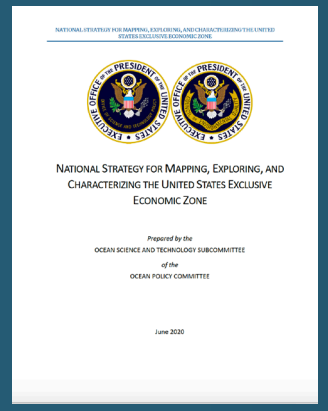
- CEOS Mission: International coordination of civil space-based Earth observation for societal benefit and informed decision making
  - Consortium of 61 international agencies operating 172 satellites worldwide.
  - Now in its third decade, CEOS is a dynamic international forum
  - 2021 Theme: “Space-based Earth Observation Data for Open Science and Decision Support.”
    - Theme amplified by Group on Earth Observations (GEO)
    - Work plan in place

CEOS Committee on Earth Observation Satellites

ESD Role in Interagency Activities

- Recent additions beyond USGCRP/SGCR, OST, IARPC, and USGEO, include:





- Fast Track Action Committee on Earth System Predictability: NASA provided one of three co-chairs for overall committee and members of writing teams developing plan; public-facing report released in October. Multiple NASEM activities held. NASA released RFI for community input.
- National Ocean Mapping, Exploration, and Characterization Council: Established to help implement the new National Strategy for Mapping, Exploring, and Characterizing the United States Exclusive Economic Zone (report released in June). NASA has representatives on two subgroups (Ocean & Coastal Mapping, Ocean Exploration; and Characterization).
- Interagency Council for Advancing Meteorological Services (ICAMS): Established in response to the 2017 Weather Research and Forecasting Innovation Act of 2017, including establishment of four committees (Observational Systems, Cyber, Facilities, and Infrastructure, Services, and Research and Innovation). NASA has members on all four and provides co-chairs for two (observations, research/innovation). Subcommittee structure is being developed and committee members are being named. ICAMS principals have met twice so far. An Interagency Meteorology Coordination Office (IMCO) will subsume the functions of the Office of the Federal Coordinator for Meteorology.
- Climate Security Advisory Council (CSAC): The Climate Security Advisory Council (CSAC) is a partnership between the U.S. Intelligence Community and the Federal Science community to better understand and anticipate the ways climate change affects U.S. national security interests and equities, and to help inform senior policymakers analyze short- and long-term risks and opportunities.

EO 14008
Addressing the Climate Crisis at Home and Abroad

Executive Order 14008: Addressing the Climate Crisis at Home and Abroad

Key sections of EO 14008 related to NASA Earth Science

At Home

Government-wide Approach to Climate Crisis

201. Alignment with general policy
203. National Climate Task Force: NASA now on TF
207. Possible connections with POWER
211. a. Office of Strategic Infrastructure addressing
     b. ESD support with information products
213. Support infrastructure and climate risk analysis
214. Coastal resilience
215. Civilian Climate Corps – Partnership opportunity
216. Conservation goal of 30% by 2030
217. Reducing methane emissions

219-223. Connections on Environmental Justice

Abroad

Climate in Foreign Policy & Natl. Security

102. Purpose

Numerous activities for ESD to support

f. SERVIR is part of USAID climate financing efforts with developing countries

g. SERVIR working REDD+ activities

103. Climate in Foreign Policy & National Security

a. SERVIR: Climate in strategies and implementation plans

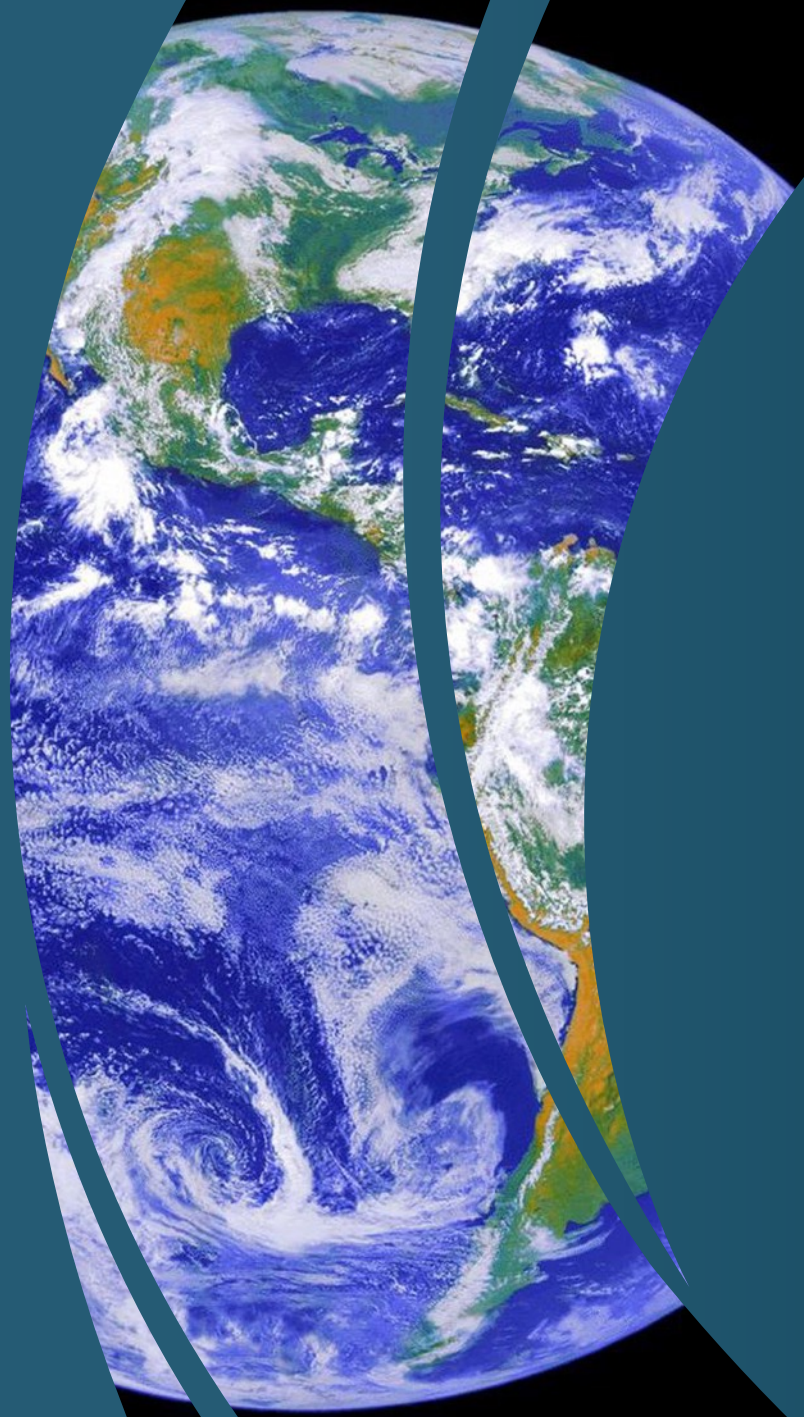
c. NASA is part of working group on security implications of climate change, including climate risk analysis

Supporting U.S. actions related to rejoining the Paris Climate Agreement

Leadership in the required Global Stocktake

- NASA, JAXA, ESA unique satellite-based GHG observations
- Other satellite assets (operational/research) for ocean/land biomass
- NOAA and international in situ (ground, aircraft) observations
- NOAA/OAR CarbonTracker (modeling) for data assimilation
- NASA-related modeling research
- Collaboration with Copernicus services
- Active engagement with WMO IG3IS activity and related international coordination

