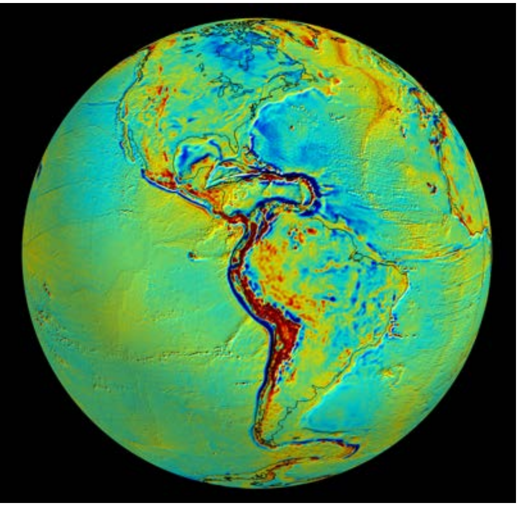
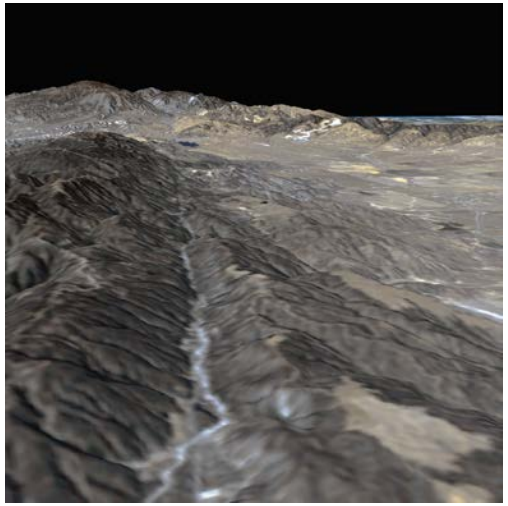
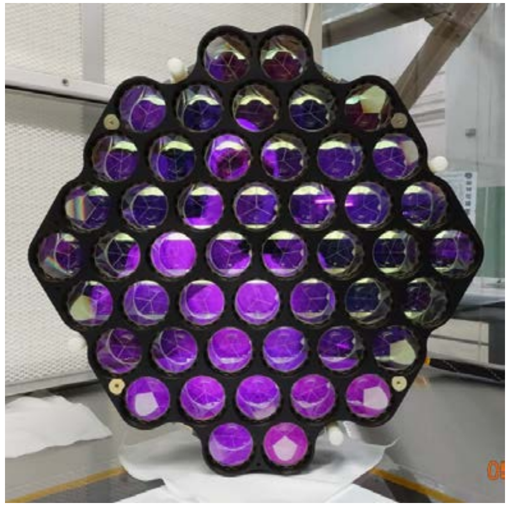
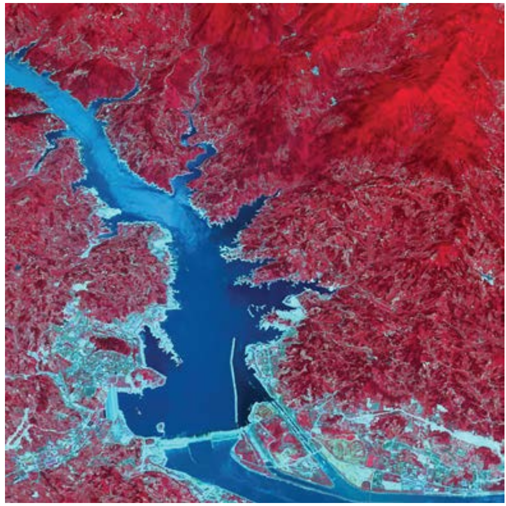
NASA Solid-Earth Science at Plate Boundaries



Benjamin R. Phillips

Earth Surface & Interior Focus Area, Earth Science Division, NASA

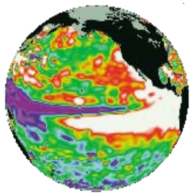
2019 GeoPRISMS TEI Synthesis & Integration
Hotel Menger, San Antonio, Texas
February 27, 2019

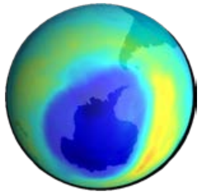
Outline

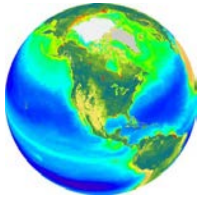
- NASA Earth Science overview
- Relevant NASA missions
- Research case studies
- Next generation observing systems
- How to participate
- Summary: needs and opportunities

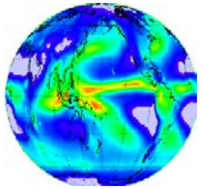
NASA Earth Science Research

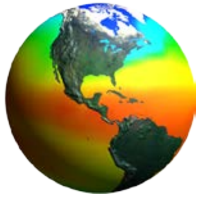
 Earth Surface & Interior

 Climate Variability & Change

 Atmospheric Composition

 Carbon Cycle & Ecosystems

 Water & Energy Cycle

 Weather

Earth Surface and Interior

Challenges and Opportunities for Research in ESI (CORE) (2016)

http://go.nasa.gov/2hmZLQO

1. What is the nature of **deformation associated with plate boundaries** and what are the implications for earthquakes, tsunamis, and other related natural hazards?
2. How do **tectonic processes and climate variability** interact to shape Earth's surface and create natural hazards?
3. How does the solid Earth respond to climate-driven **exchange of water among Earth systems** and what are the implications for **sea-level change**?
4. How do **magmatic systems** evolve, under what conditions do volcanoes erupt, and how do eruptions and volcano hazards develop?
5. What are the dynamics of **Earth's deep interior** and how does Earth's surface respond?
6. What are the dynamics of **Earth's magnetic field** and its interactions with the rest of Earth system?
7. How do **human activities** impact and interact with Earth's surface and interior?

NAS Decadal Survey (2018), most important solid-Earth science questions

https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

Surface Dynamics, Geological Hazards and Disasters	**(S-1)** How can large-scale geological hazards be accurately forecasted and eventually predicted in a socially relevant timeframe? **(S-2)** How do geological disasters directly impact the Earth system and society following an event? **(S-4)** What processes and interactions determine the rates of landscape change?


