Natural Hazards and Disasters

Why are you taking the class?

What is the relevance of natural hazards and disasters for you?

Natural Hazards and Disasters

Guest Opinion: Finding our way back to the wilderness

Robert C. Koehler
For Peacevoice
August 30, 2018

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The science gets ever more dire. The politics runs the other way.

We've claimed hold of the planet, but cluelessly, like the sorcerer's apprentice. Welcomed to the Anthropocene: the age of humanity intertwined with nature.

"Climate change is not a problem we have to make go away, in a sense that you don't make adolescence go away," astrophysicist Adam Frank said to Chris Hedges. "It is a dangerous transition that you have to navigate... The question is, are we smart enough to deal with the effects of our own power?"

The planet itself is transitioning, to God knows what. There may be no human race on the other side of that transition, but maybe there will be. Either way, we have to reach well beyond ourselves.

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https://www.postindependent.com/opinion/guest-opinion-finding-our-way-back-to-the-wilderness/

We have entered the “Anthropocene”

Plag, 2010

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But we have not learned to wield the power wisely!

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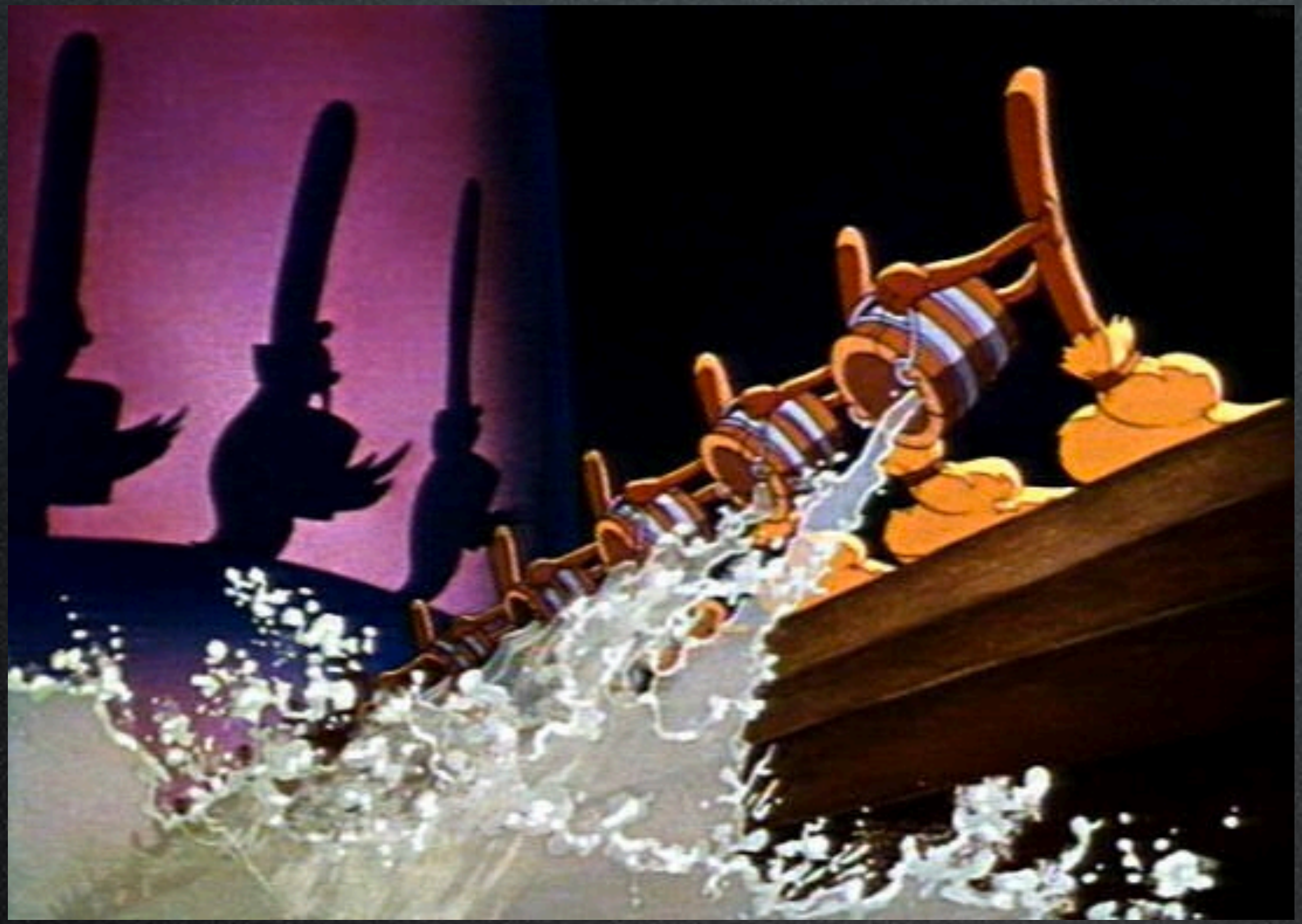

The sorcerer's apprentice

Having gained the power to change Earth, we need to take a new look at humanity and ask the question who we are

Plag, 2010

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Natural Hazards and Disasters

Class 1: Introduction to the Course and Basic Concepts (continued)

- Practicalities
- Course Contents
- The Earth's Life-Support System and Sustainability
- Hazards, Vulnerabilities, and Disasters
- Concept of Risk
- Thresholds
- Resilience
- Disasters and Sustainability

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ON THE EDGE

The Year 2015: The Start of a New Decade of Making it Right?

Building a global resilient community

Posted by Prof. Hans-Peter Plag, PhD on October 3, 2014 in Columns, Fall 2014, On the Edge

Finally, in August this year it was published: "The Collapse of Western Civilization – A View from the Future".1 Taking the view of a historian in the Second Peoples Republic of China, who in 2393 looks back and analyzes why 300 years earlier the western culture collapsed, Naomi Oreskes and Erik M. Conway (yes, the same authors who worked together on Merchants of Doubt)2 paint a beautifully scary picture of what might happen in t

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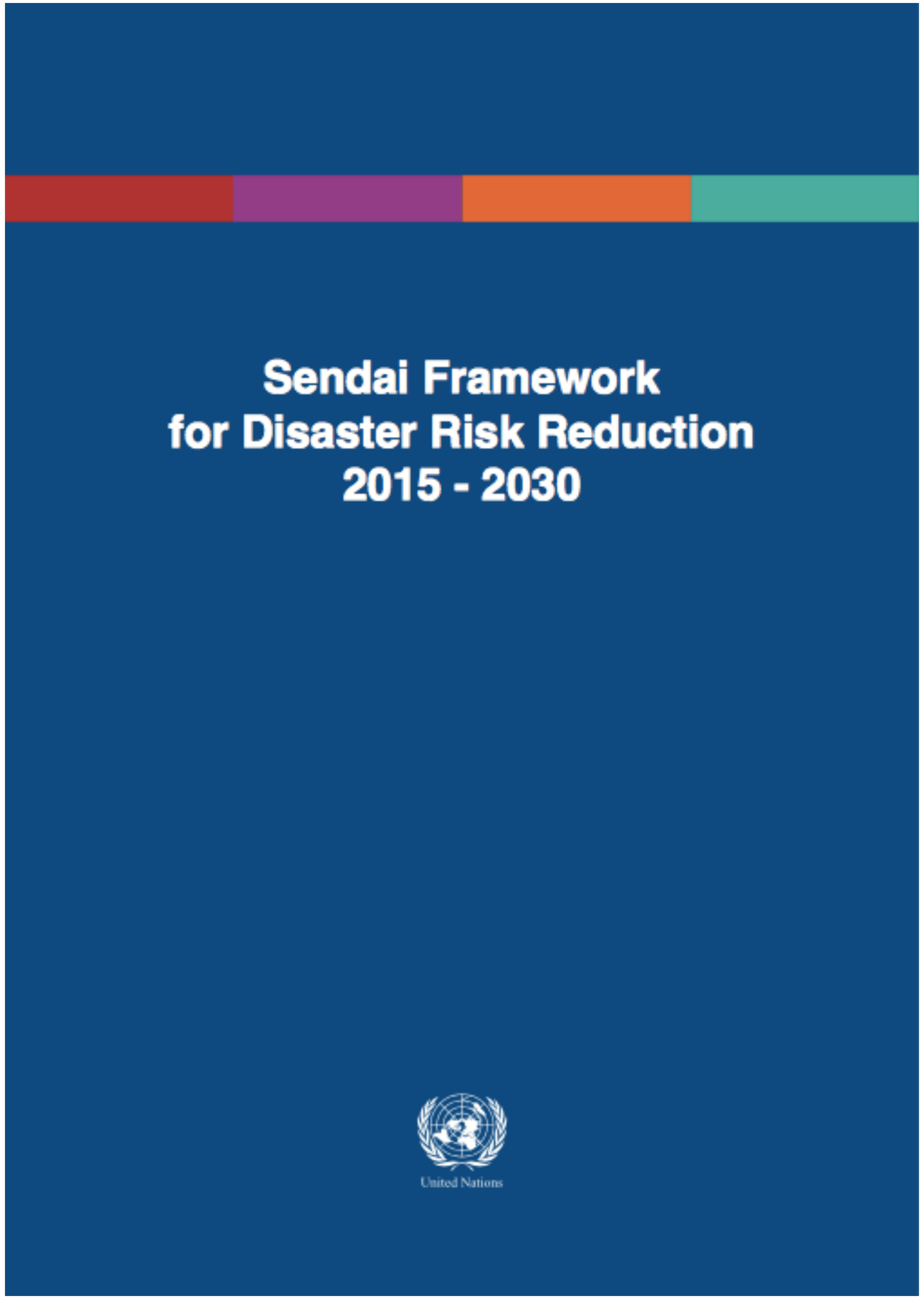
Disasters and Sustainability



Sendai Framework
for Disaster Risk Reduction
2015-2030

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What is Disaster Risk Reduction?

DISASTER RISK REDUCTION (DRR)

There is no such thing as a 'natural' disaster, only natural hazards.

Disaster Risk Reduction (DRR) aims to reduce the damage caused by natural hazards like earthquakes, floods, droughts and cyclones, through an ethic of prevention.

Disasters often follow natural hazards. A disaster's severity depends on how much impact a hazard has on society and the environment. The scale of the impact in turn depends on the choices we make for our lives and for our environment. These choices relate to how we grow our food, where and how we build our homes, what kind of government we have, how our financial system works and even what we teach in schools. Each decision and action makes us more vulnerable to disasters - or more resilient to them.

Disaster risk reduction is about choices.

Disaster risk reduction is the concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters. Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness and early warning for adverse events are all examples of disaster risk reduction.

The Third World Conference on Disaster Risk Reduction took place in 2015.

Our regional office is in Bangkok, Thailand.

Where We Work →

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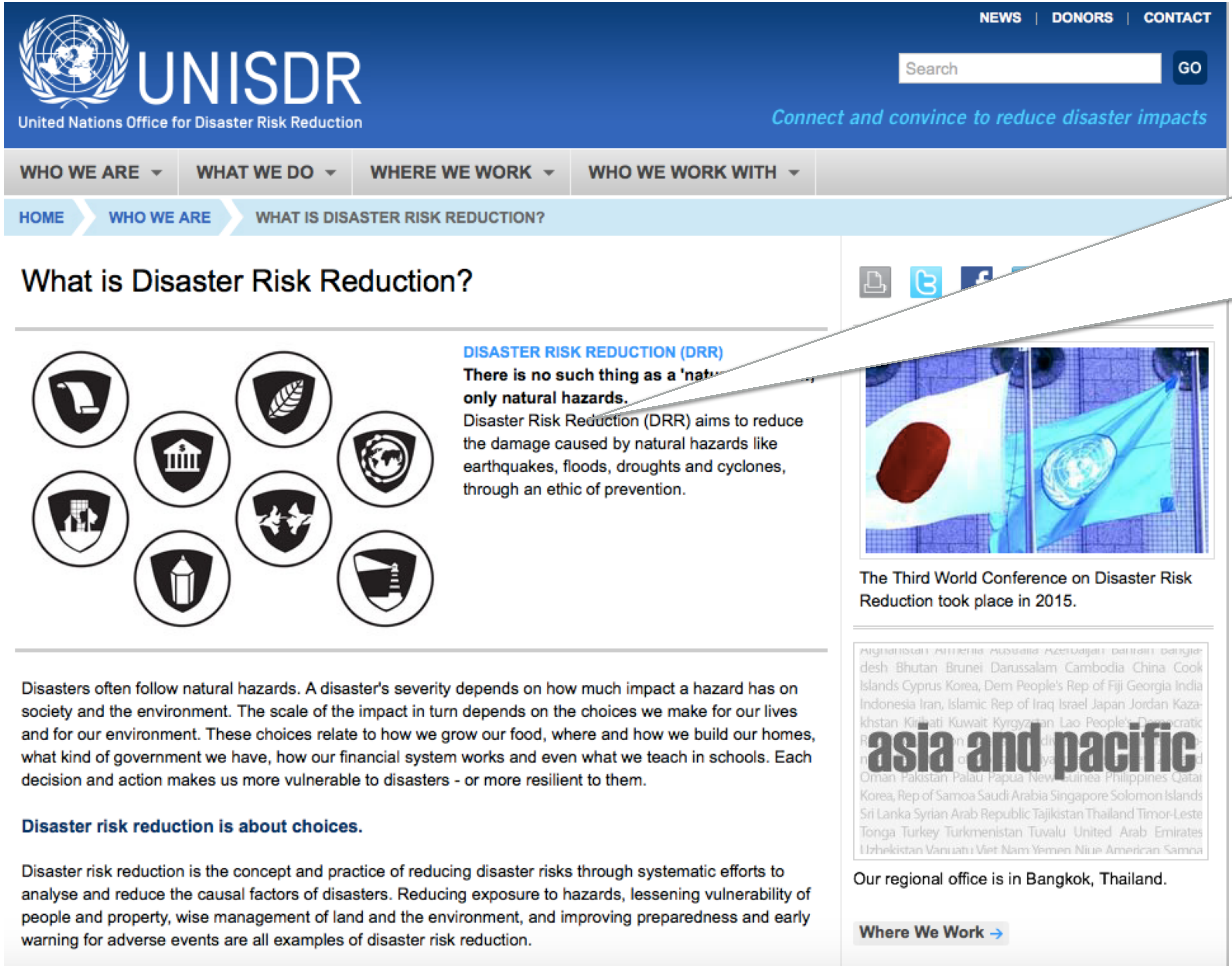

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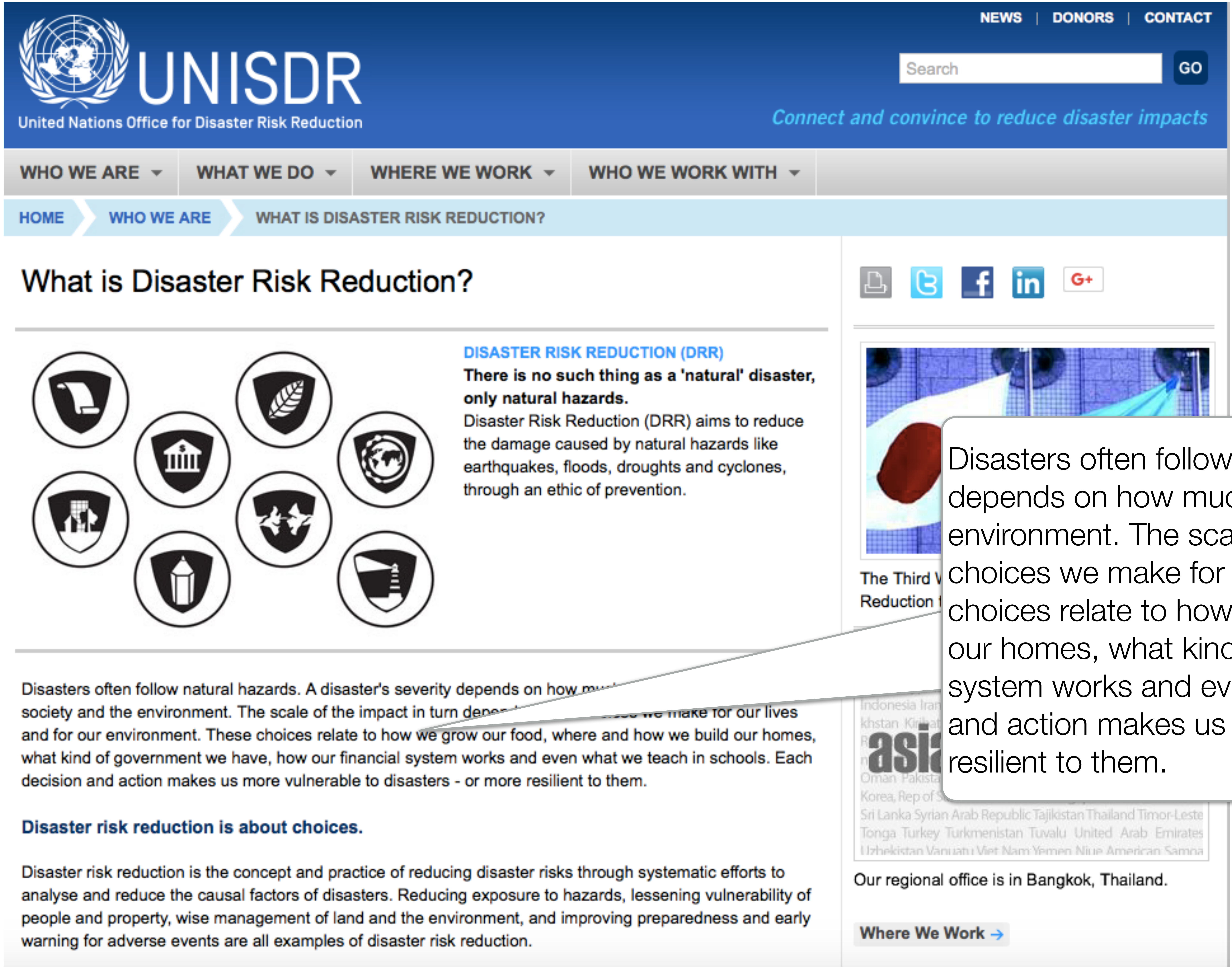
Observing Systems for a Dynamic Planet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The Third W... Reduction ...

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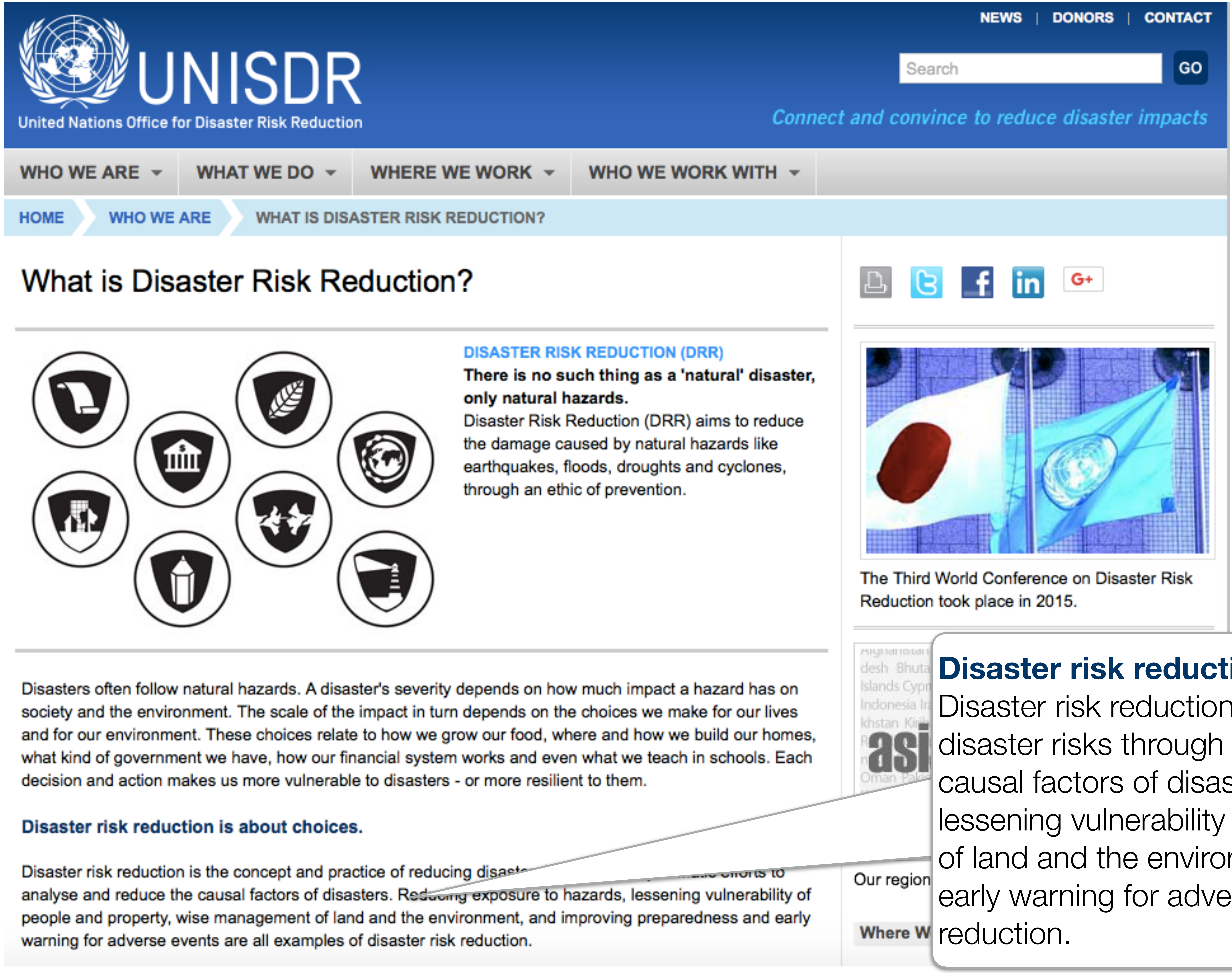
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Uzbekistan Vanuatu Viet Nam Yemen Niue American Samoa

Our regional office is in Bangkok, Thailand.

Where We Work →

Disaster risk reduction is everyone's business.

Disaster risk reduction includes disciplines like disaster management, disaster mitigation and disaster preparedness, but DRR is also part of sustainable development. In order for development activities to be sustainable they must also reduce disaster risk. On the other hand, unsound development policies will increase disaster risk - and disaster losses. Thus, DRR involves every part of society, every part of government, and every part of the professional and private sector.

https://www.unisdr.org/

Disasters and Sustainability

Disasters and Sustainability

Each Goal comes with up to 10 Targets and each Target with up to 2 Indicators.

Only Goal 11 addresses disaster risk in three Targets.

Disasters and Sustainability

Sustainable Development Goal 11: Sustainable Cities and Communities
"Make cities and human settlements inclusive, safe, resilient and sustainable"

Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations

Target 11.b: By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

Target 11.c: Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials

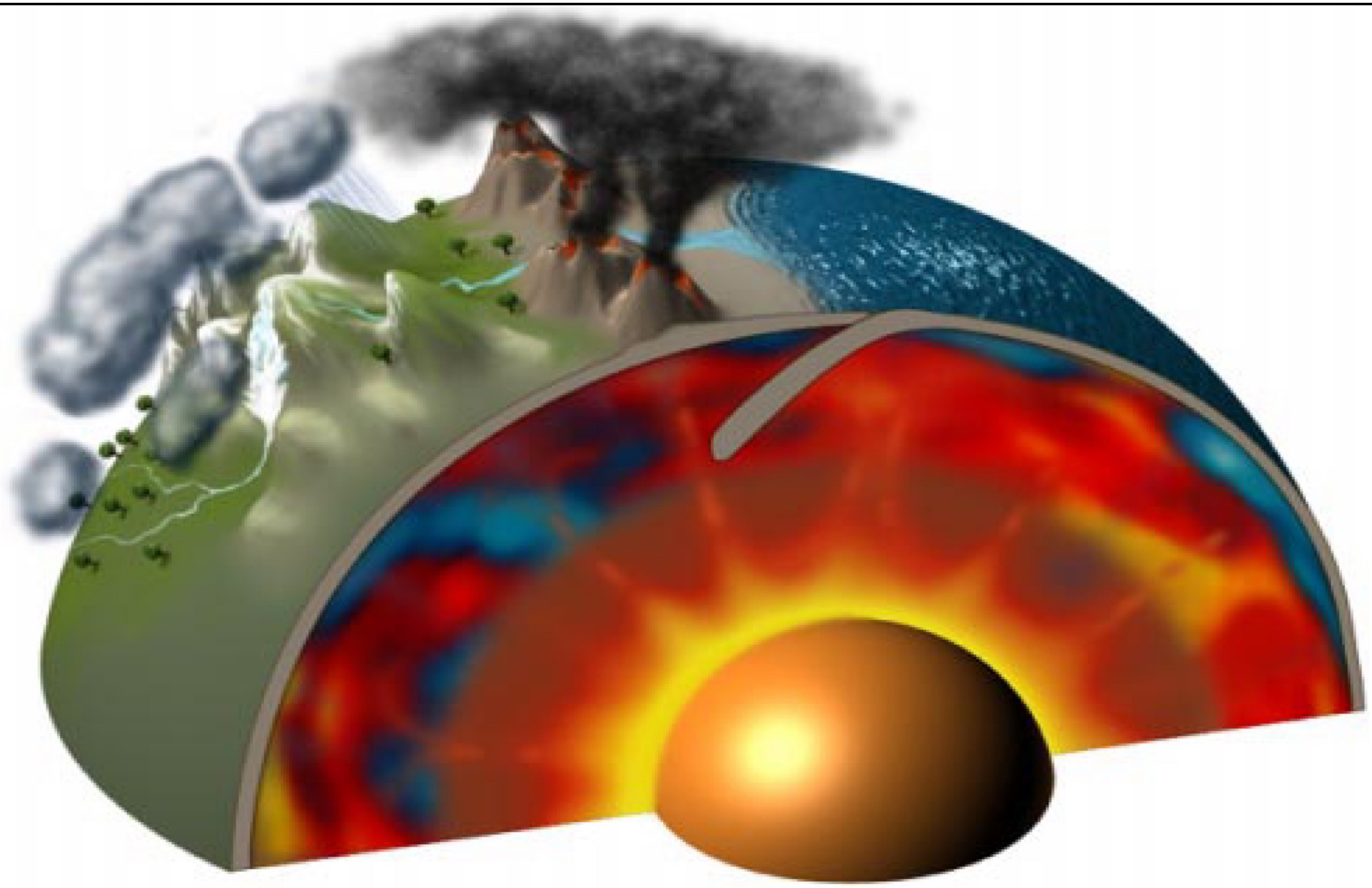
Natural Hazards and Disasters

Class 2: Observing Hazards and Disasters

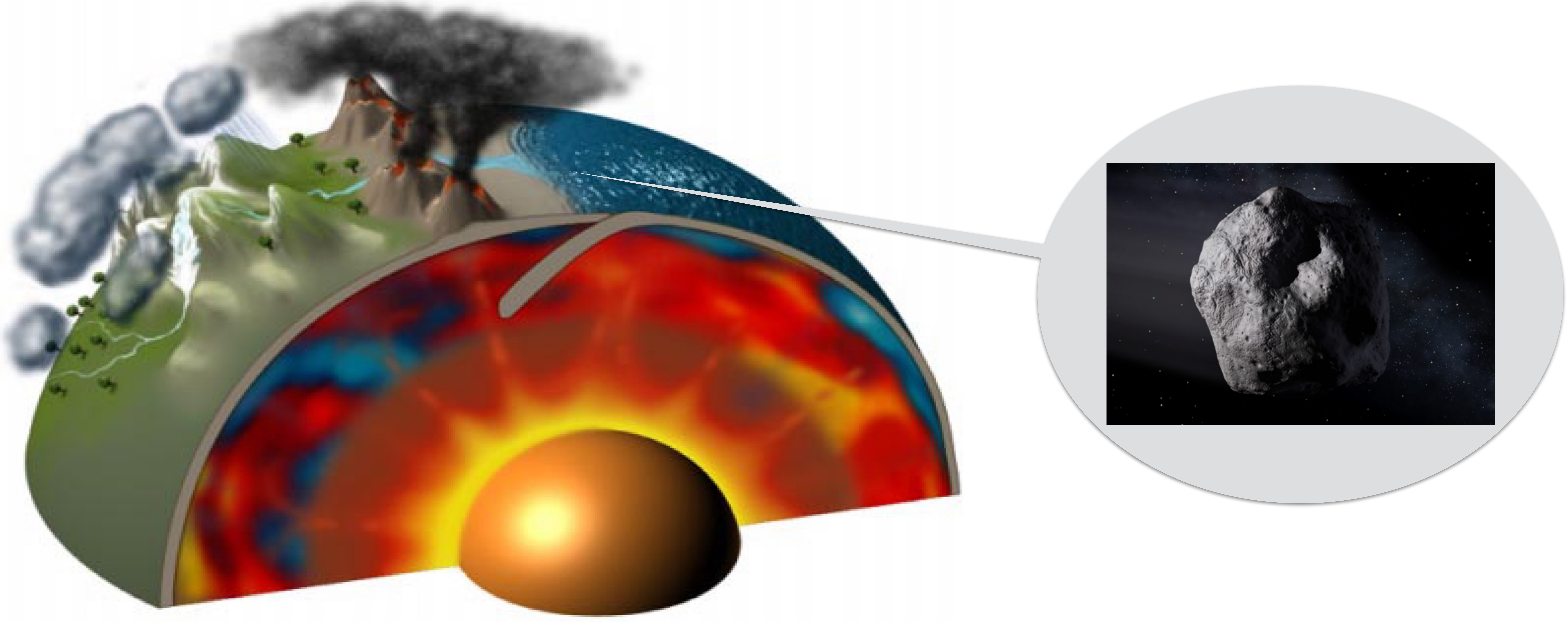
- A dynamic Planet
- Observing Systems for a Dynamic Planet
- Reference Systems and Frames
- Monitoring Small Changes

A dynamic Planet

A dynamic Planet



A dynamic Planet



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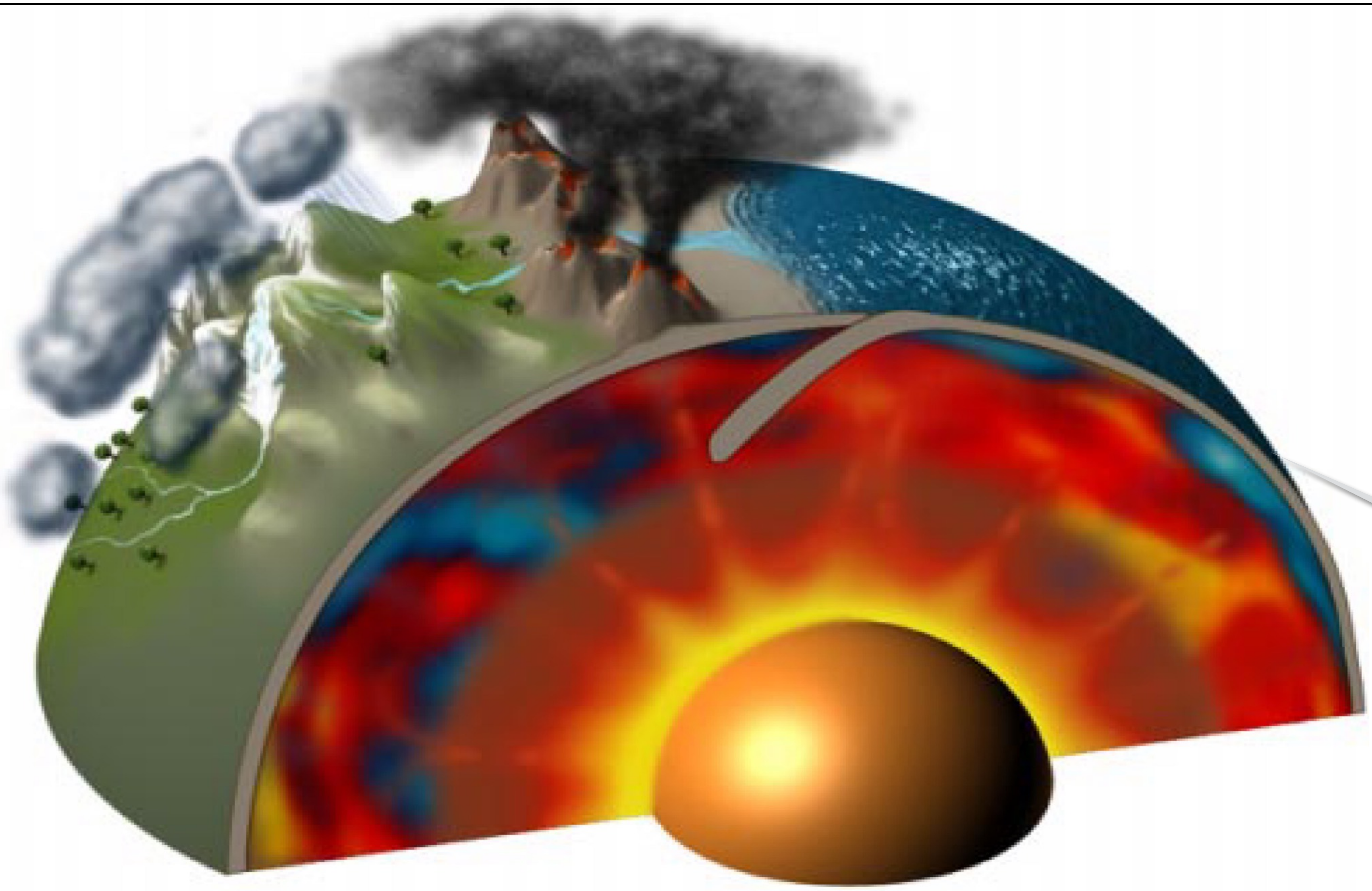

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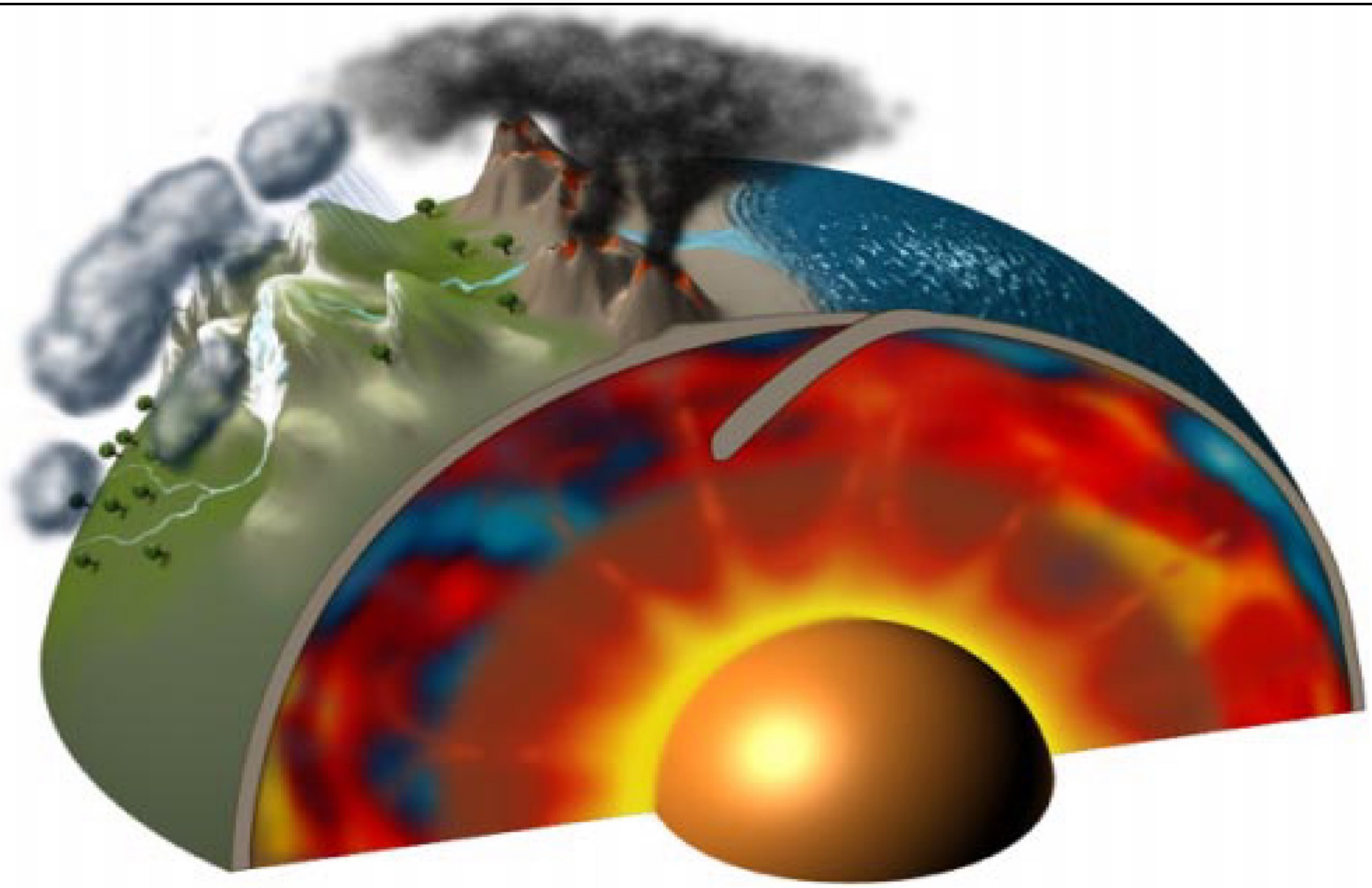

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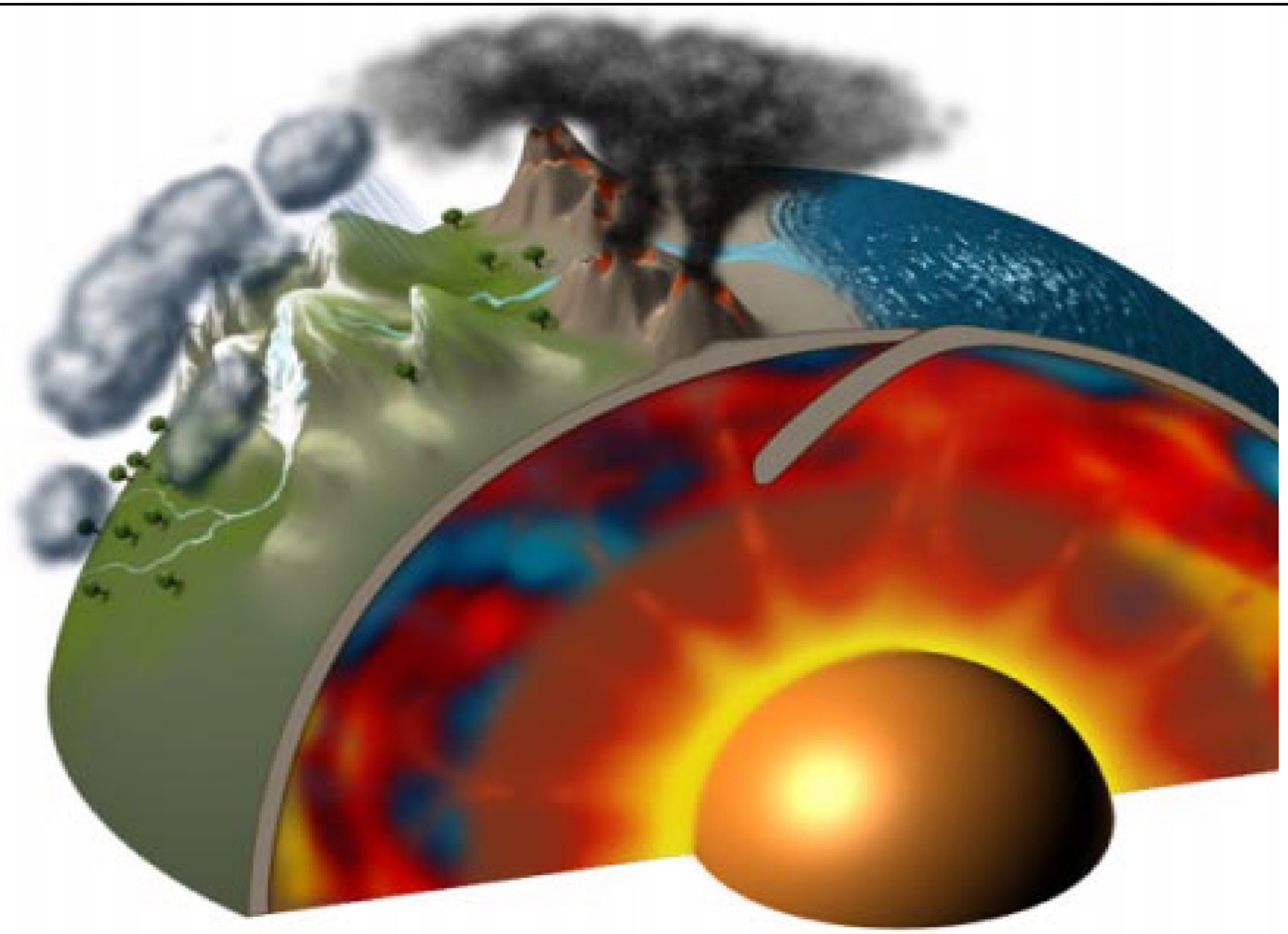