Concluding Remarks



Excellence in Earth Science

Deliver on current commitments

- Maintain portfolio balance
- Manage COVID-19 impacts

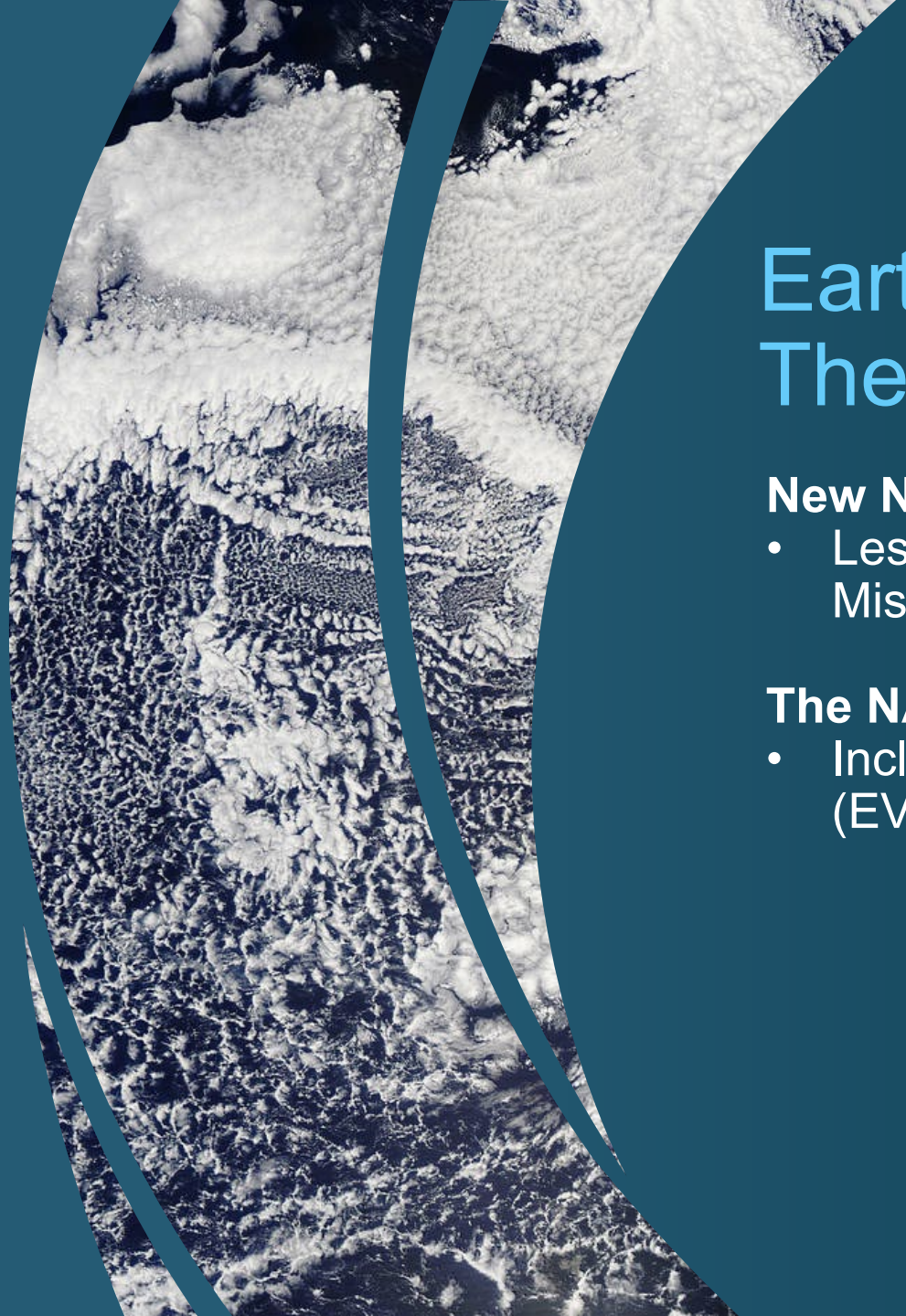
Decadal Execution & Innovation

- Decadal Survey Progress & Planning
- Innovation & Industry Engagement throughout the value chain

Achieve excellence through teamwork, diversity and inclusivity

- Active inclusion and removal of barriers
- Accelerate discovery and use through Open Science


EXPLORE EARTH
YOUR HOME, OUR MISSION
Questions?



Earth Venture Studies and The National Academies

New NASEM study:

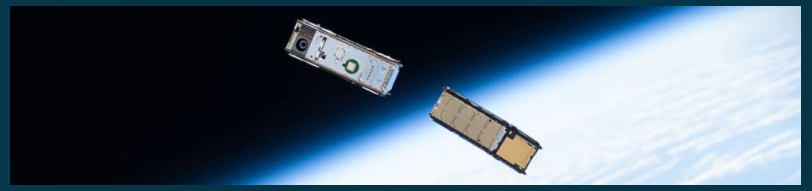
- Lessons-Learned in the Implementation of the Earth Venture Mission (EV-M) and Earth Venture Instrument (EV-I)

The NASEM mid-term study:

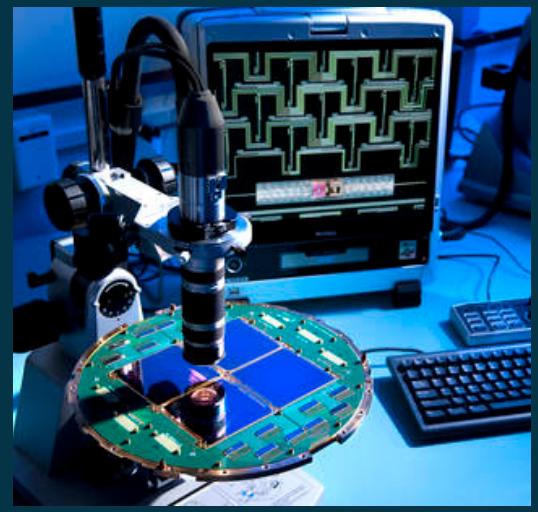
- Includes a focused review of the Earth Venture Suborbital (EV-S) program as specified in the 2017 Decadal Survey