UNEDITED PREPUBLICATION—SUBJECT TO FURTHER EDITORIAL CORRECTION

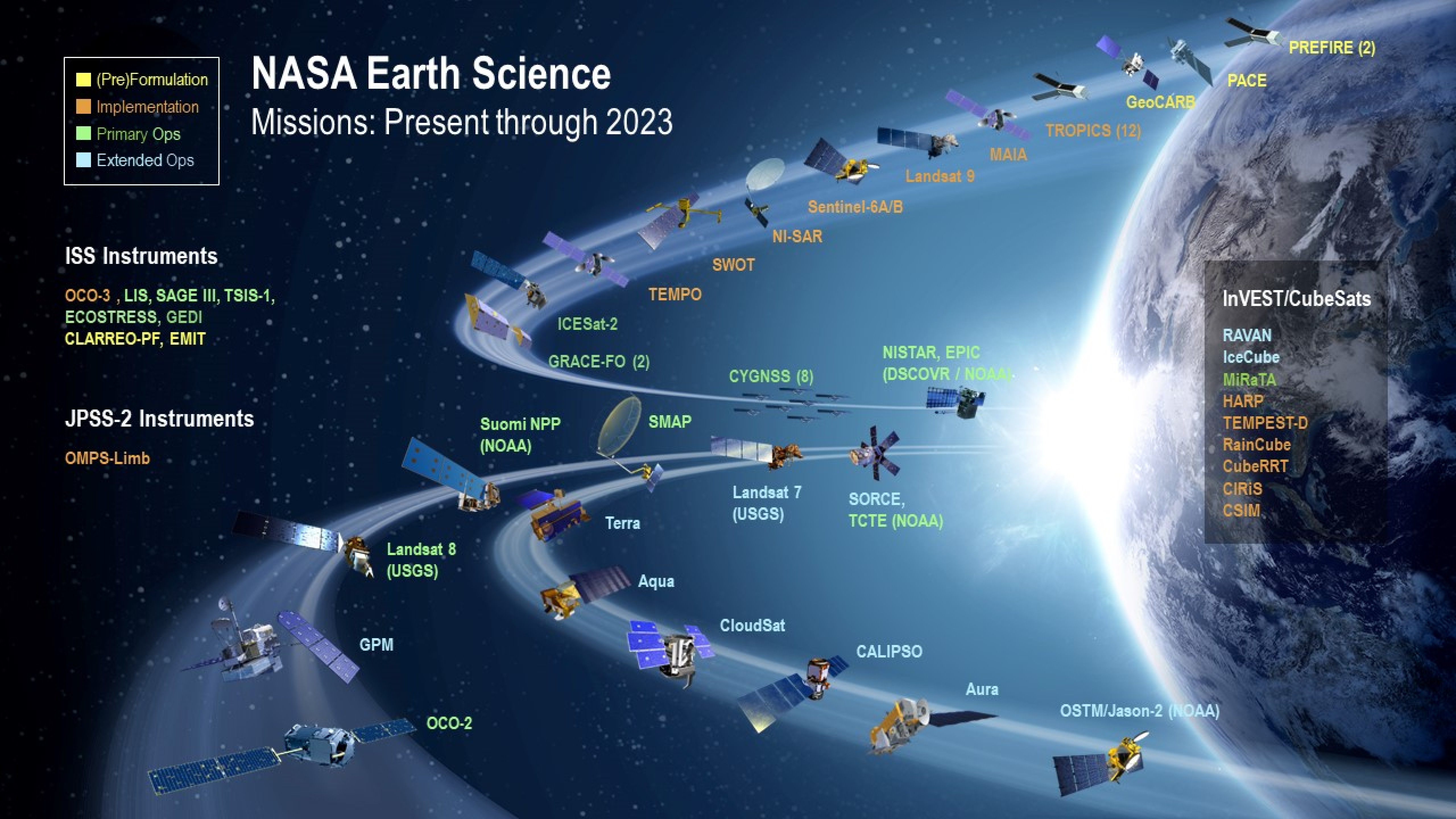
Thriving on Our Changing Planet:
A Decadal Strategy for Earth Observation from Space

Committee on the Decadal Survey for Earth Science and Applications from Space
Space Studies Board
Division on Engineering and Physical Sciences

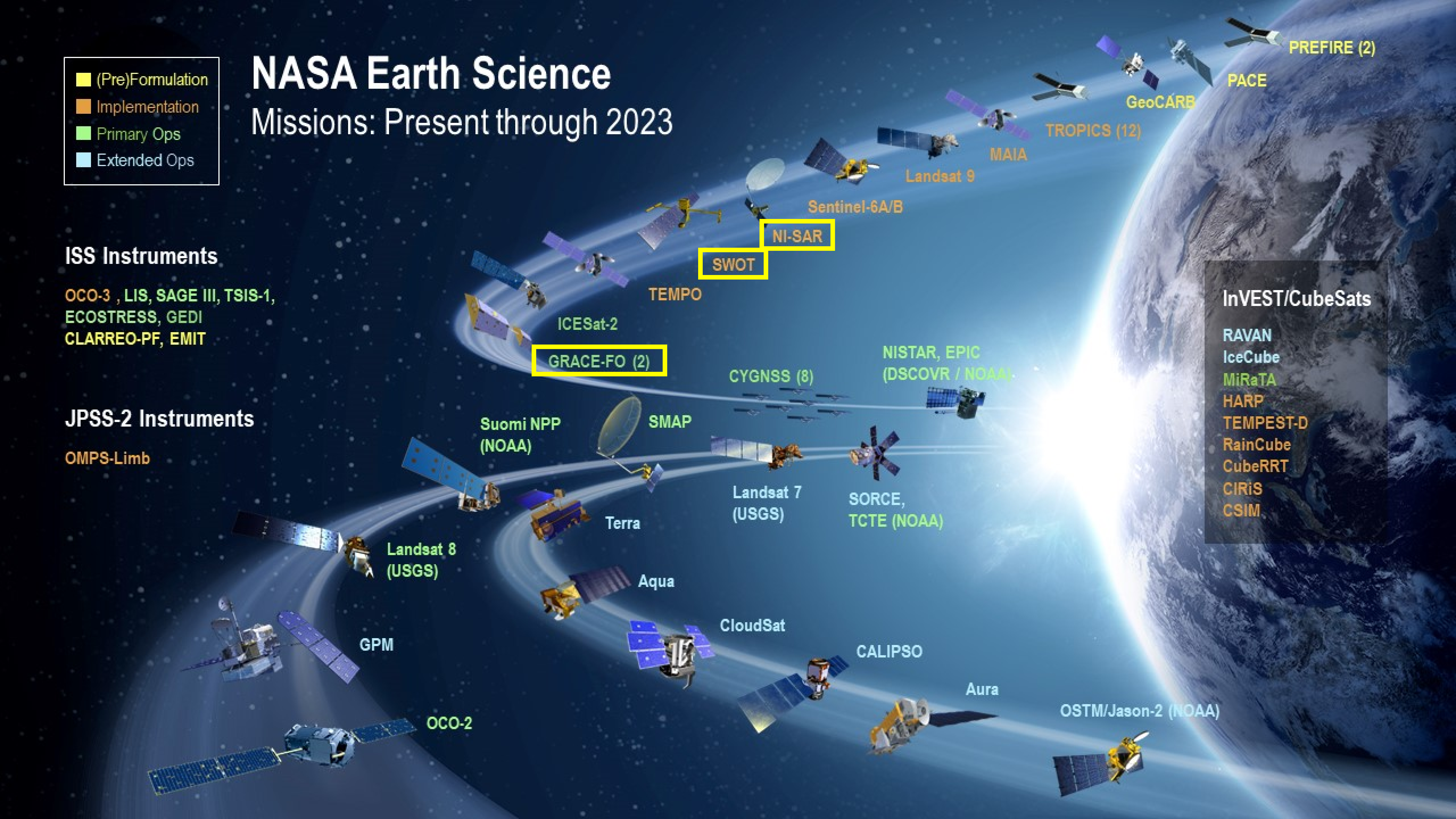
A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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