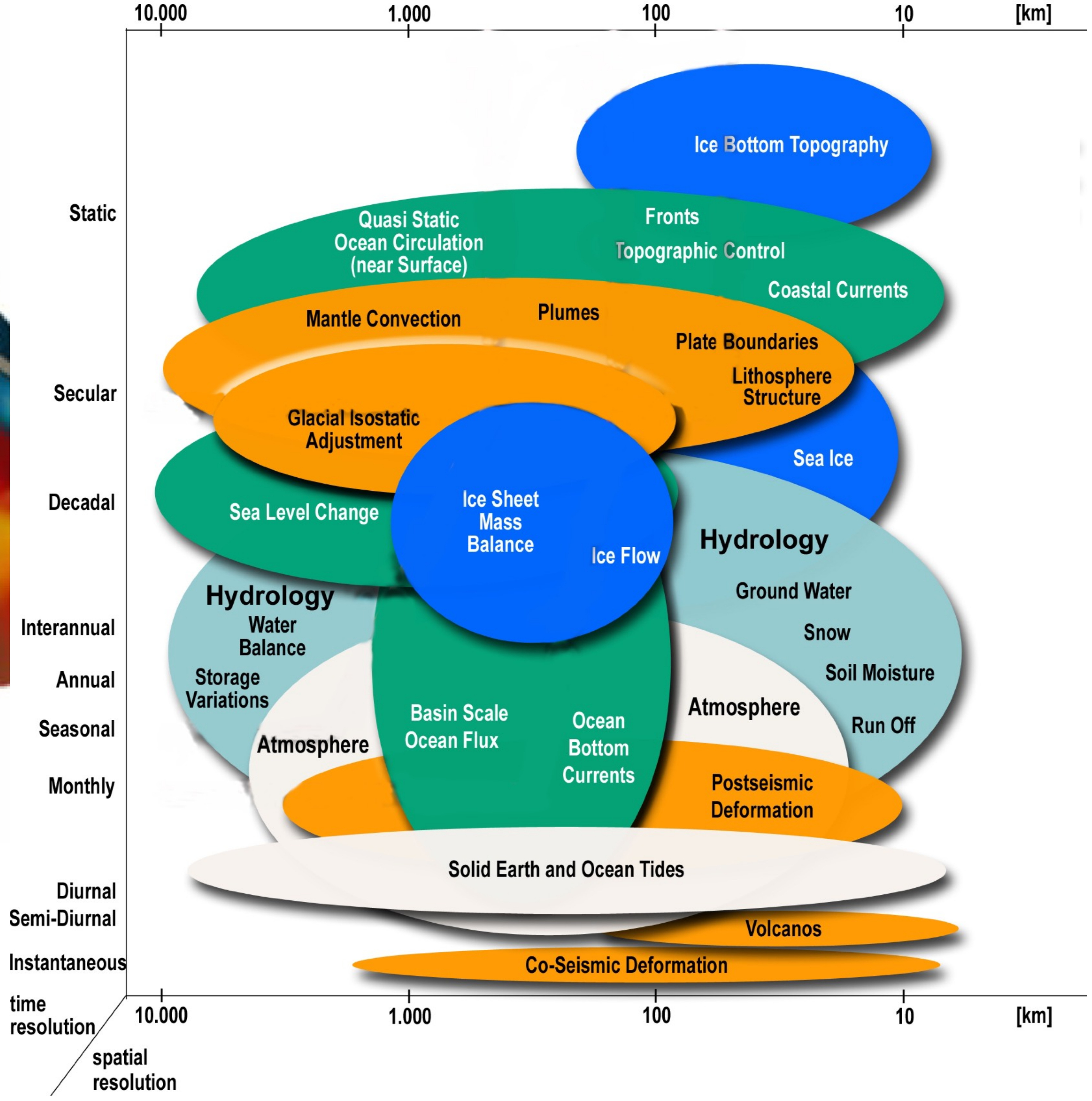

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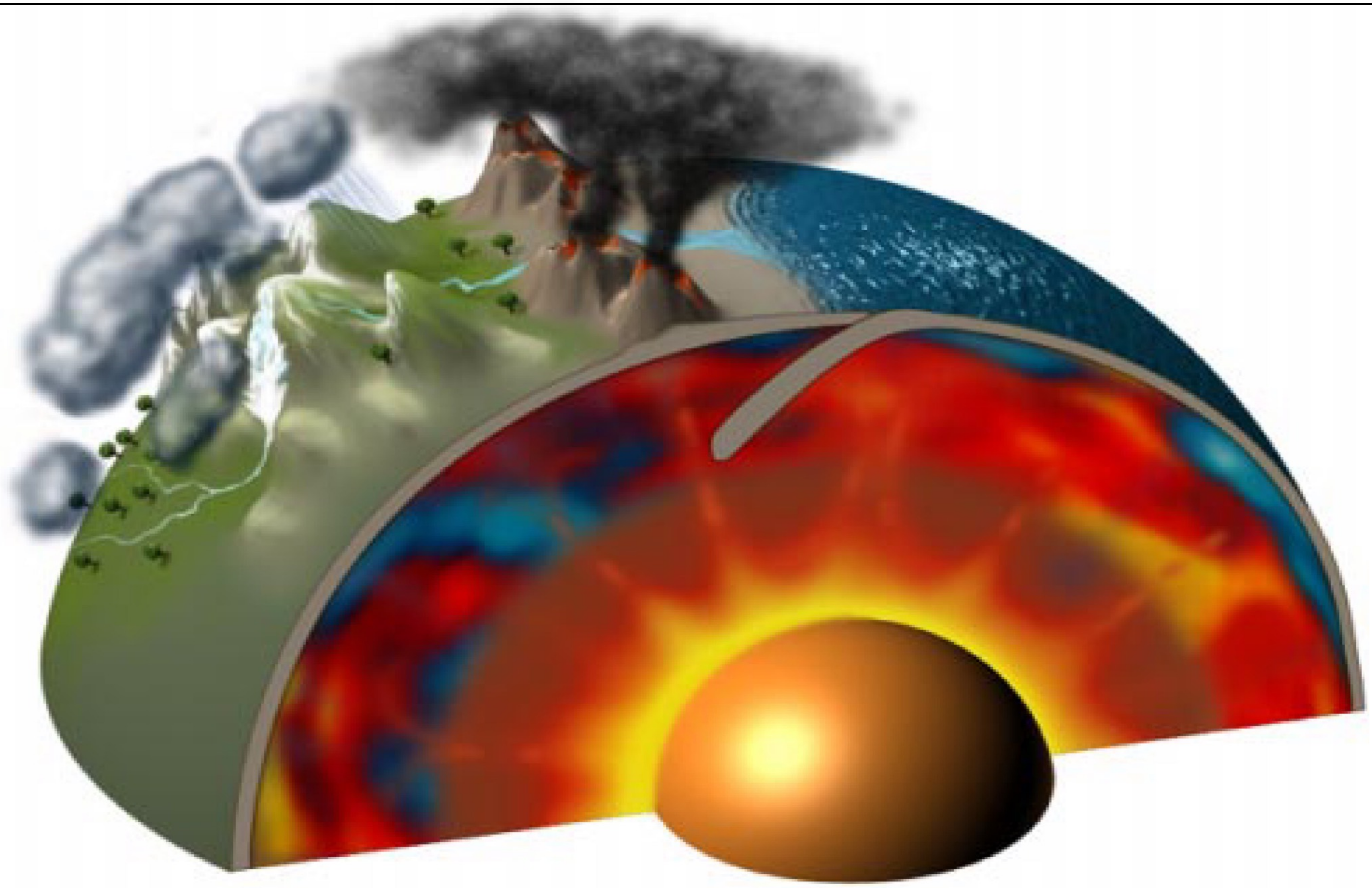

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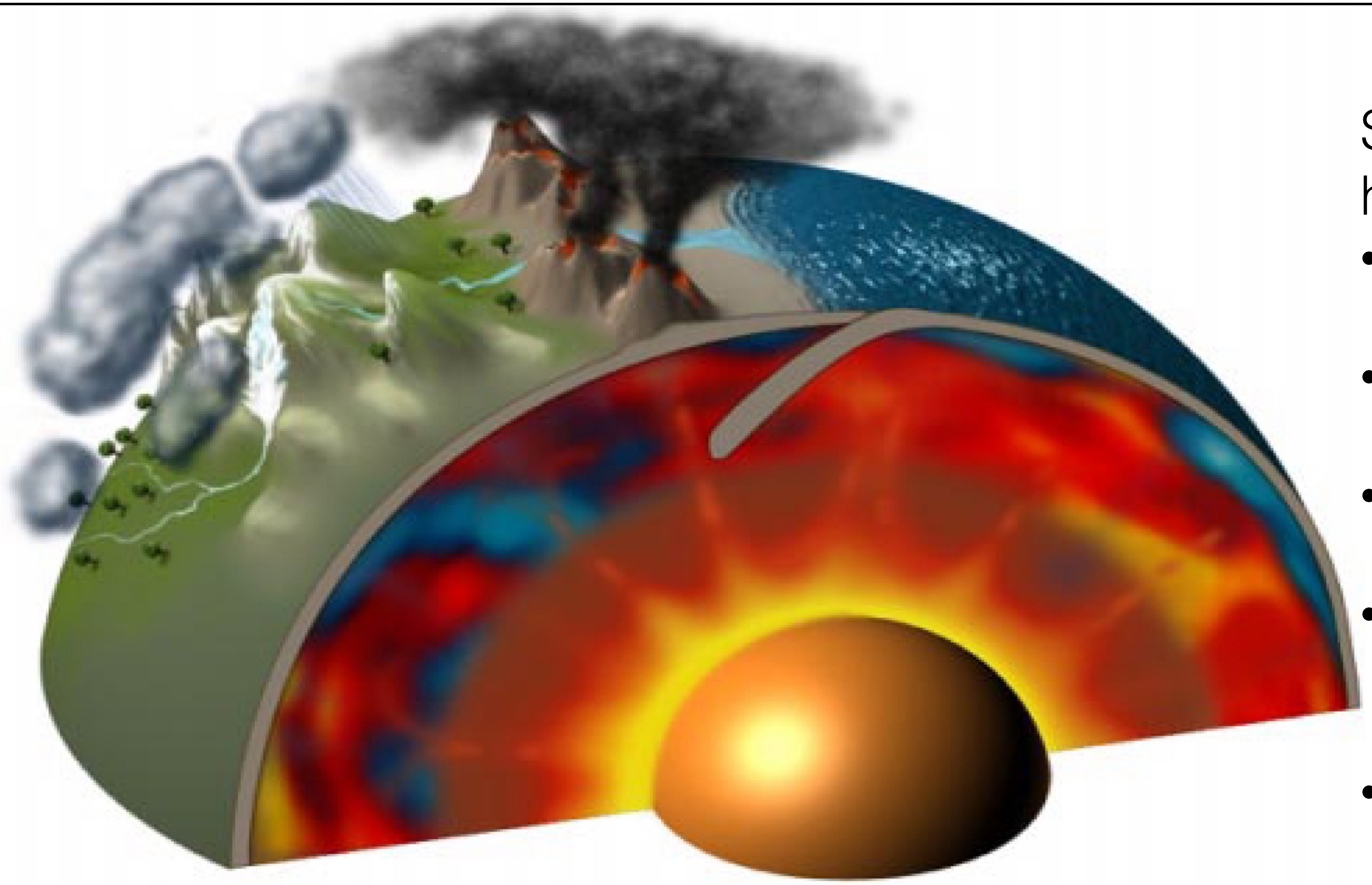

Science questions relevant for hazards:

- Plate tectonics: location of and processes at plate boundaries;
- Ice sheets/glaciers: ice load history, including present-day changes;
- Sea level: quantification of different contributions;
- Hydrological cycle: better quantification of fluxes; groundwater movements; land water storage;
- Earthquakes: strain/stress accumulation and earthquakes; physical processes;
- Volcanoes: location, state,

Modified from Rummel et al., 2009

Natural Hazards and Disasters

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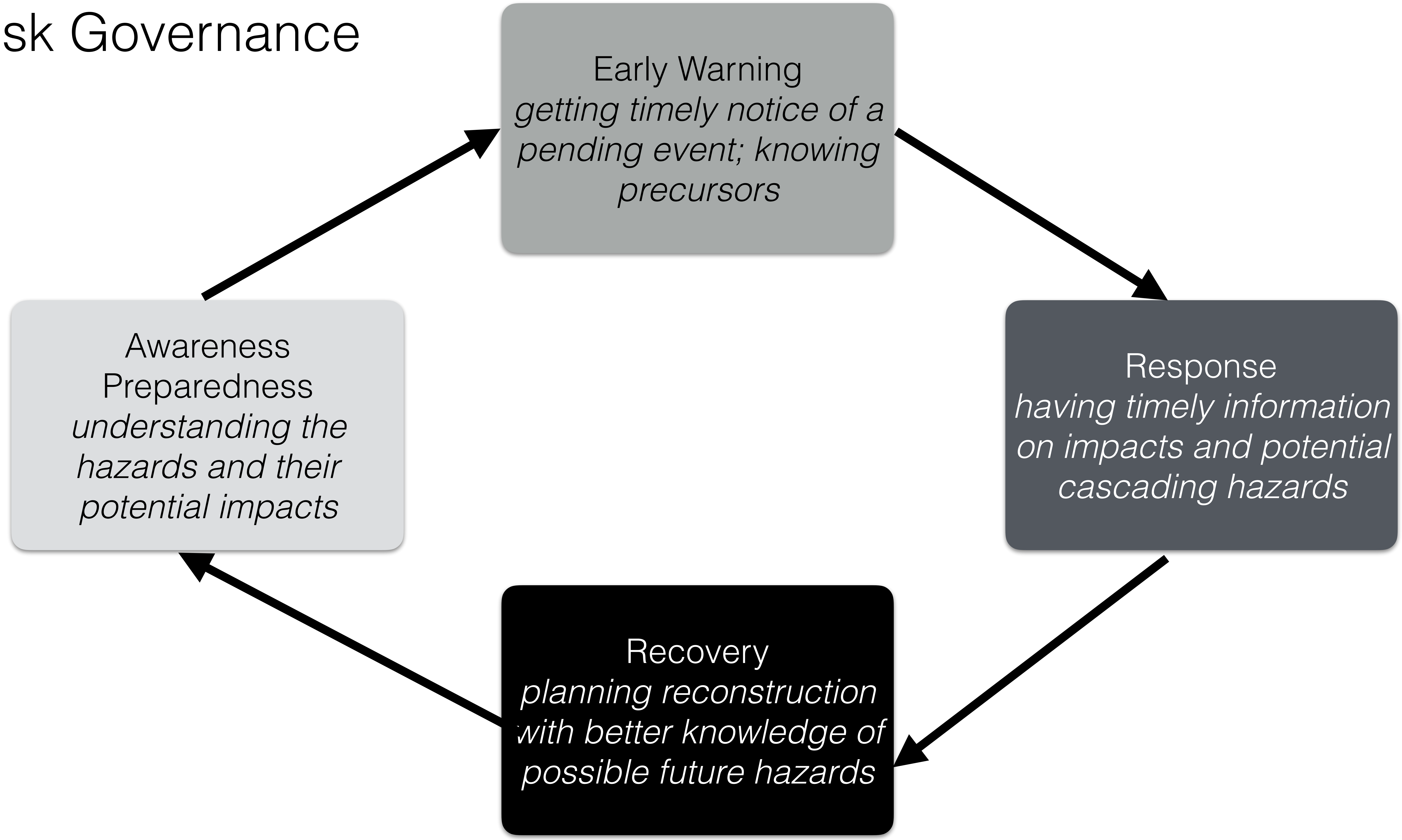
Disaster Risk Governance



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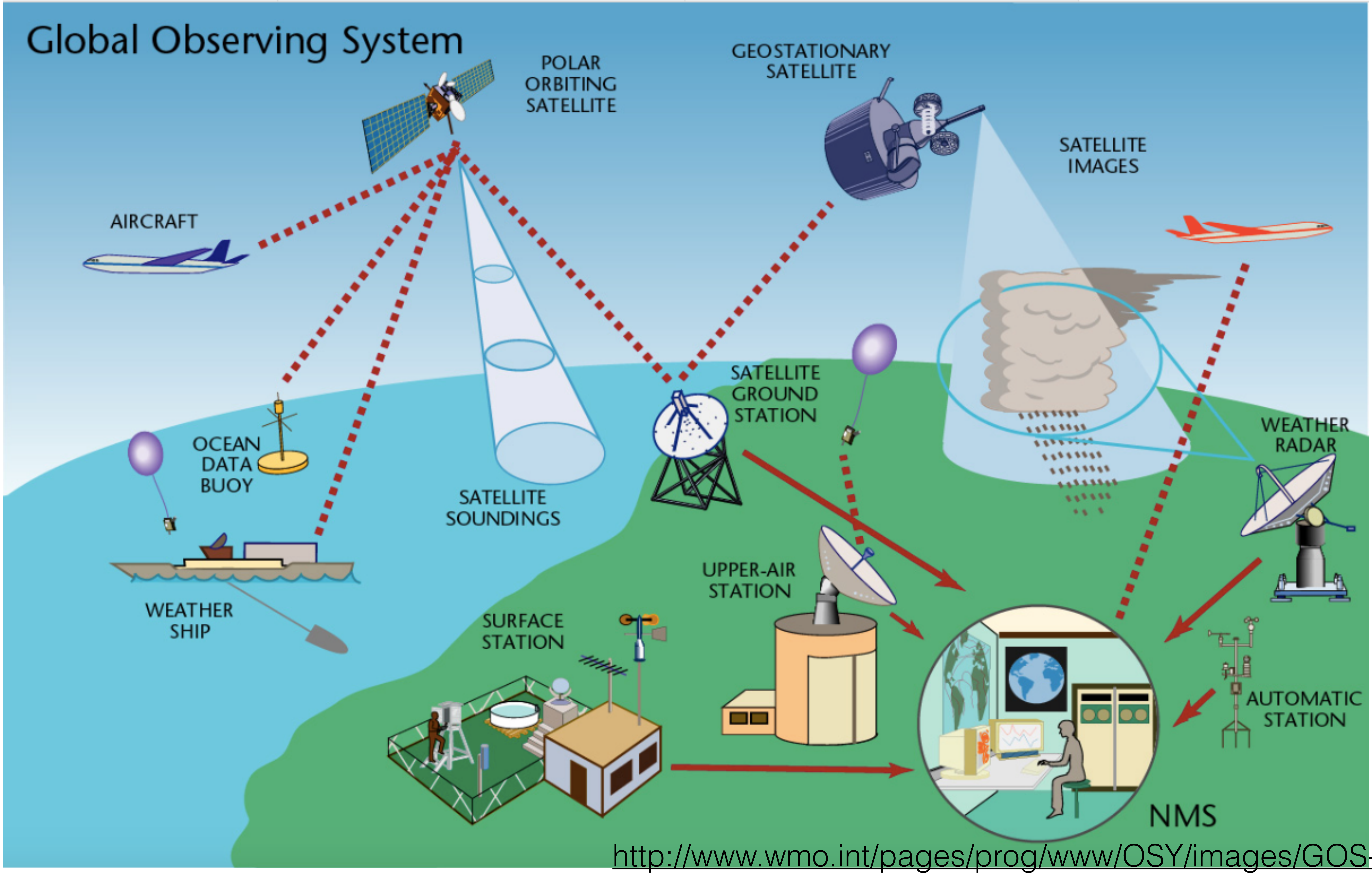

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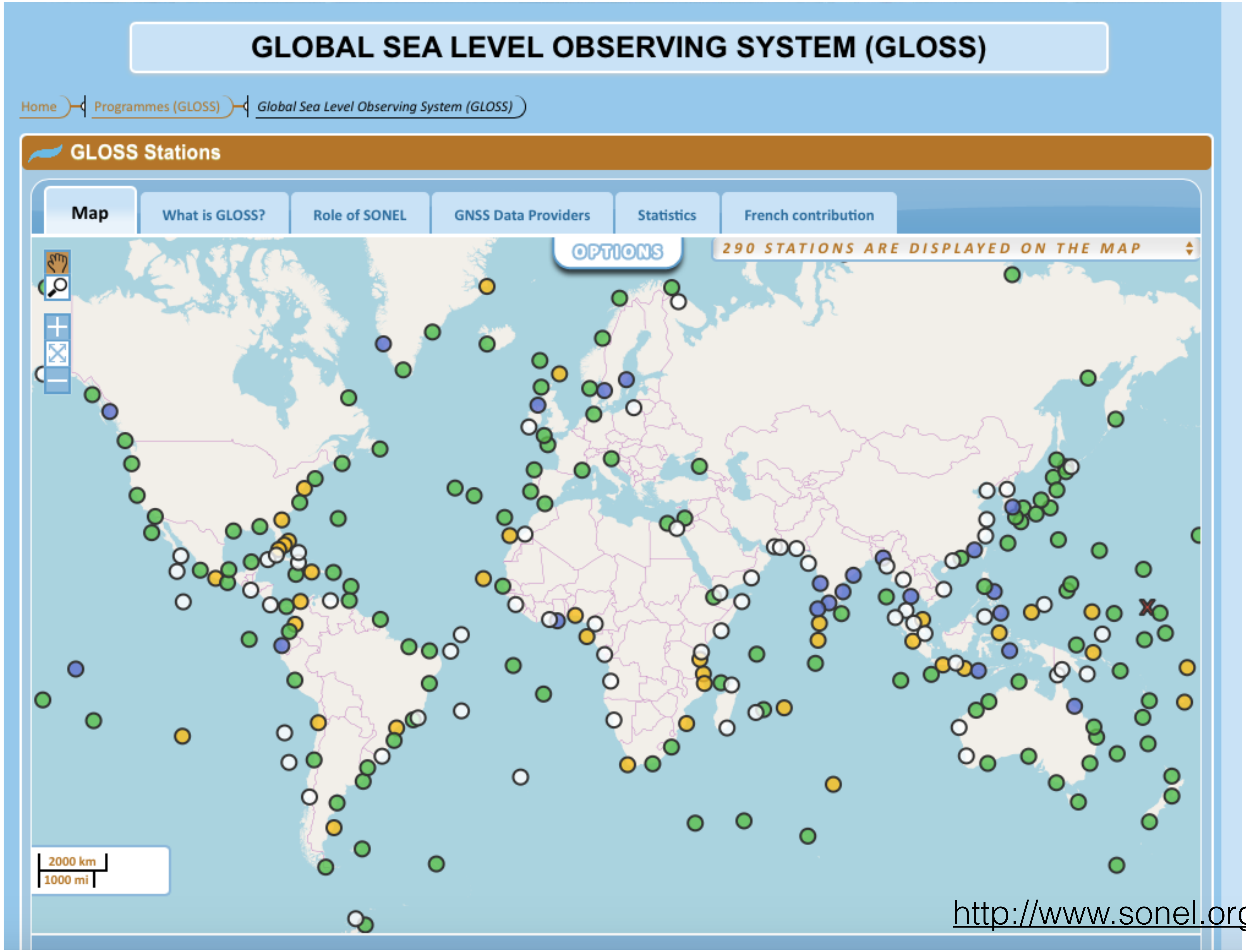

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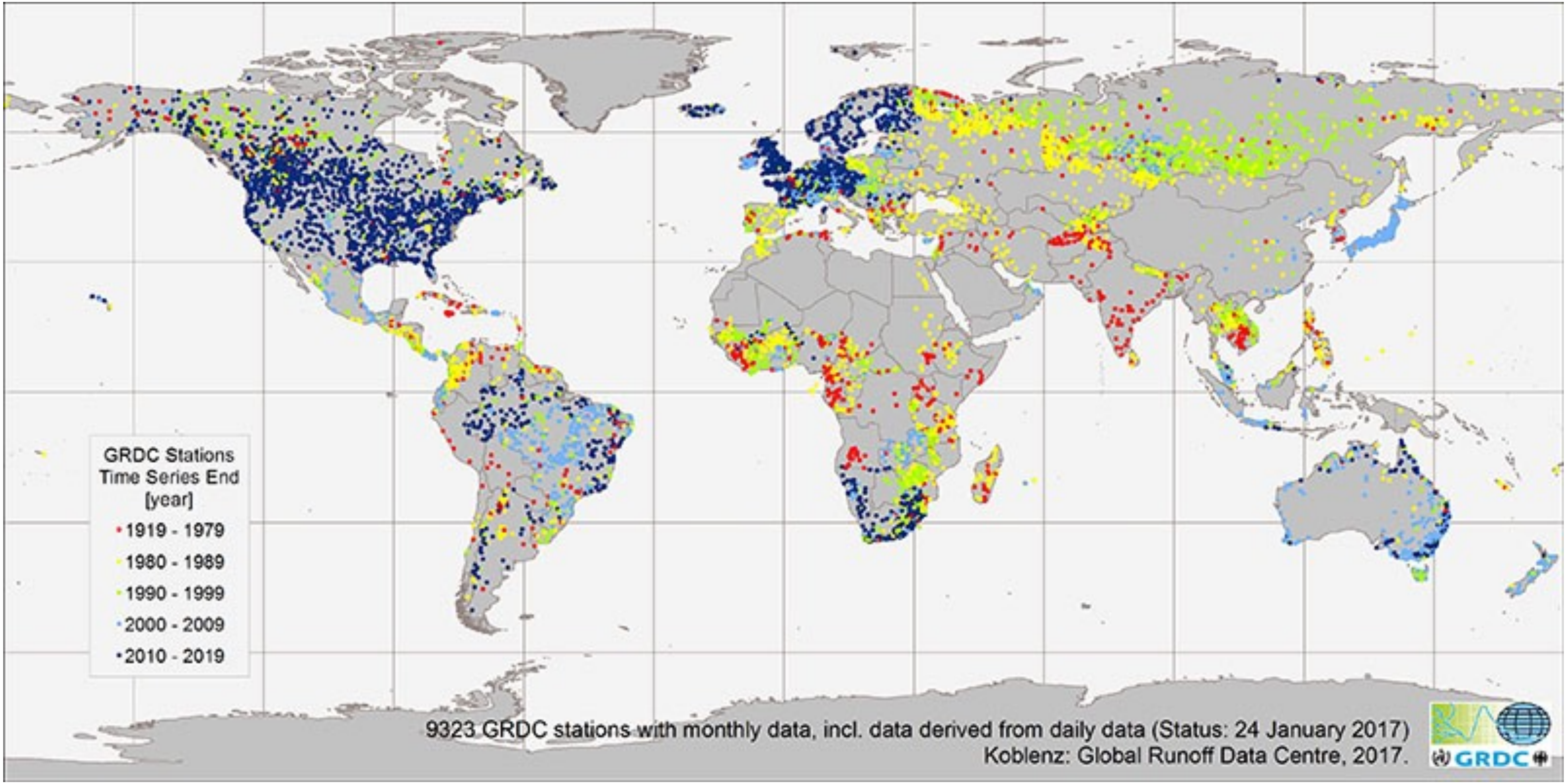
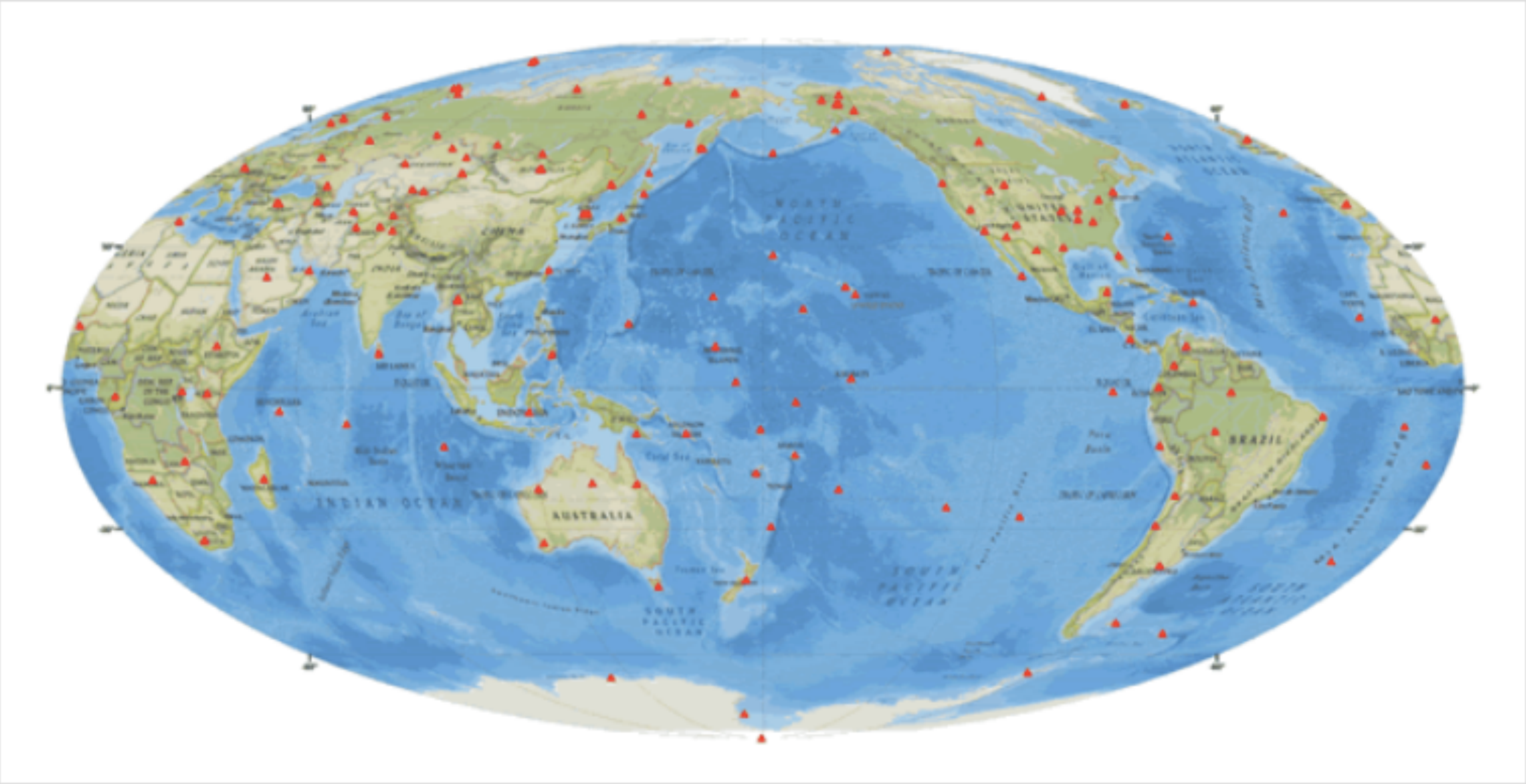


Observing Systems for a Dynamic Planet

USGS
science for a changing world

Earthquake Hazards Program

GSN – Global Seismographic Network



The Global Seismographic Network is a permanent digital network of state-of-the-art seismological and geophysical sensors connected by a telecommunications network, serving as a multi-use scientific facility and societal resource for monitoring, research, and education. Formed in partnership among the USGS, the National Science Foundation (NSF) and the Incorporated Research Institutions for Seismology (IRIS), the GSN provides near-uniform, worldwide monitoring of the Earth, with over 150 modern seismic

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science for a changing world

Earthquake Hazards Progra

← Monitoring

- National Earthquake Information Center-NEIC
- ANSS-Advanced National Seismic System
- GSN-Global Seismographic Network
- Volunteer Monitoring
- Seismogram Displays
- Earthquake Monitoring of Structures
- NSMP-National Strong Motion Project
- Crustal Deformation Monitoring

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IRIS Incorporated Research Institutions for Seismology

NSF

RESEARCH Data, derived products, software, web services

EDUCATION Lessons, lectures, videos, public displays

FACILITIES Directorates, programs, networks, centers

EARTHQUAKES Recent earthquakes, teachable moments

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RESOURCES Publications, webinars, posters, newsletters, proposals

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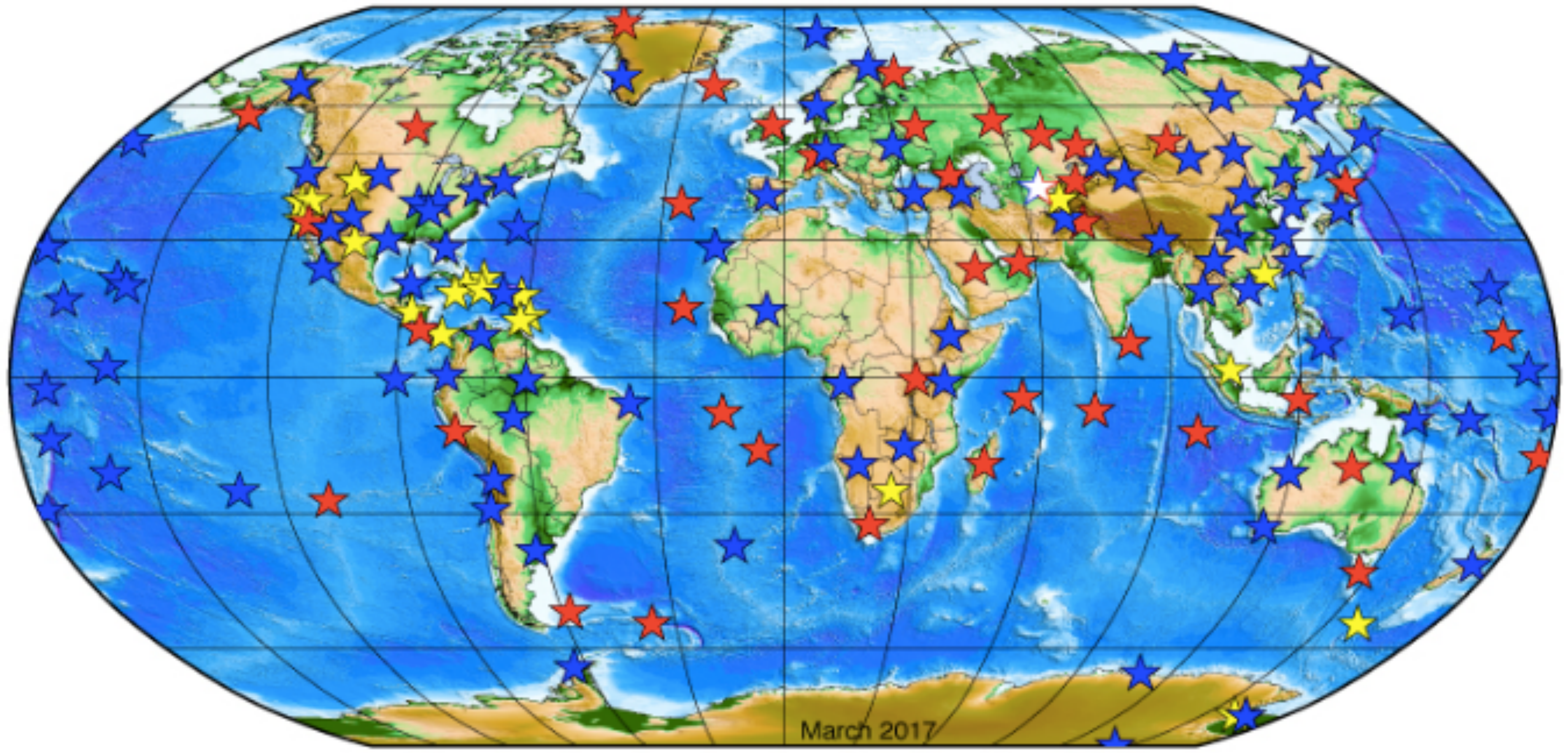
  - GSN Instrumentation
  - GSN Data Quality
  - GSN Data Access
  - GSN Documentation
  - GSN Review 2015
  - GSN Standing Committee
- **Portable Networks (PASSCAL)**
- **The Ocean Bottom Seismograph Instrument Pool**
- **Transportable Array**
- **Magnetotelluric Array**
- **Polar**
- **Greenland Ice Sheet Monitoring Network**
- **Global Reporting Observatories in Chile (GRO Chile)**

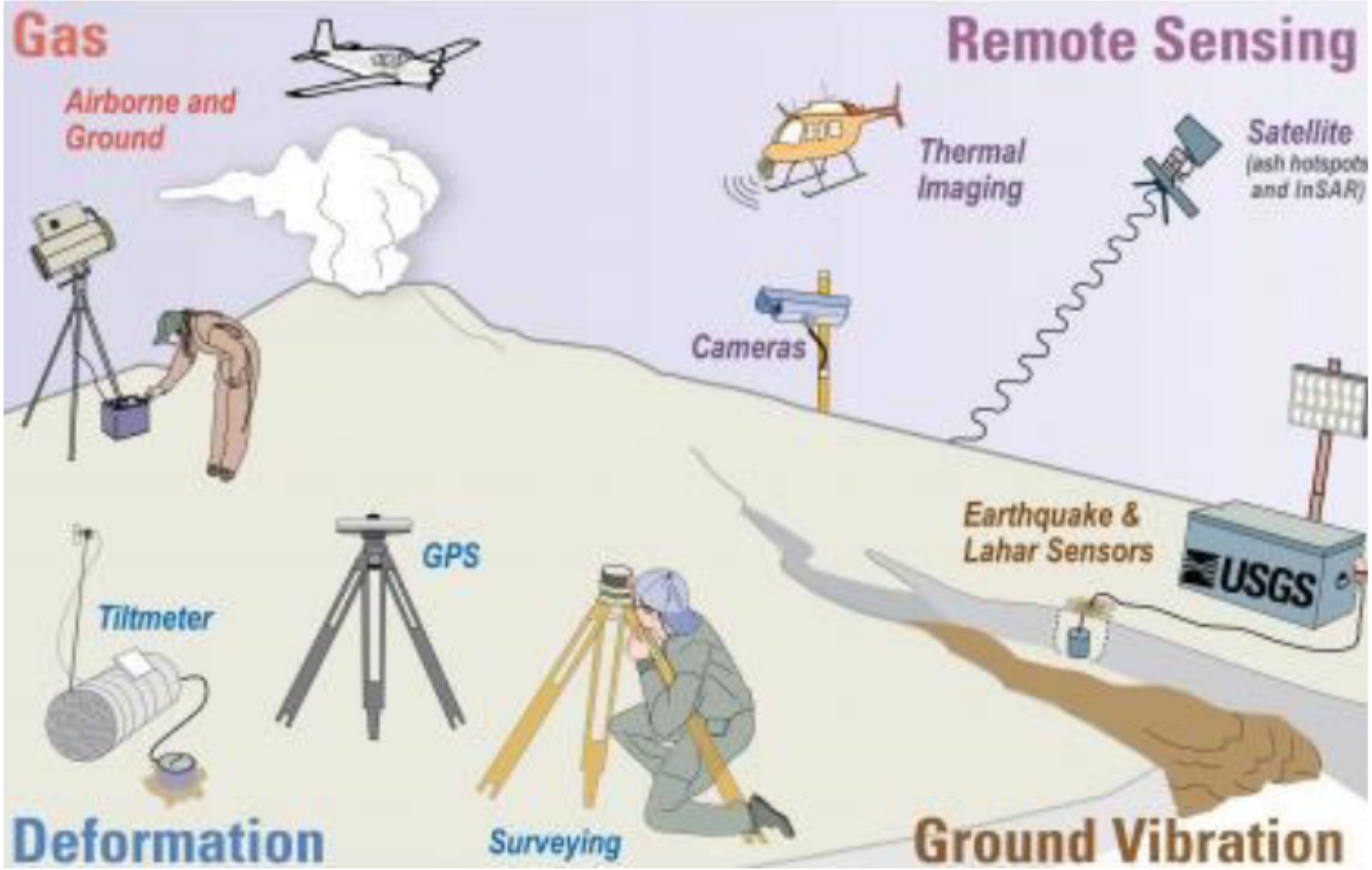
Global Seismographic Network



IRIS/IDA Stations · IRIS/USGS Stations · Affiliate Stations · Planned Stations

The Global Seismographic Network (GSN) is a 150+ station, globally distributed, state-of-the-art digital seismic network that provides free, realtime, open access data through the IRIS DMC. The map above shows the distribution of the current station network with respect to network operations.