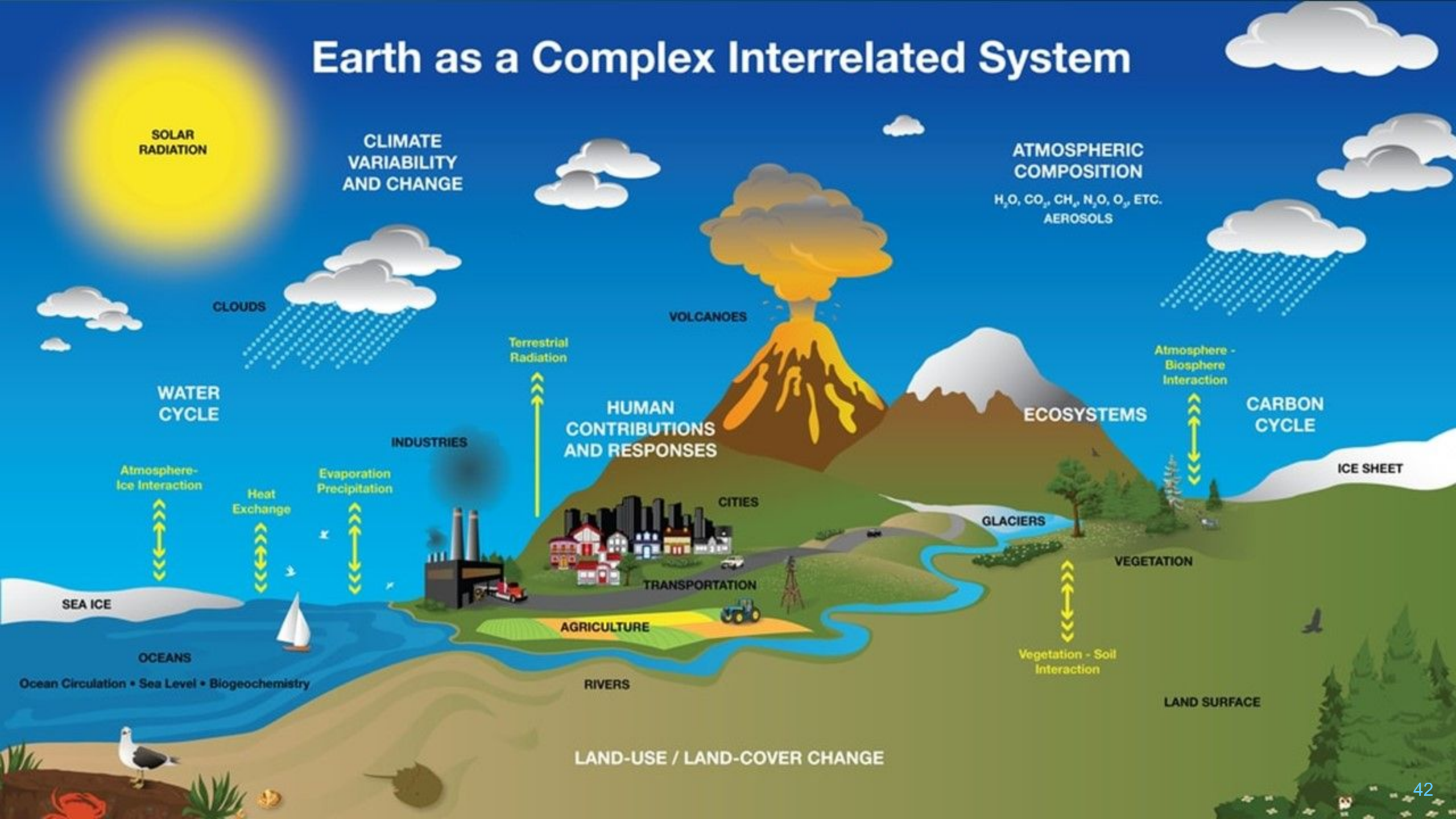
The National Academies of
SCIENCES · ENGINEERING · MEDICINE
Advising the Nation

Engaging Private Sector in Future System Planning



- SmallSat/CubeSat Constellations have been awarded and underway
- Payload hosting on Commercial Satellites have been awarded and underway
- Data Processing/Data Storage/Cloud Computing contracts have been awarded and underway
- Out-of-the-box enabling commercial technologies have been awarded and underway
- Data buys under the Commercial Satellite Data Acquisition program.
- Planning on an increase in competed, Principal Investigator (PI)-led missions via the Earth Science Explorer Program to encourage better cost and schedule management, infuse new technologies, and contribute to workforce.
- Increased industry participation via competed approaches such as Announcements of Opportunities and Request for Proposals in the missions resulting from the Designated Observables Studies.
- Non-traditional stakeholders and partnerships, such as philanthropists, non-profits, and foundations




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

Applied Science

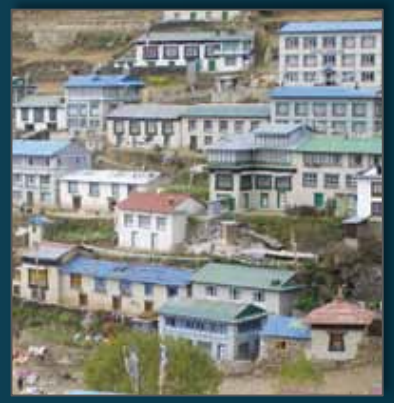
Science Mission Directorate
Earth Science Division

Applied Sciences

Program Elements:
Applications Areas and Capacity Building

Earth. Science. Action.

Agriculture



Capacity Building

Disasters

Ecosystems

Health & Air Quality

Water Resources

Space for US: NASA Applications at Work in Every State

Gold Awards from:

- MARCOM Awards for marketing and advertising.
- Academy of Interactive and Visual Arts

https://www.nasa.gov/SpaceforUS

OpenET Set to Launch in 2021

Web-based platform using NASA data on evapotranspiration (ET) to improve water management of agricultural crops and other plants

- Evapotranspiration: how water goes from land – from soil (evaporation) and plants (transpiration) – to the atmosphere

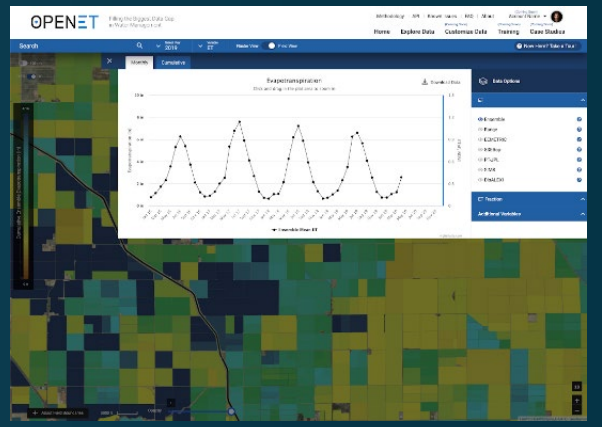
Publicly available data and open source models in areas as small as a quarter-acre at daily, monthly and annual intervals

OpenET will be available to the public next year, supplying data across 17 Western U.S. states

A project of NASA, the Environmental Defense Fund (EDF), the Desert Research Institute (DRI) and Google

OPENET

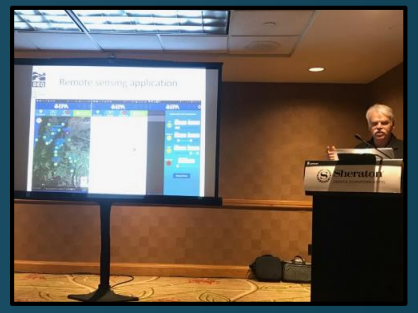
https://openetdata.org/

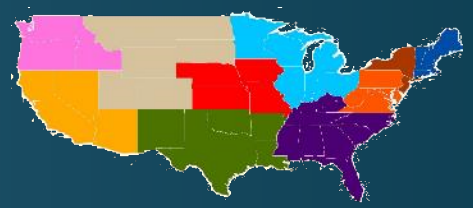


OpenET monthly report

Earth observations help U.S. state agencies monitor and respond to harmful algal blooms