UNEDITED PREPUBLICATION–SUBJECT TO FURTHER EDITORIAL CORRECTION



NASA Earth Science
Missions: Present through 2023
(Pre)Formulation
Implementation
Primary Ops
Extended Ops
ISS Instruments
OCO-3 , LIS, SAGE III, TSIS-1,
ECOSTRESS, GEDI
CLARREO-PF, EMIT
JPSS-2 Instruments
OMPS-Limb
PREFIRE (2)
PACE
GeoCARB
TROPICS (12)
MAIA
Landsat 9
Sentinel-6A/B
NI-SAR
SWOT
TEMPO
ICESat-2
GRACE-FO (2)
CYGNSS (8)
NISTAR, EPIC
(DSCOVR / NOAA)
Suomi NPP
(NOAA)
SMAP
Landsat 7
(USGS)
SORCE,
TCTE (NOAA)
Terra
Landsat 8
(USGS)
Aqua
GPM
CloudSat
CALIPSO
Aura
OSTM/Jason-2 (NOAA)
OCO-2
InVEST/CubeSats
RAVAN
IceCube
MiRaTA
HARP
TEMPEST-D
RainCube
CubeRRT
CIRiS
CSIM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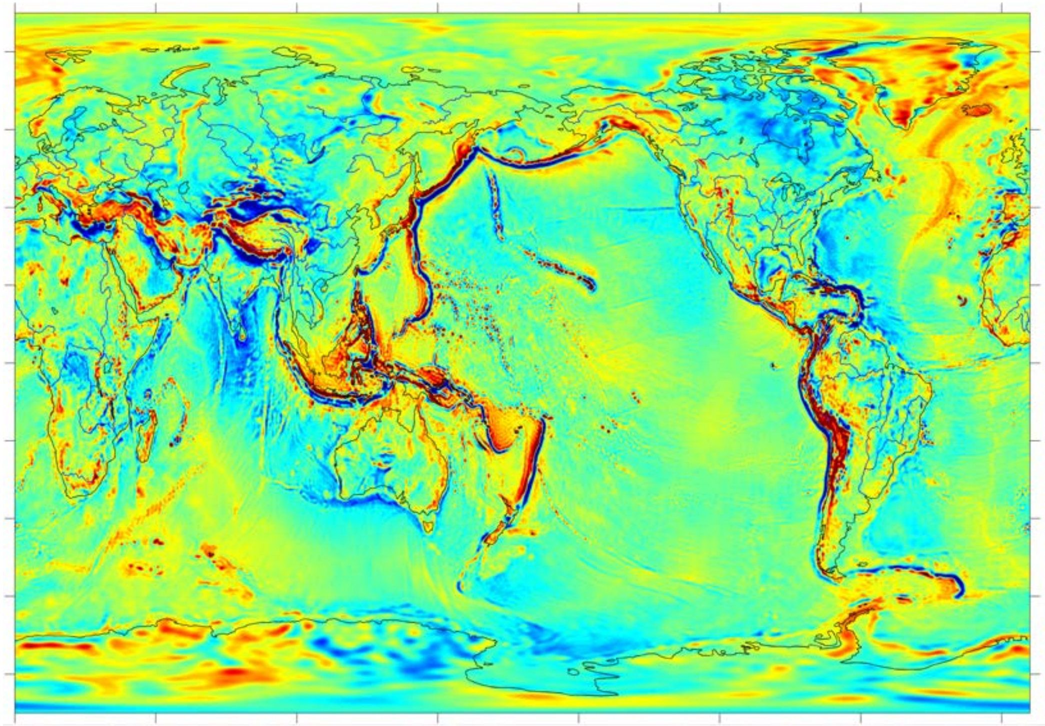
InVEST/CubeSats
RAVAN
IceCube
MiRaTA
HARP
TEMPEST-D
RainCube
CubeRRT
CIRiS
CSIM

GRACE-FO

Gravity Recovery and Climate Experiment – Follow-On

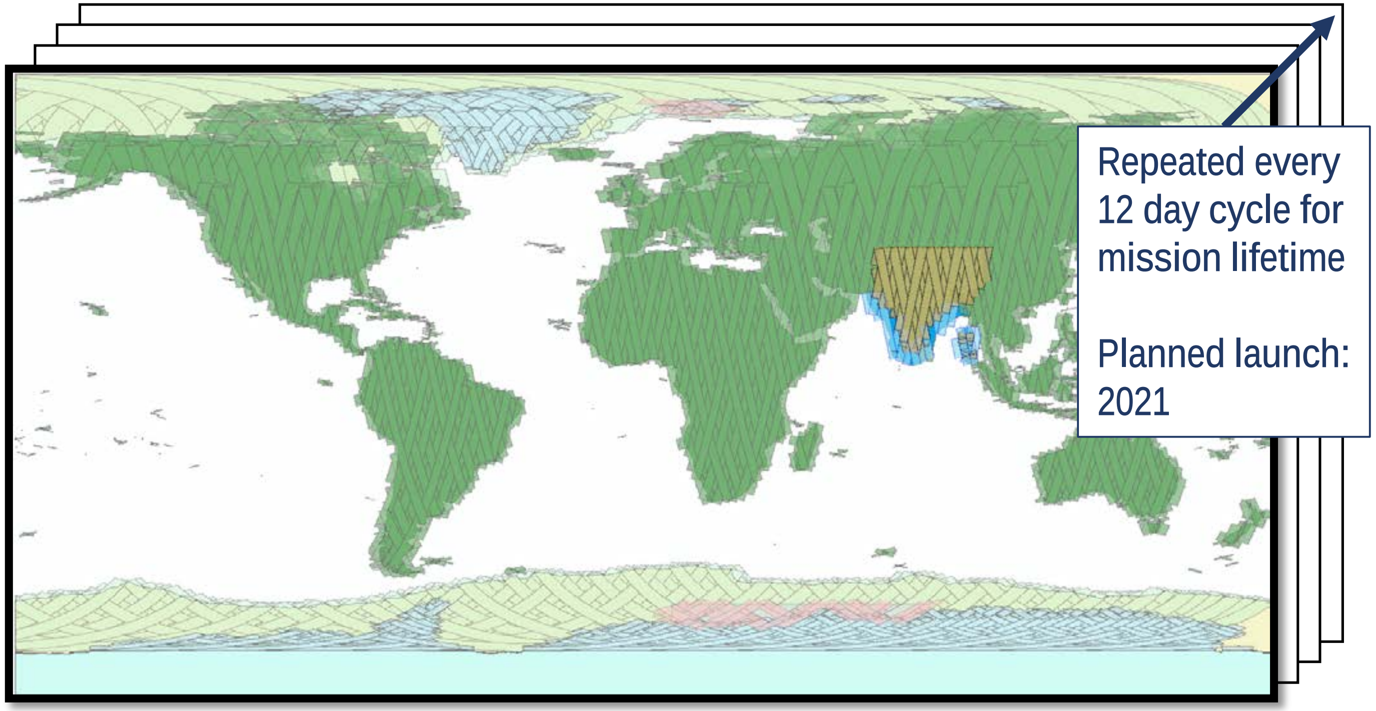
- Launched May 22 and will soon be providing science data
- Follows on the 15-year GRACE era (2002-2017) when most earthquakes M > 8.0 had a significant post-seismic gravimetric signals that have been used to advance understanding of the solid-Earth response to these great events



NISAR

NASA-Indian Space Research Organization Synthetic Aperture Radar mission

- Joint L- & S-band SAR/InSAR mission under construction at JPL
- Measure time-varying displacements over Earth's land and ice-covered surfaces
- 12-day global repeat sampling
- All data free and open
- Target launch Dec. 2021