Observing Systems for a Dynamic Planet



USGS Monitoring System for Geohazards

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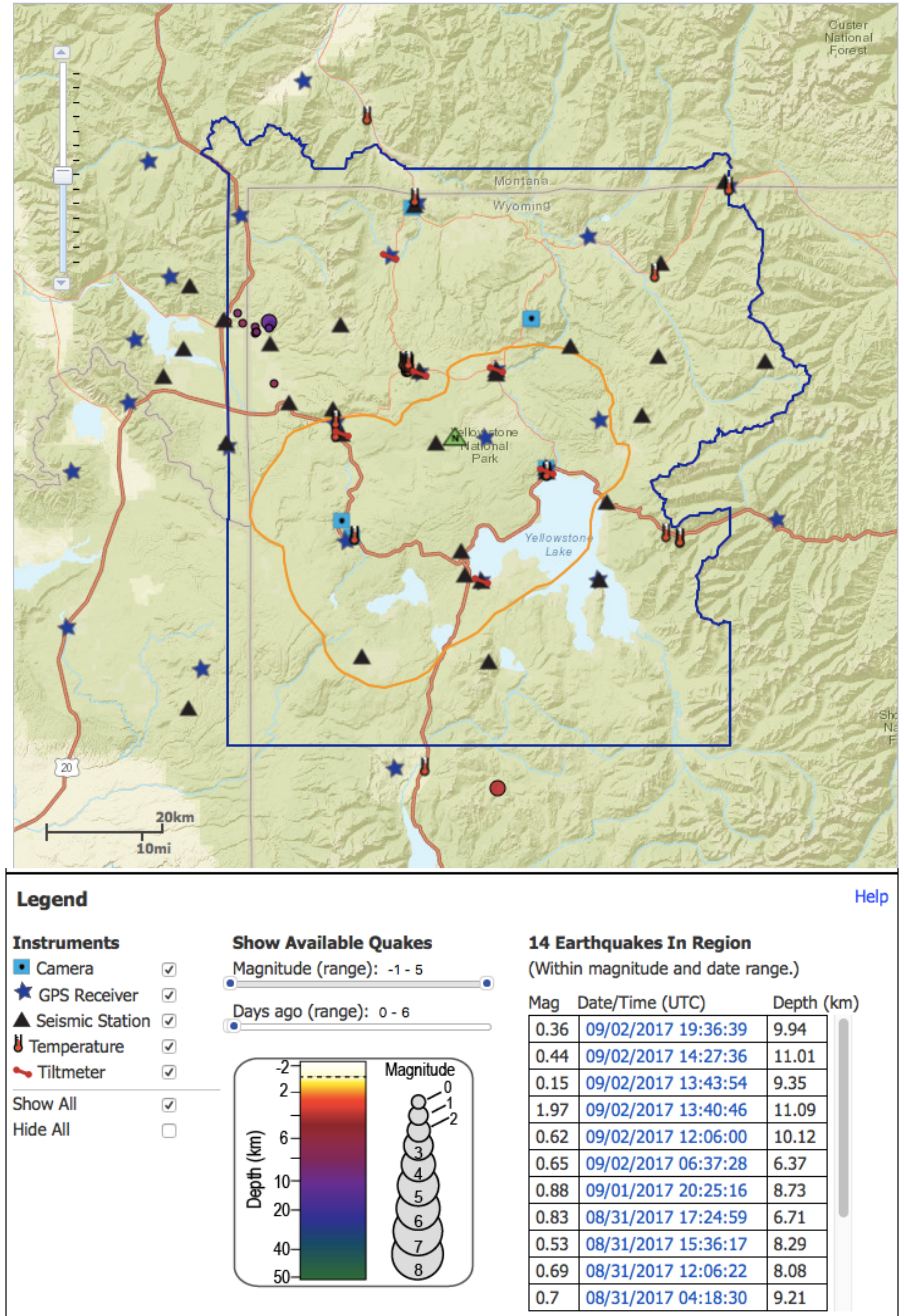

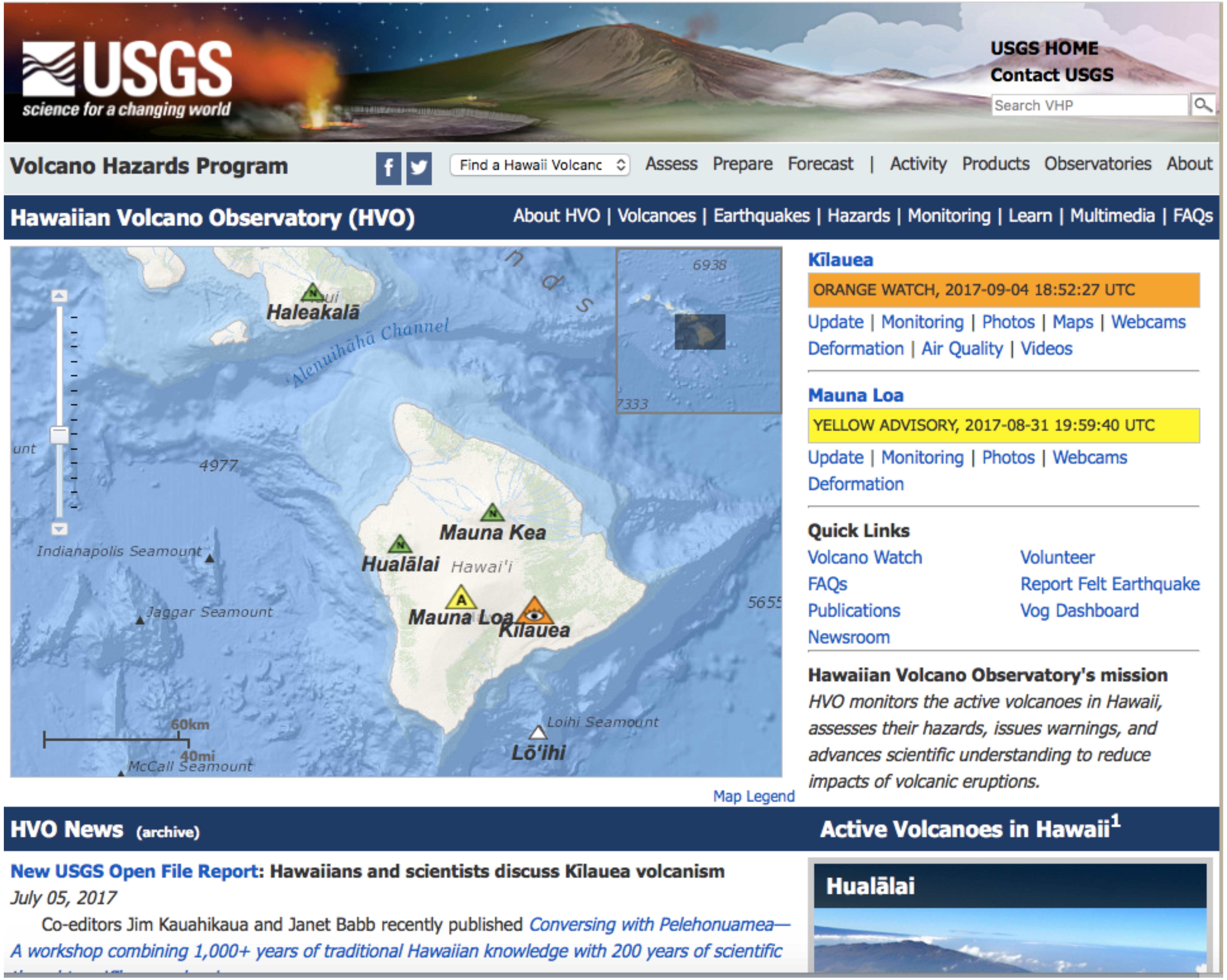

https://volcanoes.usgs.gov/volcanoes/yellowstone/monitoring_map.html

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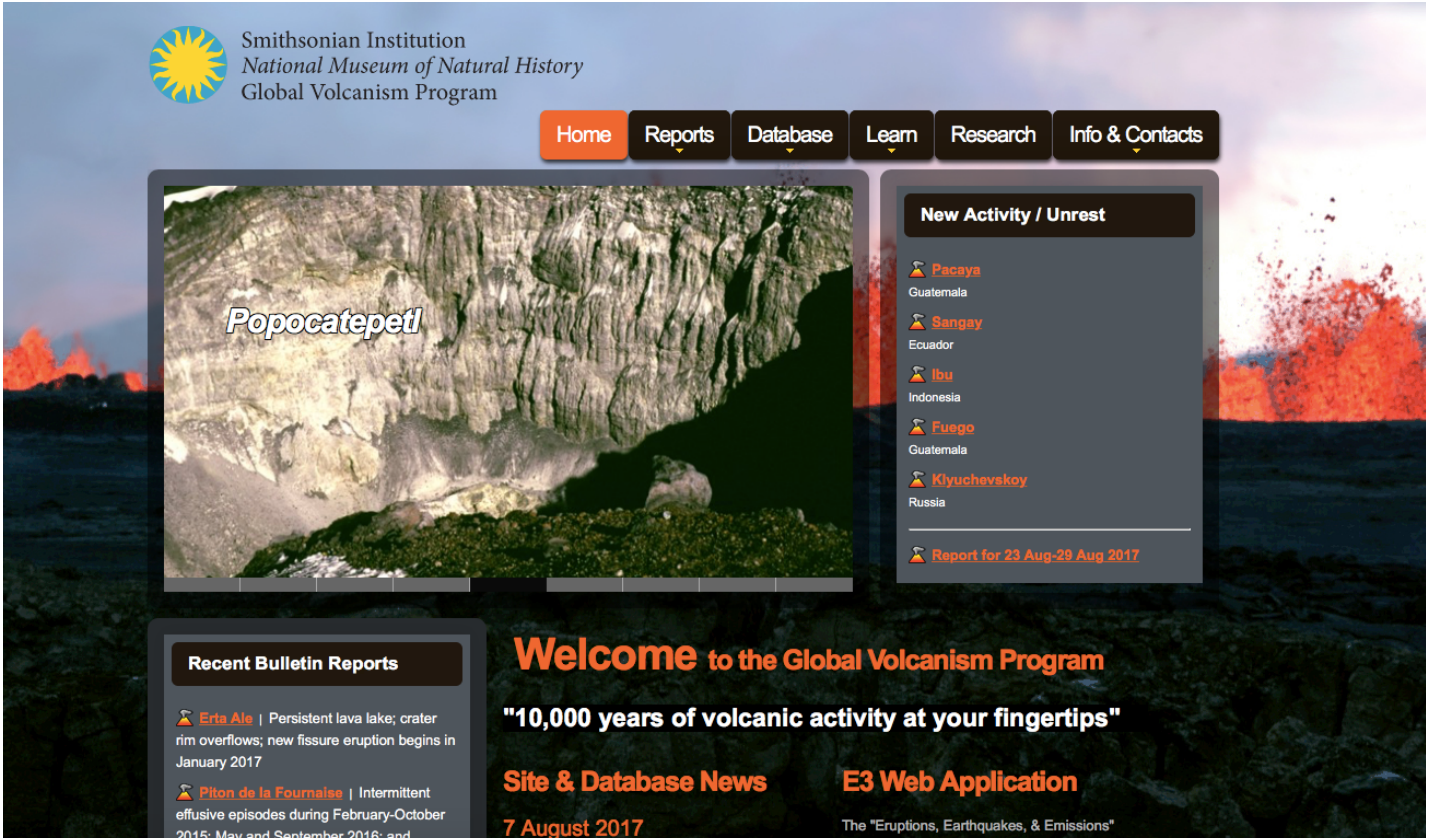

Figure 2. Geographical location of the volcanoes involved in the NOVAC project as of April 2009. The project is open to participation by any interested institution, so the network may be expanded in the future. Also see Table 1. (© Google 2009 and Europa Technologies 2009.)

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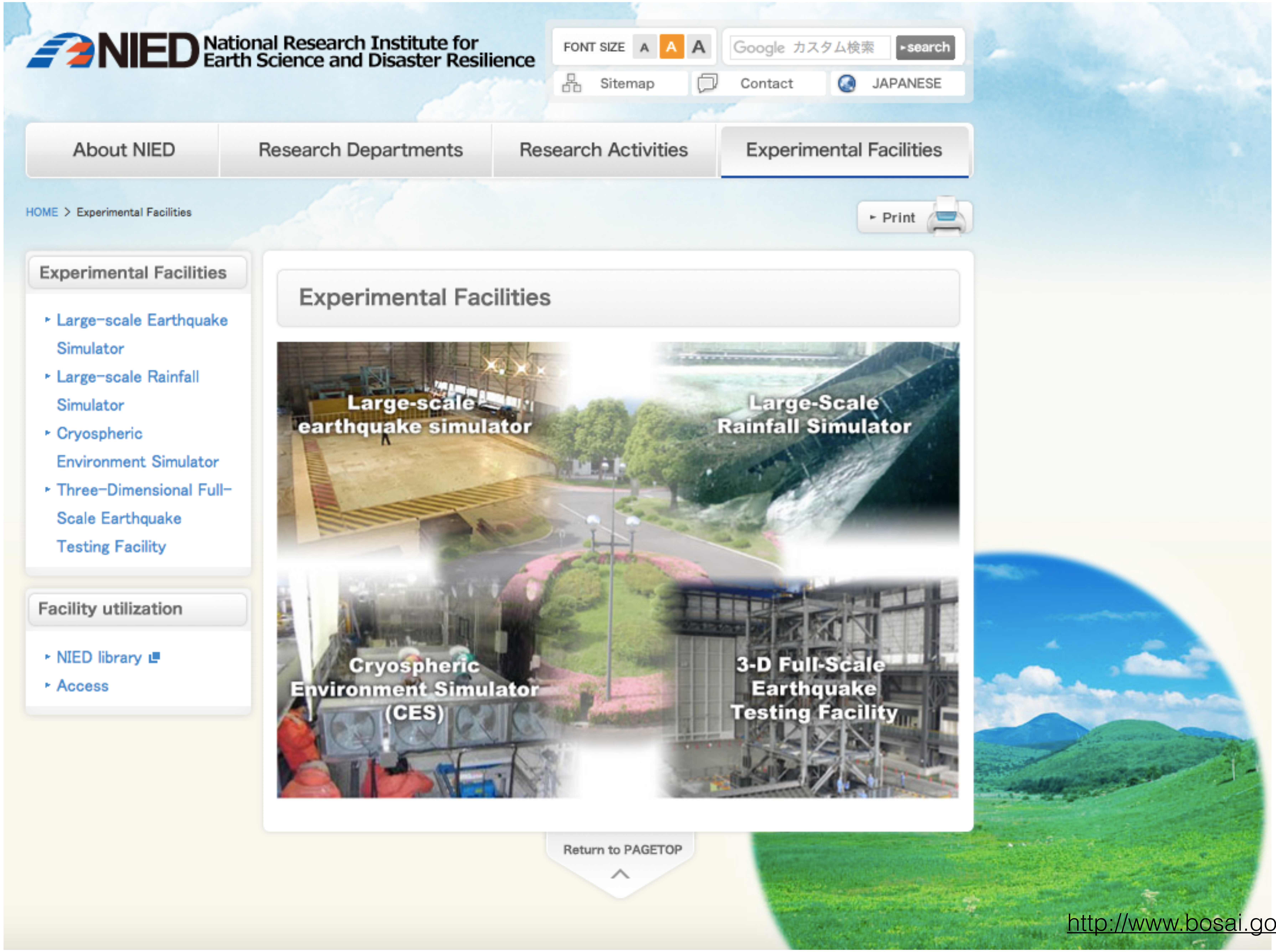

http://www.bosai.go.jp/e/research/the_second/volcano/faclities.html

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Projects

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- **Major Projects**
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    - Overview
    - Science
    - History
    - Instrumentation & Networks
    - Maintenance
    - Data
    - Documentation

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- *PBO Instrumentation*
- *PBO Network Monitoring*
- *PBO GPS Core Data*
- *PBO High Rate Data*
- *Custom Data Request*
- *SINEX format at IERS*

EarthScope - Plate Boundary Observatory (PBO)

Overview

The Plate Boundary Observatory (PBO) component of the EarthScope precisely measures Earth deformation resulting from the constant motion of the Pacific and North American tectonic plates in the western United States.

The GAGE Facility, operated by UNAVCO, Inc., is responsible for instrument installation, ongoing maintenance, communications, data archiving, data processing, and data availability for the geodetic instruments that comprise the Plate Boundary Observatory.

The Principal Investigator (PI) for for the Plate Boundary Observatory is UNAVCO President, Dr. M. Meghan Miller (**meghan@unavco.org**) and the Co-PI is Director of UNAVCO Geodetic Infrastructure, Dr. Glen Mattioli (**mattioli@unavco.org**).

https://www.unavco.org/projects/major-projects/pbo/pbo.html

Science

A primary objective of the PBO is to quantify three-dimensional deformation and its temporal variability across the active boundary zone between the Pacific and North American plates.

Centimeter to millimeter-level measurements of surface and near surface motion through Global Positioning System (GPS) stations, borehole geophysics, laser strainmeters, accelerometers, and geodetic imaging has far reaching implications regarding earthquakes, volcanic unrest, subsidence, landslides, extraction or injection of fluids, loading or unloading of water, ice or snow, and other Earth processes.

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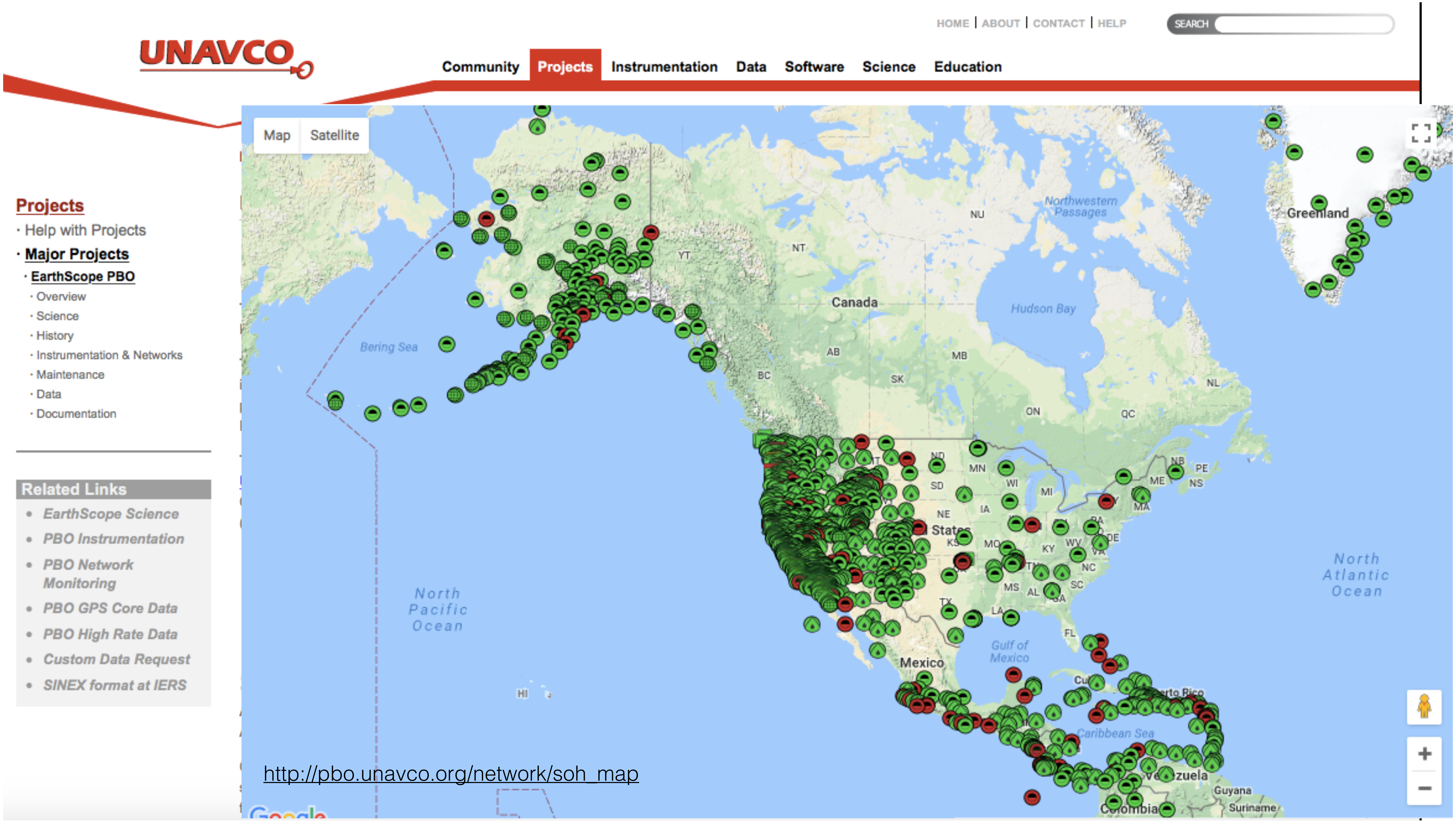

http://pbo.unavco.org/network/soh_map

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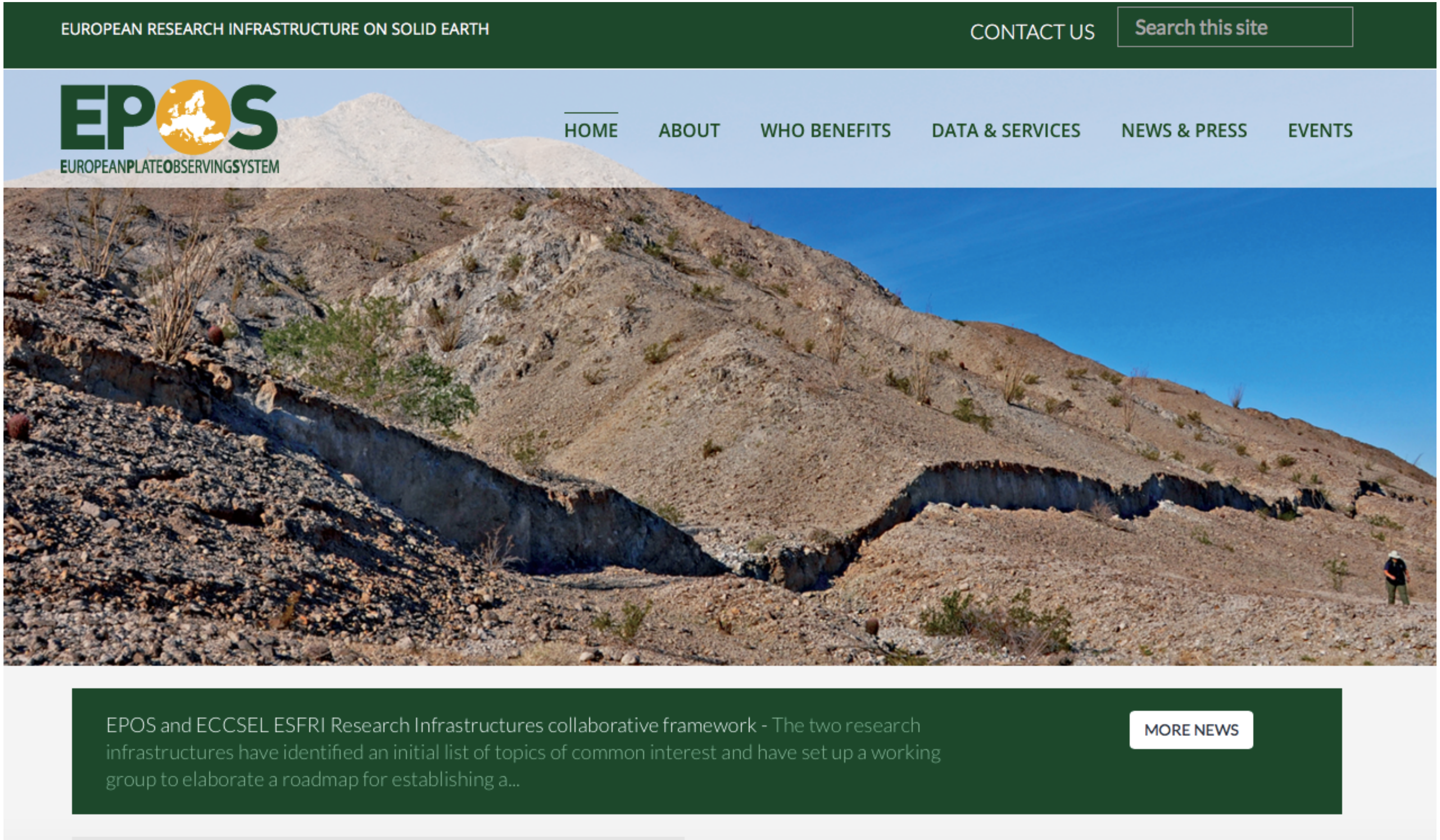

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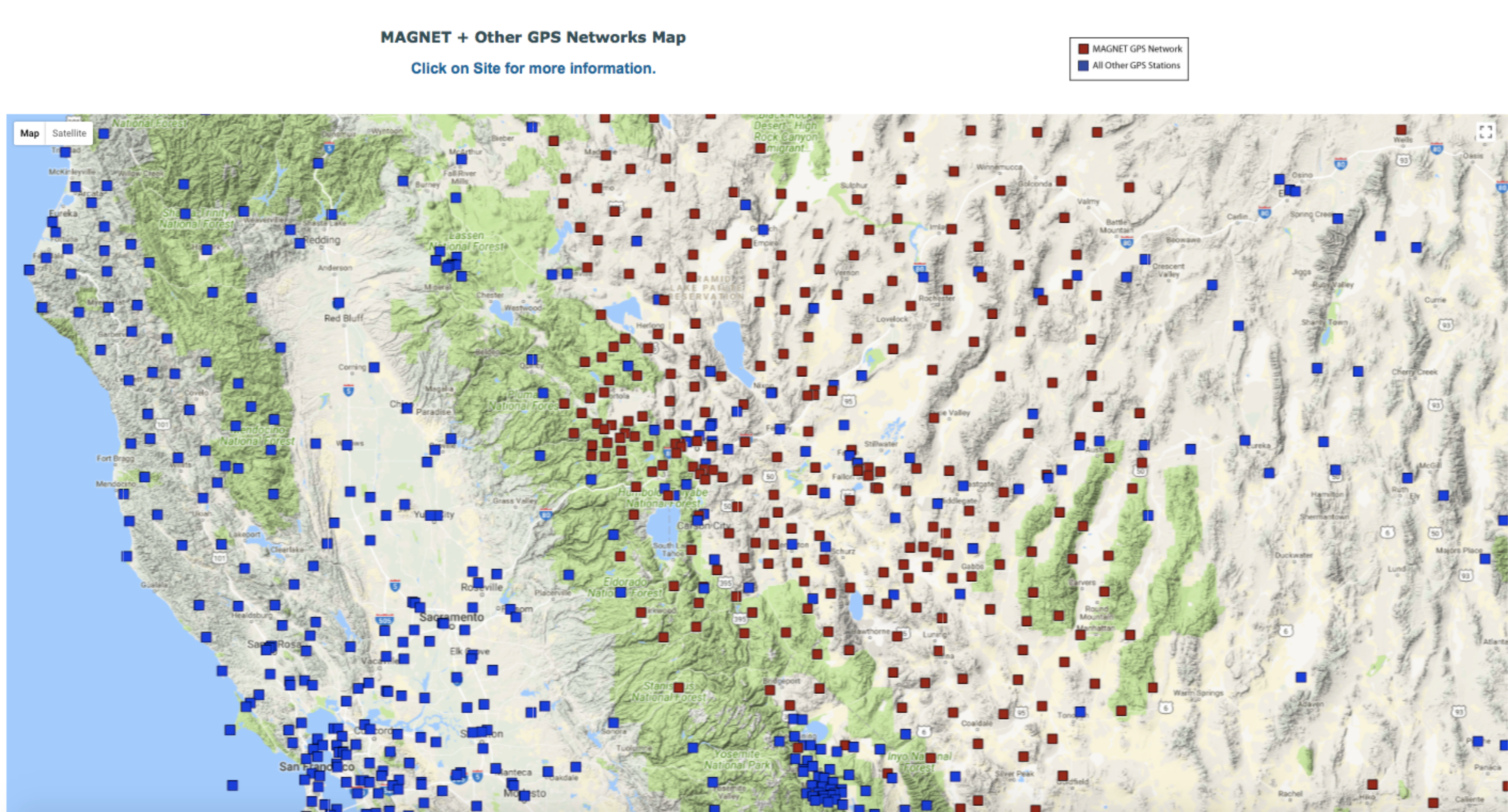
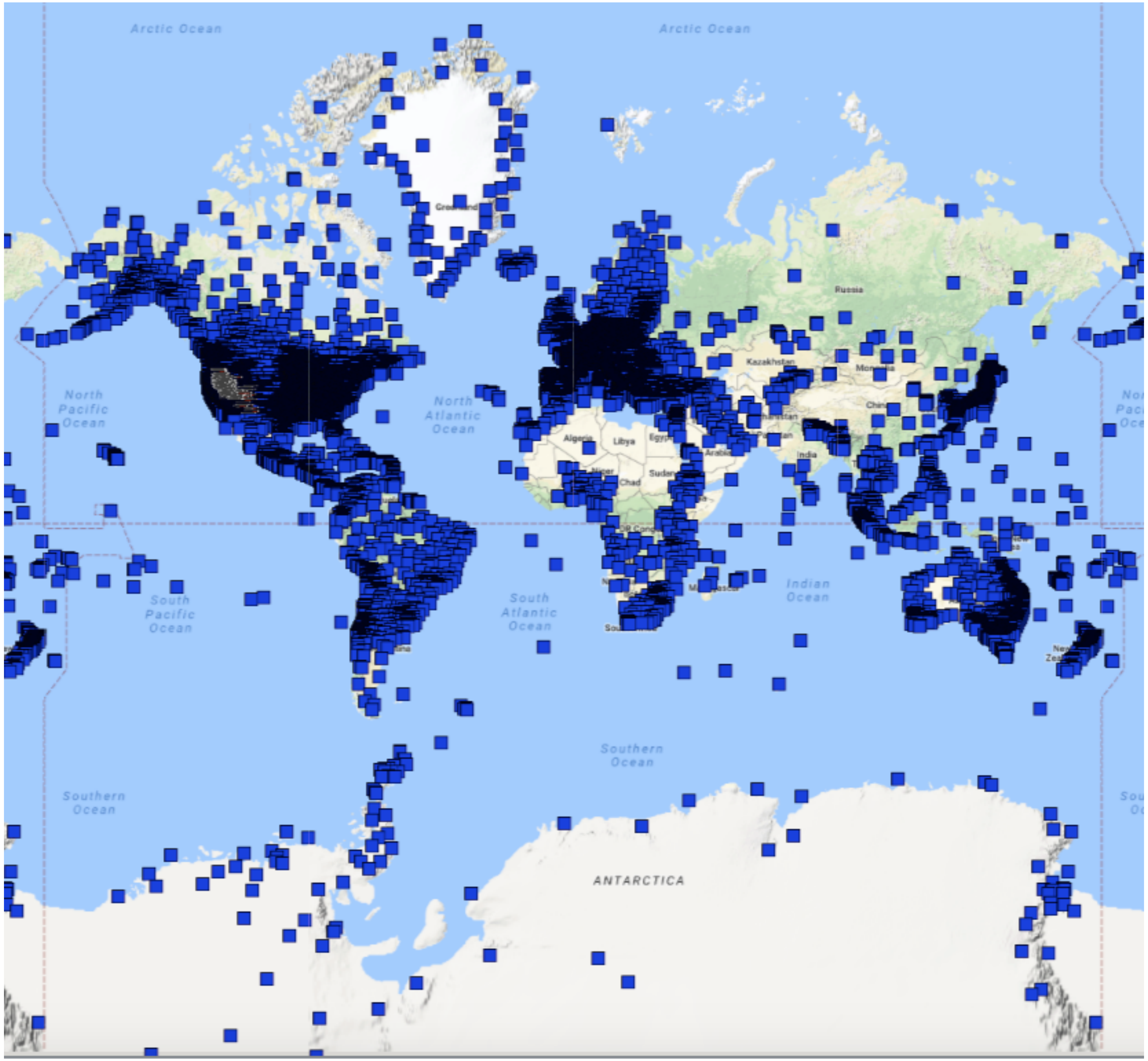
GPS: Global Positioning Service

Observing Systems for a Dynamic Planet



GPS: Global Positioni

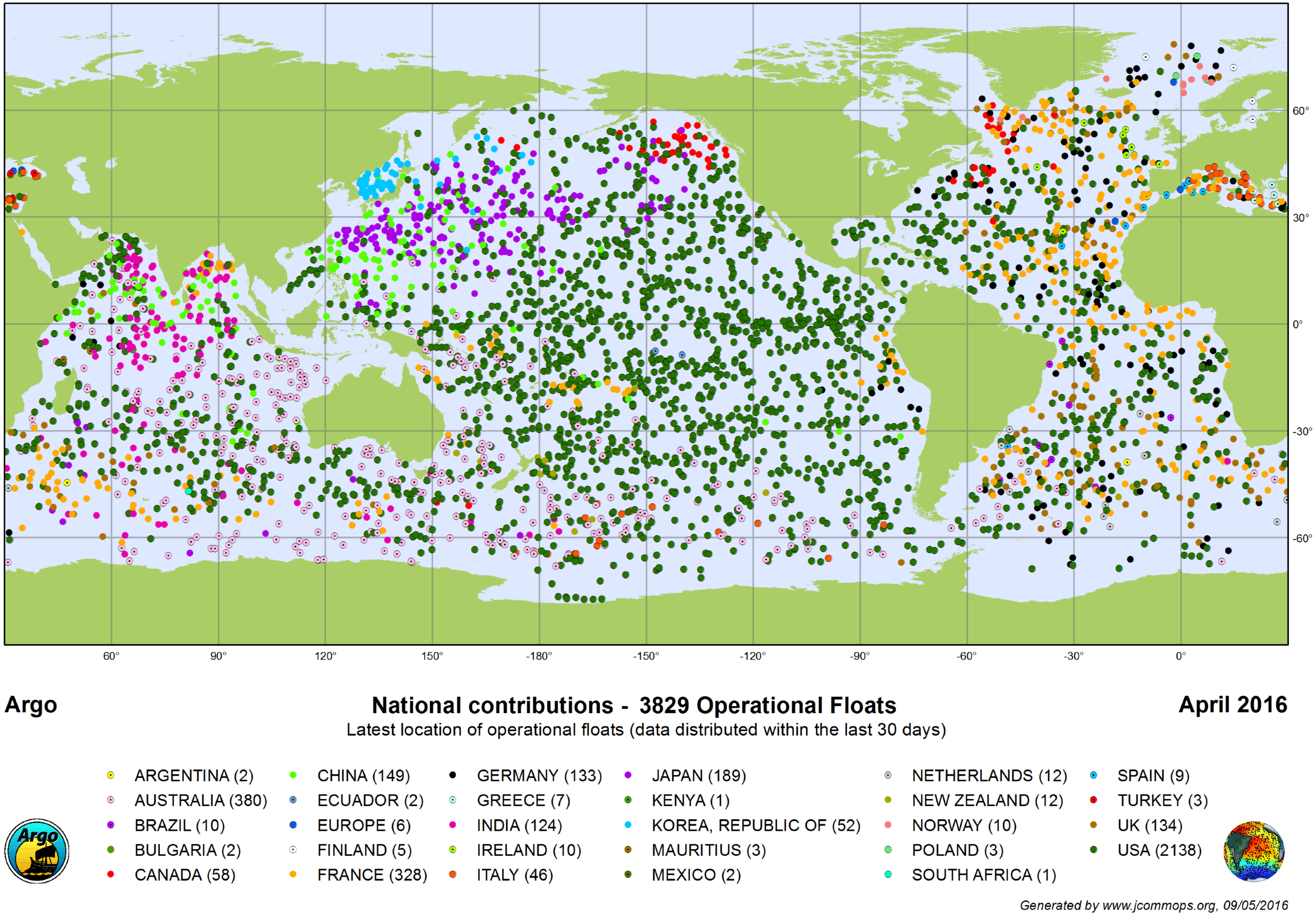
Observing Systems for a Dynamic Planet

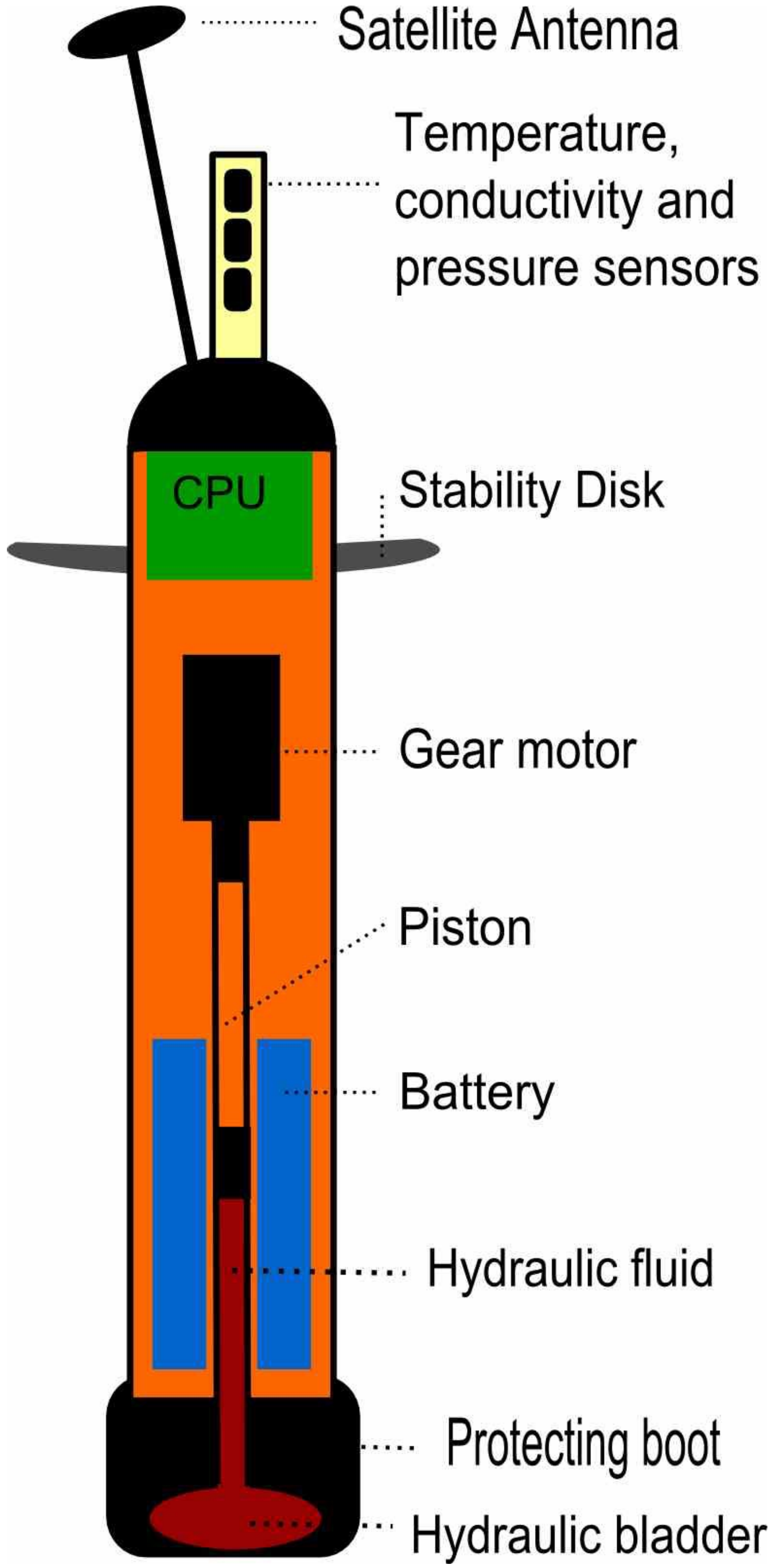


Observing Systems for a Dynamic Planet

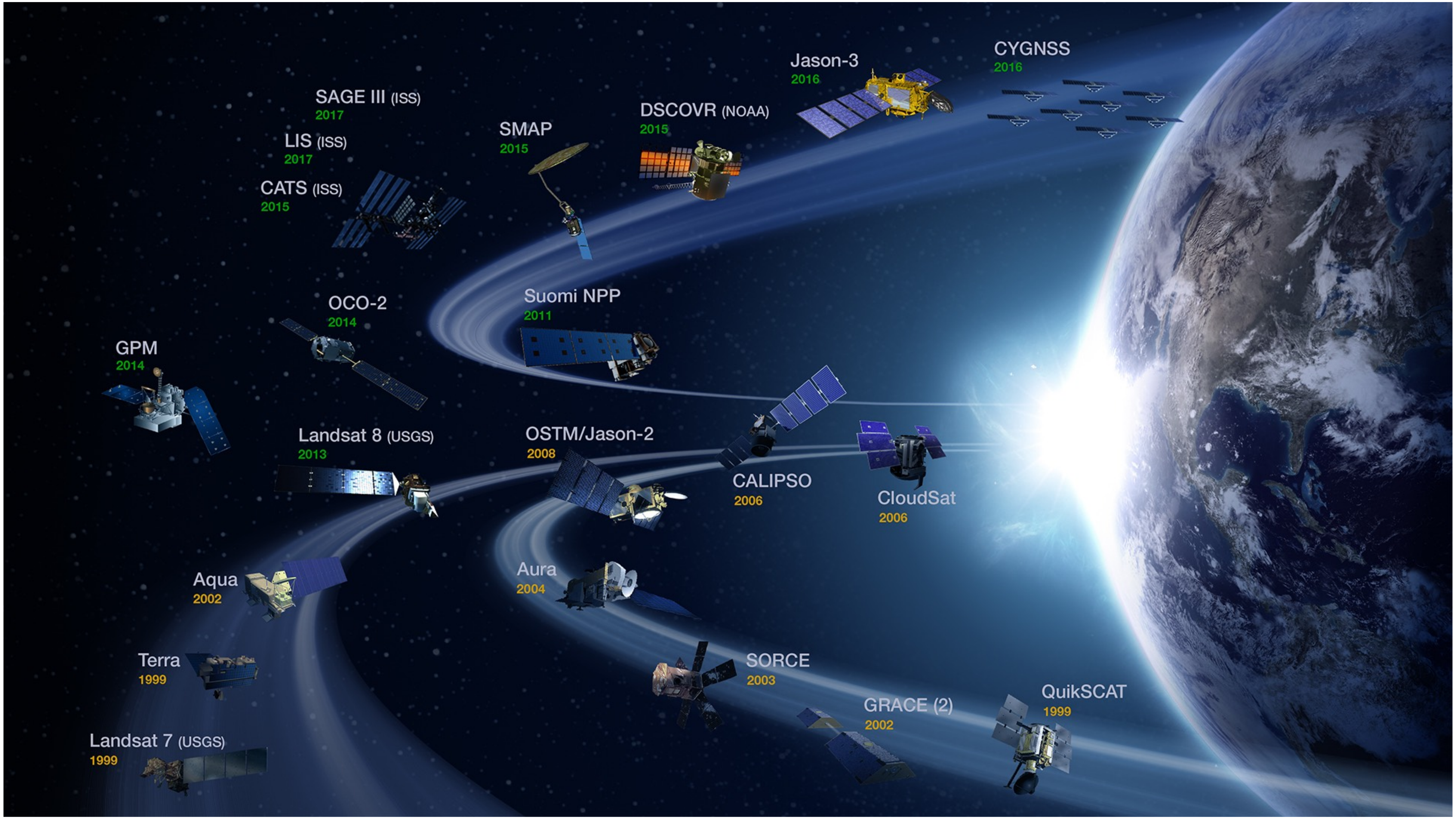
Observing Systems for a Dynamic Planet

Observing Systems for a Dynamic Planet





Observing Systems for a Dynamic Planet



From: https://eospso.gsfc.nasa.gov

See also: https://eospso.gsfc.nasa.gov/files/mission_profile.pdf

Observing Systems for a Dynamic Planet

→ EUROPEAN SPACE AGENCY | ABOUT US | OUR ACTIVITIES | CAREERS AT ESA | FOR MEDIA | FOR EDUCATORS | FOR KIDS

observing the earth esa

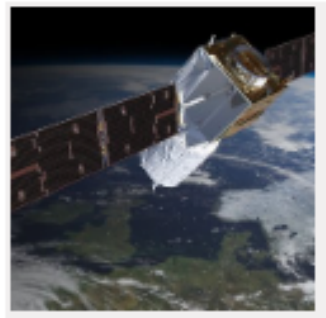
ESA | OBSERVING THE EARTH | UNDERSTANDING OUR PLANET | SECURING OUR ENVIRONMENT | BENEFITTING OUR ECONOMY