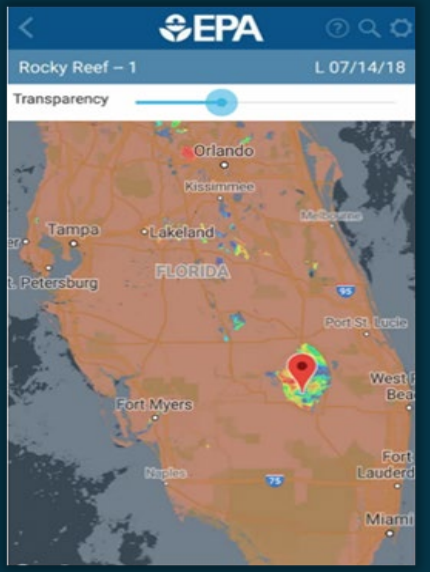
Partnership of US EPA, NASA, NOAA, USGS





CYANOBACTERIA ASSESSMENT NETWORK

Mobile App on Google Play – link



- Utah: Tracked harmful algal blooms (HABs) at two lakes; informed water sample collection, locations and analysis
- Wyoming: coordinated information for HAB advisory for various lakes/reservoirs and HAB action plan
- Oregon: coordinated information to avoid an intake shutdown/water advisory

- Uses satellite data for changes in color of water
- Alerts users that a harmful algal bloom could be forming
- Swimmers, pet owners, boaters, and others have water quality updates at their fingertips
- Supports more than 2,000 of the largest lakes and reservoirs across the United States.
- Users can drop pins in locations of interest (left)

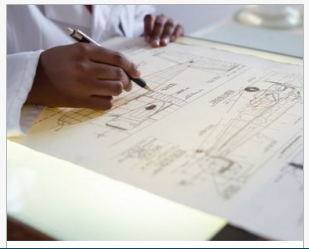
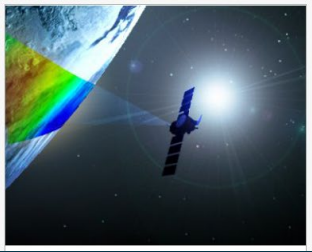
NASA International Space Apps Challenge 2020

- 5 space agencies (NASA, CSA, CNES, JAXA, ESA)
- 26,000+ registered participants
- ~150 countries/territories represented
- 2,300+ projects submitted
- Winners Announced January 27, 2021

NASA INTERNATIONAL SPACE APPS CHALLENGE

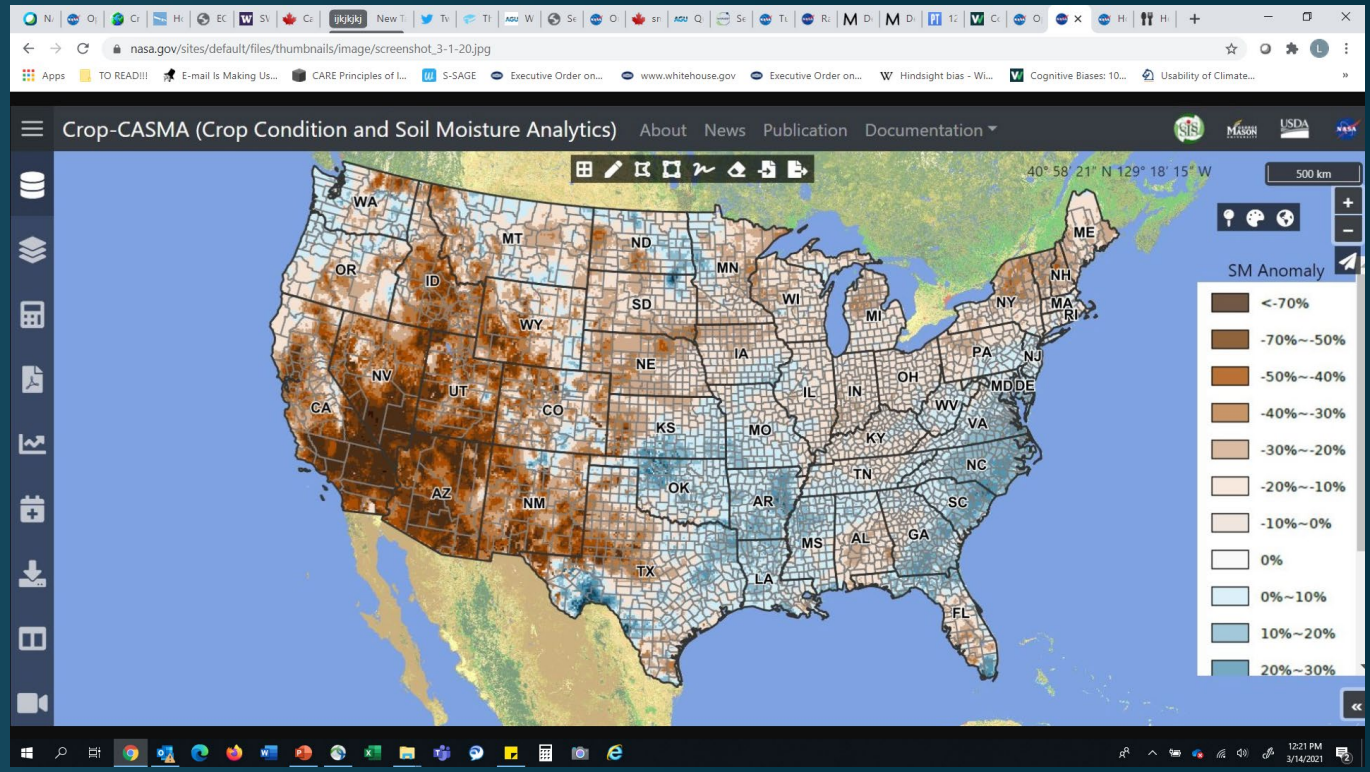
spaceappschallenge.org

Seven Categories:

Observe	Inform	Sustain	Create	Confront	Connect	Invent Your Challenge
						

New USDA Soil Moisture Portal: Providing Open Access to NASA Satellite Data

Placeholder:
Slide is in work



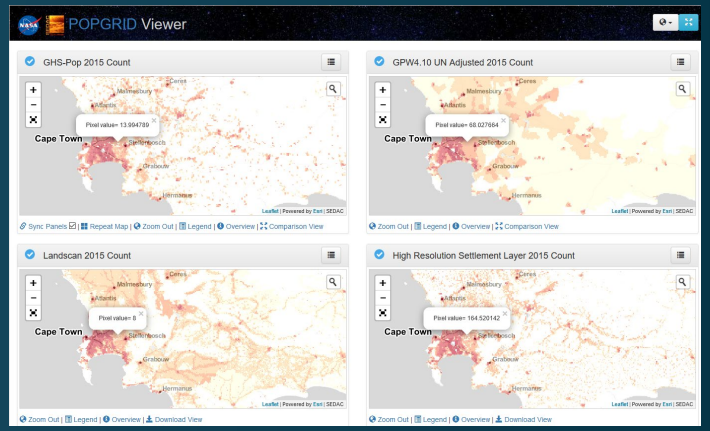
TOOLKIT LAUNCH

Earth Observations Toolkit for
SUSTAINABLE CITIES AND HUMAN SETTLEMENTS

PURPOSE

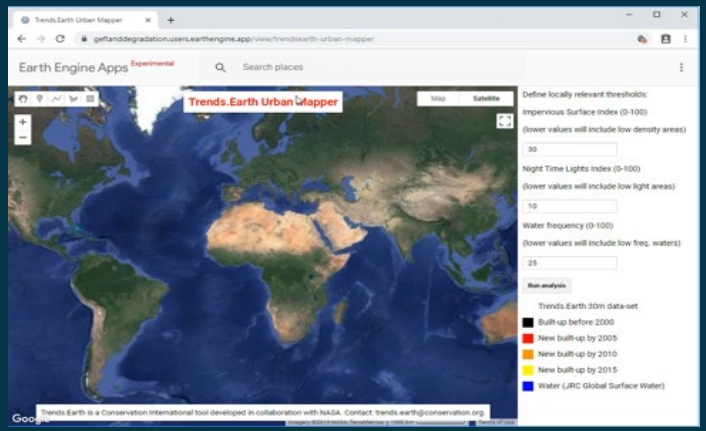
- Make urban-related EO data and tools easy to find and use
- Put EO data and tools into context for analysts and decision makers
- Facilitate knowledge sharing, skill-building, and collaboration among local communities, cities, countries, and EO experts