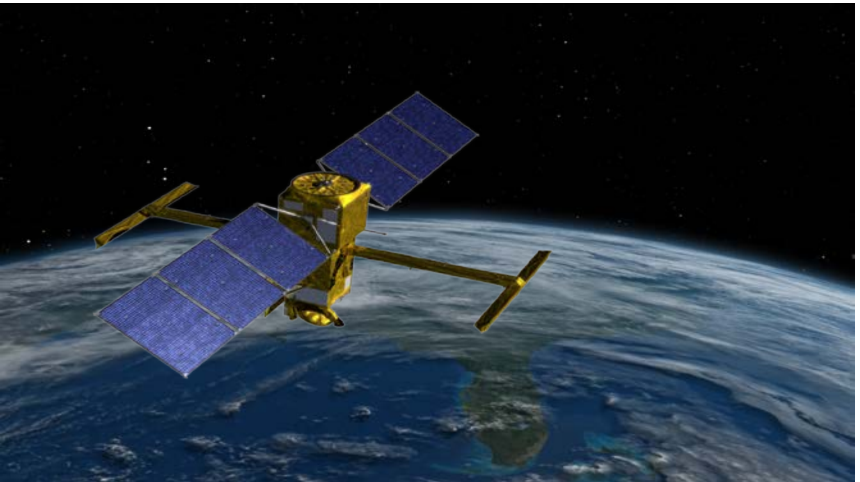


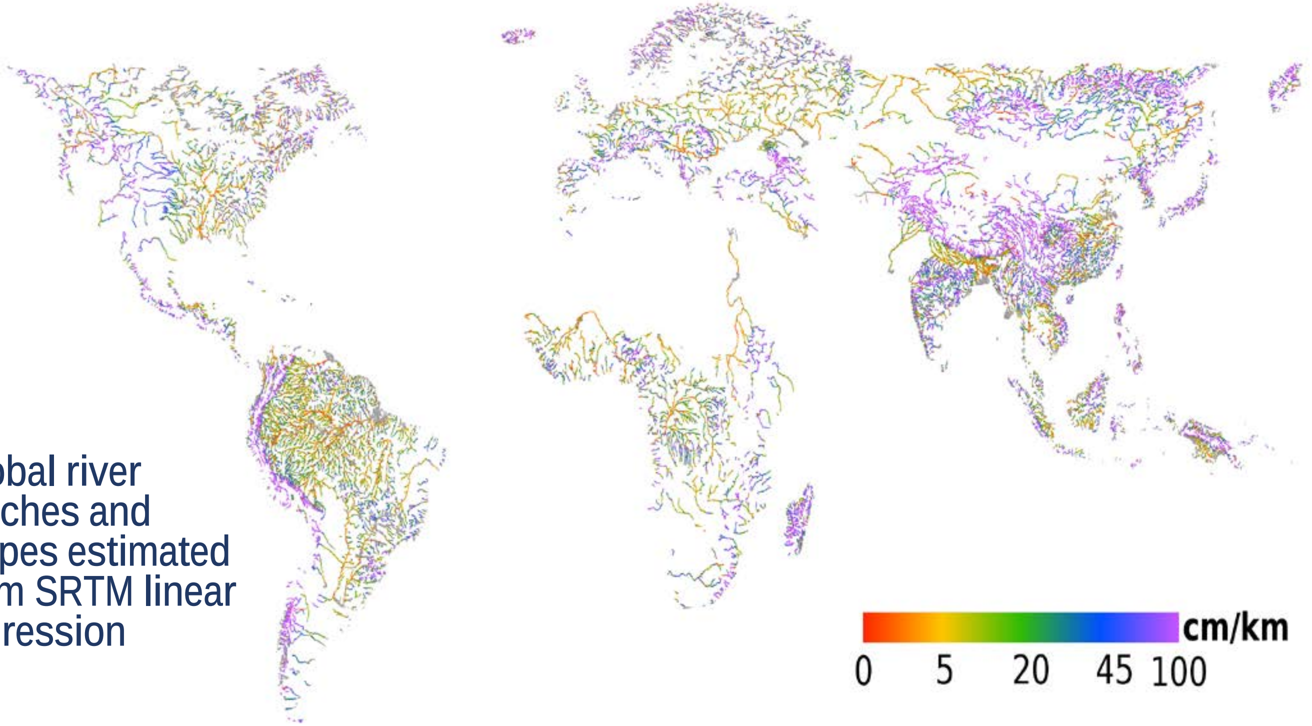
C. Ballard, JPL

SWOT

Surface Water Ocean Topography mission

- Ka-band radar interferometer will map all terrestrial water bodies > 250m^2 (lakes, reservoirs, wetlands), rivers > 100 m wide, and sea surface height every 21 days
- Order of magnitude improvement in spatial resolution
- Anticipate quadrupling the number of seamounts mapped
- Target launch Apr. 2021



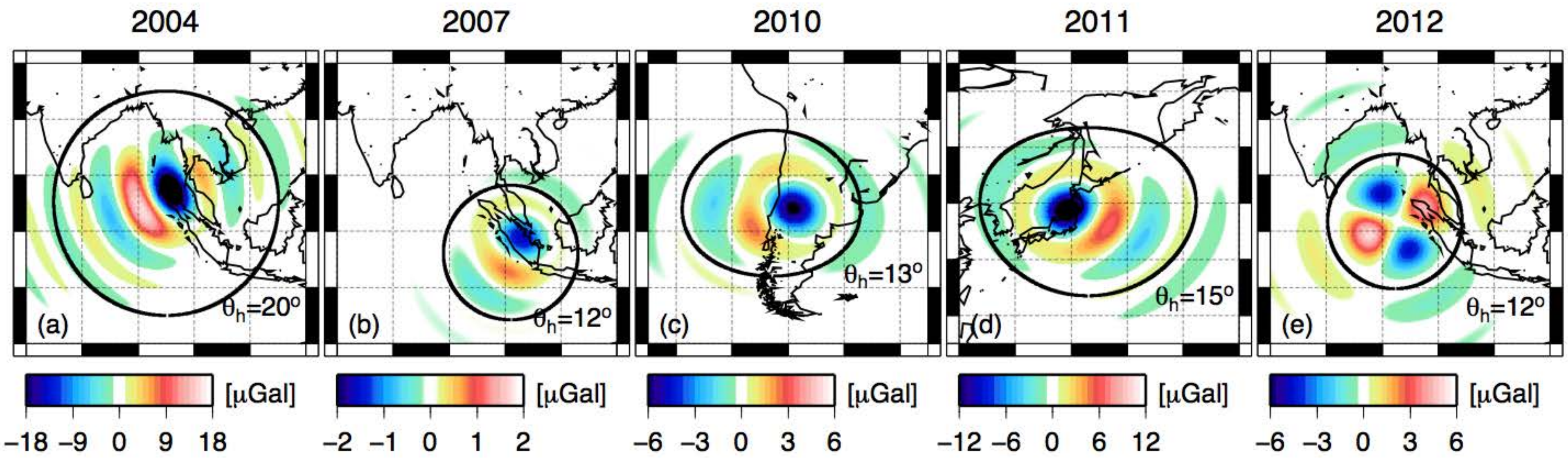


Global river reaches and slopes estimated from SRTM linear regression

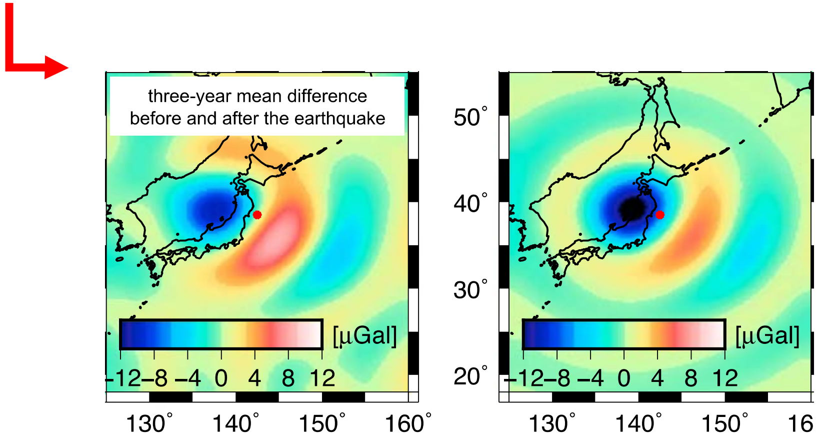
GRACE coseismic gravity changes for recent earthquakes

Han, S.-C., R. Riva, J. Sauber, and E. Okal (2013), JGR, doi:10.1002/jgrb.50116

M 9.2 Sumatra | M 8.6 Bengkulu | M 8.8 Maule | M 9.1 Tohoku-Oki | M 8.6, 8.2 Indian Ocean



- GRACE gravimetric data have been used to independently solve for earthquake source parameters, and compared to seismically-derived coseismic slip models
- Focal mechanisms and moments represent the behavior of the sources on temporal and spatial scales exceeding the seismic and geodetic spectrum
- Provides new synoptic constraints on the rheological structure of the Earth
- Anticipate GRACE-FO will continue capture gravity change for events M ≥ 8.0



Remote sensing time series at 47 Latin American volcanoes

Reath, K., Pritchard, M., Poland, M., Delgado, F., Carn, S., Coppola, D., et al. (2019), JGR, doi:10.1029/2018JB016199