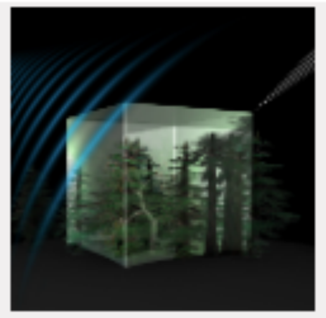
EARTH OBSERVATION MISSIONS

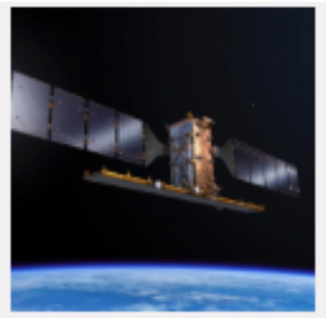
ESA has been dedicated to observing Earth from space ever since the launch of its first Meteosat weather satellite back in 1977. With the launch of a range of different types of satellites over the last 40 years, we are better placed to understand the complexities of our planet, particularly with respect to global change. Today's satellites are used to forecast the weather, answer important Earth-science questions, provide essential information to improve agricultural practices, maritime safety, help when disaster strikes, and all manner of everyday applications.

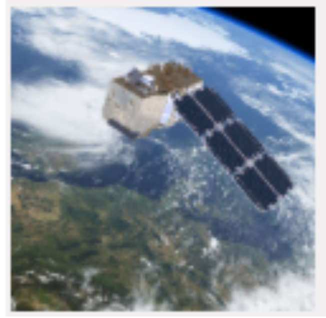
The need for information from satellites is growing at an ever-increasing rate. With ESA as world-leader in Earth observation, the Agency remains dedicated to developing cutting-edge spaceborne technology to further understand the planet, improve daily lives and support effect policy-making for a more sustainable future.

Back to the homepage

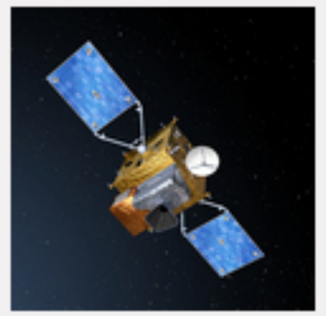

Aeolus
Wind mission
From 2018


Biomass
Forest mission
From 2020


Copernicus Sentinel-1
Radar vision
2014–present

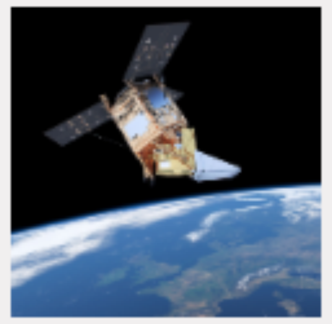

Copernicus Sentinel-2
Colour vision
2015–present

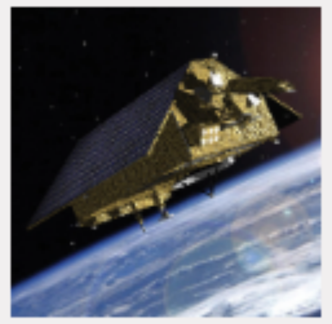

Copernicus Sentinel-3
Bigger picture
2016–present


Copernicus Sentinel-4
European air monitoring
From 2020

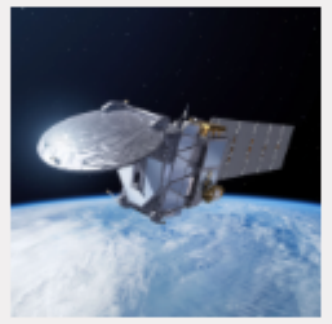
http://www.esa.int/ESA/Our_Missions


Copernicus Sentinel-5
Global air monitoring
From 2021


Copernicus Sentinel-5P
Global air monitoring
2017 (to be launched)


Copernicus Sentinel-6
Surfing the seas
From 2020

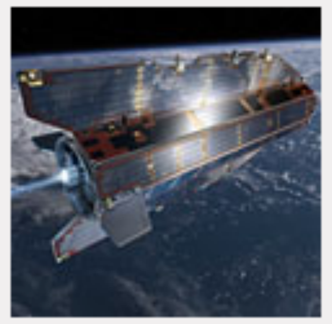

CryoSat
Ice mission
2010–present

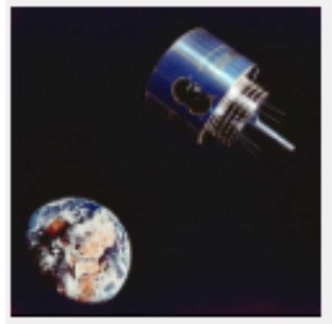

EarthCARE
Cloud and aerosol mission
From 2019


Envisat
Environmental monitoring
2002–12

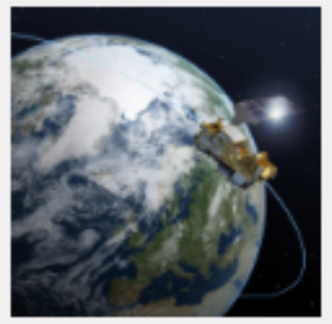

ERS
European Remote Sensing
1991–2011

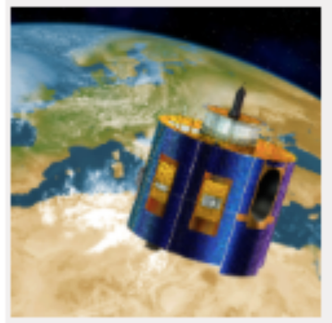

FLEX
Fluorescence mission
From 2022

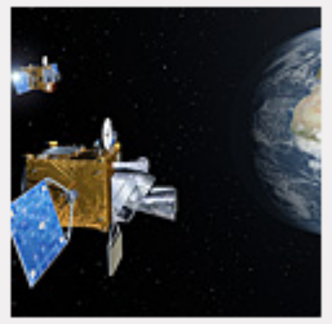

GOCE
Gravity mission
2009–13


Meteosat series
Weather satellites
1977–2017

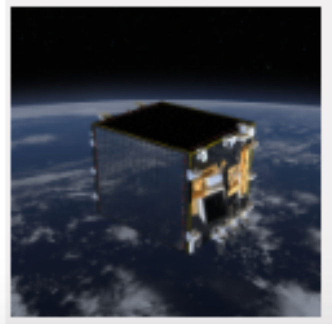

MetOp series
Weather satellites
2006–present


MetOp-SG series
Weather satellites
From 2021

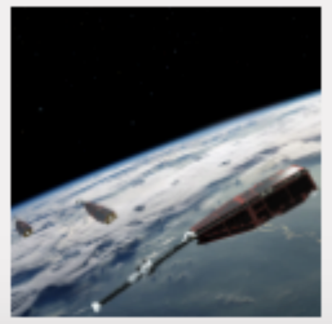

MSG series
Weather satellites
2002–present


MTG series
Weather satellites
From 2021


Proba-1
Technology demonstrator
2001–present


Proba-V
Vegetation monitoring
2013–present


SMOS
Water mission
2009–present


Swarm
Magnetic field mission
2013–present

Observing Systems for a Dynamic Planet

List of space agencies [edit]

The capabilities of the space agencies are color-coded as follows

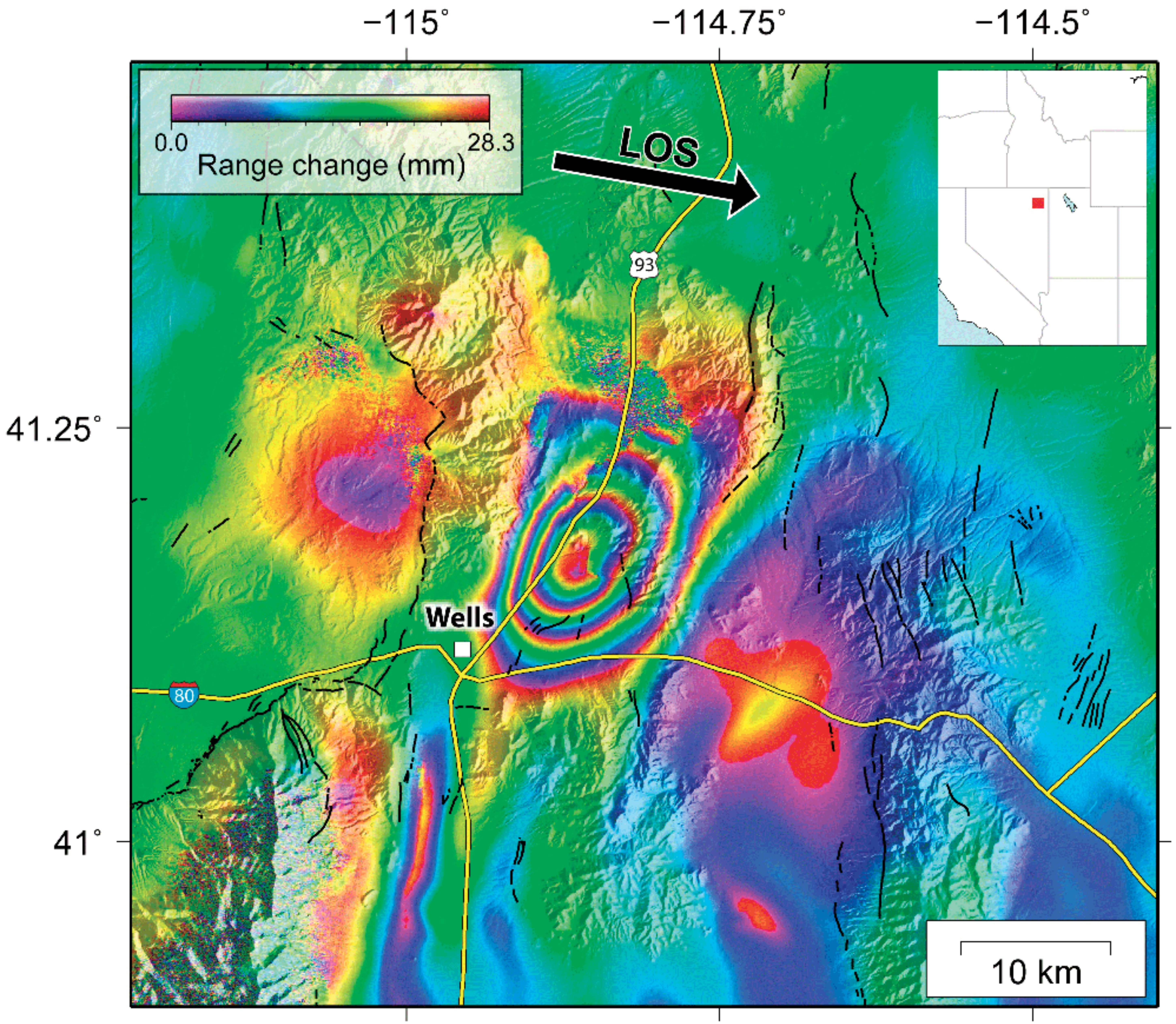
- Manned Lunar Exploration + Operates Space Station + Manned Space Flight + Operates Extraterrestrial Probes + Launch Capability + Operates Satellites
- Station + Manned Space Flight + Operates Extraterrestrial Probes + Launch Capability + Operates Satellites
- Manned Space Flight + Operates Extraterrestrial Probes + Launch Capability + Operates Satellites
- Operates Extraterrestrial Probes + Launch Capability + Operates Satellites
- Launch Capability + Operates Satellites
- Operates Satellites
- None Of The Above

https://en.wikipedia.org/wiki/List_of_government_space_agencies

Name	Initialisms/Acronym	Country	Founded	Terminated	Capabilities of the space agency				Ref(s)
					Astronauts	Operates Satellites	Sounding Rockets capable	Recoverable Biological Sounding Rockets capable	
Belarus Space Agency	BSA	Belarus	2010	—	No	No	Yes	No	[1]
Spanish: *Asociación Centroamericana de Aeronáutica y el Espacio* (Central American Association for Aeronautics and Space)	ACAE	Costa Rica	2010	—	No	Yes	No	No	[2]
Aeronautics and Space Research and Diffusion Center[citation needed] (Spanish: *Centro de Investigación y Difusión Aeronáutico-Espacial*)	CIDA-E	Uruguay	5 August 1975	—	No	No	No	No	—
Mexican Space Agency (Spanish: *Agencia Espacial Mexicana*)	AEM	Mexico	30 July 2010	—	Yes	Yes	Yes	No	—
Algerian Space Agency French: *Agence Spatiale Algérienne* Berber: Tafullut Tadzayrit n Tallunt Arabic: الوكالة الفضائية الجزائرية	ASAL	Algeria	16 January 2002	—	No	Yes	No	No	—
Asia Pacific Multilateral Cooperation in Space Technology and Applications[citation needed] (Chinese: 亚太空间技术应用多边合作会议)	AP-MCSTA	International[show]	February 1992	—	No	Yes	No	No	—
Asia-Pacific Regional Space									

Observing Systems for a Dynamic Planet

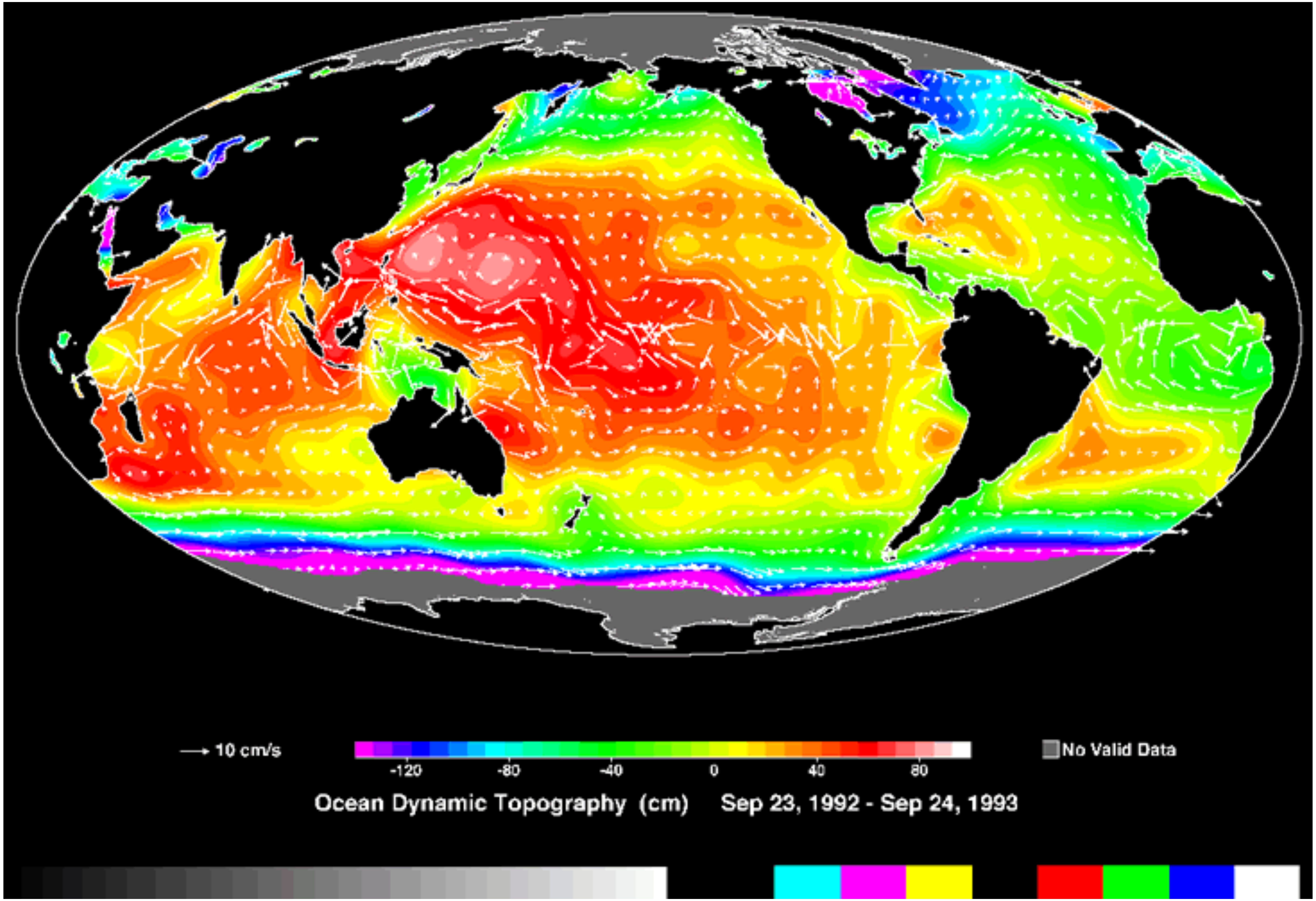
Satellite imagery shows Category 4 Hurricane Irma approach the Bahamas, followed by Hurricane Jose approaching the Leeward Islands. Hurricane Katia spins in the southwestern Gulf of Mexico.



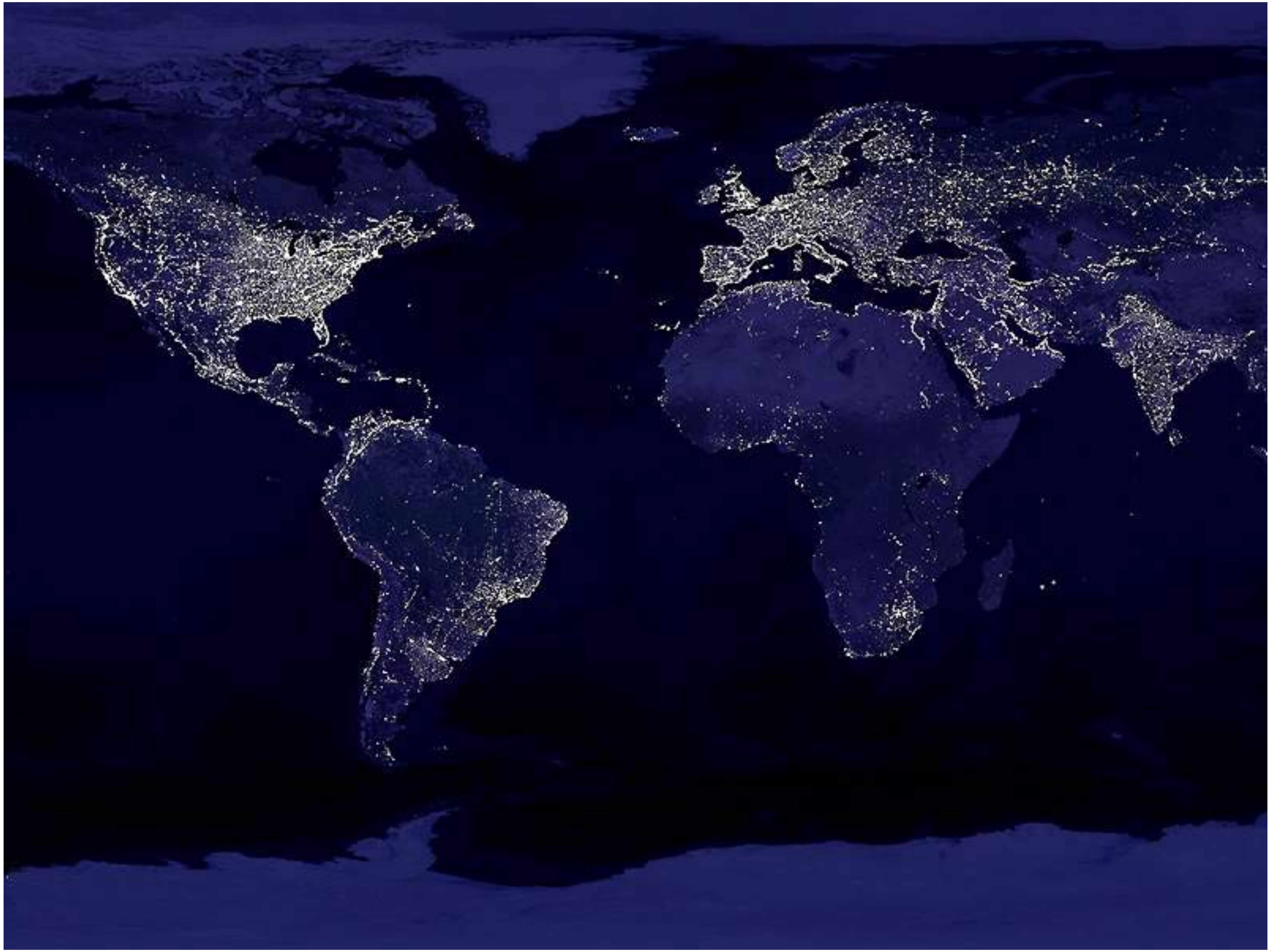
−115°
−114.75°
−114.5°
41.25°
41°
0.0
28.3
Range change (mm)
LOS
93
Wells
80
10 km

Observing Systems for a Dynamic Planet

Observing Systems for a Dynamic Planet



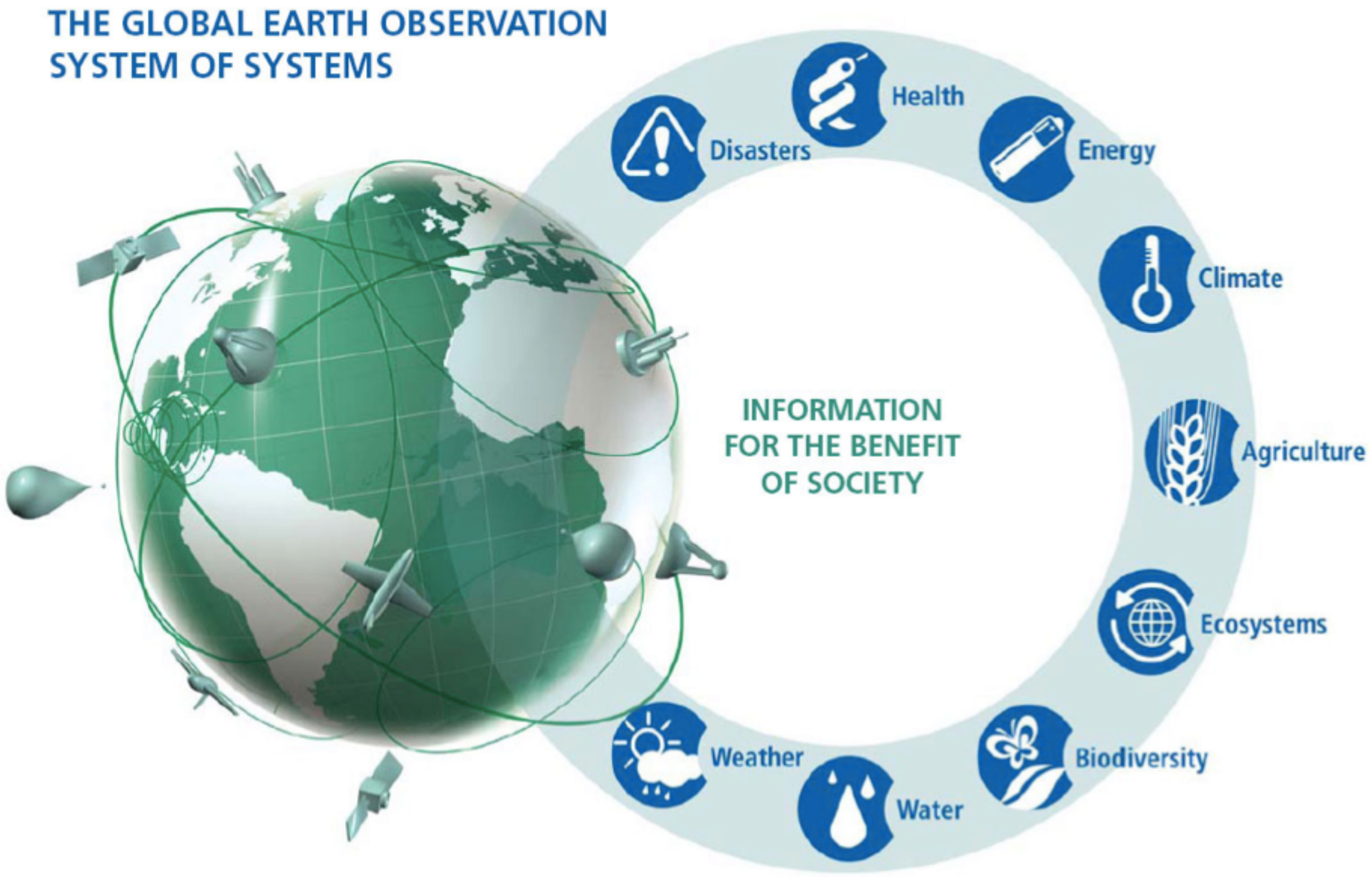
Observing Systems for a Dynamic Planet

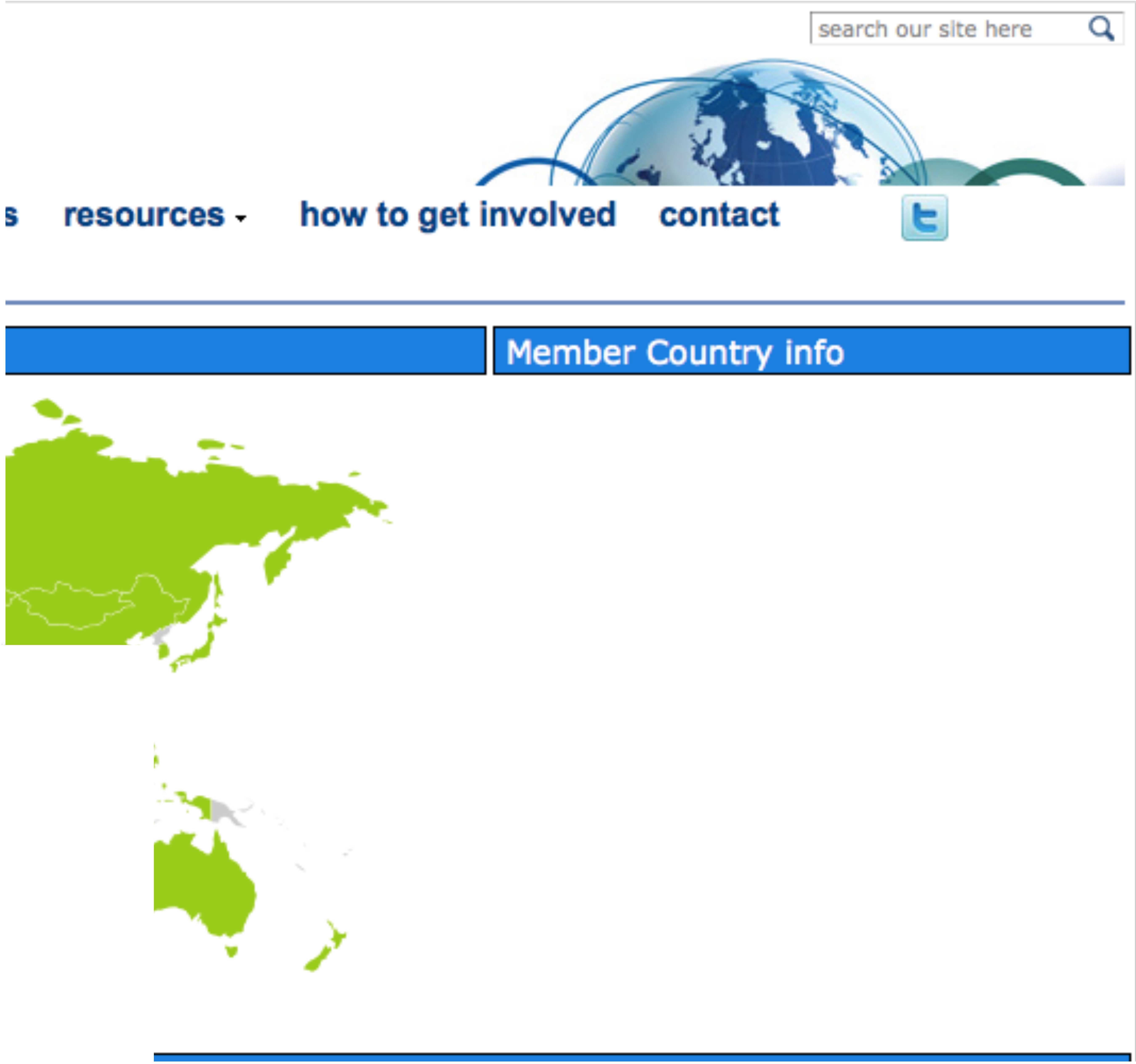


Observing Systems for a Dynamic Planet

http://www.earthobservations.org

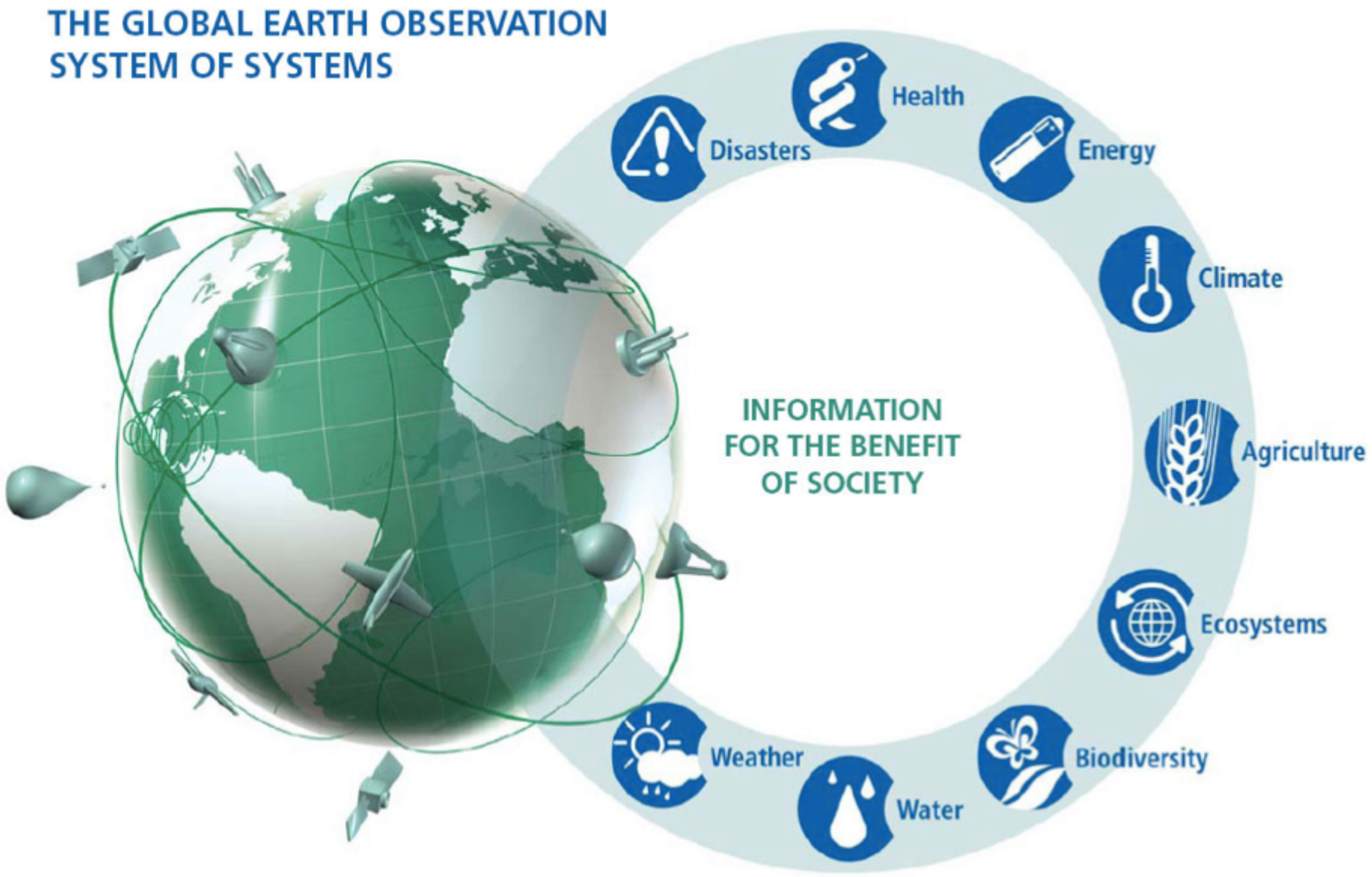
Observing Systems for a Dynamic Planet





http://www.earthobservations.org

Observing Systems for a Dynamic Planet



http://www.earthobservations.org

Observation types:

(1) Sensor-based:
- In situ: observations of ambient conditions (e.g., thermometer)
- Remote sensing: Using a signal to sense something in the distance (e.g., radar)

(2) Sample-based:
- in situ
- in laboratory
- counting, assessing

Observation Mode:

- on the Earth surface (fixed and moving);
- satellite-borne
- dedicated air-borne, ship-borne
- opportunity (ships, airplanes, …)
- balloons, robots, drones (within atmosphere, ocean, …)
- citizen scientists
- Big Data

Natural Hazards and Disasters

Class 2: Observing Hazards and Disasters

- A dynamic Planet
- Observing Systems for a Dynamic Planet
- Reference Systems and Frames
- Monitoring Small Changes

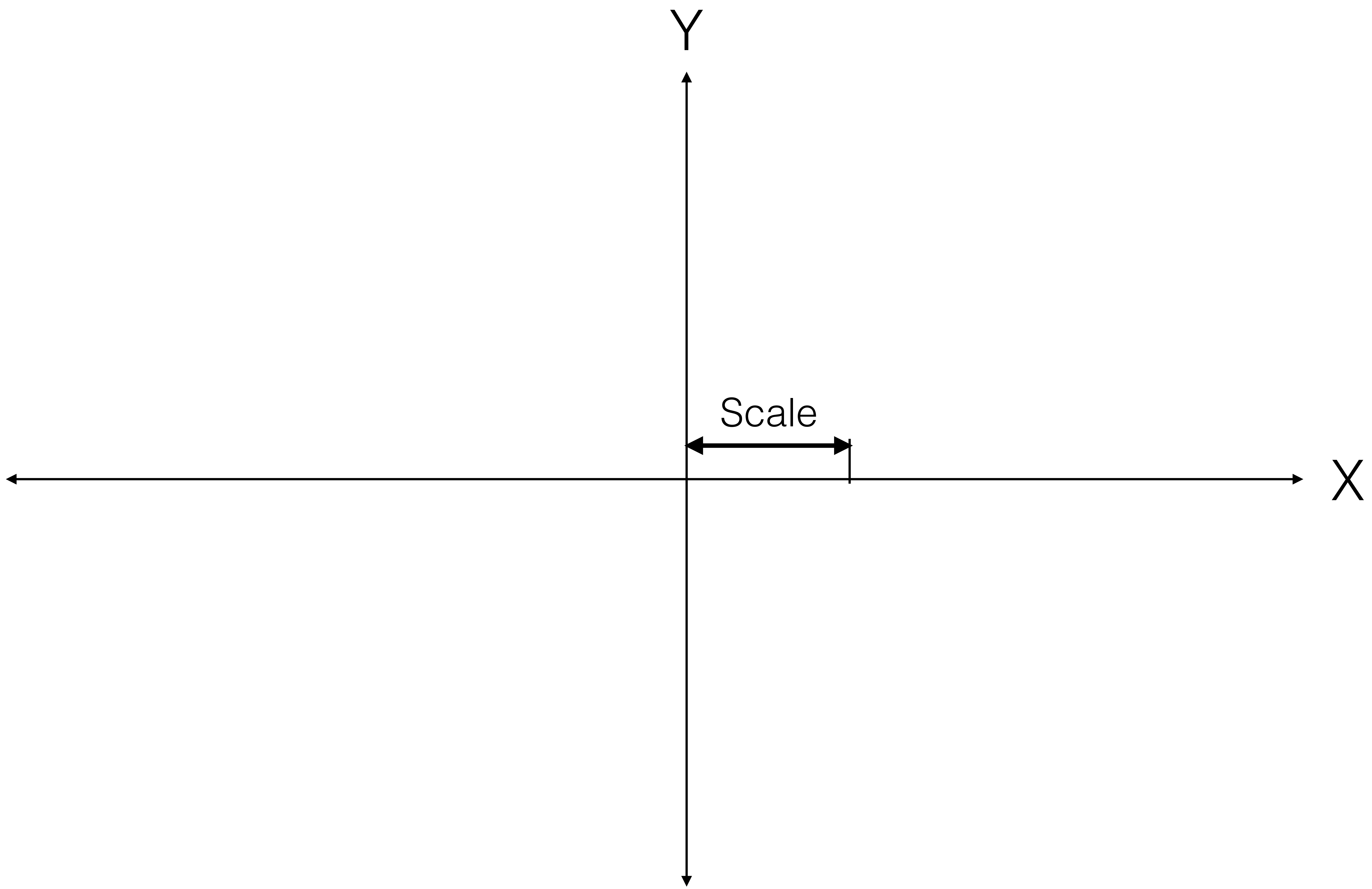
Reference Systems and Reference Frames

Reference Systems and Reference Frames

Measuring position and motion requires a coordinate system:

Reference Systems and Reference Frames

Measuring position and motion requires a coordinate system:



Reference Systems and Reference Frames

Reference Systems and Reference Frames

Assigning coordinates to points and objects on Earth, and to describe Earth's motion in space, we need to measure Earth's shape, gravity field, and rotation.