LAUNCHED AT A SIDE EVENT AT THE UNITED NATIONS STATISTICAL COMMISSION ON FEBRUARY 25, 2021
https://2o4.short.gy/SDGgeospatial



POPGRID VIEWER
Enables direct comparison of different population datasets for user-defined areas of interest

TRENDS.EARTH
Allows users to track changes in urban extent and estimate the ratio of land consumption rate to population growth rate



- ✓ More than 25 data sets
- ✓ More than 10 interactive tools
- ✓ Over 10 uses cases
- ✓ Directory of EO experts, city and country POCs
- ✓ Contribute and feedback forms

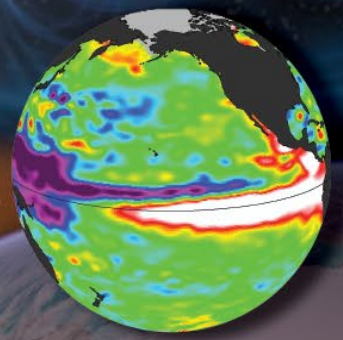
VISIT: https://eo-toolkit-guo-un-habitat.opendata.arcgis.com

Research & Analysis

National Aeronautics and Space Administration

Earth System Science

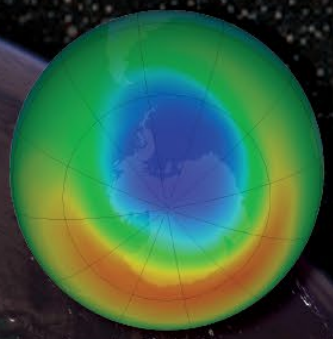
Climate Variability and Change



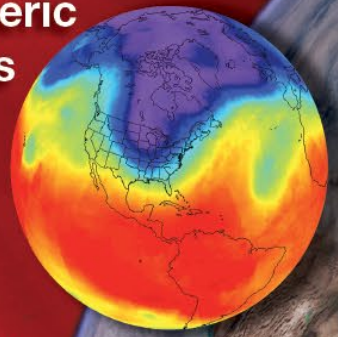
Carbon Cycle and Ecosystems

Earth Surface and Interior

Atmospheric Composition



Weather and Atmospheric Dynamics



Water and Energy Cycle

www.nasa.gov

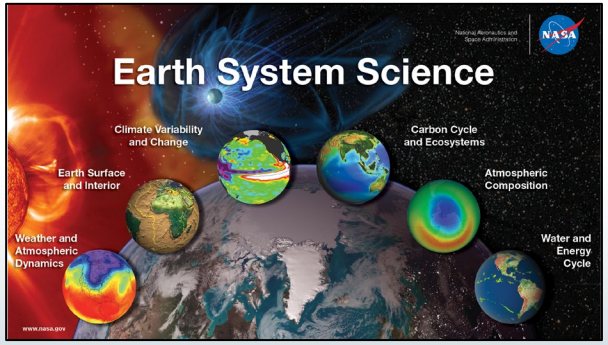
Earth Science Research and Analysis Program

See our latest top research results at: https://science.nasa.gov/earth-science/programs/research-analysis/year-in-review-2020

Scientific Research

Core Funding for Disciplinary Programs

R&A is organized around six focus areas that provide a framework for studying the Earth System



Cross-Cutting Research

- *Interdisciplinary Science (competed every 3 years)*
- *Future Investigators in NASA Earth and Space Sciences Technology (FINESST)*
- *New Investigator Program (NIP)*

Enabling Capabilities

Combining measurements and computer modeling allows scientists to see new connections and improve the accuracy of (calibrate) and confirm (validate) existing measurements.

Ground Networks: *~11 networks*

Airborne : *~50 campaigns*

Global Modeling and Assimilation Office (GMAO)

Computing

International and Domestic Partnerships

International

- *World Meteorological Organization (WMO)*
- *Coordination Group for Meteorological Satellites (CGMS)*
- *Global Energy and Water Exchanges (GEWEX)*
- *Committee on Earth Observation Satellites (CEOS)*

Interagency

- *U.S. Global Change Research Program (USGCRP)*
- *Interagency Arctic Research Policy Committee (IARPC)*
- *Arctic Observing Network*
- *Subcommittee on Ocean Science and Technology (SOST)*
- *Interagency Council for Advancing Meteorological Services (ICAMS)*
- *Earth System Predictability Fast Track Committee (FTAC)*

Education and Outreach

GLOBE

International science and education program that lets students and the public participate in data collection and the scientific process

- *Supported by NSF, NOAA, and Dept. of State*

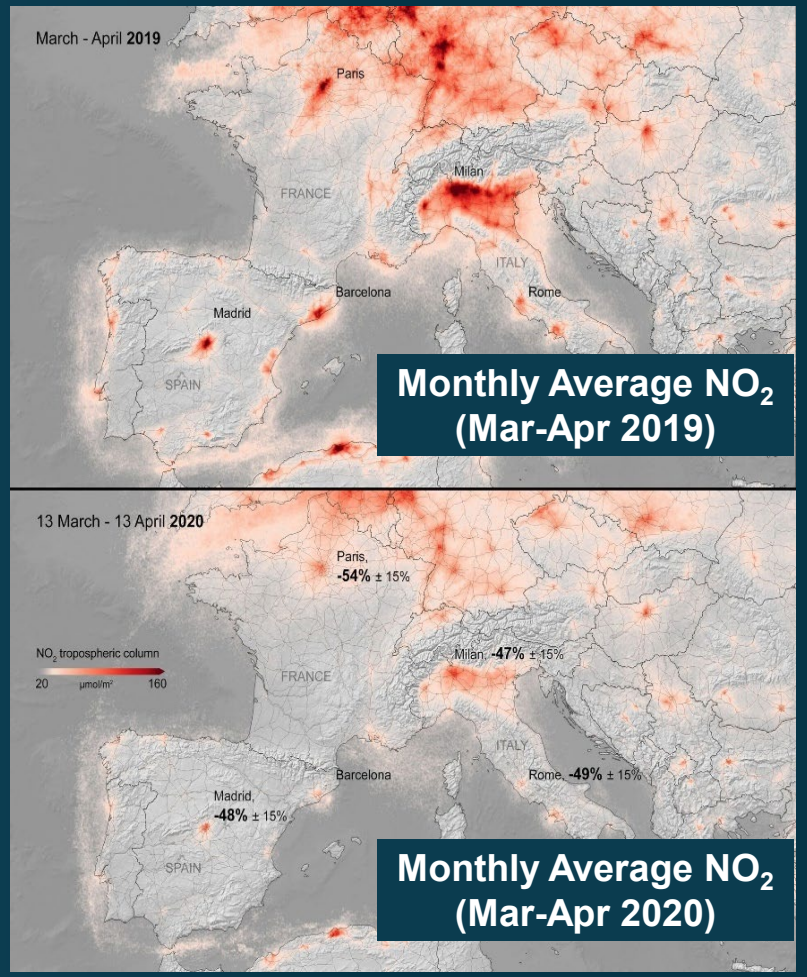
Student Airborne Research Program (SARP)