Background:
- Combine deformation, degassing and thermal remote sensing for 17 years

Data:
- Degassing: OMI (SO_2)
- Thermal: MODIS & ASTER
- InSAR: international constellation (RADARSAT, ALOS, CSK, Sentinel-1A/1B, TerraSAR-X, TanDEM-X)

Findings:
- Tested open vs. closed volcano classification
- More open in Central America & Peru
- More closed in central Andes & Galapagos
- 28% do not fall into either category

Significance:
- Value to integrating diverse sensors across decades & entire regions

Classification of the 47 most active Latin American volcanoes in 4 categories based on 17 years of combined degassing, thermal and deformation remote sensing

Imaging the next great Cascadia earthquake: Optimal design for a seafloor acoustic-GNSS network

Eileen L. Evans (PI), Sarah E. Minson (Co-I), C. David Chadwell (Collaborator)

Background:

- Offshore geodetic observations (seafloor geodesy) can constrain strain accumulation rate and estimate future earthquake slip in Cascadia

Data and Analysis:

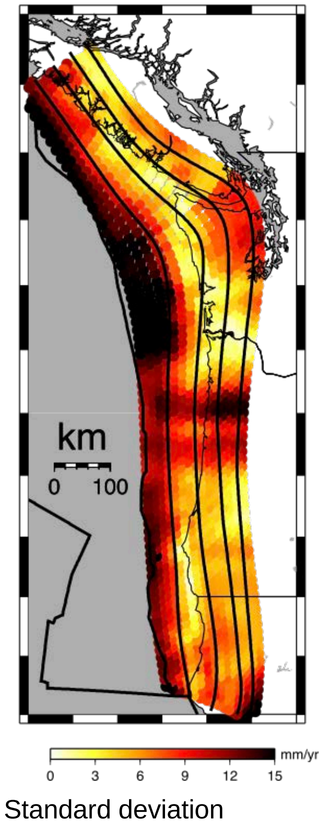
- Minimize differential entropy (e.g., Shannon, 1948) to optimize future geodetic observations
- Perform minimization within a suite of Pacific Northwest models to account for epistemic uncertainty

Findings (preliminary):

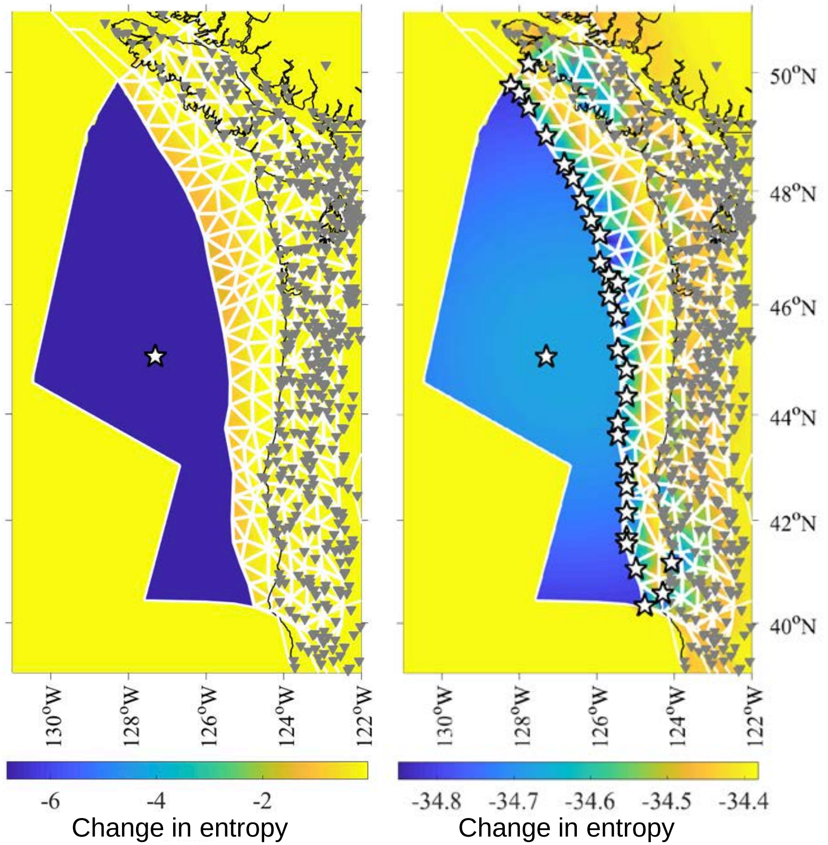
- Constraining active convergence rate requires (at least one) observation on the Juan de Fuca plate
- Additional stations located along the trench

Significance:

- Entropy approach can enable well-informed decisions about expanding current geodetic networks to maximize information about a future Cascadia earthquake



Comparison of locking estimates: highest uncertainties are near the trench (Pollitz and Evans, 2015)

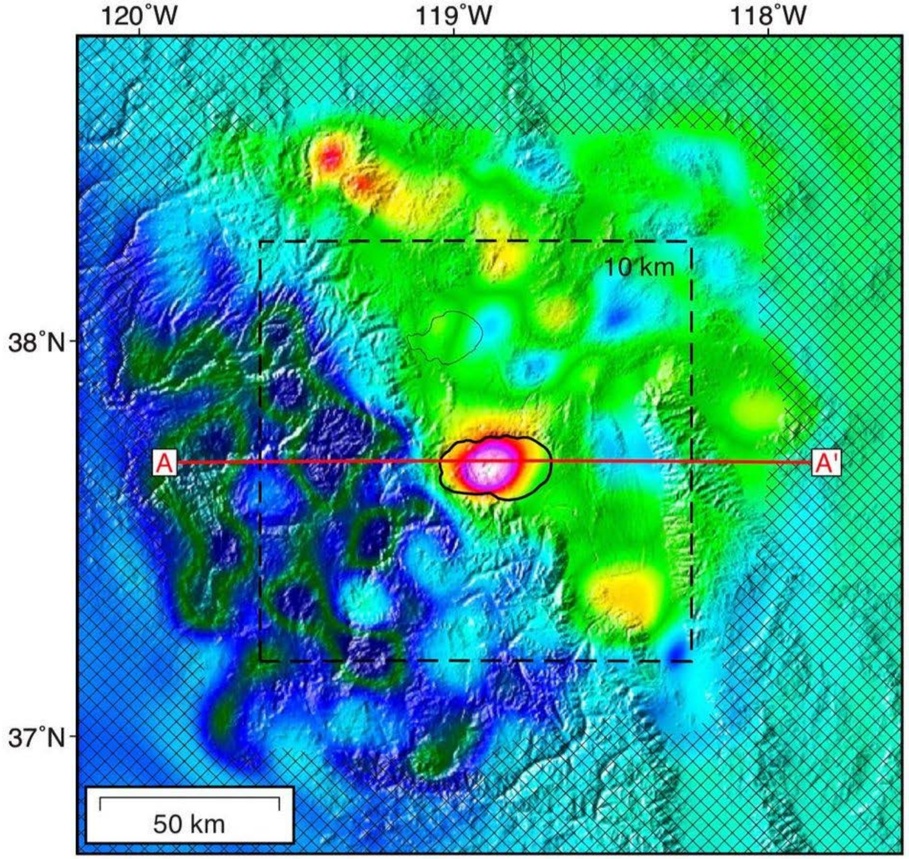


Preliminary results (simple block model): first optimal observation located on the Juan de Fuca plate, subsequent observations along trench

Enabling Advanced Modeling & Simulation

- NASA Ames Research Center has extensive HPC capabilities and expertise
  - High-end & Cloud Computing
    Pleiades, 5.95 Pflop/s LINPACK rating (#27 on Nov 2018 TOP500)
    Electra, 5.44 Pflop/s LINPACK rating (#33 on Nov 2018 TOP500)
  - Hyperwall Data Visualization
  - Archival Storage
- Participating in the Modeling Collaboratory for Subduction RCN

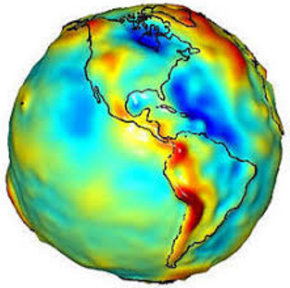
ARC Hyperwall 128-screen tiled LCD wall



Seismic tomography data analyzed on ARC supercomputers reveal evidence of significant melt beneath the Long Valley Caldera, California, USA.