Reference Systems and Reference Frames

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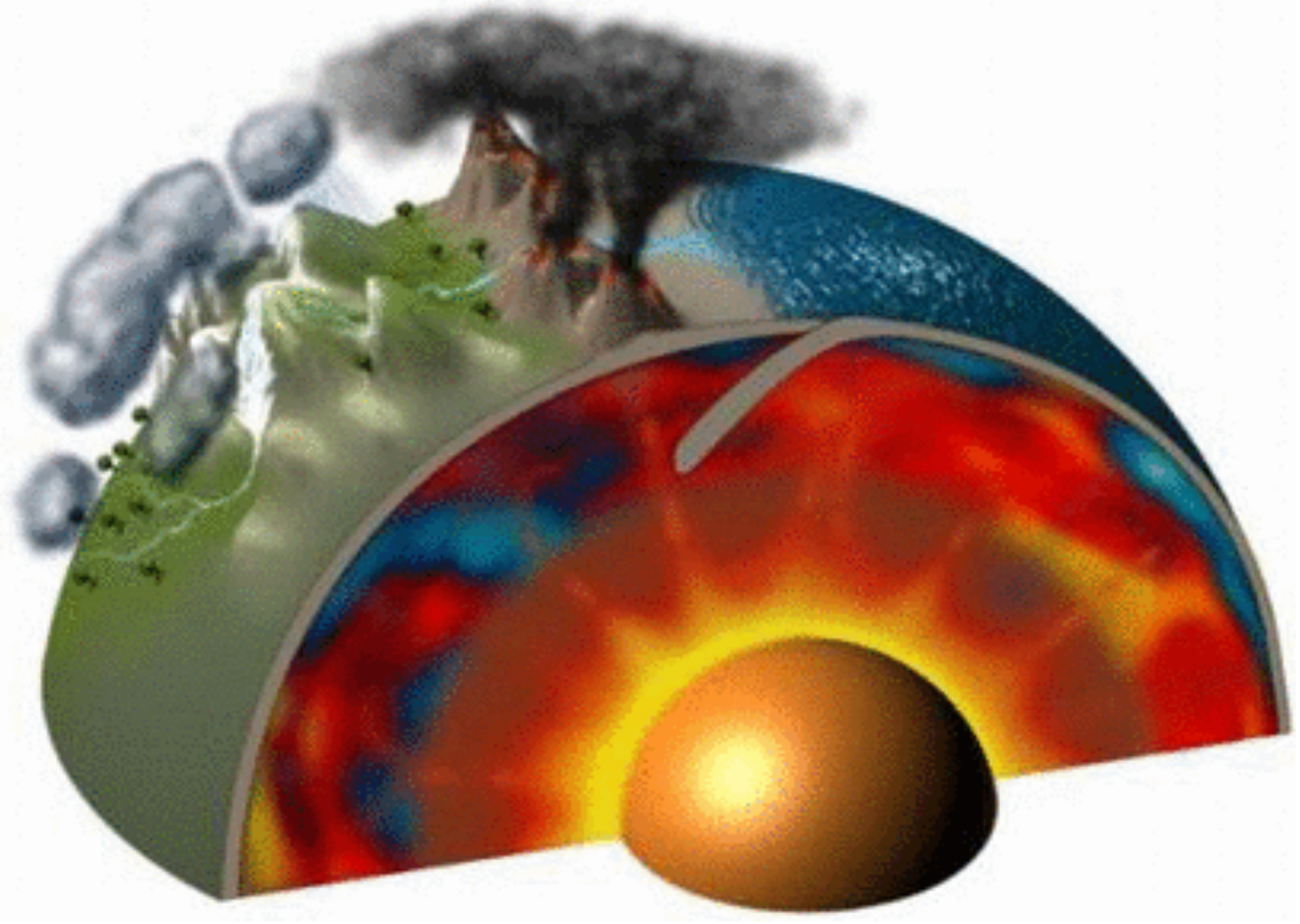

Reference Systems and Reference Frames

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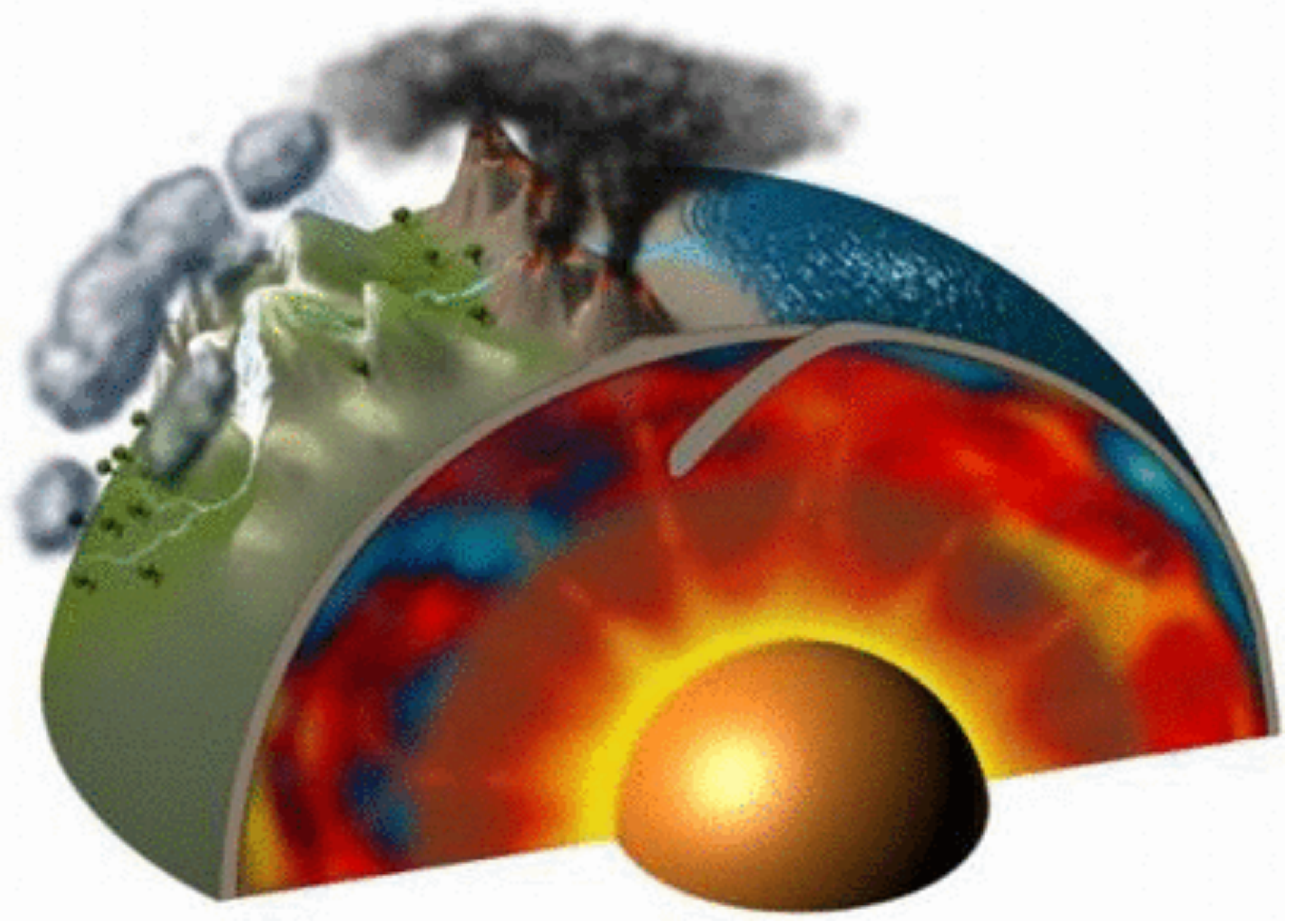
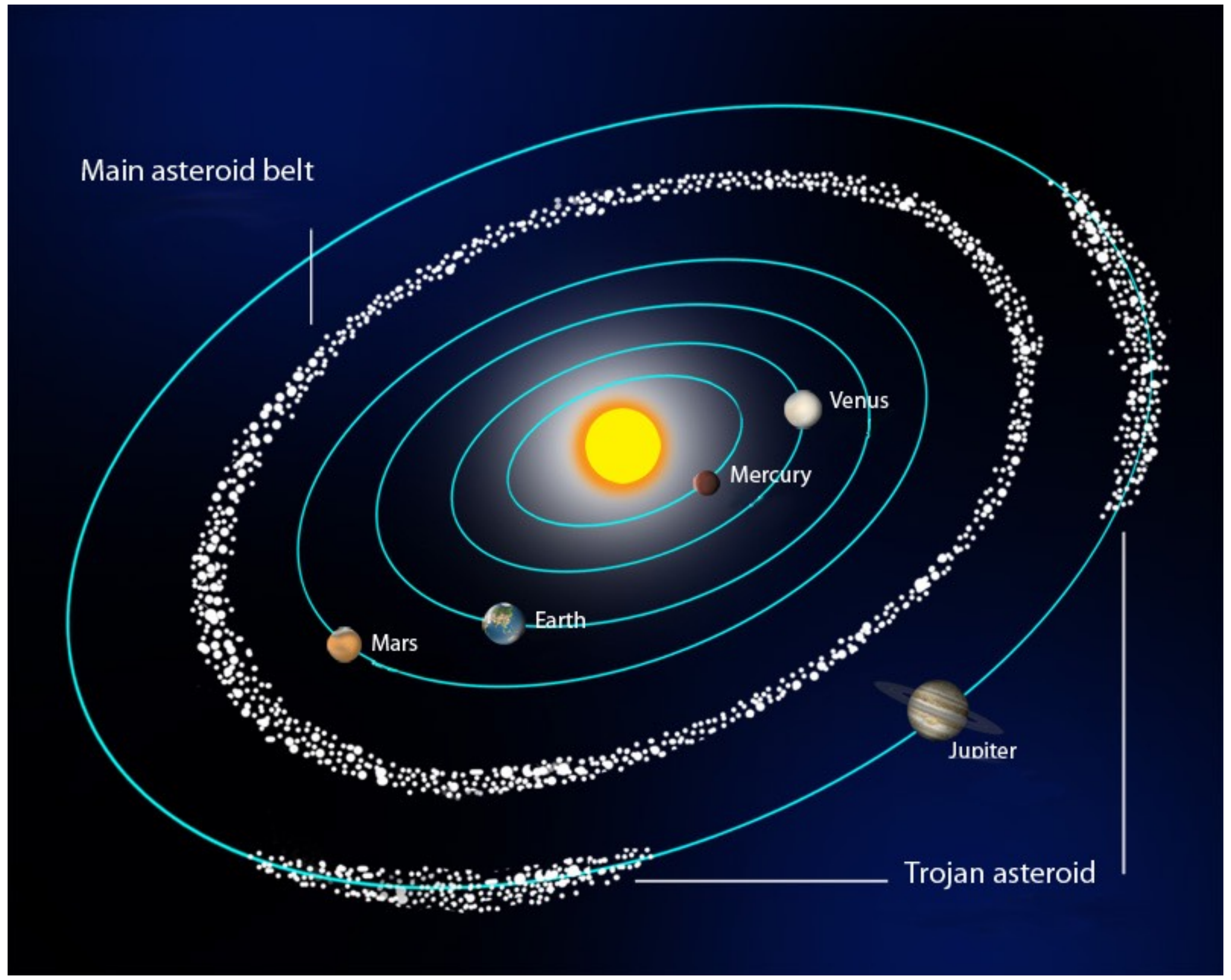




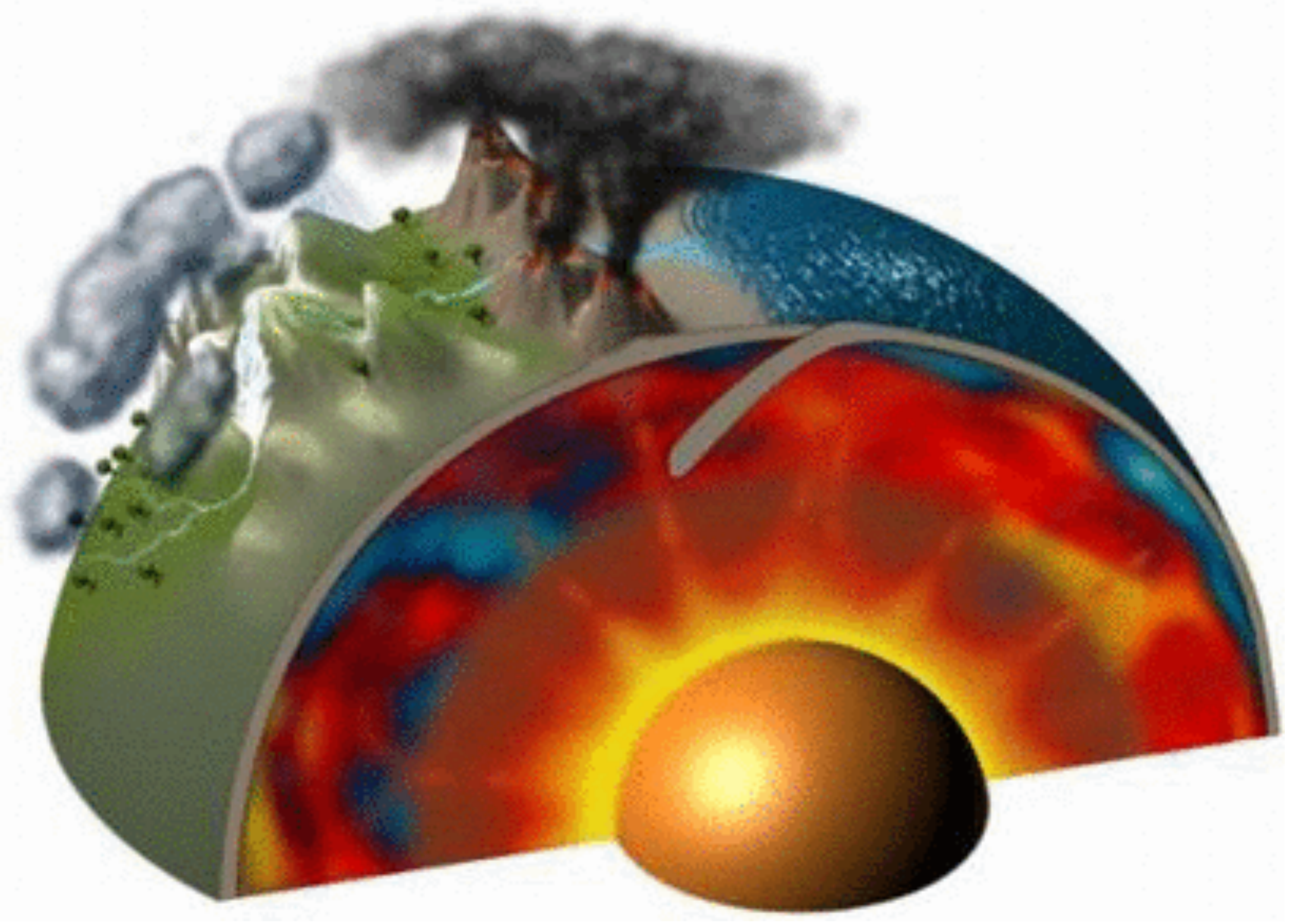
Reference Systems and Reference Frames

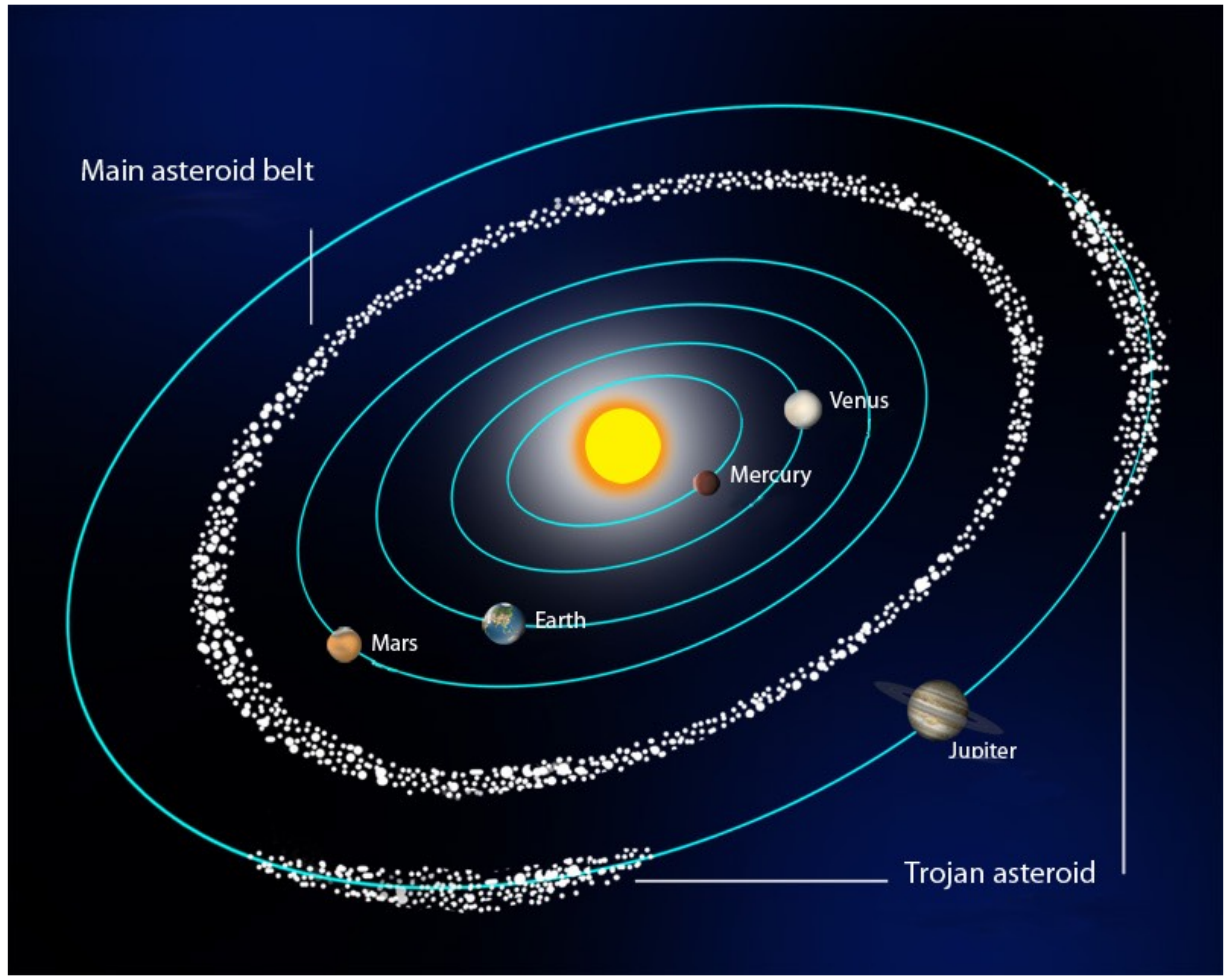
Assigning coordinates to points and objects on Earth, and to describe Earth's motion in space, we need to measure Earth's shape, gravity field, and rotation.

For this purpose, two reference systems are intrinsic in geodesy:

- International Celestial Reference System (ICRS)
- International Terrestrial Reference System (ITRS)

and these are connected through Earth Rotation.





Reference Systems and Reference Frames

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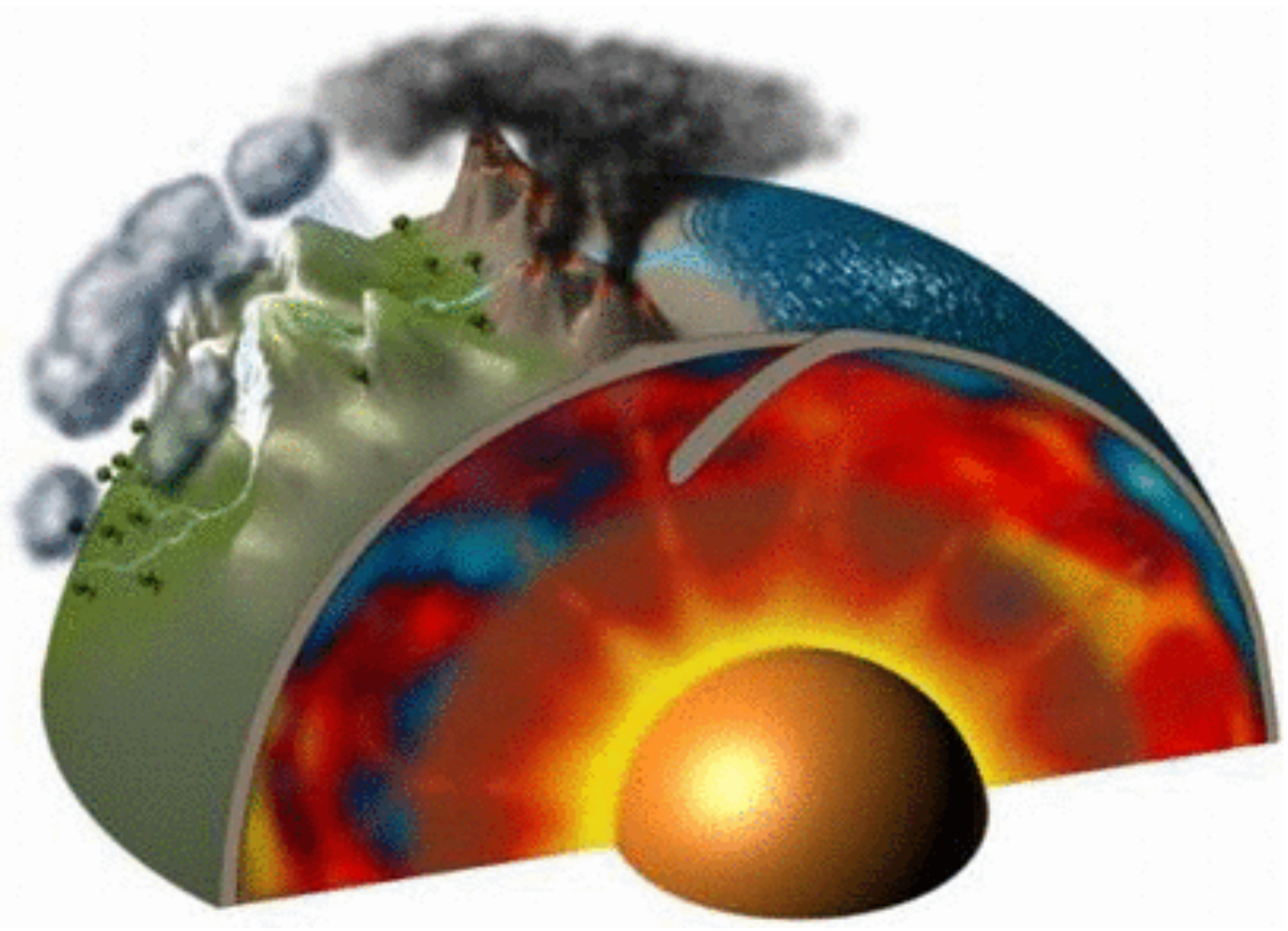

For this purpose, two reference systems are intrinsic in geodesy:

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- International Terrestrial Reference System (ITRS)

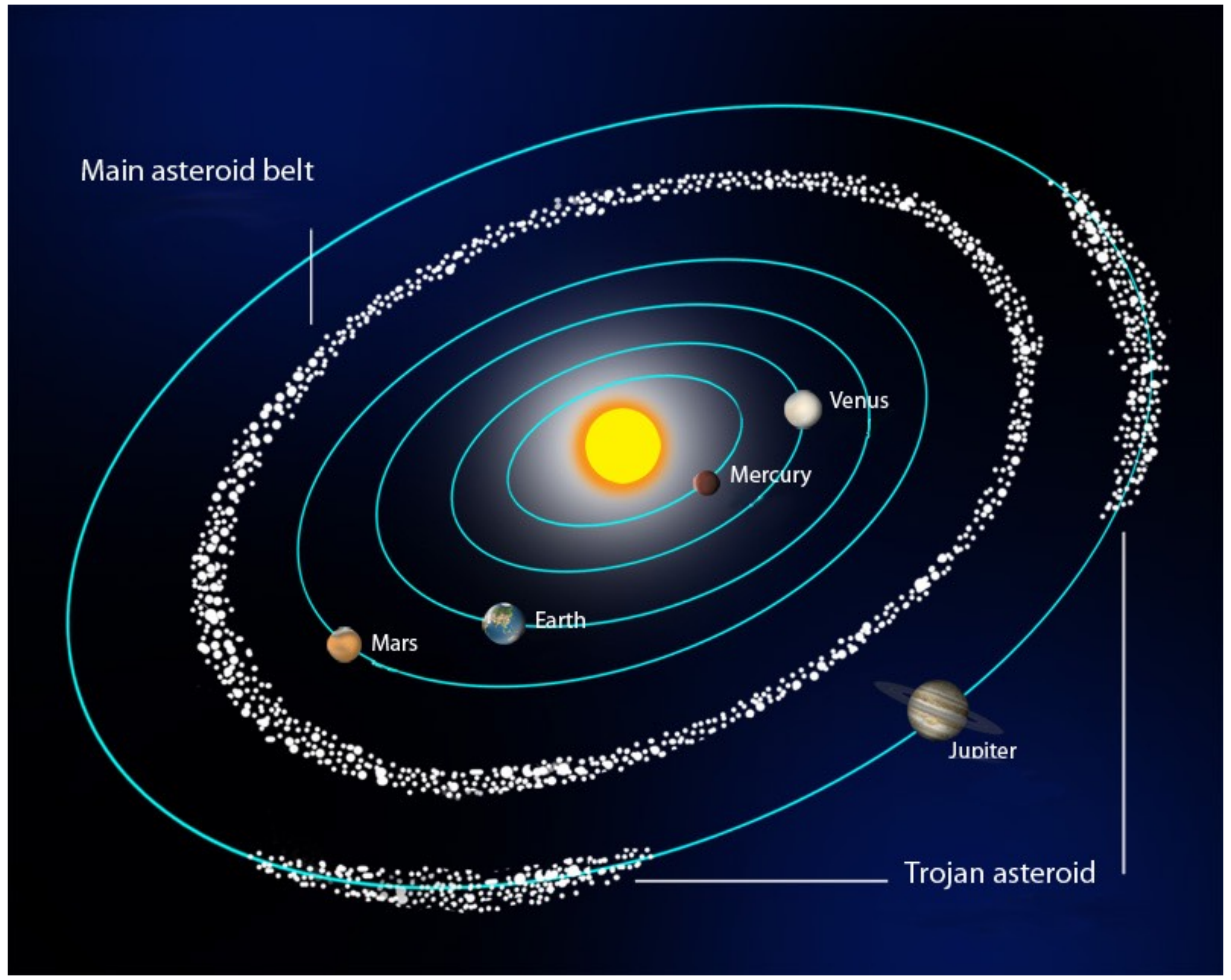
and these are connected through Earth Rotation.

The two reference systems are realized through reference frames:

- International Celestial Reference Frame (ICRF)
- International Terrestrial Reference Frame (ITRF)

and the connections is provided by the

- Earth Orientation Parameters (EOPs).

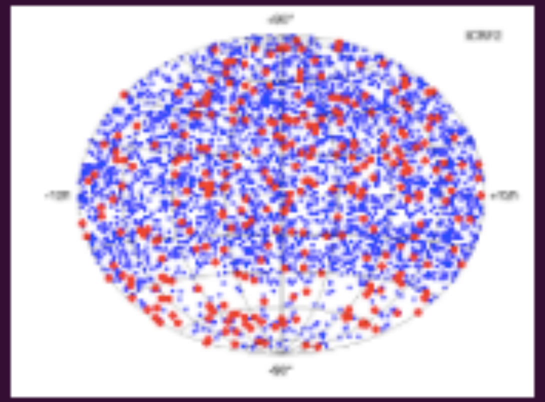


Reference Systems and Reference Frames

This pages provide data of successives realizations of the International Celestial Reference Frame (ICRF) by VLBI. Please, refer to the article (link to ADS) or to the ReadMe files for more informations on each realization.

ICRF2

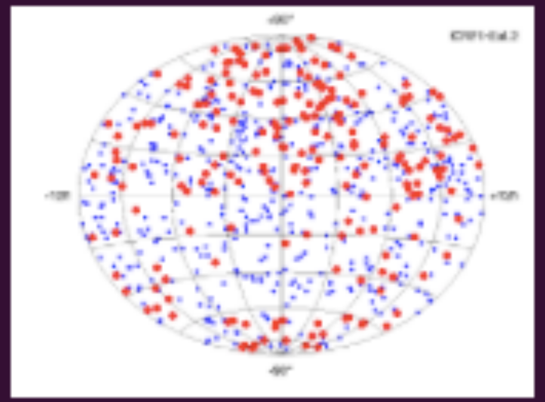
Data (.txt) — Fey et al. (2015) (link to ADS) — ReadMe



3,414 objects

ICRF1 Extension 2

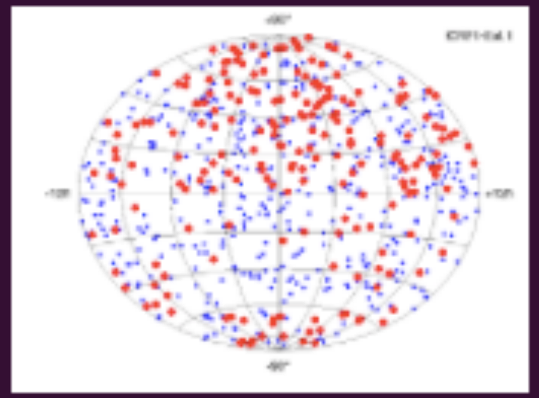
Data (.txt) — Fey et al. (2004) (link to ADS) — ReadMe



717 objects

ICRF1 Extension 1

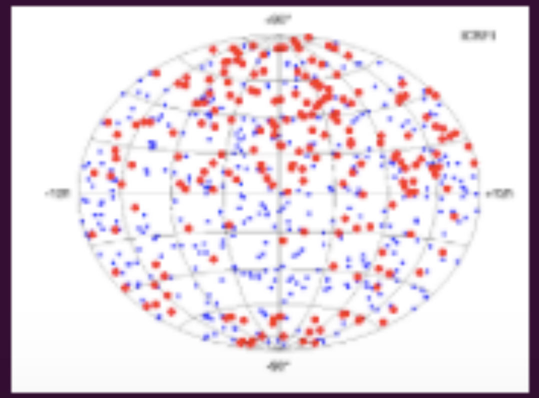
Data (.txt) — Gontier et al. (2002) (link to ADS) — ReadMe



667 objects

ICRF1

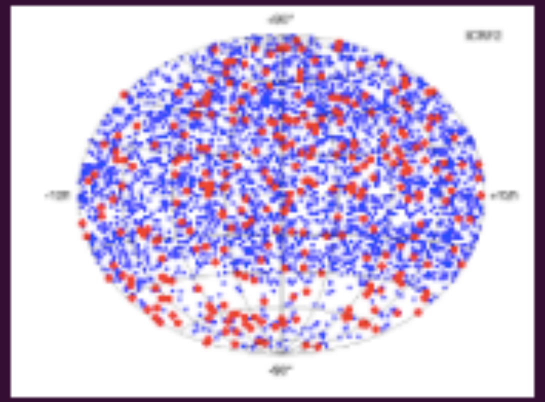
Data (.txt) — Ma et al. (1998) (link to ADS) — ReadMe



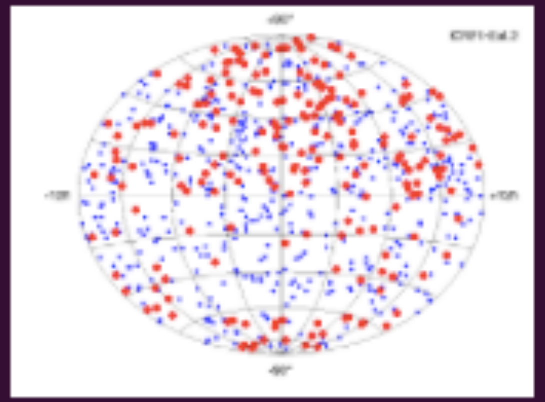
608 objects

This pages provide data of successives realizations of the International Celestial Reference Frame (ICRF) by VLBI. Please, refer to the article (link to ADS) or to the ReadMe files for more informations on each realization.