Expose and engage undergrads to NASA airborne science

- *333 alumni from 212 schools in 49 states and Puerto Rico*

COVID-19 Dashboard

- April 2020: JAXA, NASA, and ESA launched tri-agency dashboard
- Integrates satellite data records with analytical tools to allow user-friendly tracking of changes in:
  - Air and water quality
  - Economic activity
  - Agriculture
- Most visited indicators include:
  - Greenhouse Gases
  - SAR Slowdown Proxy Maps
  - Nightlights
  - Finished Goods Production: Output Inventory Level
  - Air Quality Time Series
  - Water Quality Maps: Total Suspended Matter



https://eodashboard.org/

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

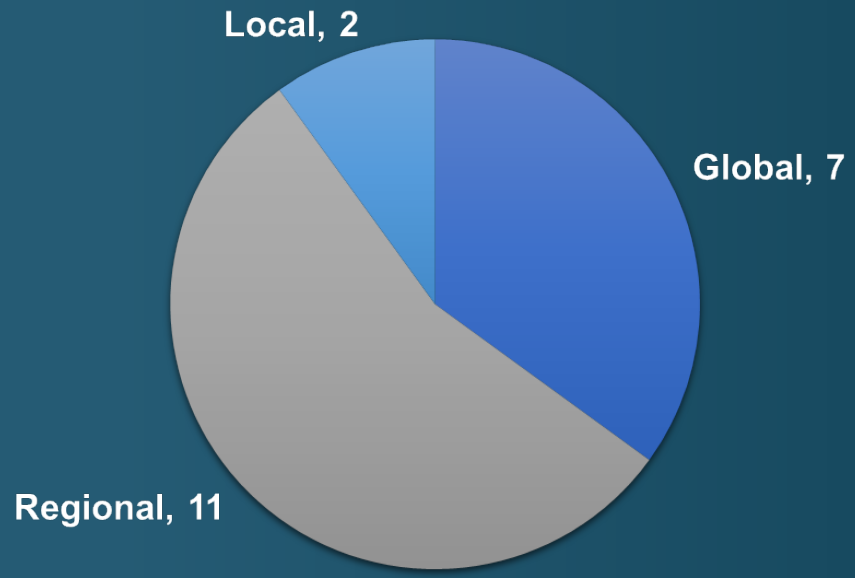
Research & Analysis Response to COVID-19: Rapid Response and Novel Earth Science (ROSES-19)

>130 inquiries

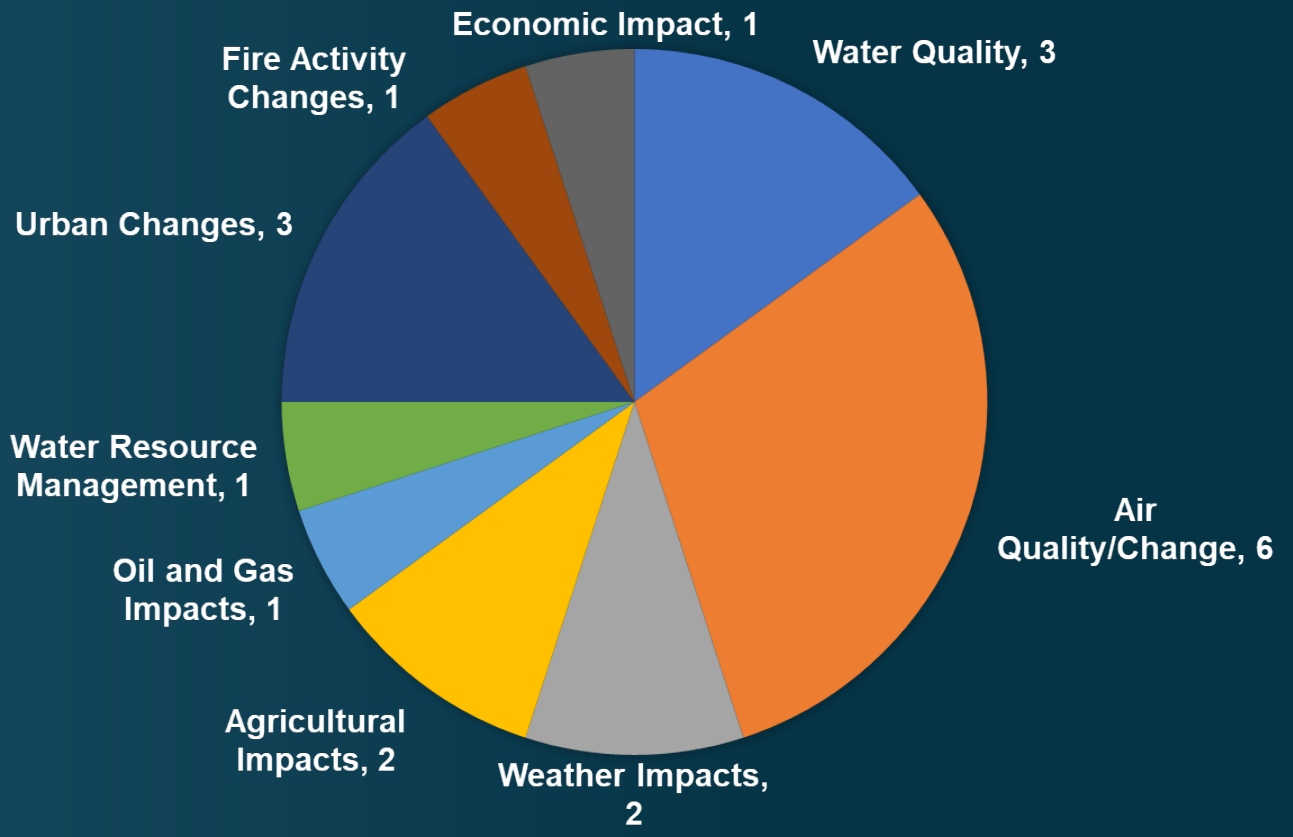
43 proposals submitted

20 selections to date

Geographic Extent of Research



Areas of Research of COVID-focused RRNES



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

Earth Science Technology

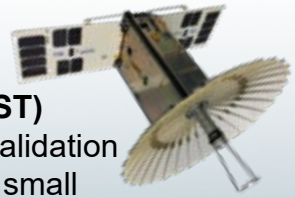
Earth Science Technology Program Elements

ESTO manages, on average, 120 active technology development projects. More than 830 projects have completed since 1998.

Advanced Technology Initiatives: ACT and InVEST

Advanced Component Technologies (ACT)
Critical components and subsystems for advanced instruments and observing systems.

12 projects awarded in 2020
Solicitations planned in FY22 and FY24
Average award: $1.2M (2-3 years)
Average selection rate: 16.4%



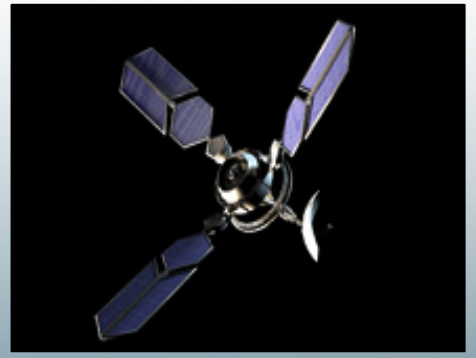
In-Space Validation of Earth Science Technologies (InVEST)
On-orbit technology validation and risk reduction for small instruments and instrument systems.