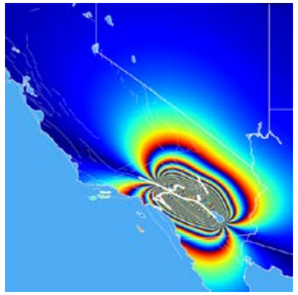
Get involved in Decadal Survey implementation

- Designated Observable studies just beginning:



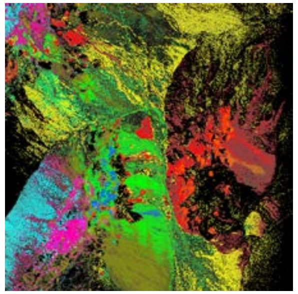
Next gravity mission

Mass Change



Next InSAR mission

Surface Deformation & Change



Next spectral imaging mission

Surface Biology & Geology

Next atmospheric science mission

Aerosols and Clouds, Convection, & Precipitation

- Science and Applications needs of this community can help inform and bolster the need for these next generation observing systems
- Future mission makeup will impact our ability to conduct and advance our science
- Get involved! Next Decadal Survey community forum webinar, March 4, 1 EST

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

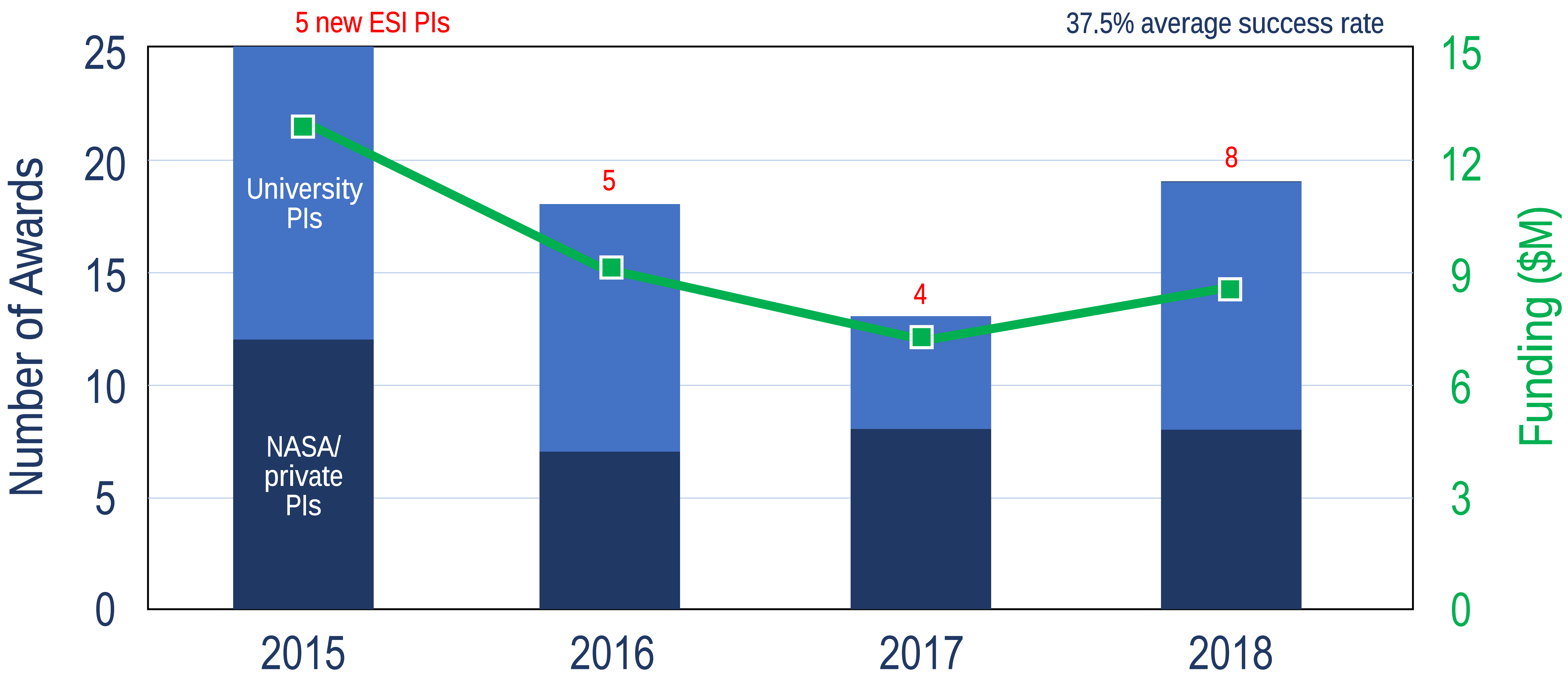
ROSES

- 2019 Research Opportunities in Space and Earth Science
  - Earth Surface and Interior
  - Global Navigation Satellite System Research
  - Interdisciplinary Research in Earth Science
  - NASA Postdoctoral Program (NPP) – next due dates March 1 and July 1, 2019
  - Future Investigators in NASA Earth and Space Science and Technology (FINESST) [graduate fellowships, previously NESSF] – due March 11, 2019

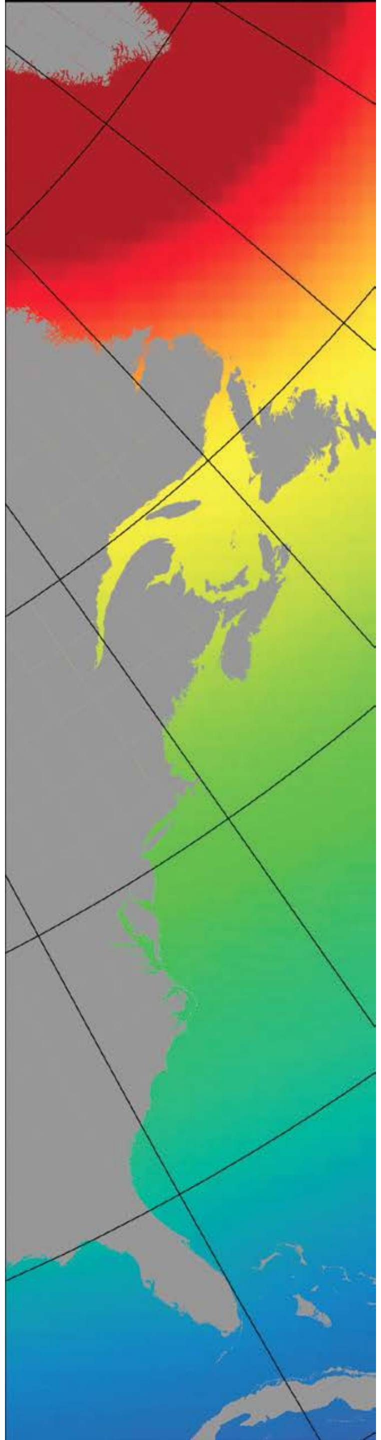
  https://science.nasa.gov/researchers/sara/grant-solicitations
- NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES)