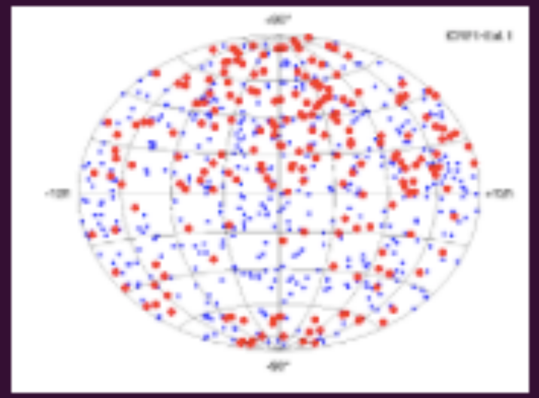
ICRF2

Data (.txt)	Fey et al. (2015) (link to ADS)	ReadMe		3,414 objects

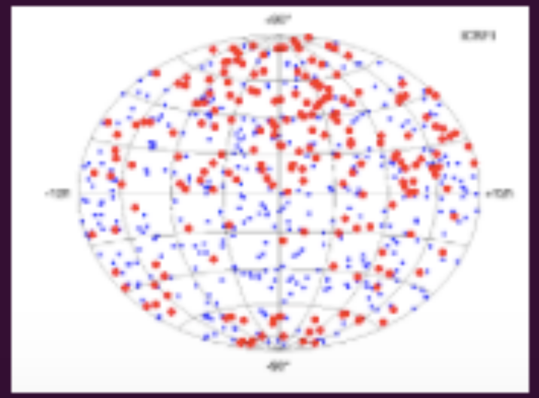
ICRF1 Extension 2

Data (.txt)	Fey et al. (2004) (link to ADS)	ReadMe		717 objects

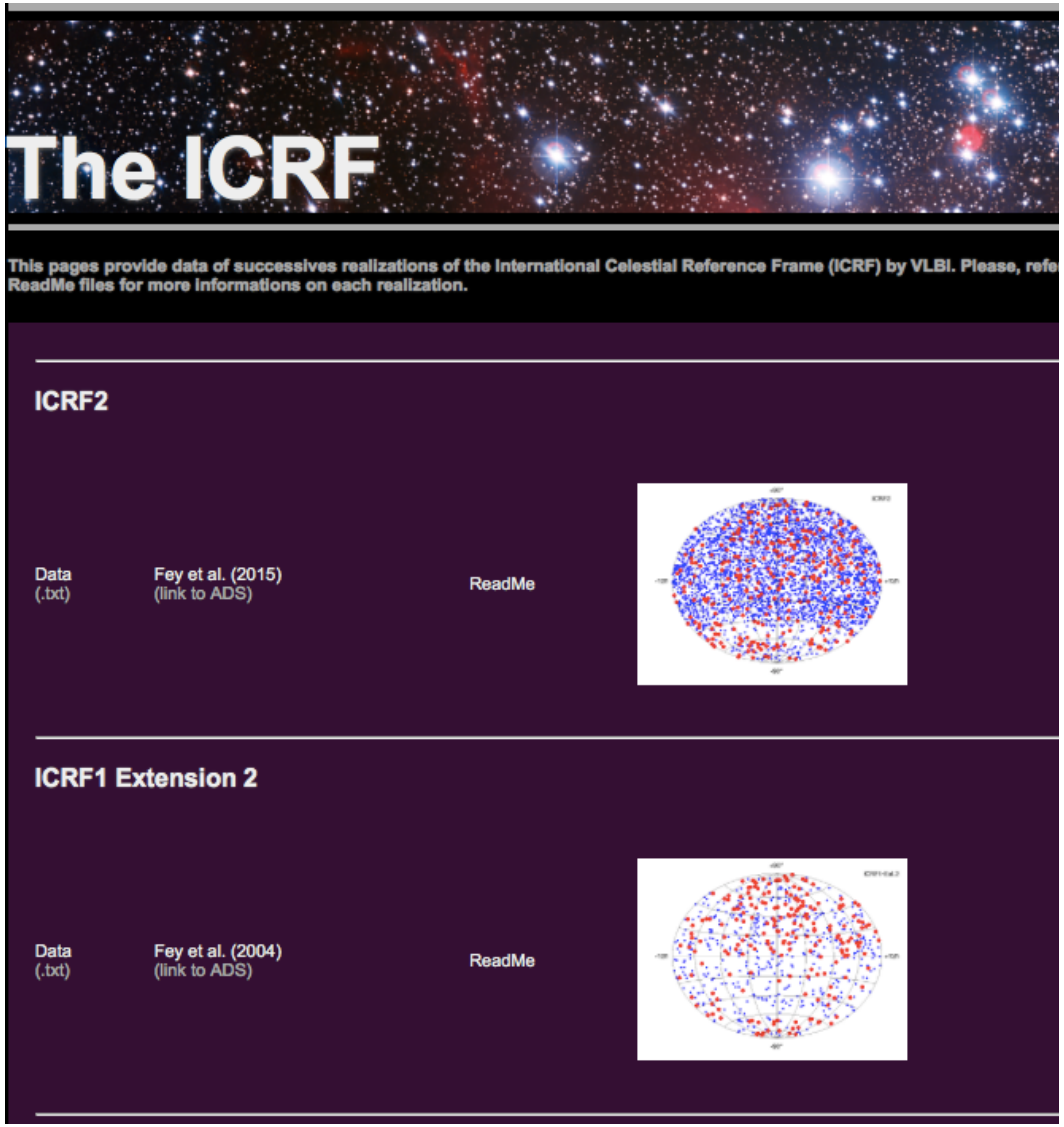
ICRF1 Extension 1

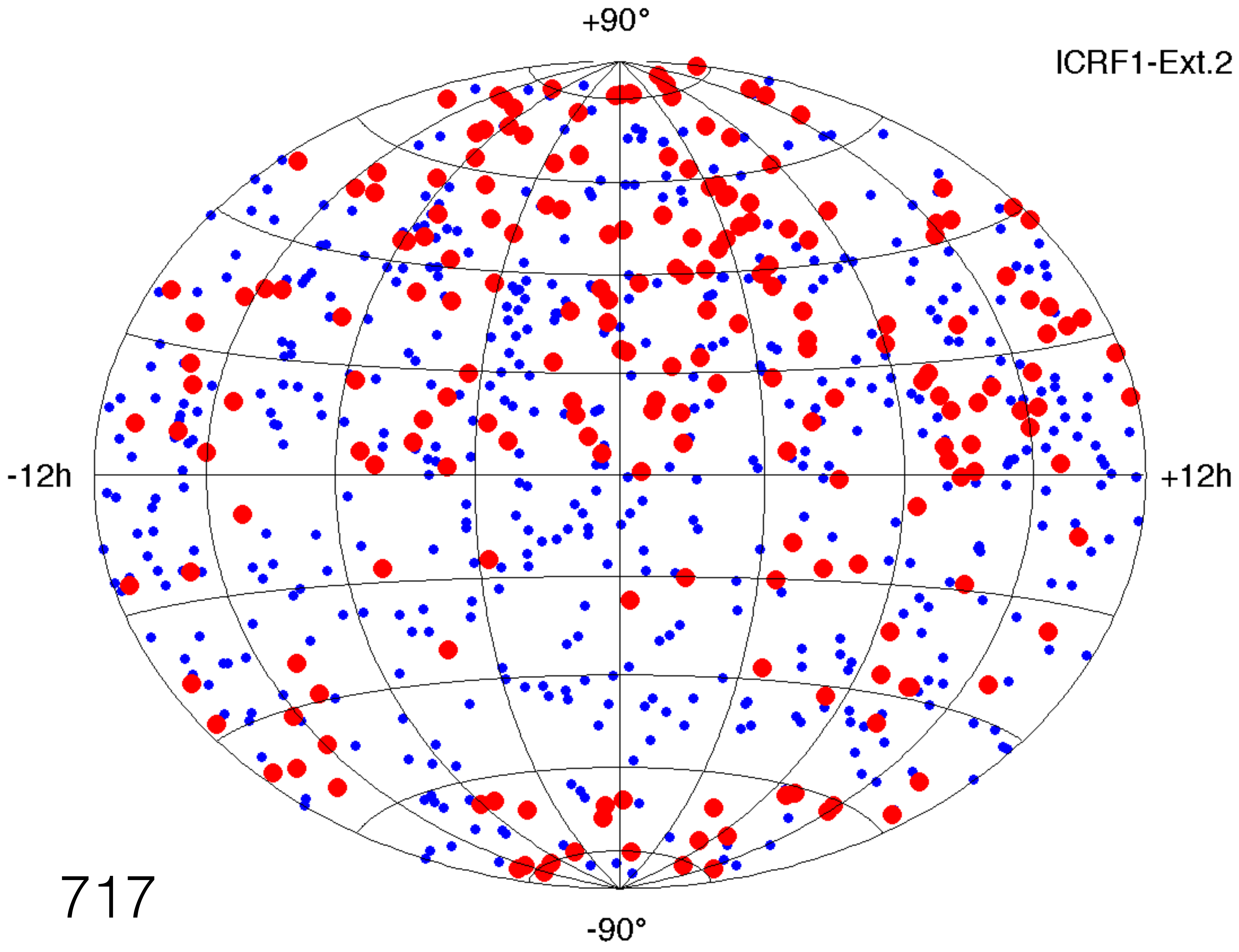
Data (.txt)	Gontier et al. (2002) (link to ADS)	ReadMe		667 objects

ICRF1

Data (.txt)	Ma et al. (1998) (link to ADS)	ReadMe		608 objects

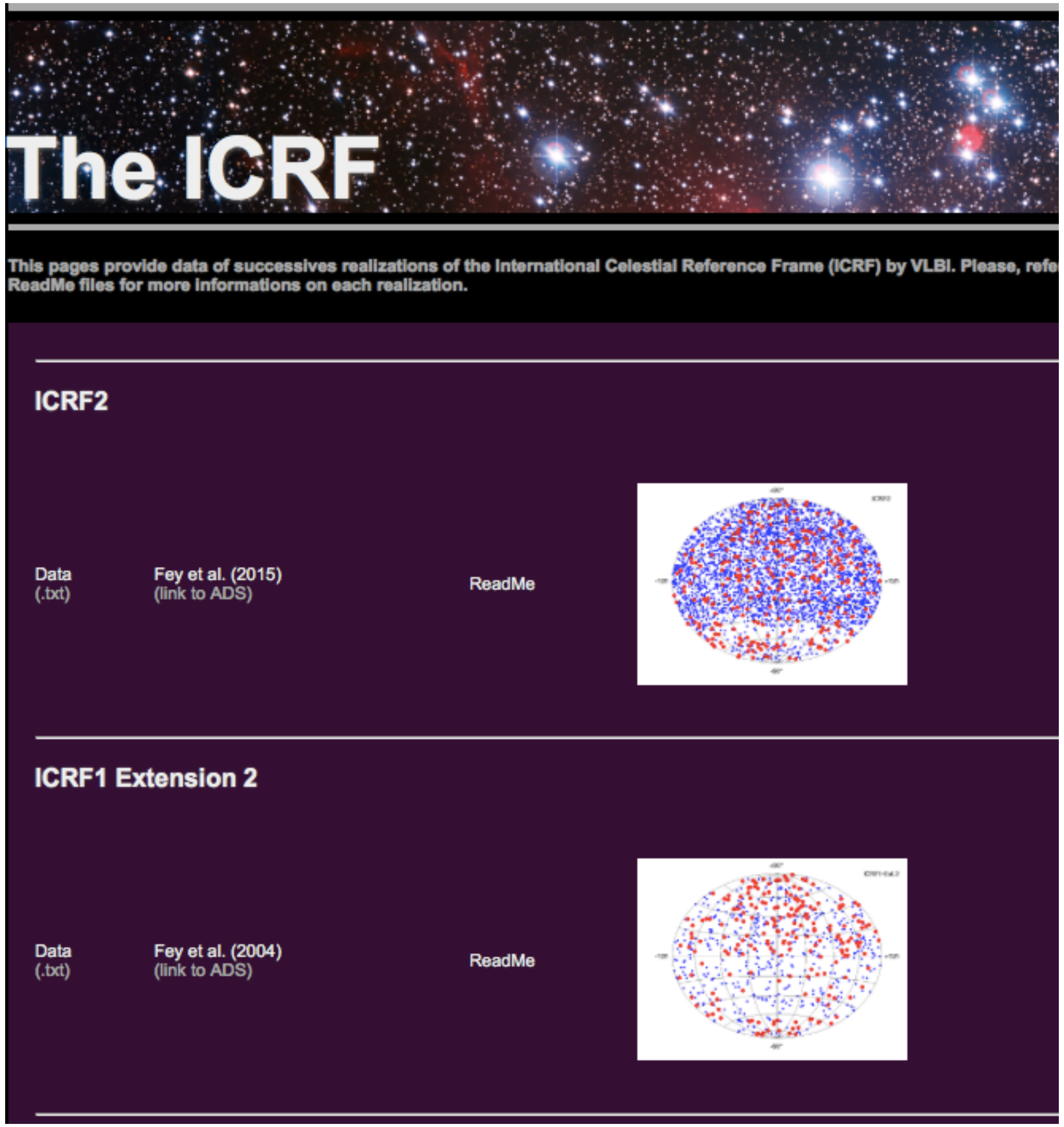
http://hpiers.obspm.fr/icrs-pc/newwww/icrf/index.php

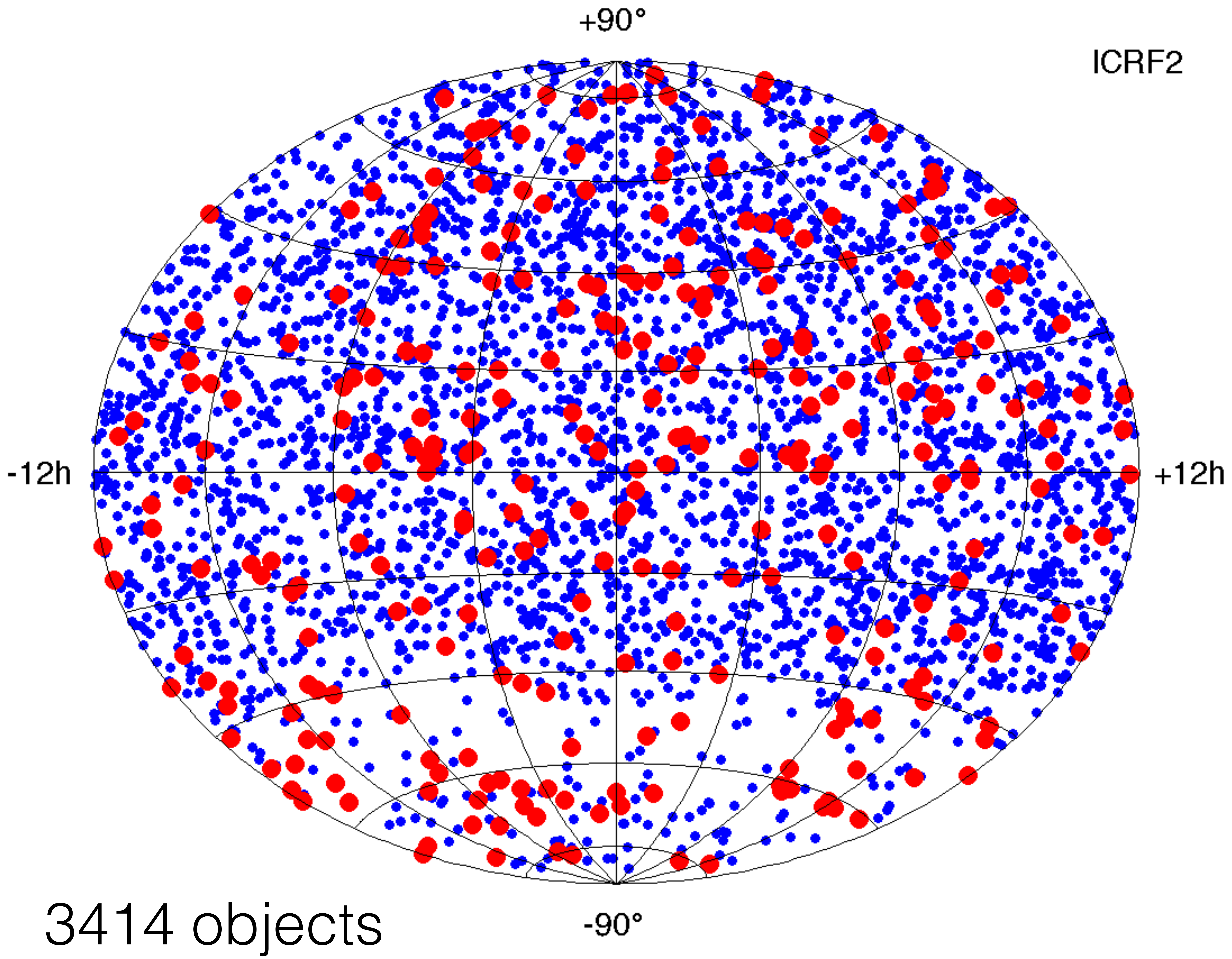




http://hpiers.obspm.fr/icrs-pc/newwww/icrf/index.php

Reference Systems and Reference Frames





3414 objects

http://hpiers.obspm.fr/icrs-pc/newwww/icrf/index.php

Reference Systems and Reference Frames

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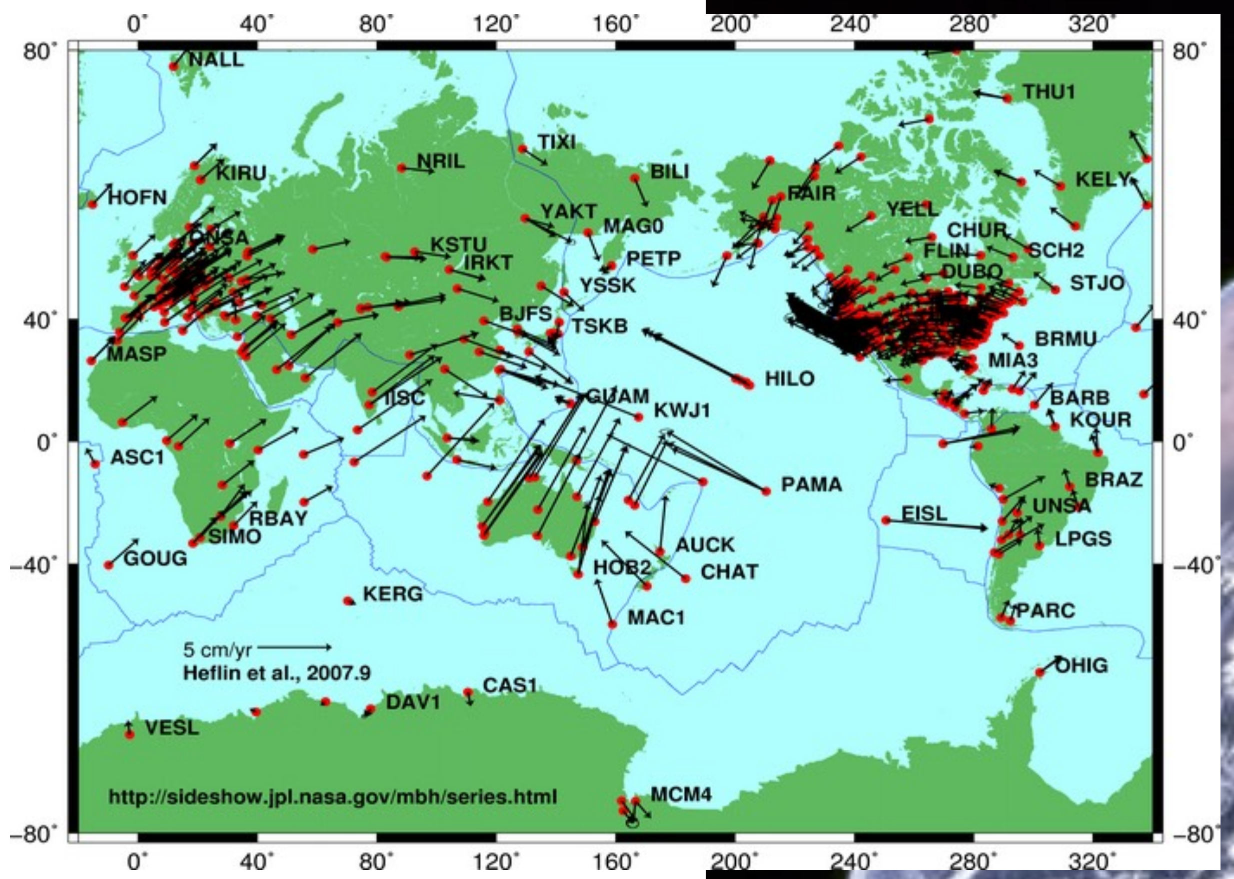

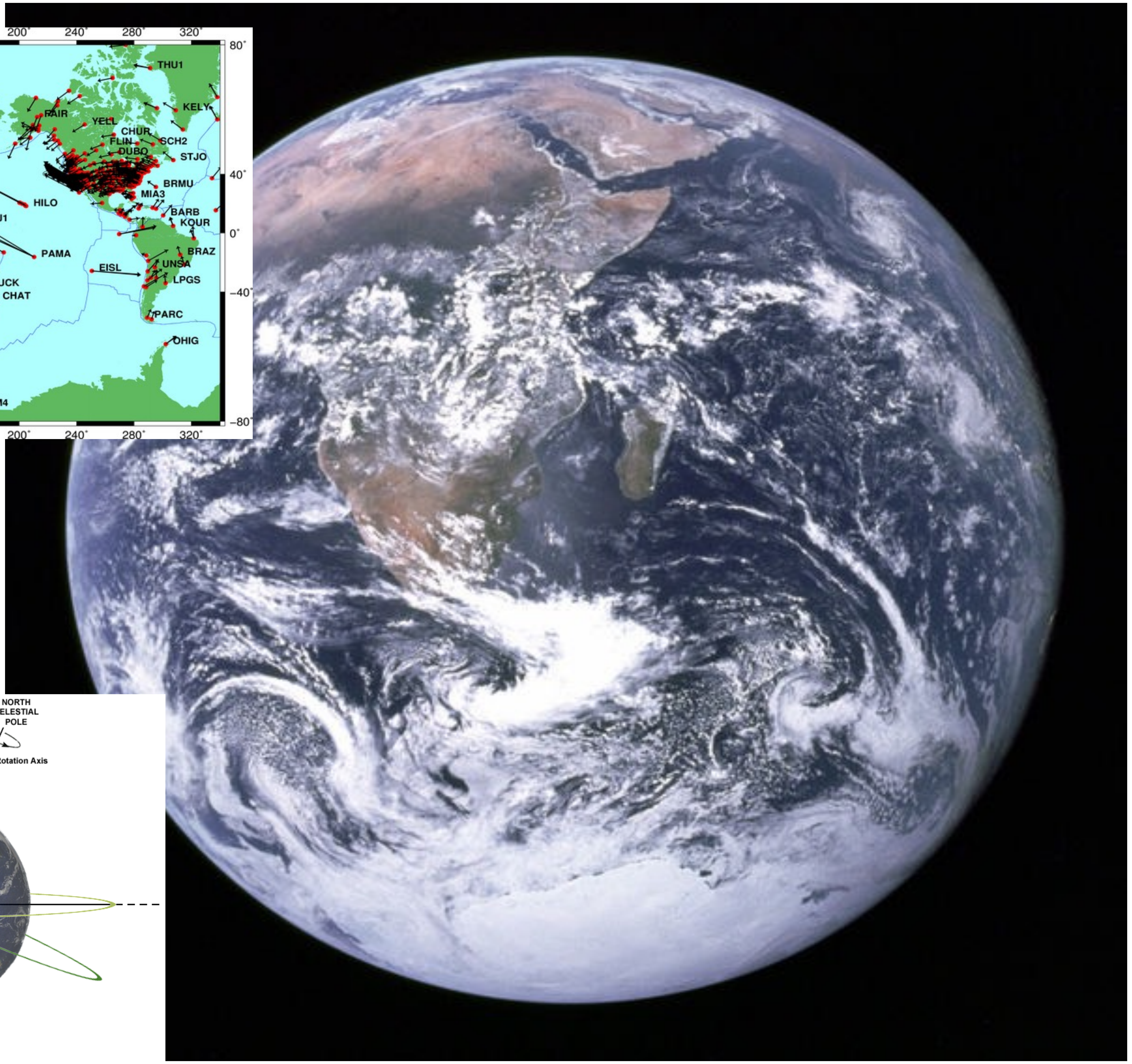

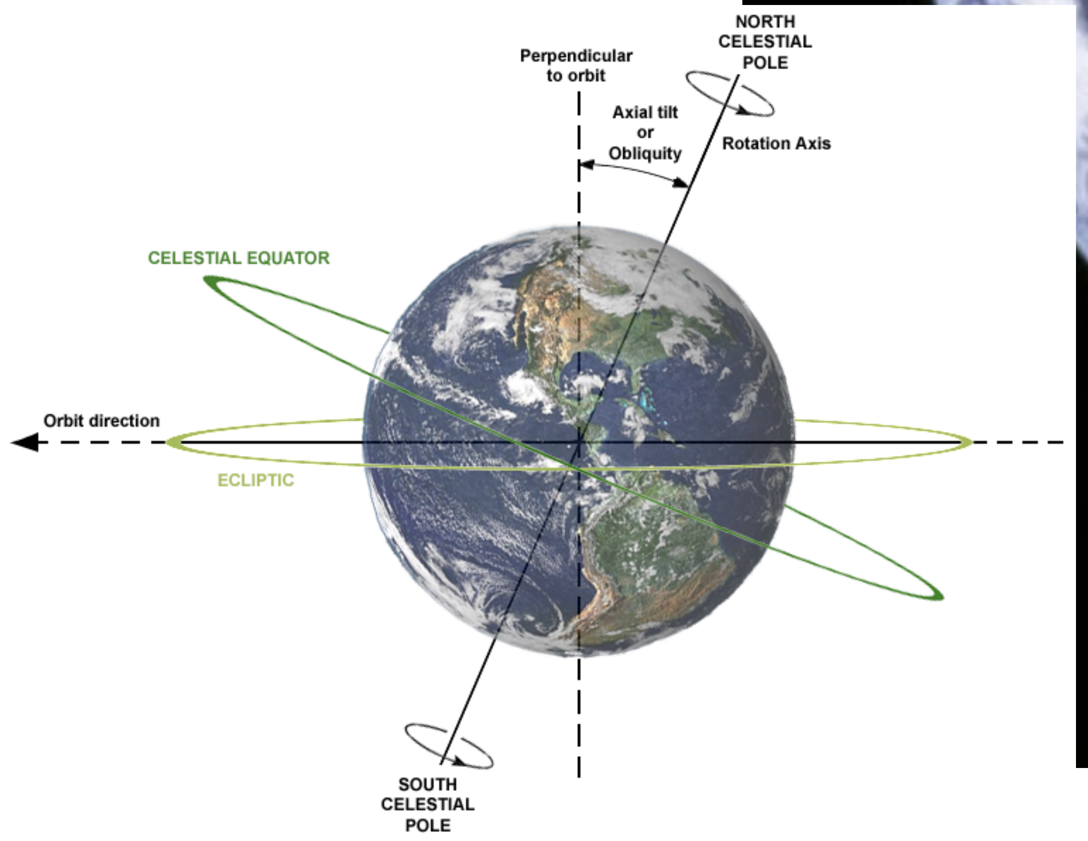

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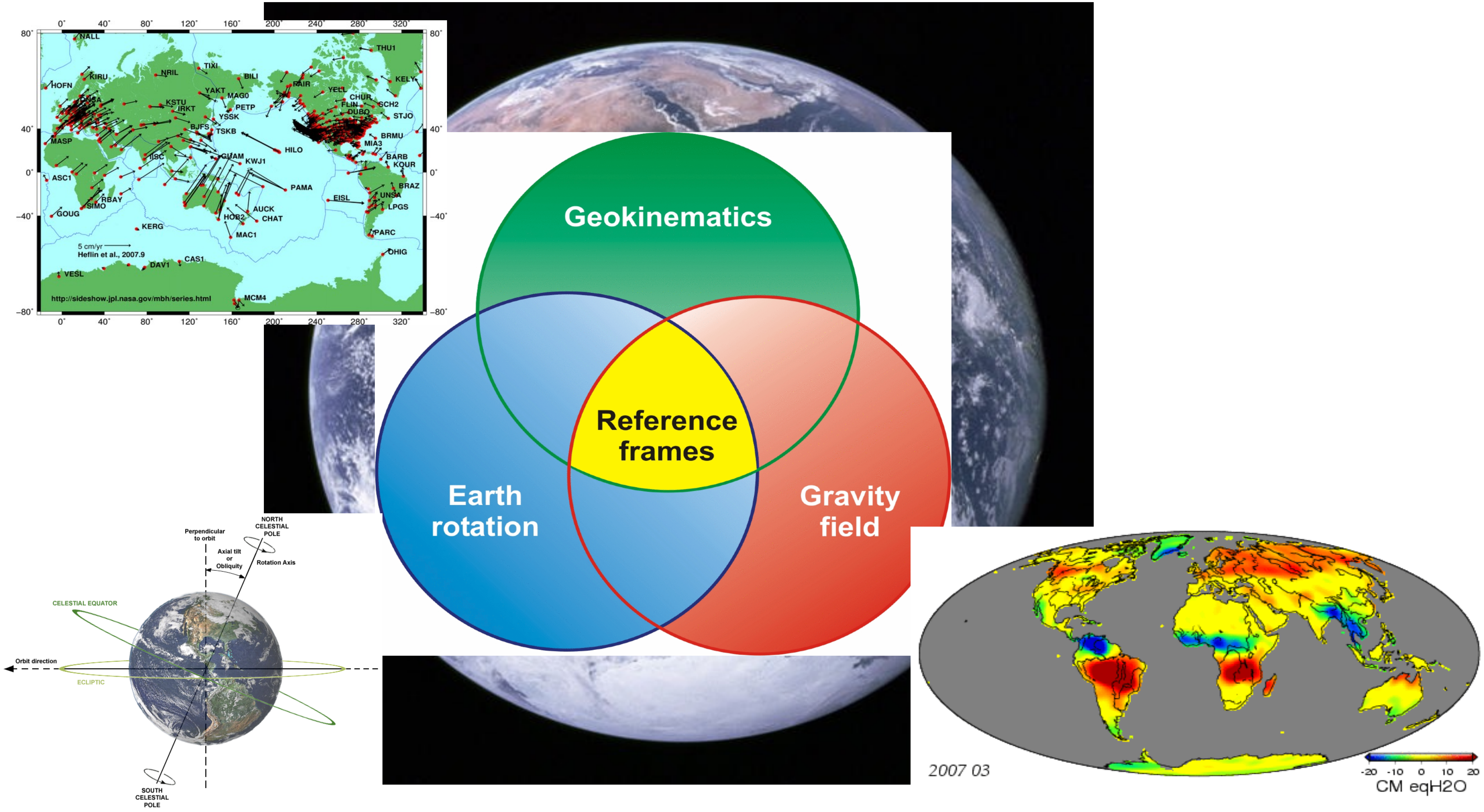
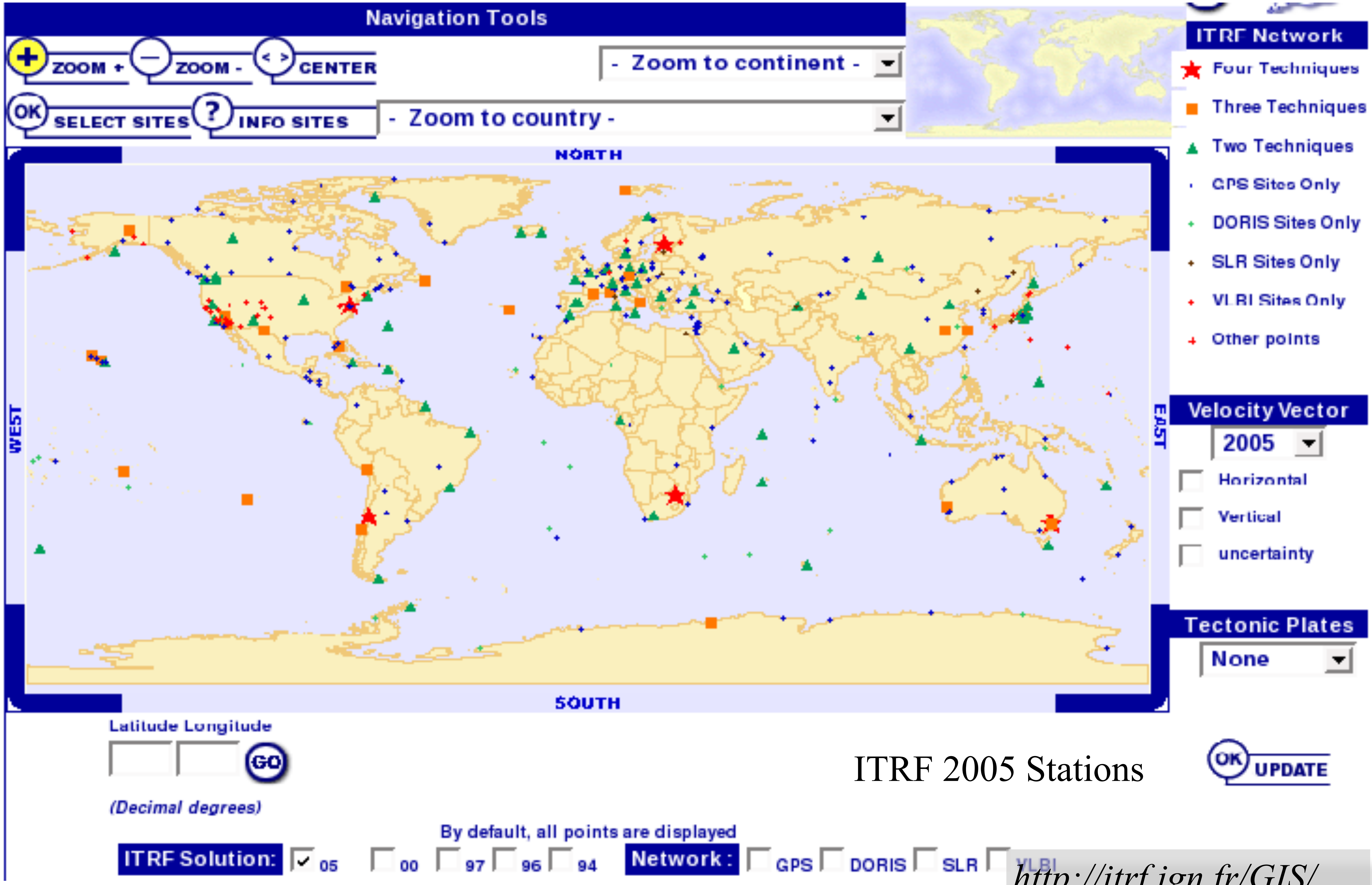


Reference Systems and Reference Frames

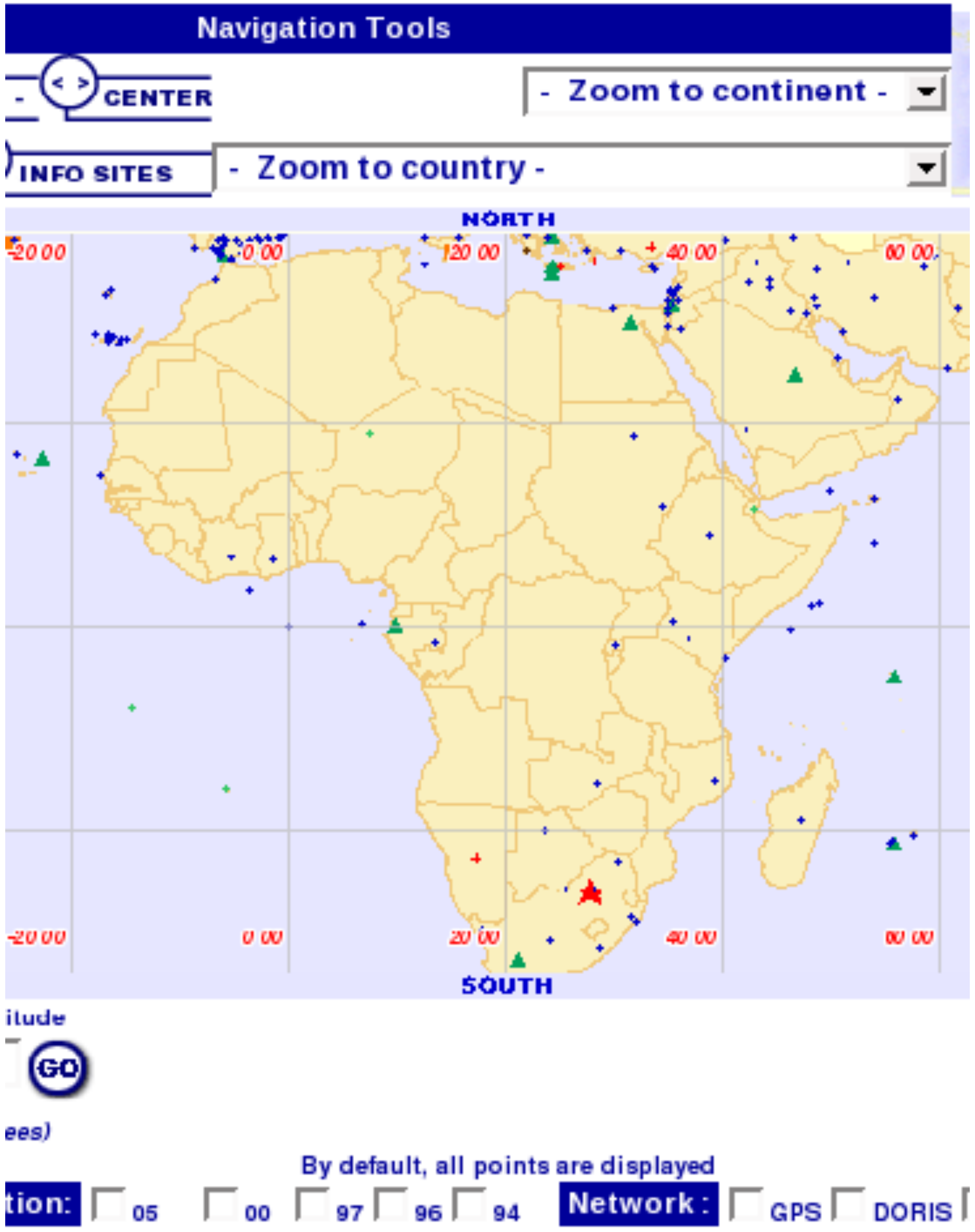
Component	Objective	Techniques	Responsibility
I. Geokinematics (size, shape, kinematics, deformation)	*Shape and temporal variations of land/ice/ocean surface (plates, intra-plates, volcanoes, earthquakes, glaciers, ocean variability, sea level)*	*Altimetry, InSAR, GNSS-cluster, VLBI, SLR, DORIS, imaging techniques, leveling, tide gauges*	*International and national projects, space missions, IGS, IAS, future InSAR service*
II. Earth Rotation (nutation, precession, polar motion, variations in length-of-day)	*Integrated effect of changes in angular momentum and inertia tensor (mass changes in atmosphere, cryosphere, oceans, solid Earth, core/mantle; momentum exchange between Earth system components)*	*Classical astronomy, VLBI, LLR, SLR, GNSS, DORIS, under development: terrestrial gyroscopes*	*International geodetic and astronomical community (IERS, IGS, IVS, ILRS, IDS)*
III. Gravity field	*Geoid, Earth's static gravitational potential, temporal variations induced by solid Earth processes and mass transport in the global water cycle.*	*Terrestrial gravimetry (absolute and relative), airborne gravimetry, satellite orbits, dedicated satellite missions (CHAMP, GRACE, GOCE)*	*International geophysical and geodetic community (GGP, IGFS, BGI)*
IV. Terrestrial Frame	*Global cluster of fiducial point, determined at mm to cm level*	*VLBI, GNSS, SLR, LLR, DORIS, time keeping/transfer absolute gravimetry, gravity recording*	*International geodetic community (IERS with support of IVS, ILRS, IGS, and IDS)*