Four projects selected in FY18
InVEST-20 proposals due 3/9/2021
Next solicitation planned in FY24
Average award: $3-5M (3 years)
Average selection rate: 18.3%

Instrument Incubator Program (IIP)

Earth remote sensing instrument development from concept through breadboard and demonstration.

19 projects awarded in Oct 2019
Solicitations planned in FY21 and FY23
Average award: $4.5M (3 years)
Average selection rate: 23.2%



Advanced Information Systems Technology (AIST)

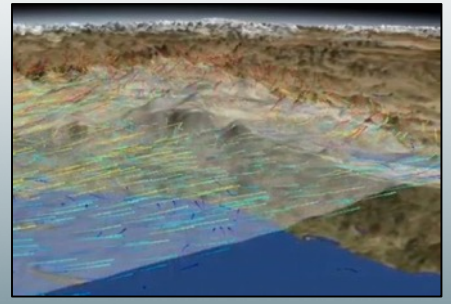
Innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products.

22 projects awarded in Sept 2019
Solicitations planned in FY21 and FY23
Average award: $1.2M (2 years)
Average selection rate: 19.6%

Decadal Incubation

Maturation of observing systems, instrument technology, and measurement concepts for Planetary Boundary Layer and Surface Topography and Vegetation observables through technology development, modeling/system design, analysis activities, and small-scale pilot demonstrations.

2 study teams awarded in FY20
Solicitation planned in FY21 and FY24

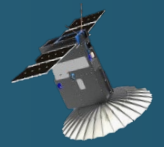


TEMPEST-D, RainCube CubeSats Capture Hurricanes

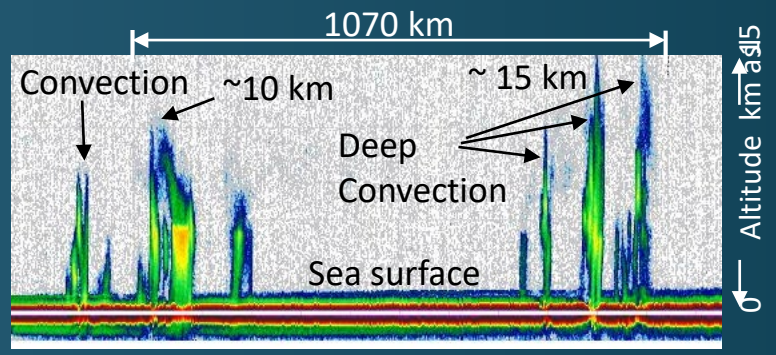
Over three days in August 2020, tropical cyclones Laura and Marco made landfall on the Gulf Coast of the United States in a one-two punch, Marco as a weakened tropical storm and Laura as a Category 4 hurricane

- **RainCube** (Radar in a CubeSat), developed at JPL, is a miniaturized precipitation-studying Ka-band radar instrument weighing just over 26 pounds. RainCube is smaller, has fewer components, and uses less power than traditional radar instruments
- The **TEMPEST-D** (Temporal Experiment for Storms and Tropical Systems Demonstration) CubeSat was developed by Colorado State University to validate a five-frequency radiometer based on newly low-noise amplifier technologies. Deployed from the ISS in July 2018, the 6-unit CubeSats are now in their third year of operations

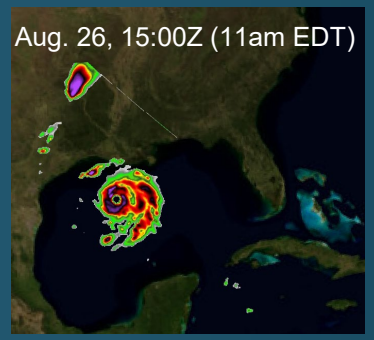
Principal Investigators: Eva Peral, JPL, and Steven Reising, Colorado State University

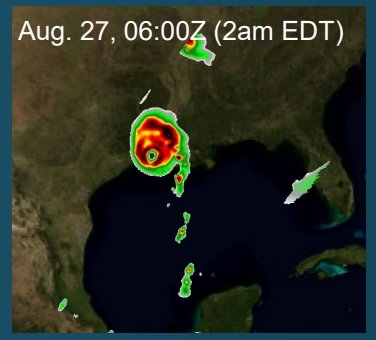


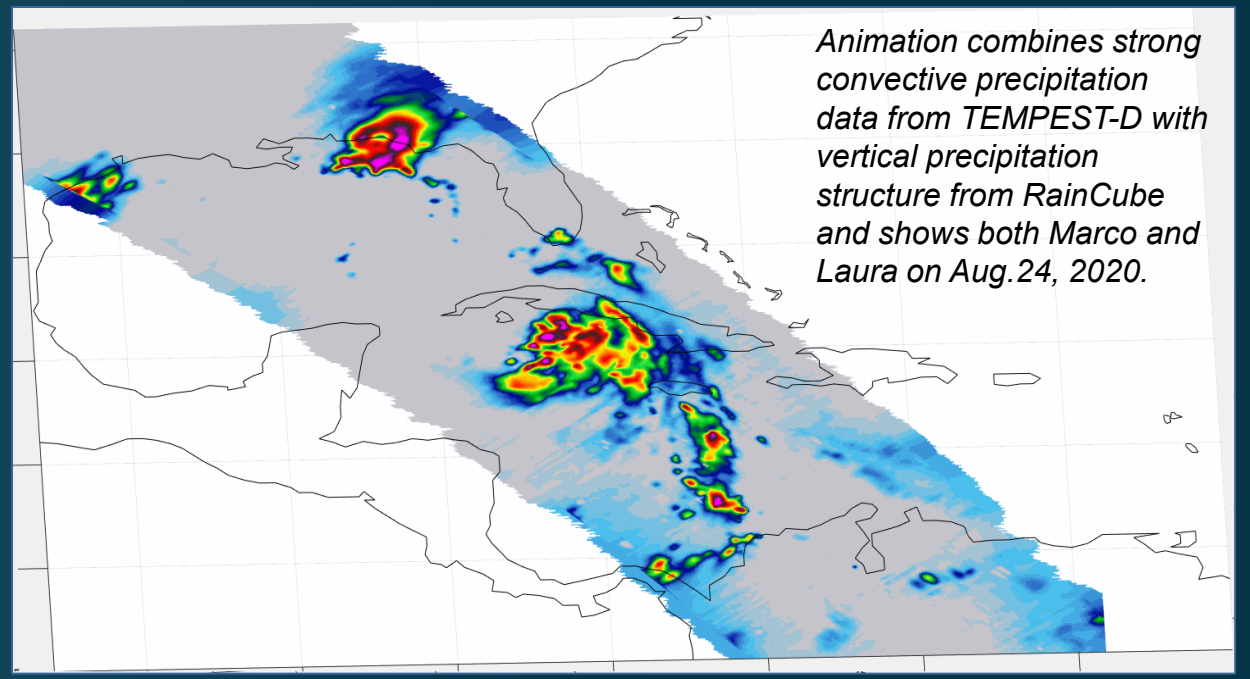
RainCube Radar reflectivity of then-Tropical Storm Laura on Aug. 24, 2020



TEMPEST-D captures Hurricane Laura before and after landfall







Animation combines strong convective precipitation data from TEMPEST-D with vertical precipitation structure from RainCube and shows both Marco and Laura on Aug.24, 2020.