  http://nspires.nasaprs.com

Earth Surface and Interior solicitations



https://science.nasa.gov/earth-science/focus-areas/surface-and-interior



Summary

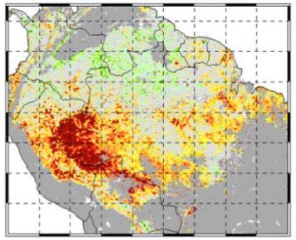
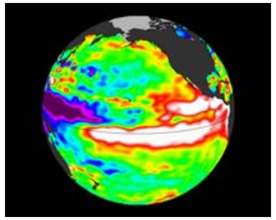
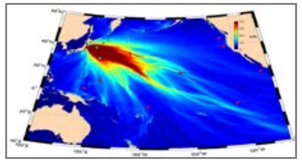
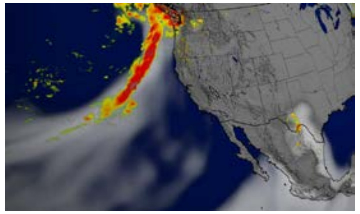
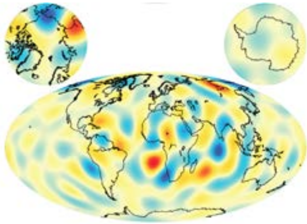
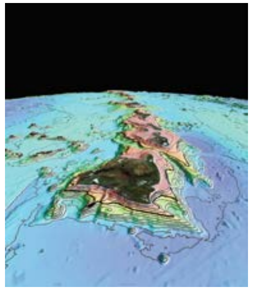
- Spaceborne sensors provide holistic views (regional/basin/arc scale) that complement in situ and modeling approaches
- Observing system simulation experiments are needed to optimize design of future satellite missions and ground networks
- A number of ongoing and pending missions will directly inform GeoPRISMS science questions
- Formulation of NASA's next-generation observing systems starts now
- GeoPRISMS community can help prioritize observational and data needs – key questions, measurement gaps, needed data products, collaboration
- NASA ESI offers opportunities that complement GeoPRISMS objectives

ben.phillips@nasa.gov

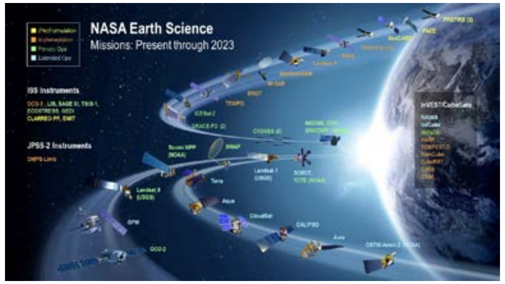
Backup

Earth Science Division

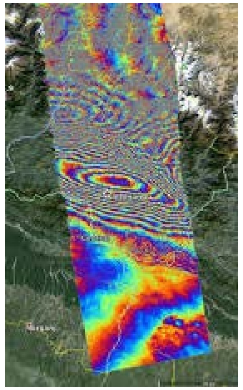
Research

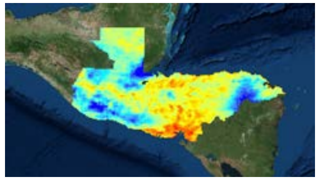
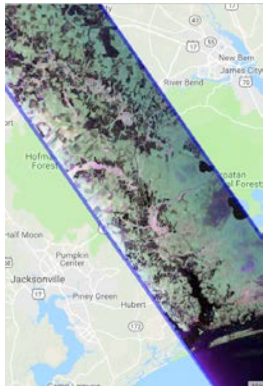







Flight

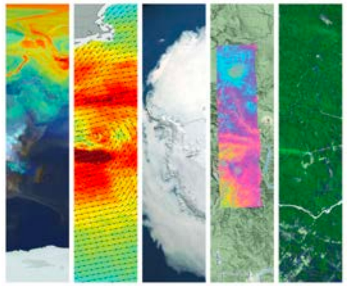
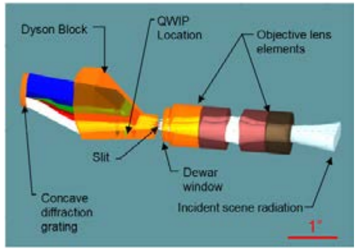


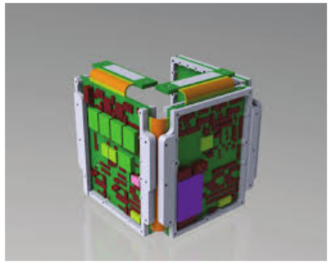
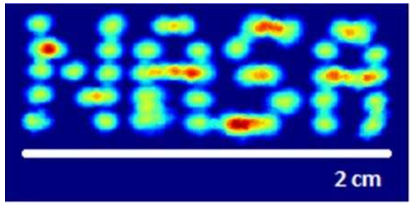