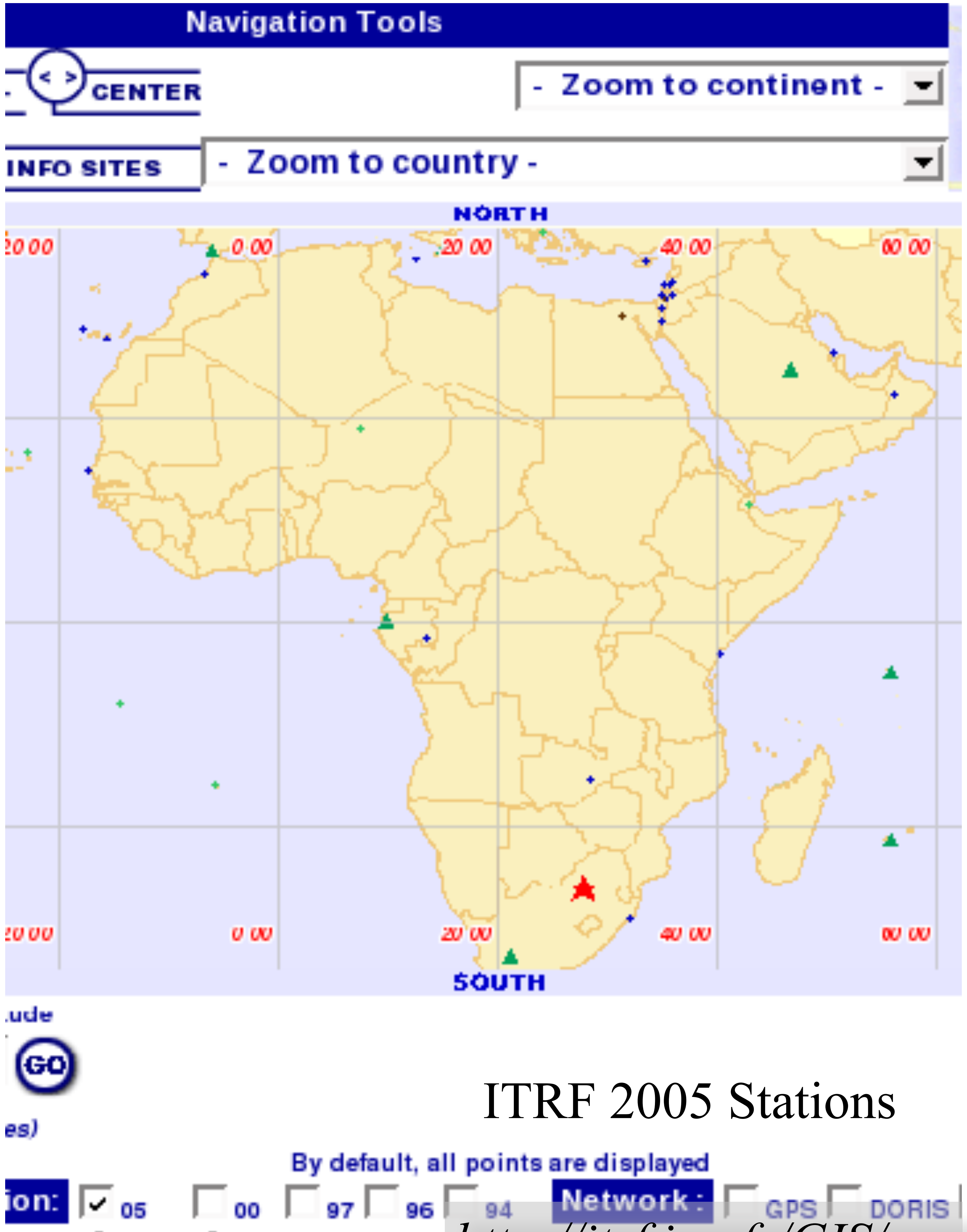


ITRF 2005 Stations

http://itrf.ign.fr/GIS/

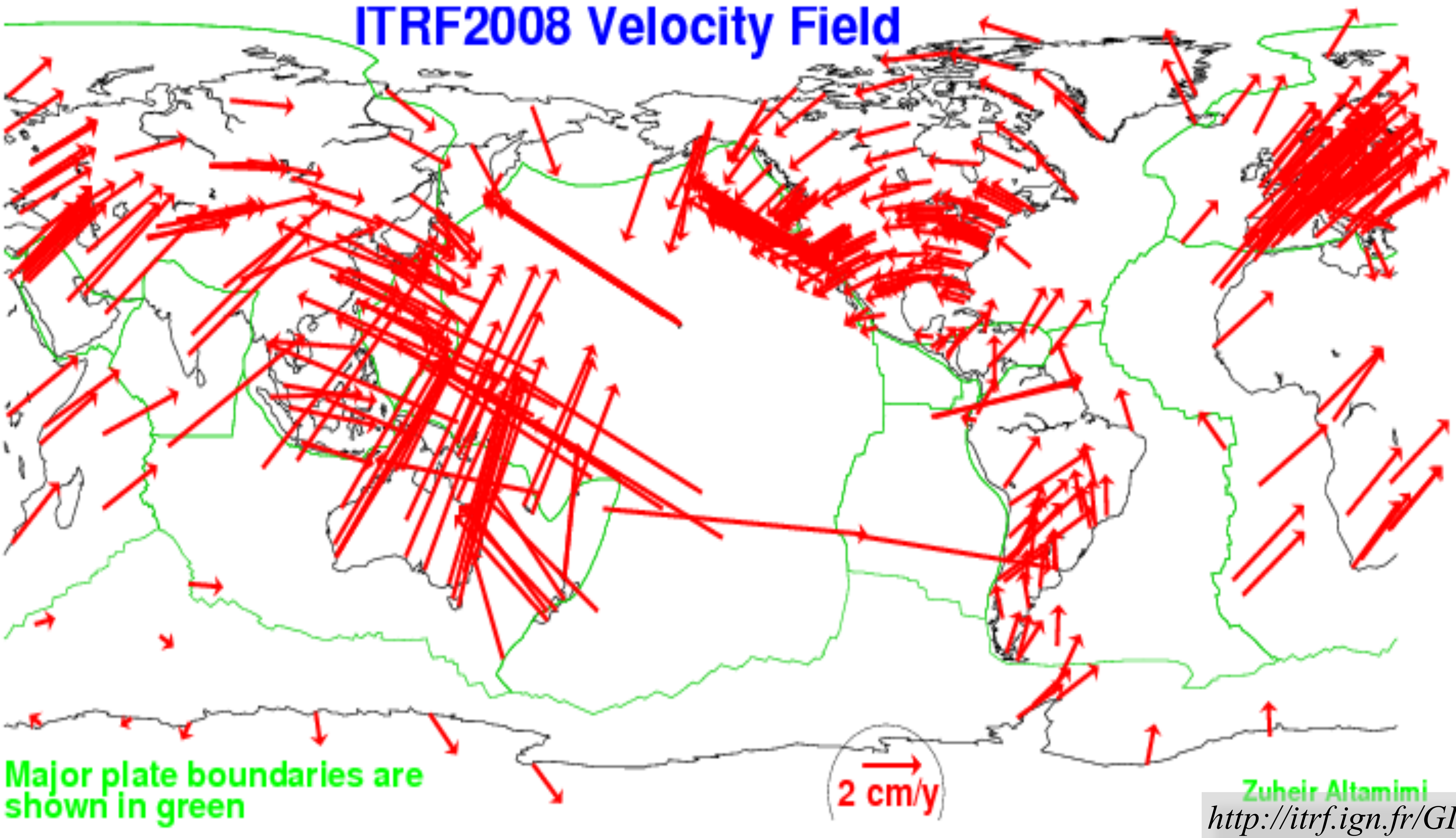
Reference Systems and Reference Frames





ITRF 2005 Stations

http://itrf.ign.fr/GIS/



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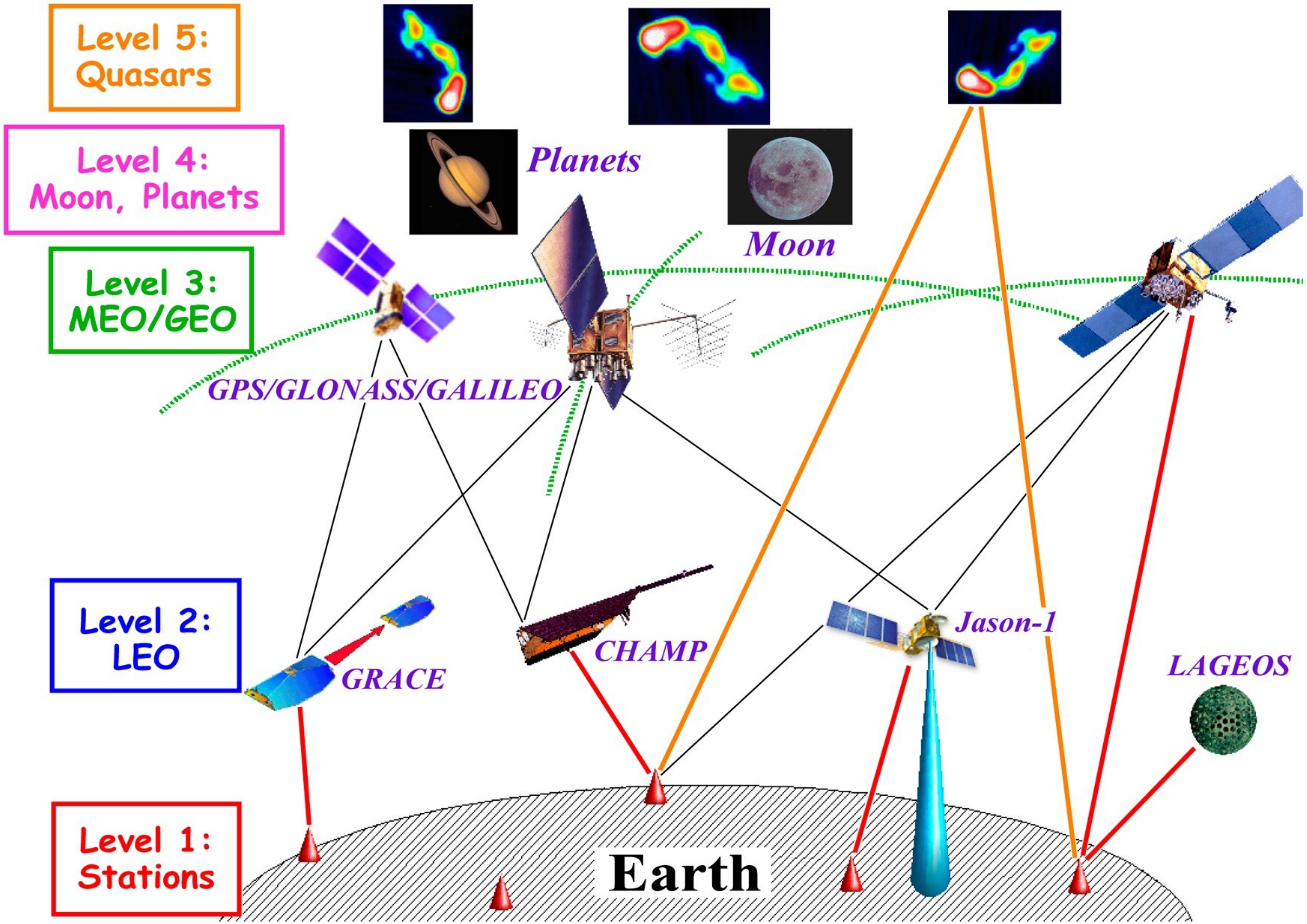
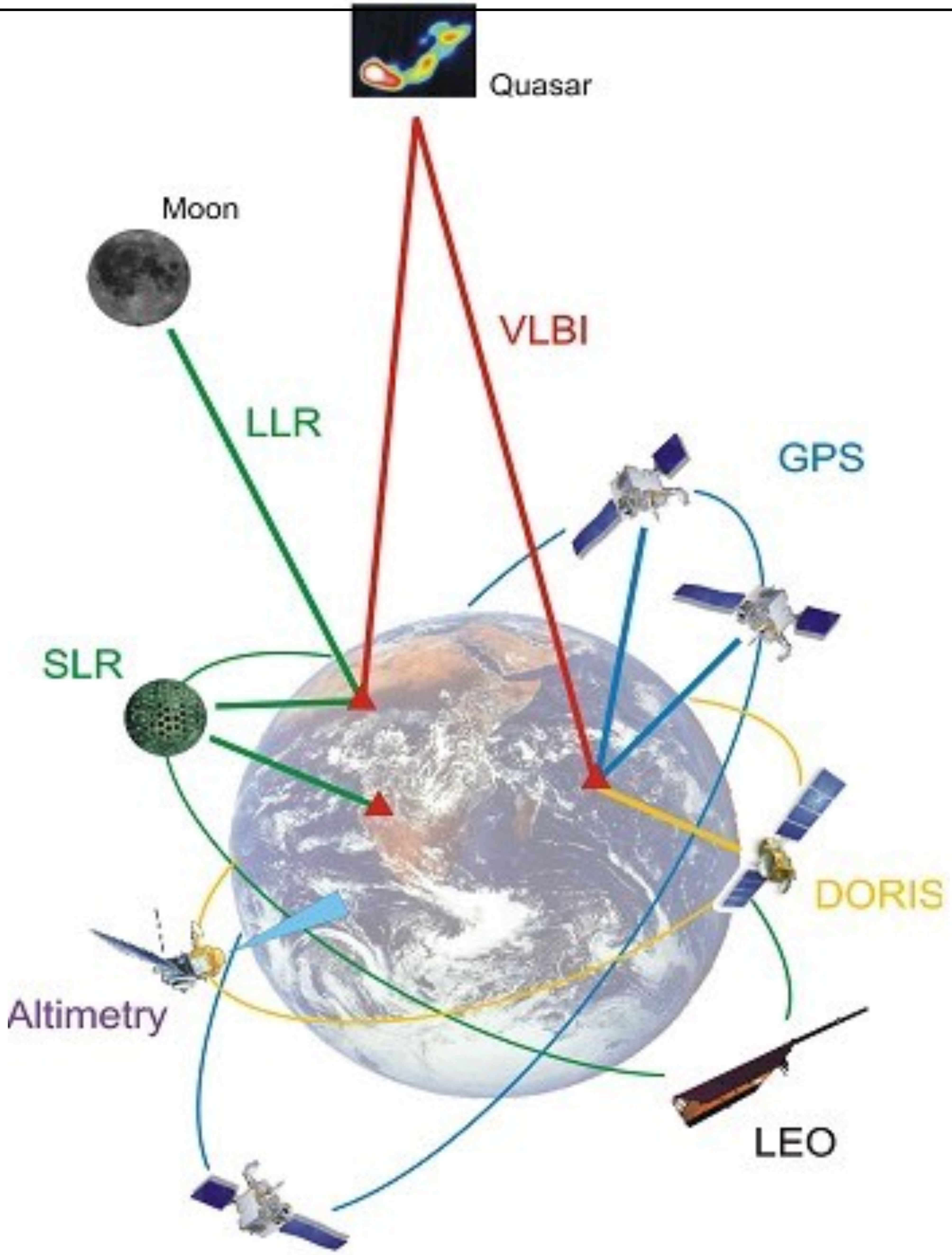
Reference Systems and Reference Frames

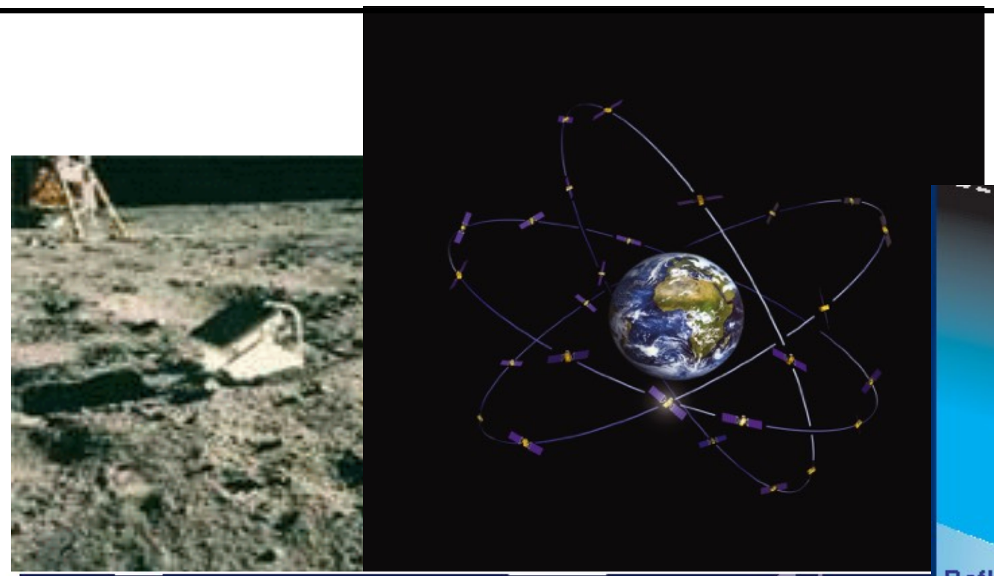


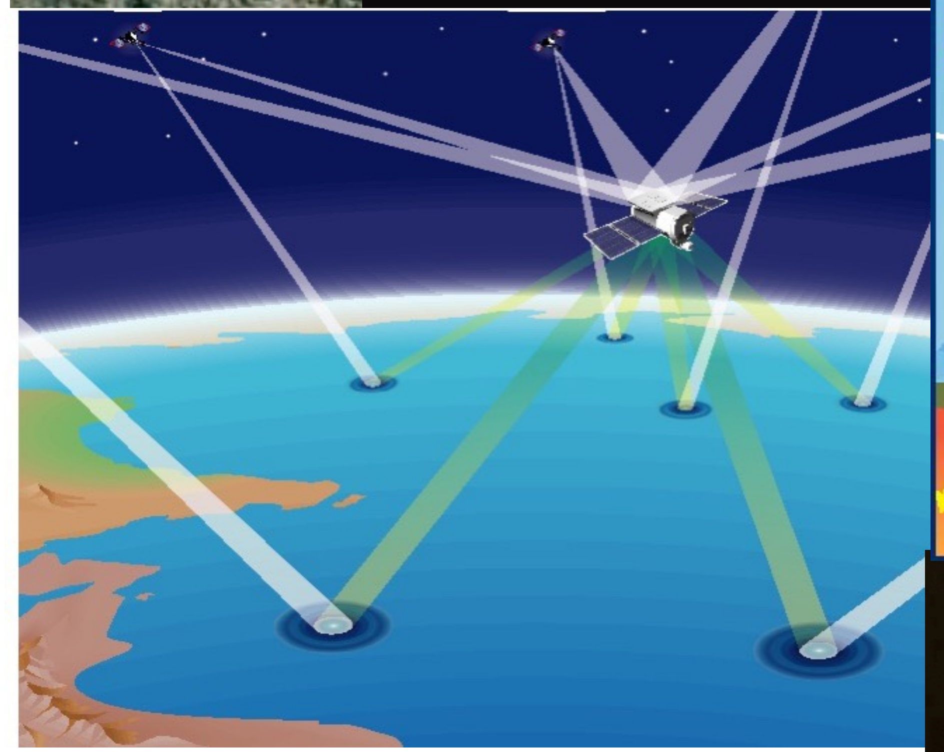
Reference Systems and Reference Frames

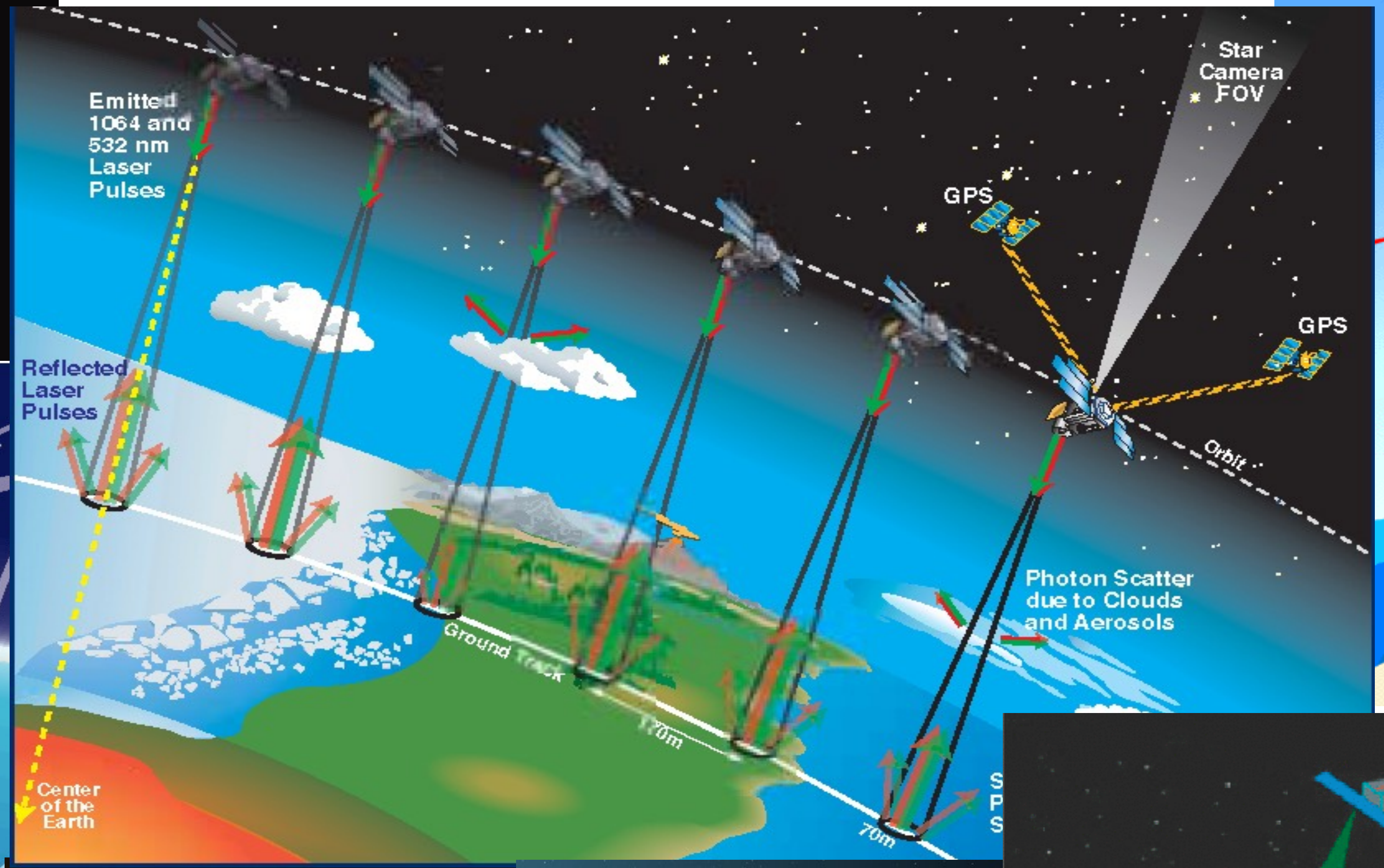


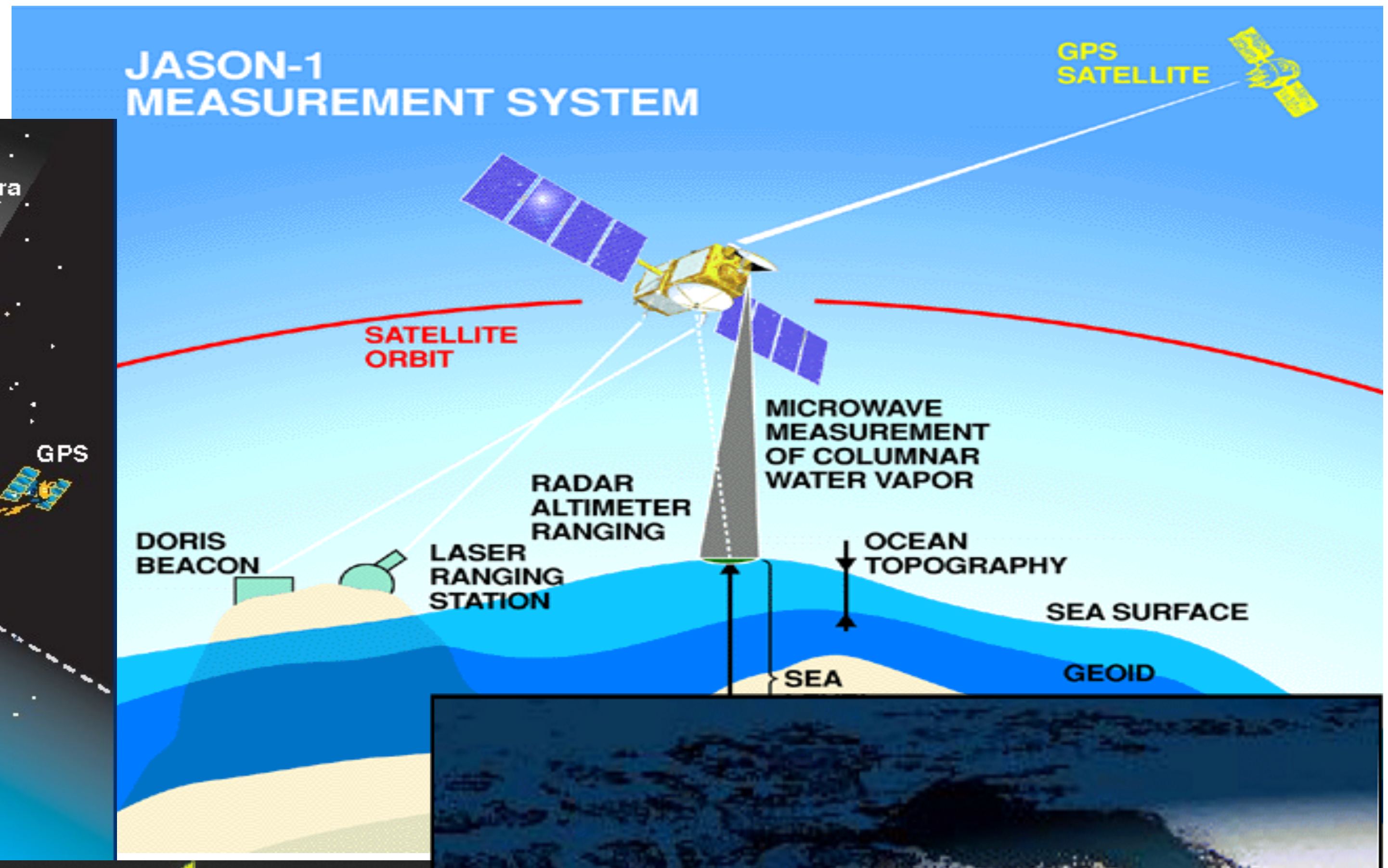
Reference Systems and Reference Frames

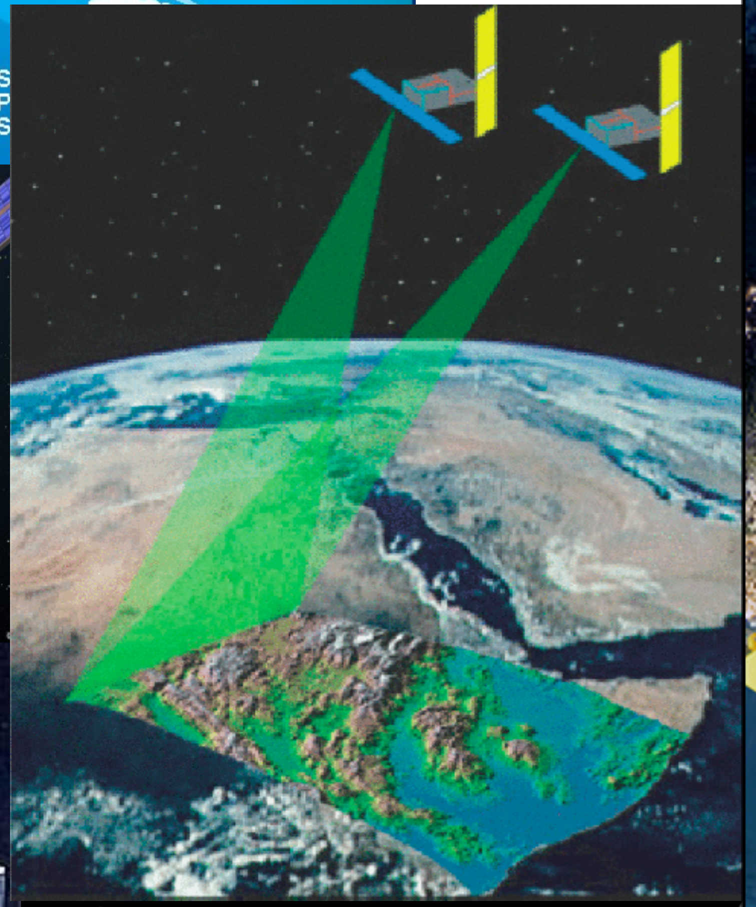
Measuring land motion with respect to the center of mass of the Earth requires a stable, global reference frame well tied to the center of mass.