Sentinel-6 Michael Freilich Launched Nov 21, 2020

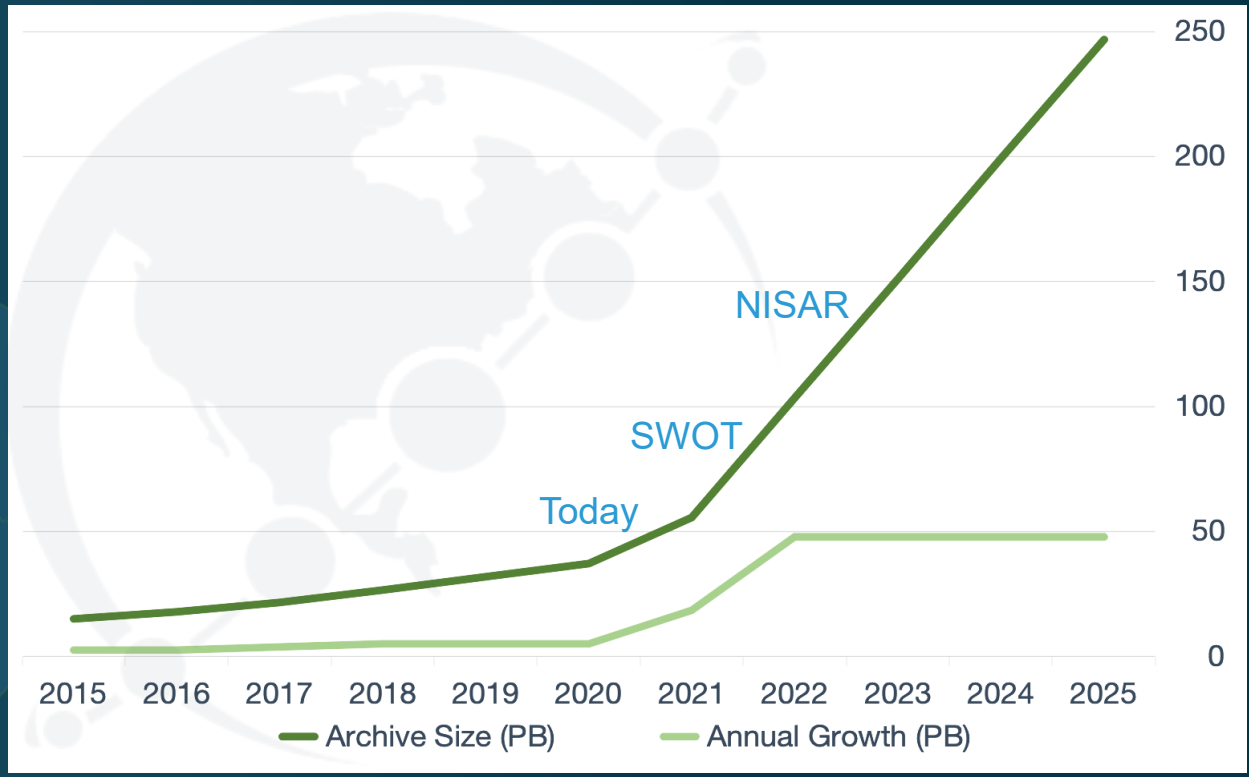
Mike Freilich's family gathers at the launch site.

Sentinel-6 Michael Freilich launches from Vandenberg Air Force Base.

ESDS Manages the Single Largest Repository of Free & Open Earth Science Data

Cloud Evolution: Our future
- Scalable growth
- Operational and analytical efficiency
- Open science enables collaboration

Commercial cloud solutions
- Agility and speed
- Constant market-driven innovation by vendors (e.g., Amazon, Google)
- Represent quickest path to enabling change



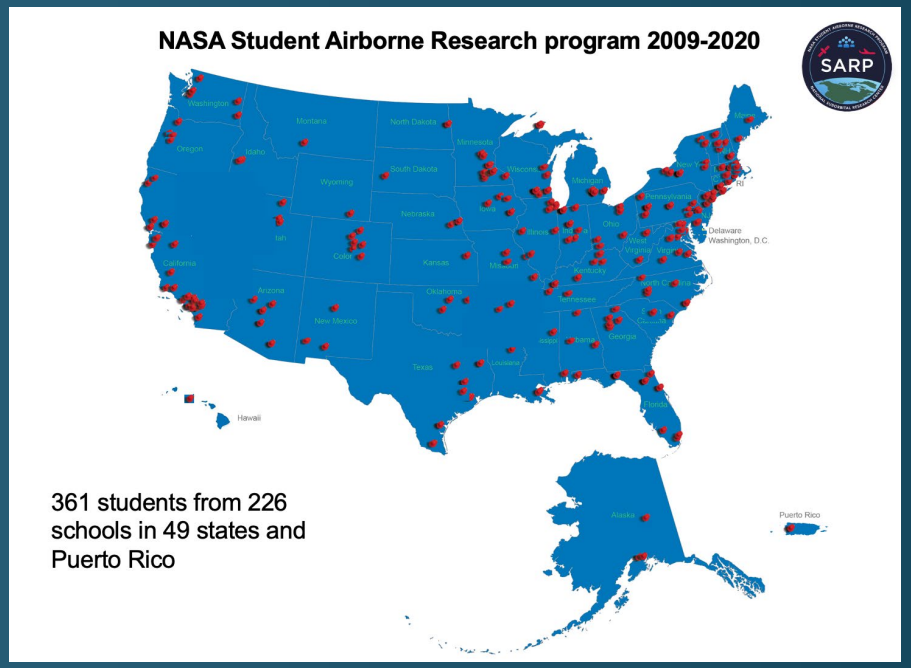
New (Early Career) Investigator Program (NIP) in Earth Science

- Objective: Support outstanding scientific research and career development of scientists and engineers at the early stage of their professional careers across all topics relevant to NASA Earth science
- The ROSES A.32 NIP-20 solicitation is now closed; the next opportunity will be in ROSES-23
  - Grants for up to three years at ~$125K/year
  - Anticipate at least 24 selections
- NIP eligibility requirements and program details for NIP-20:
  - Must be 0-6 years post-Ph.D. but could request a career interruption extension for reasons such as military service, family leave, or serious health problems
  - Cannot have tenure or equivalent (being in a tenure-track position is not required)
  - Cannot be a recipient of a previous NIP or PECASE award
  - There is no citizenship/permanent residency requirement
- NIP-20 review criterion: merit, relevance, cost, leadership
  - Leadership will be evaluated based on the PI's contributions and services to the Earth system science community
    - Can be demonstrated at an institutional, community, state, regional, national, or international level (with no preference given to a particular level)

Student Airborne Research Program (SARP) Attracts and Retains Future Scientists

- 11 peer-reviewed publications from SARP data
- 93% retention in STEM fields
- Over 50 alumni now have Ph.D.s in STEM fields

- Alumni now participating as scientists and engineers in NASA Airborne Science Program missions all over the world



SARP students, mentors, faculty, and NASA scientists took air samples near their homes that were subsequently analyzed for nearly 100 different gases.

Future Investigators in NASA Earth and Space Sciences and Technology (FINESST) Selections

- **341** proposals reviewed in disciplinary specific panels
- **62** selections in May 2020
  - Up to $45K per year for up to 3 years from Sept. 1, 2020
- FINESST grants are for student-designed research projects that contribute to SMD's science, technology, and exploration goals

62 Selections from **40** Institutions