Applied Sciences



Technology

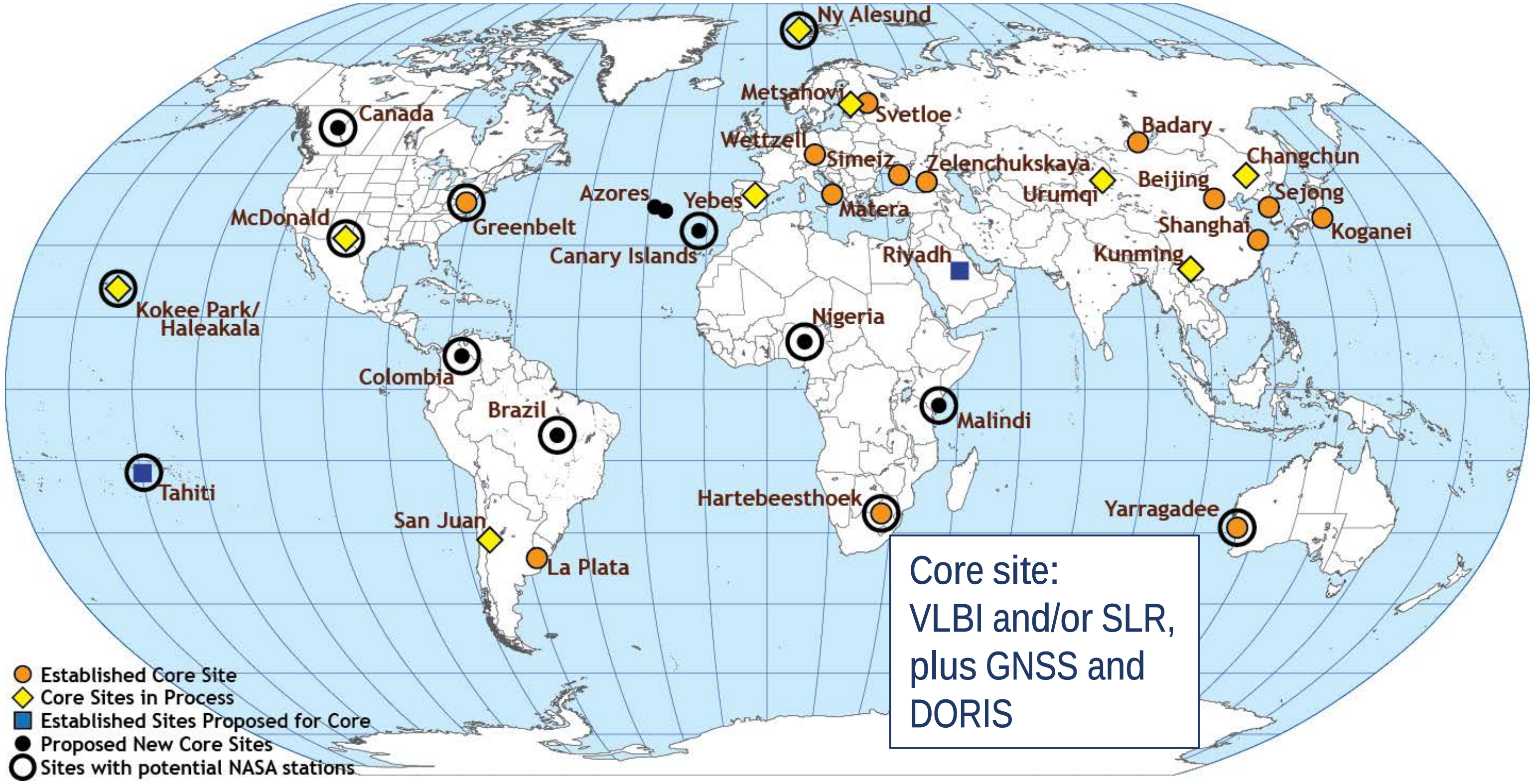



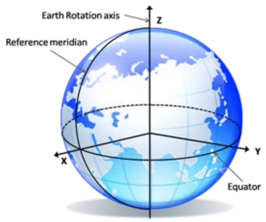
NASA's Geodetic Infrastructure

Space Geodesy Program

Current and candidate core geodetic sites

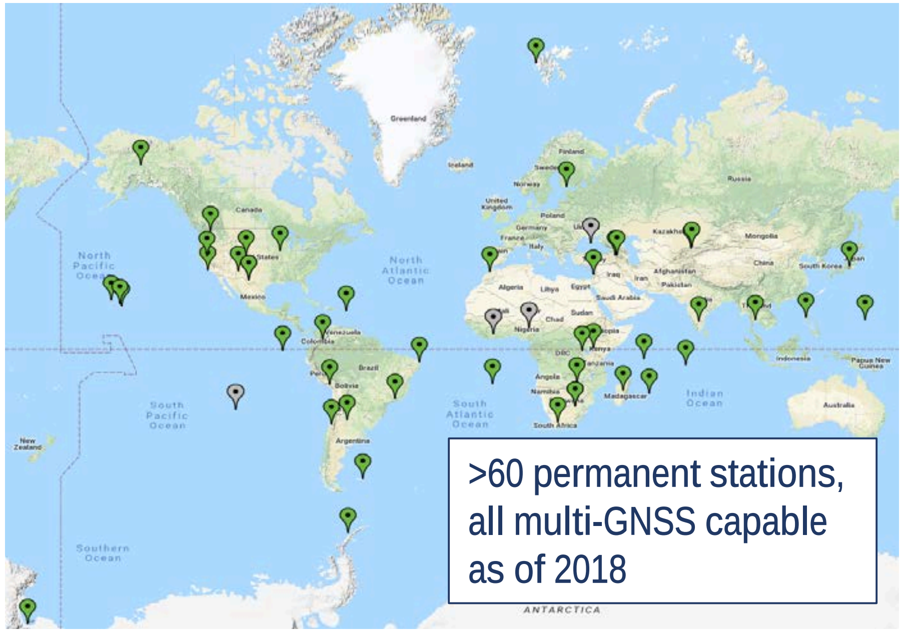


Core site:
VLBI and/or SLR,
plus GNSS and
DORIS



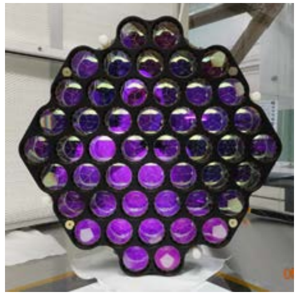
Geodetic Analysis and Terrestrial Reference Frame Combination Centers

International Coordination & Partnership



>60 permanent stations, all multi-GNSS capable as of 2018

NASA Global GNSS Network

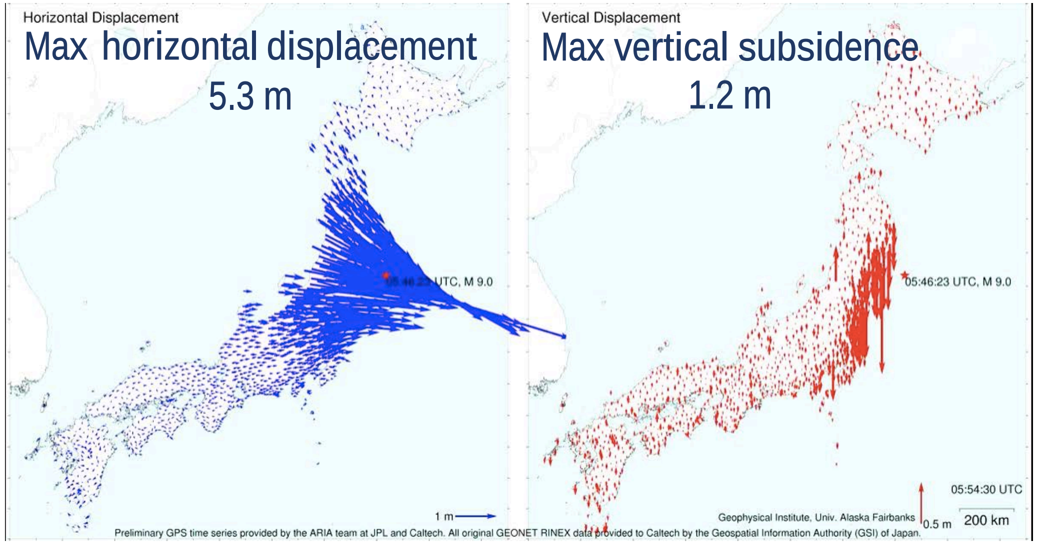


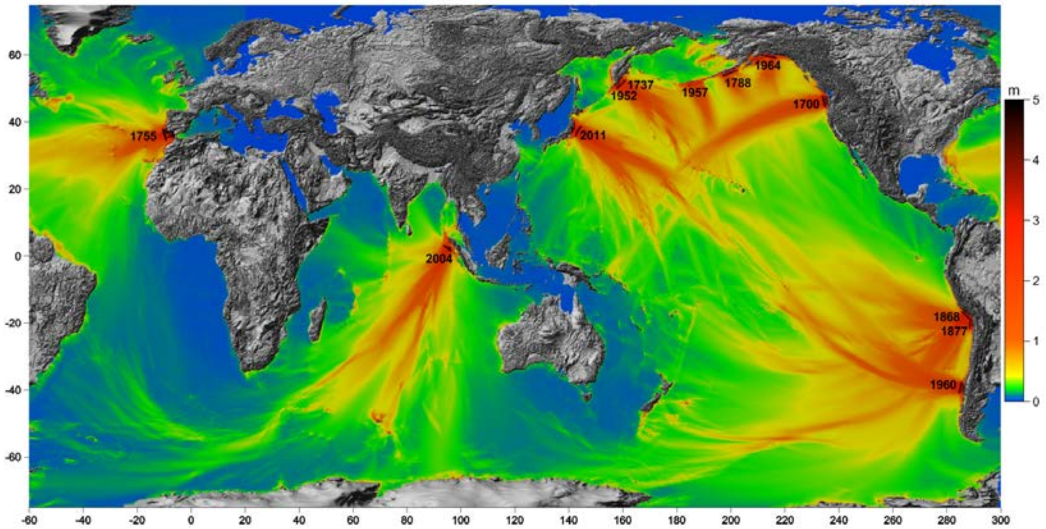
GPS Laser Retroreflector Arrays

Real-time GNSS-Enhanced Tsunami Early Warning System

- NASA co-sponsored a multi-agency Federal & University effort to develop a real-time GNSS Tsunami Early Warning system
- Increased warning accuracy with decreased latency
- Detect, characterize, and model tsunamigenic earthquakes and estimate the timing of potential tsunami landfall and inundation depth – all within minutes of the rupture initiation
- NOAA's Tsunami Warning Centers are currently integrating this capability into their workflow

GSI's GEONet GNSS displacements, Tohoku earthquake





Jet Propulsion Laboratory
California Institute of Technology
NOAA
NSF
USGS science for a changing world
UNAVCO
CWU
SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego
University of California Berkeley Seismological Laboratory

Next generation observing systems

NASEM, Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space (2018)

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, and Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

Top priority observables designated for implementation in space within the decade