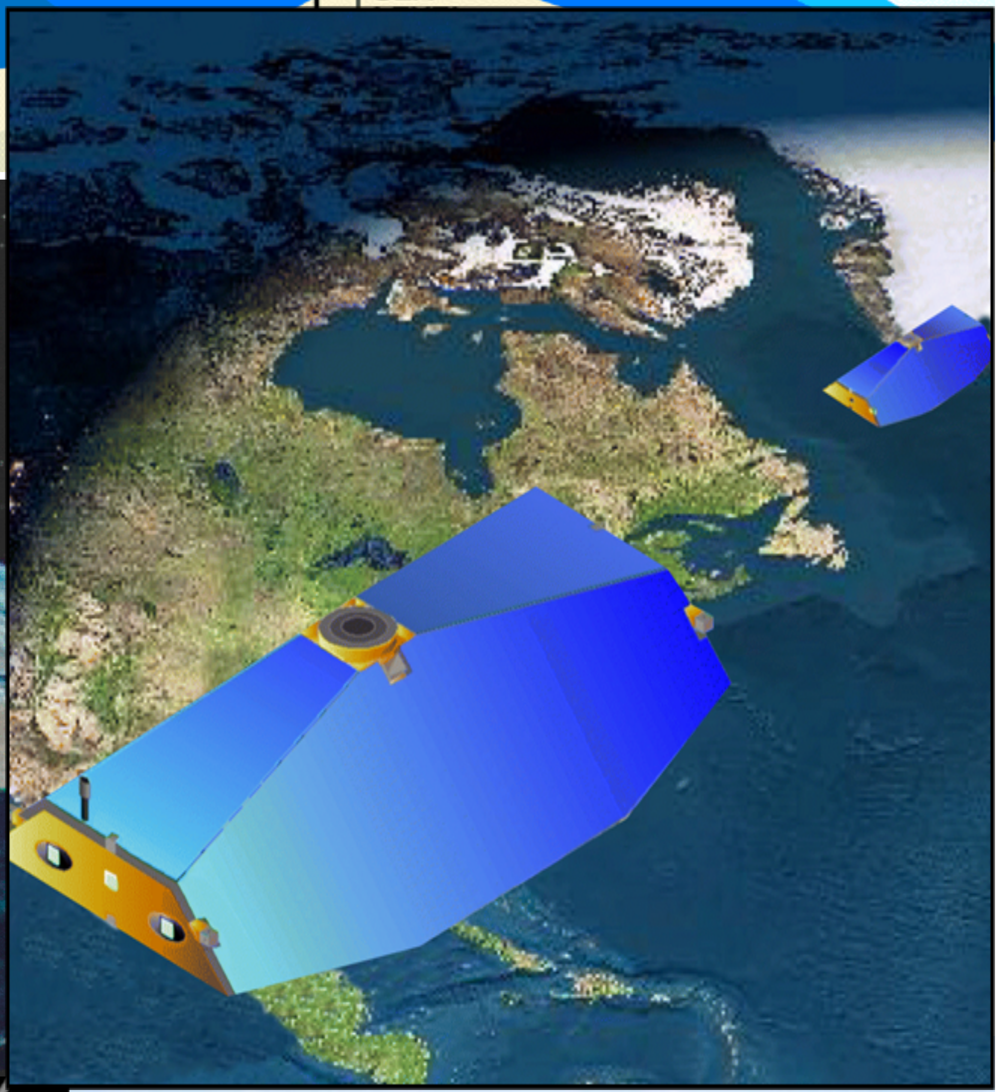




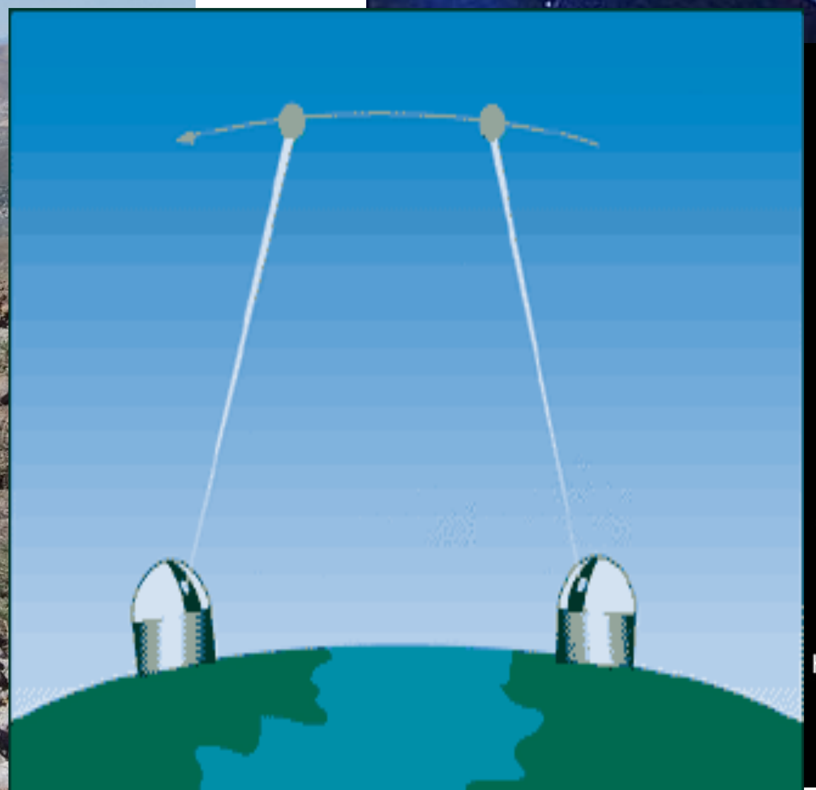


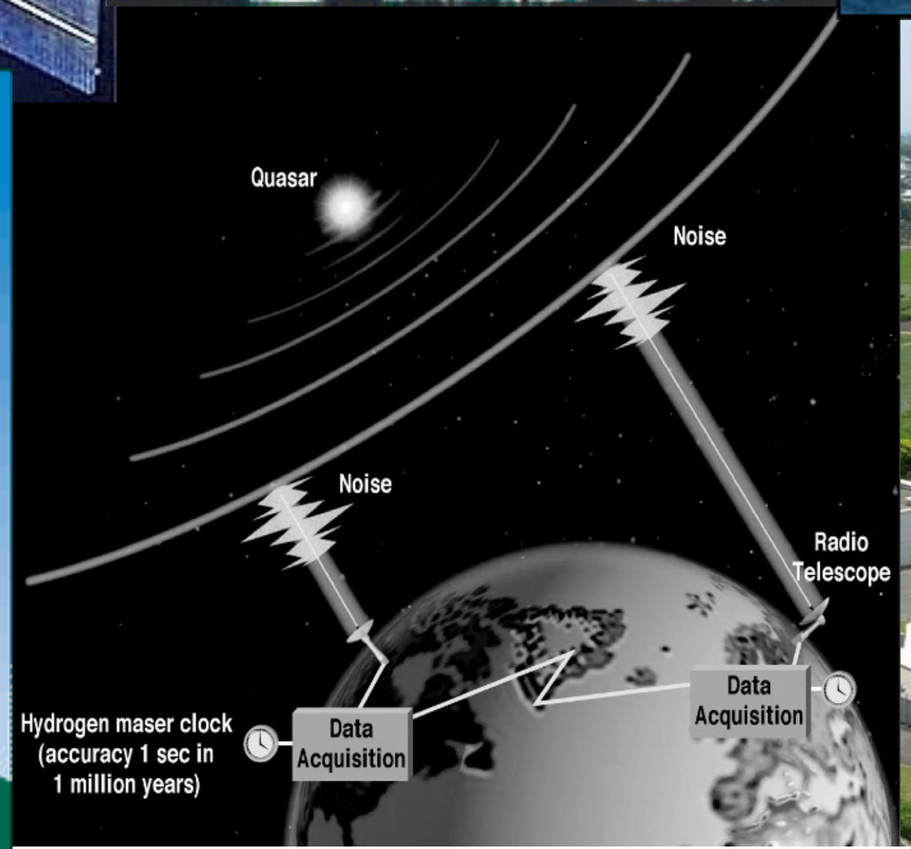






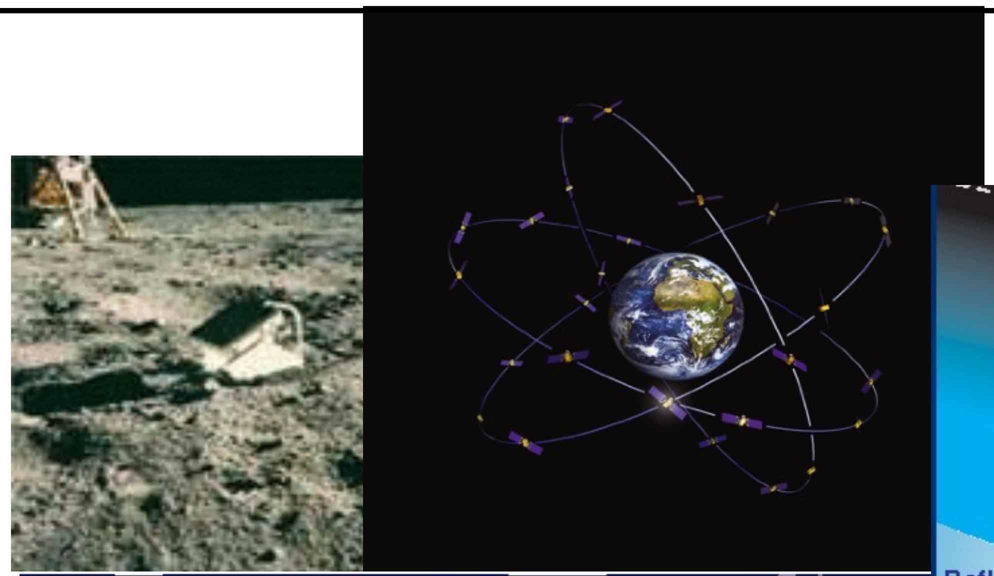
Global Geodetic Observing System

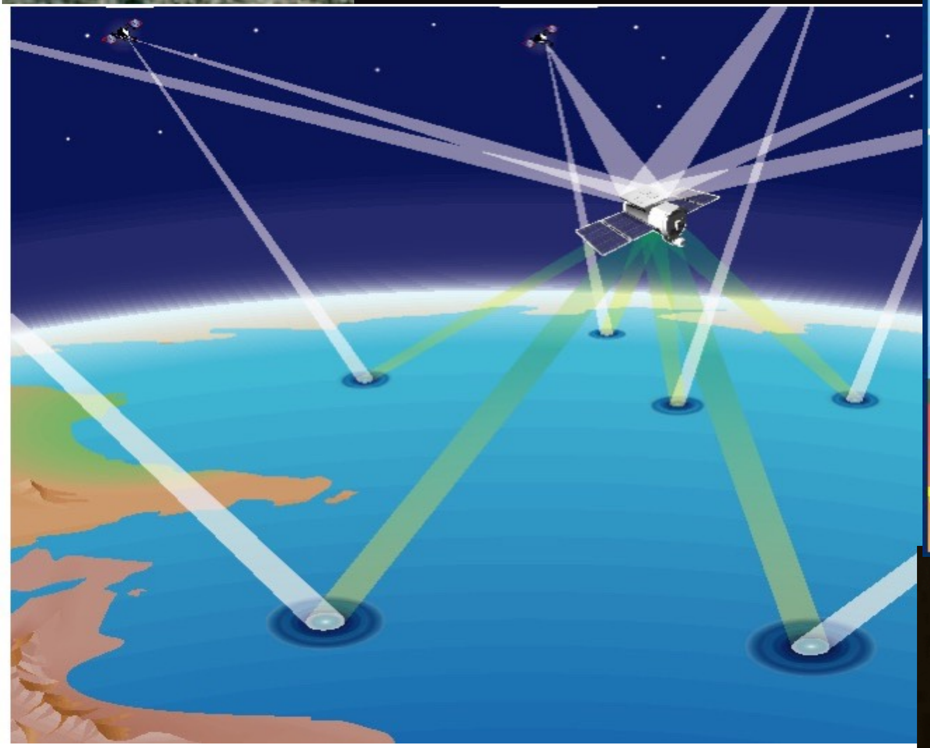


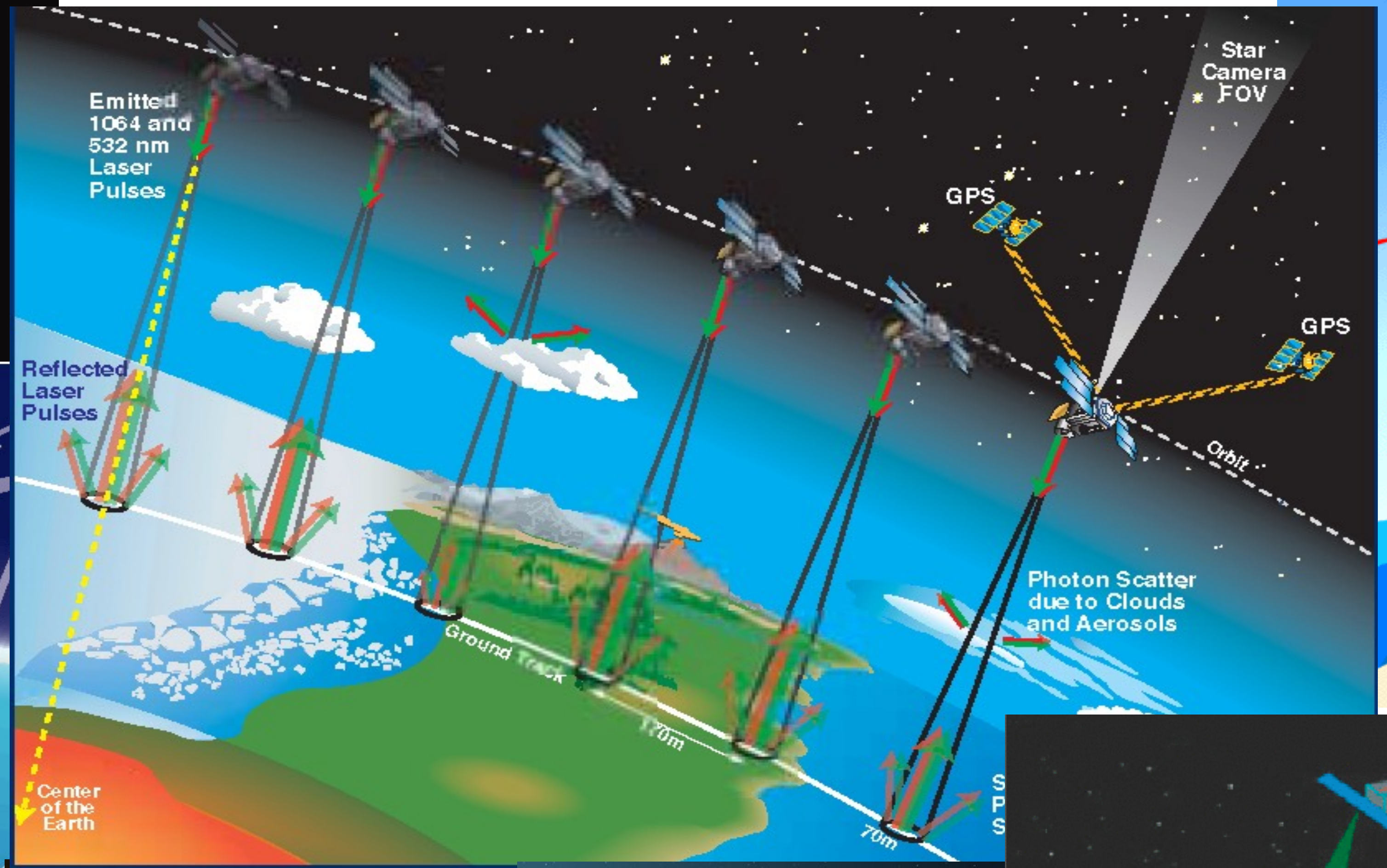


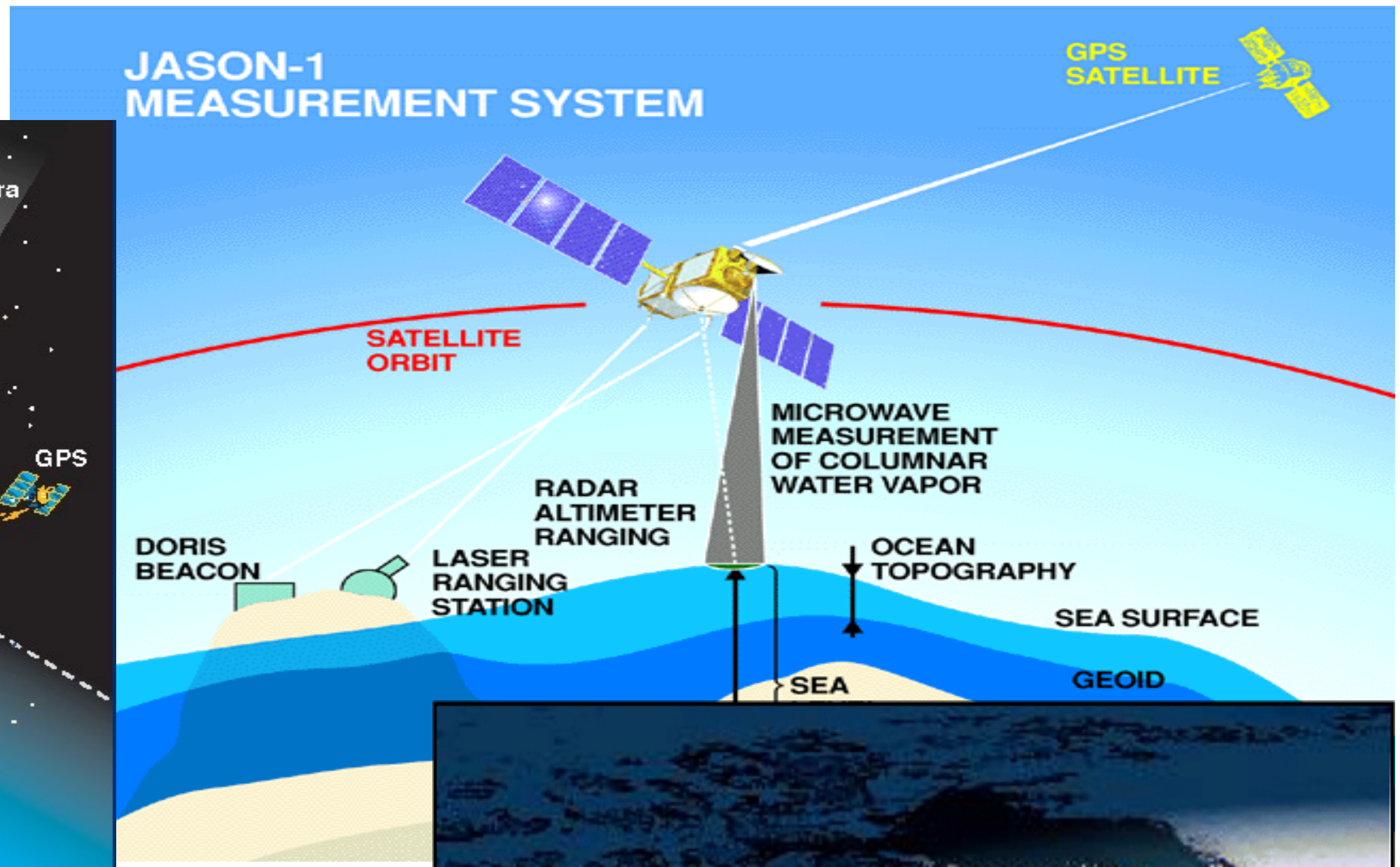
Reference Systems and Reference Frames

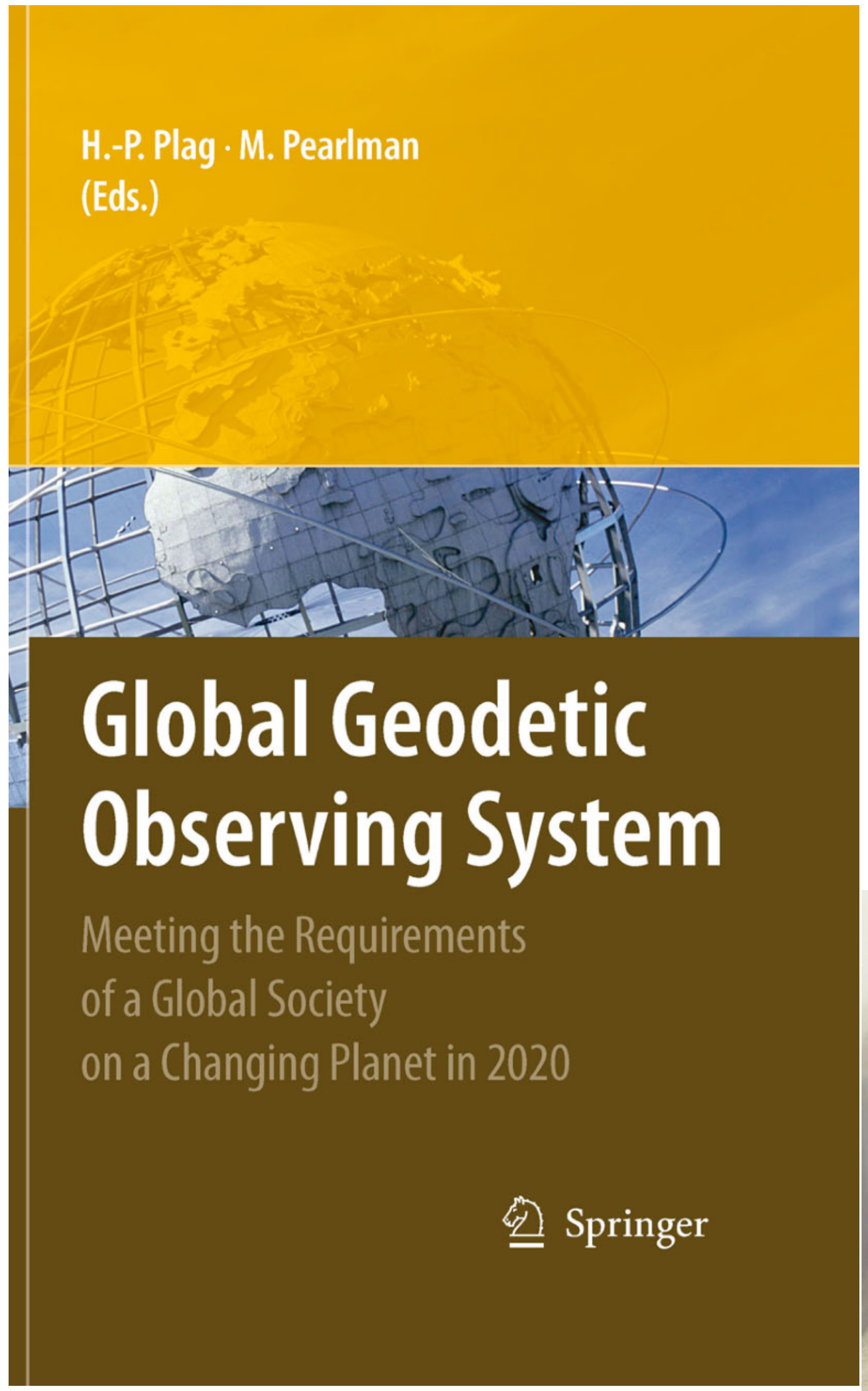
Measuring land motion with respect to the center of mass of the Earth requires a stable, global reference frame well tied to the center of mass.



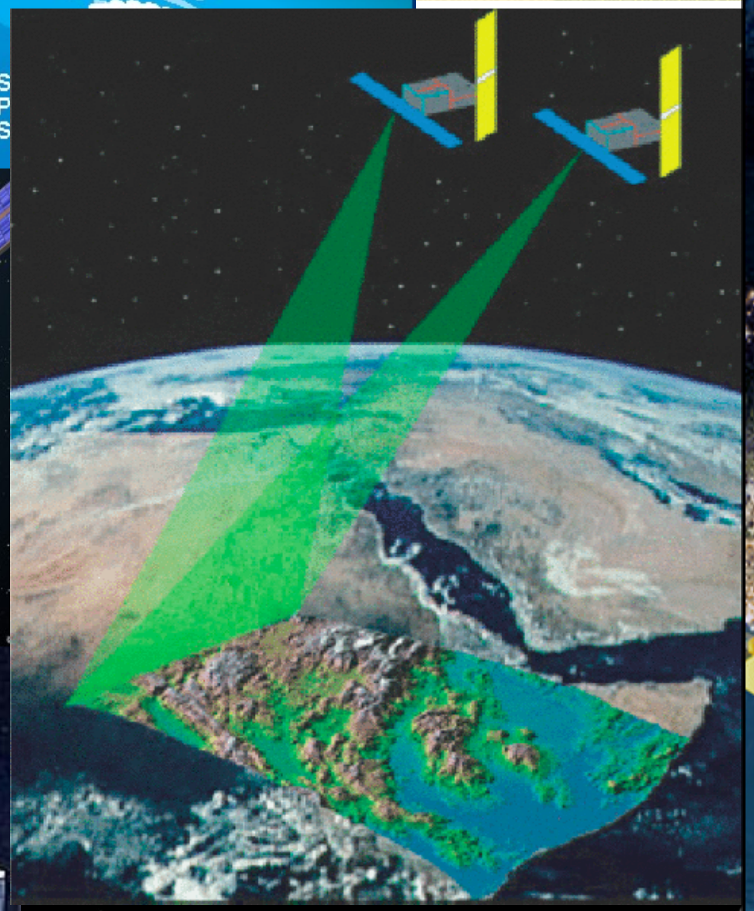


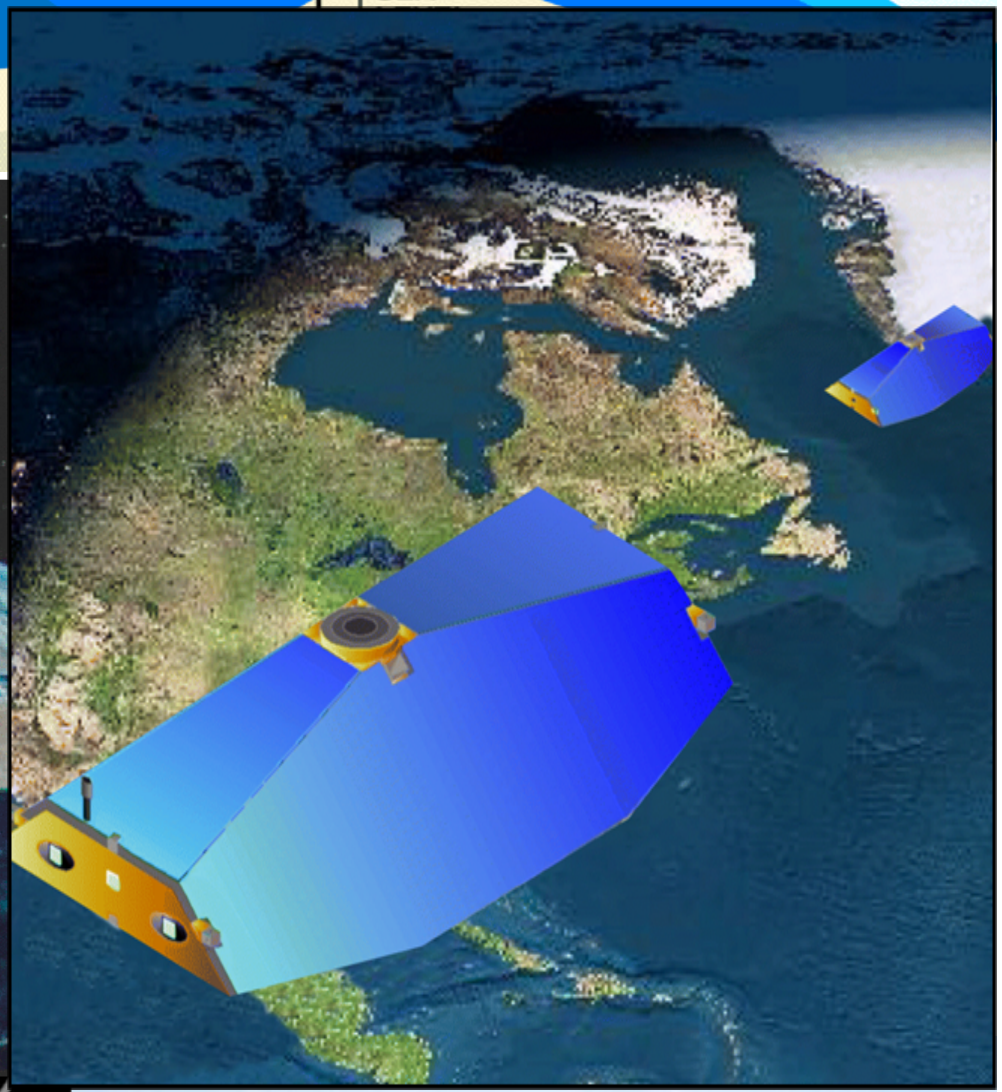


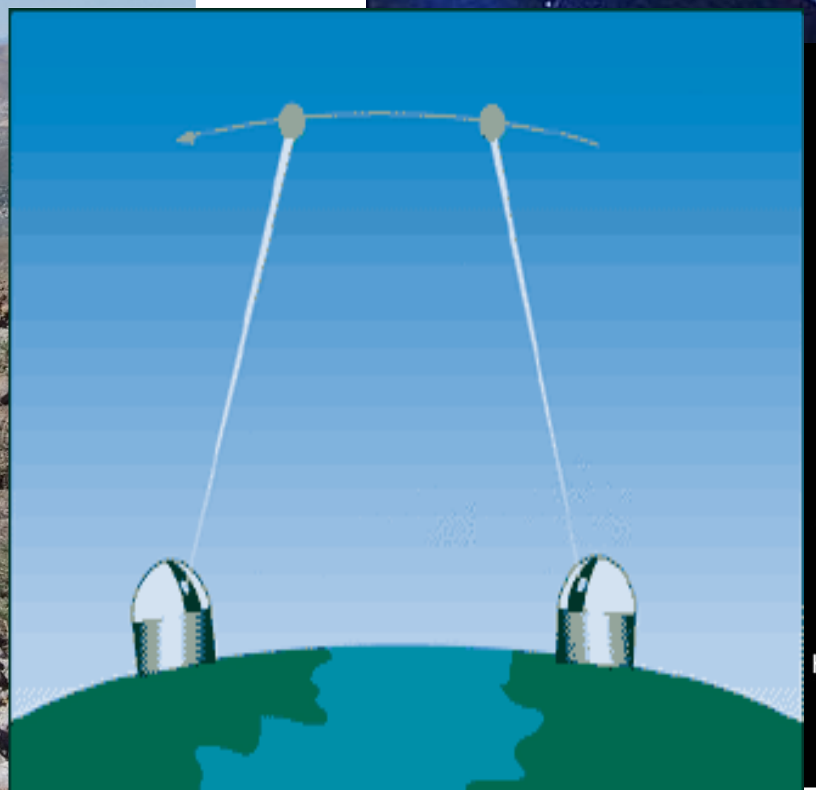


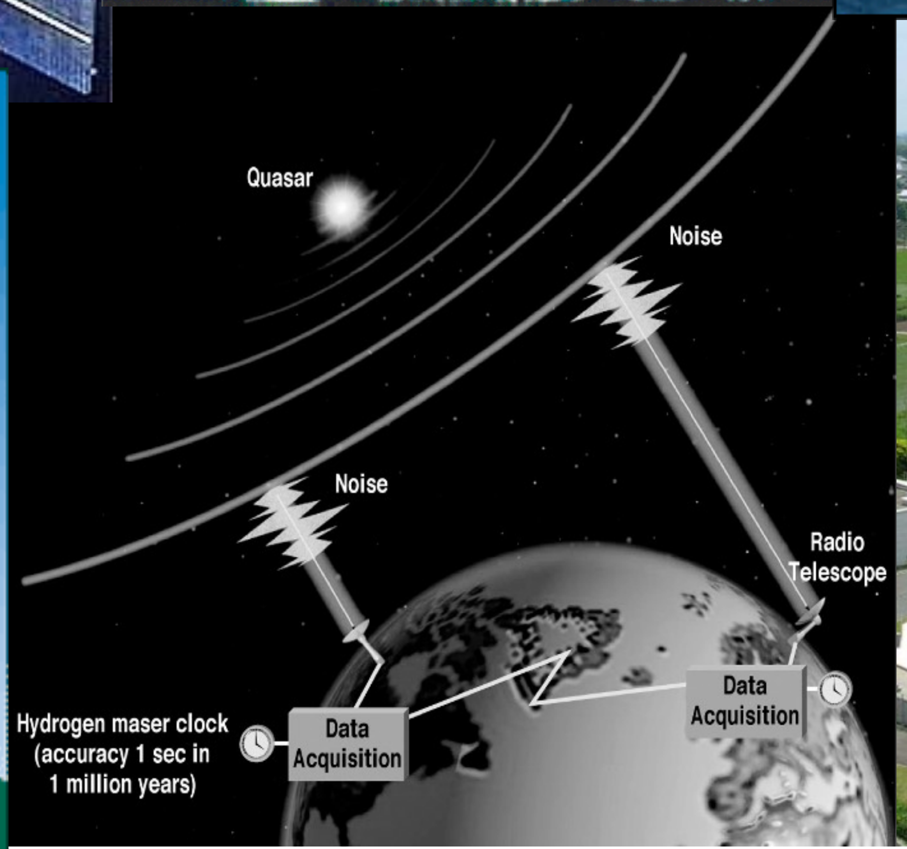


Global Geodetic Observing System







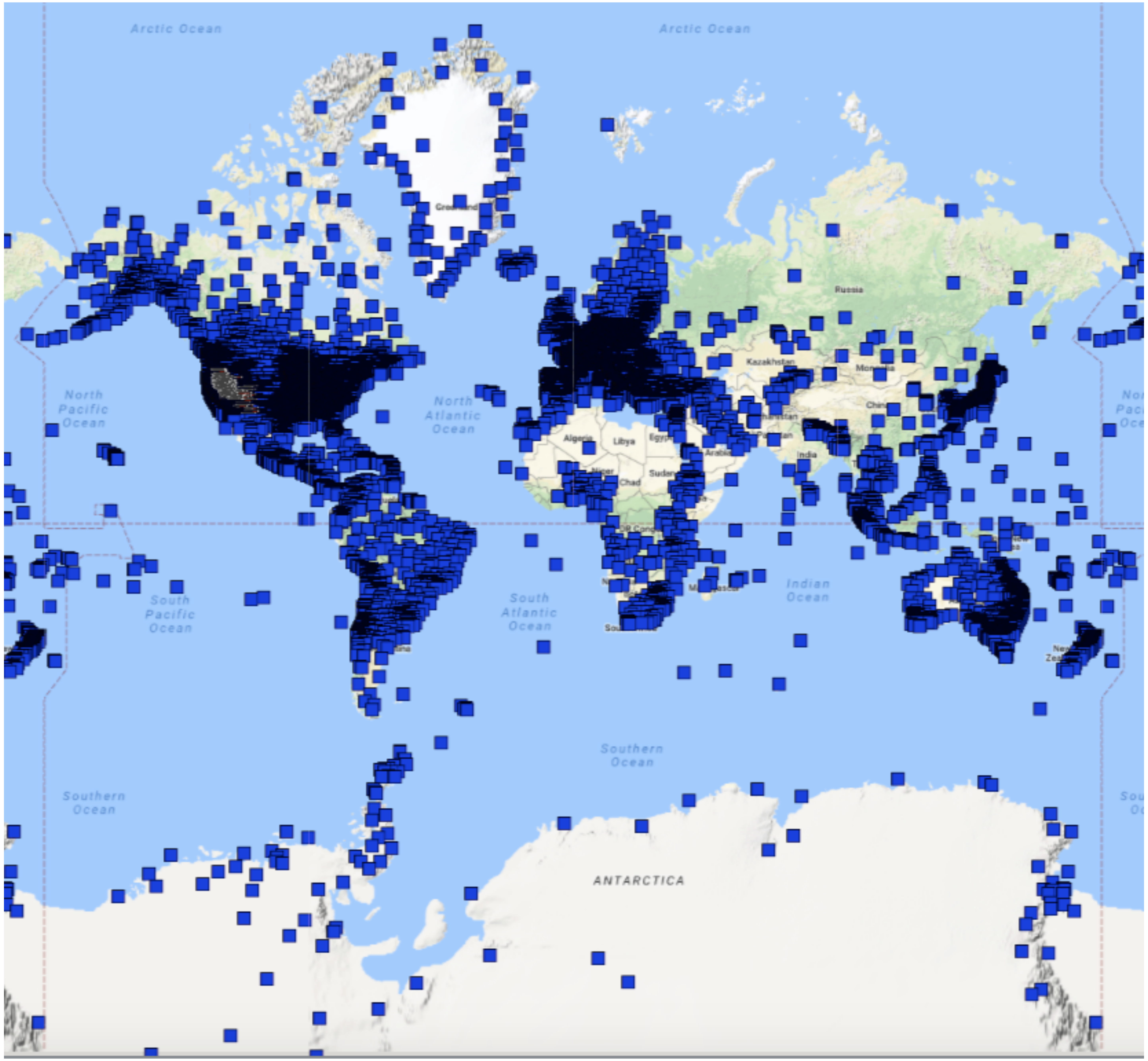


Natural Hazards and Disasters

Class 2: Observing Hazards and Disasters

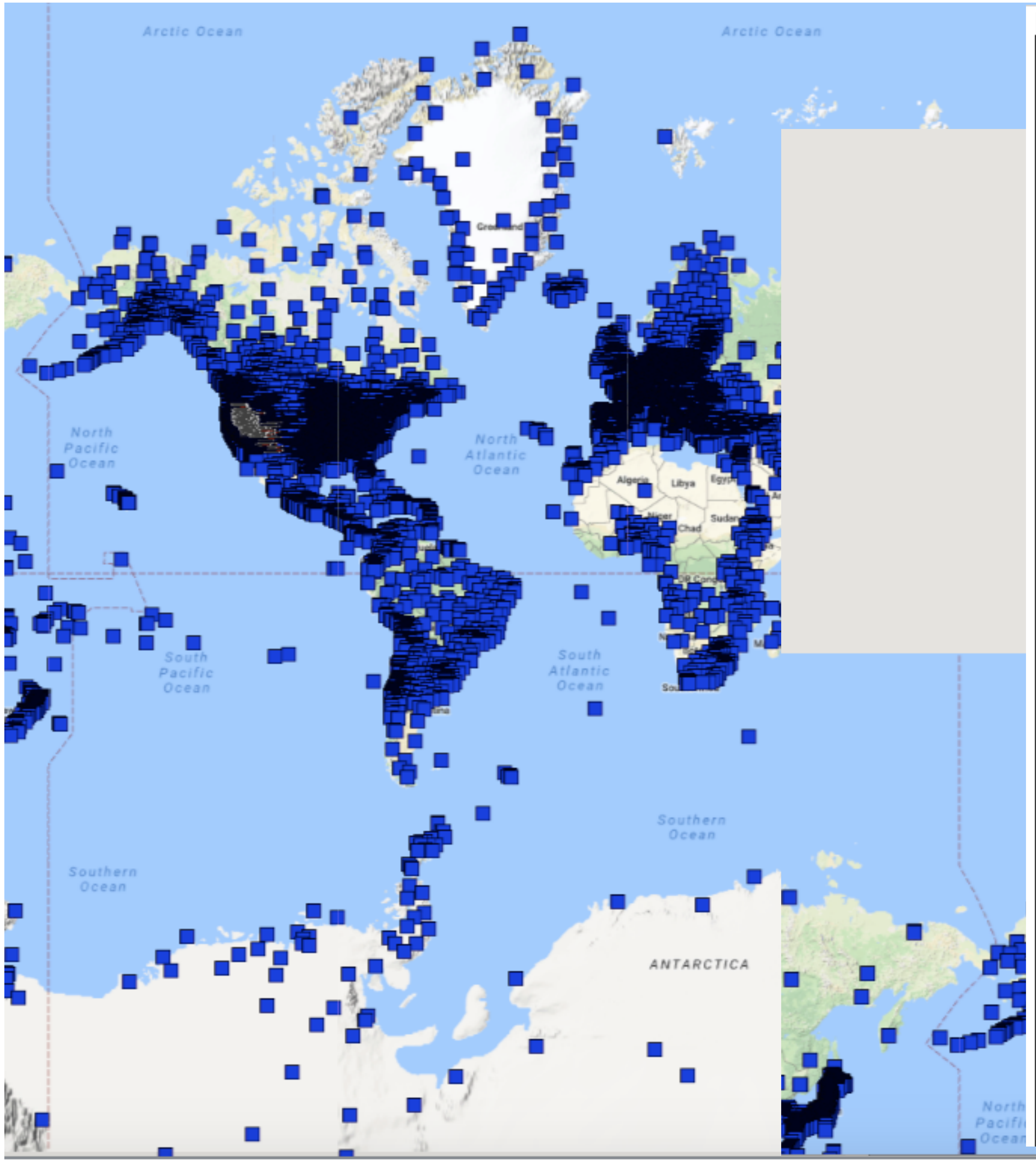
- A dynamic Planet
- Observing Systems for a Dynamic Planet
- Reference Systems and Frames
- Monitoring Small Changes

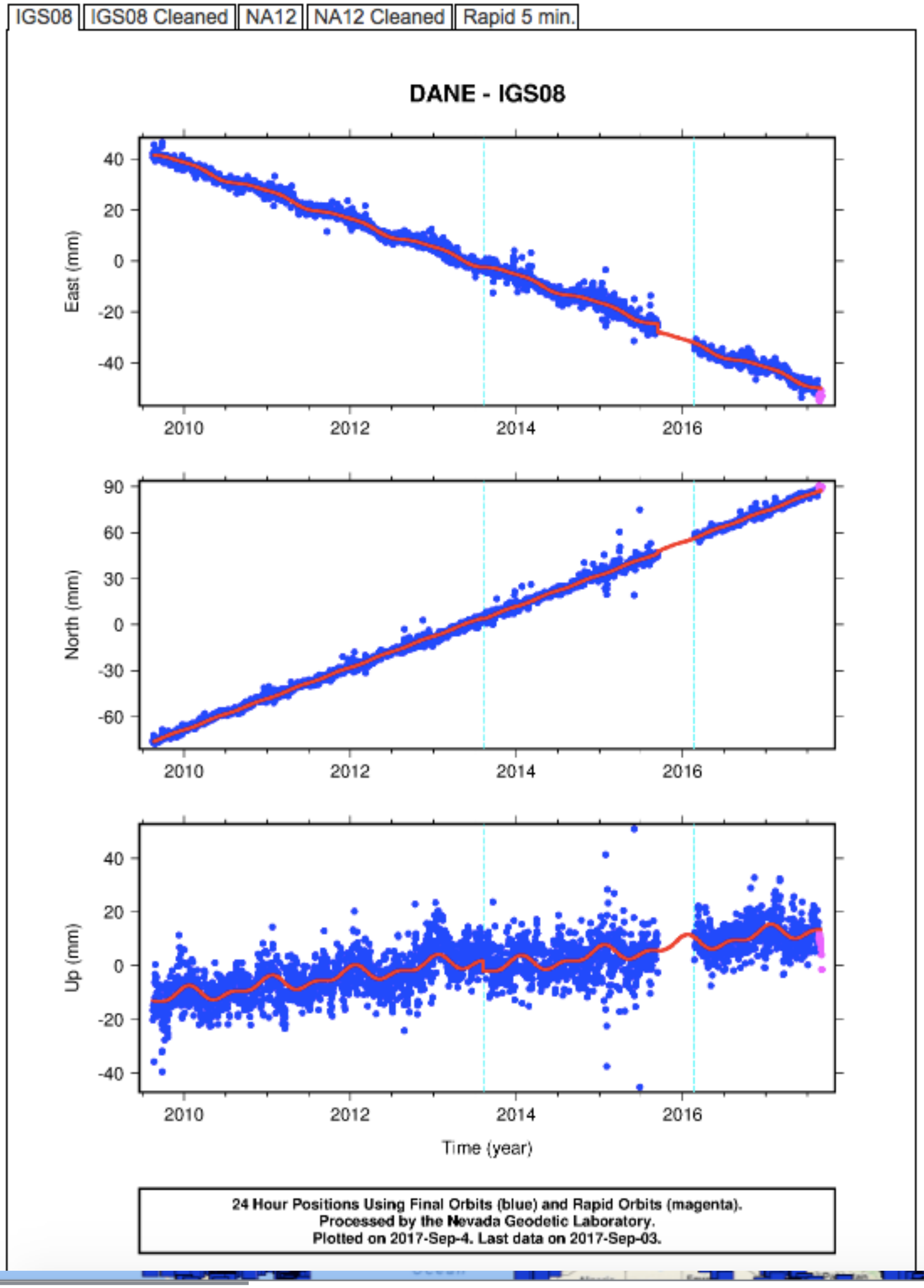
Monitoring Small Changes



Monitoring Small Changes

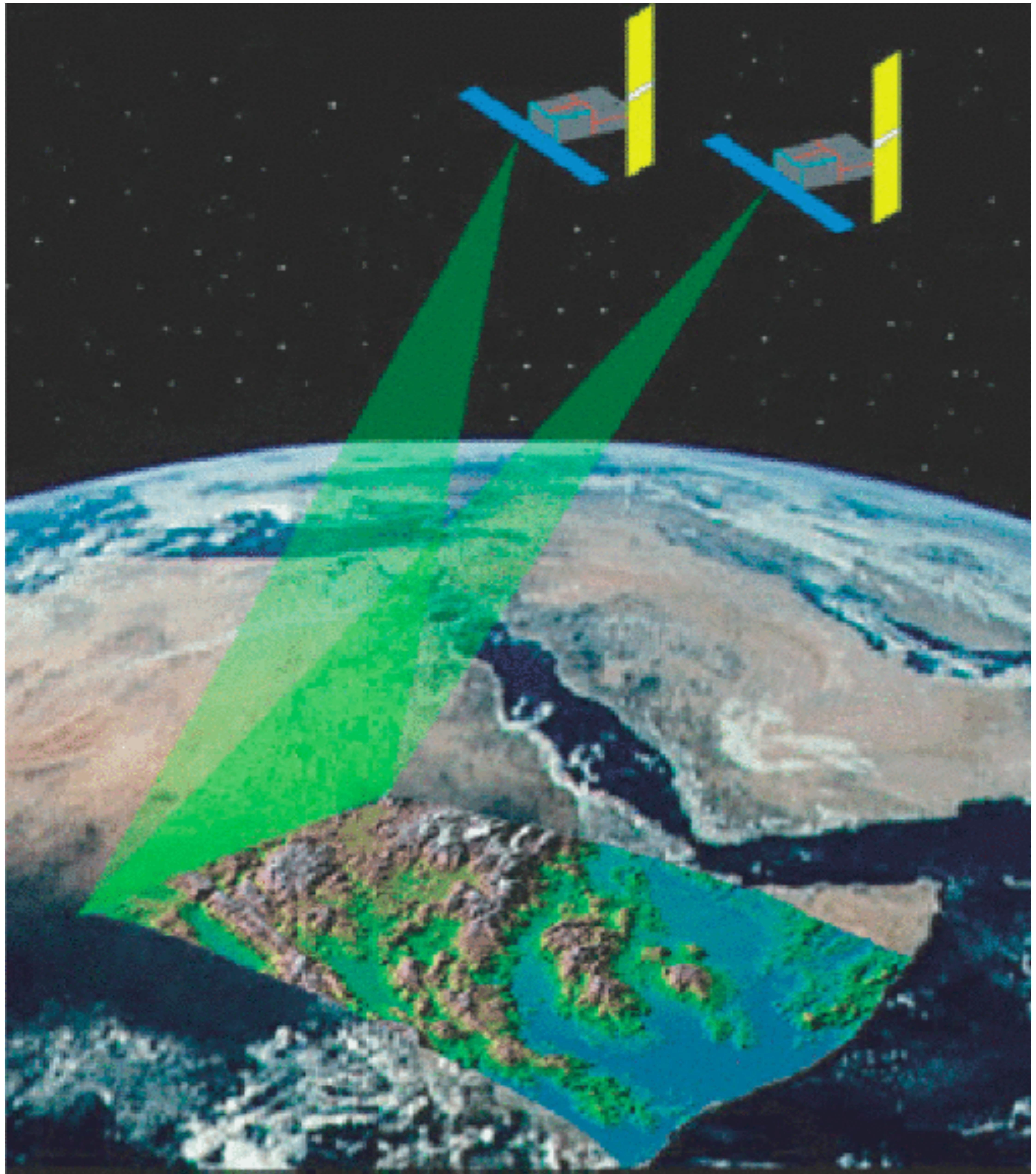
Monitoring Small Changes



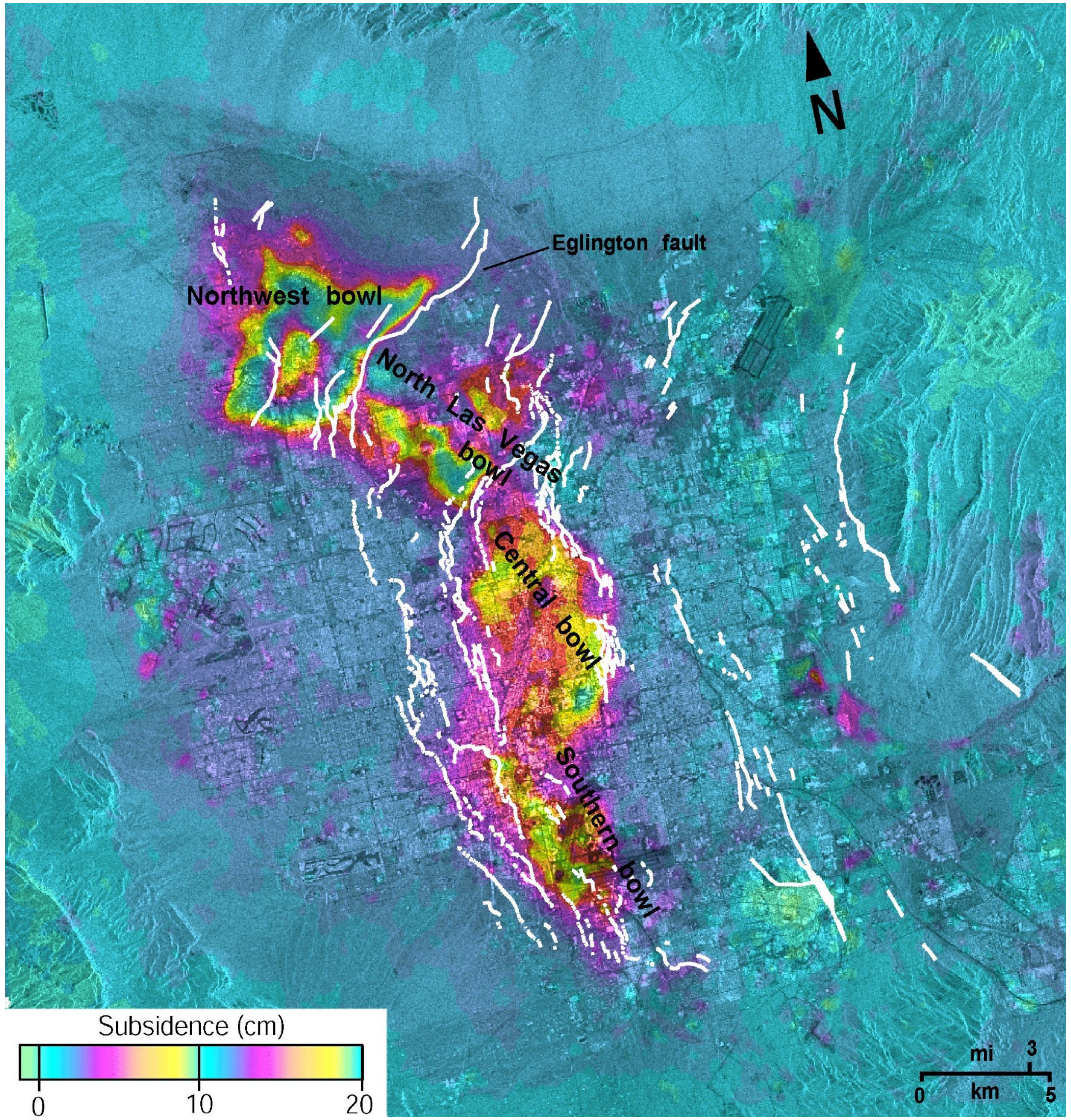


Monitoring Small Changes

Interferometric Synthetic Aperture Radar (InSAR)
Spatial scales: order 25 m
Temporal scales: < ~10 days



InSAR-Determined Surface Displacements



Subsidence 1992-1997

Four subsidence bowls

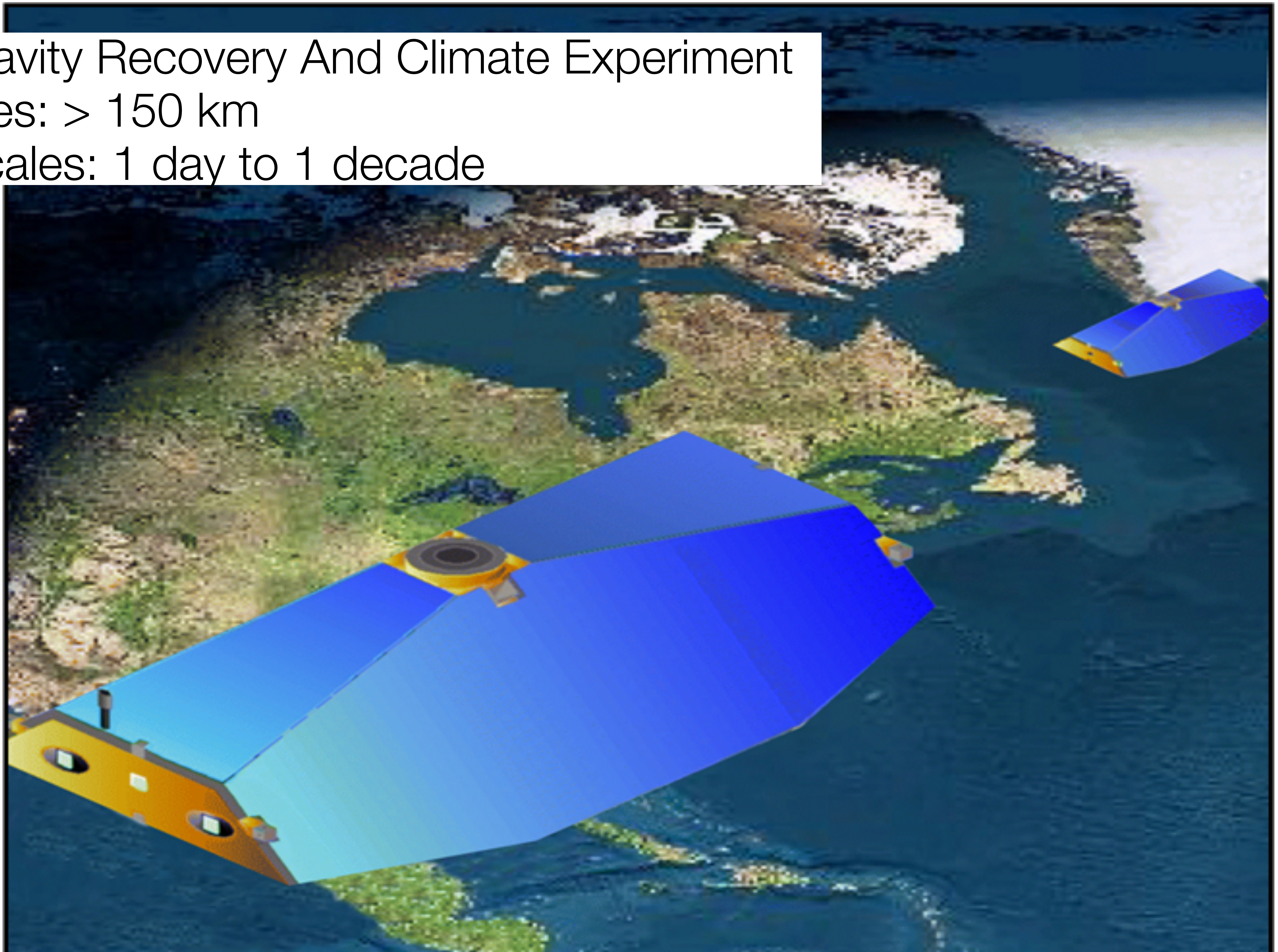
Aquifer system response strongly controlled by faults

Faults are subsidence barriers

Subsidence rate is decreasing

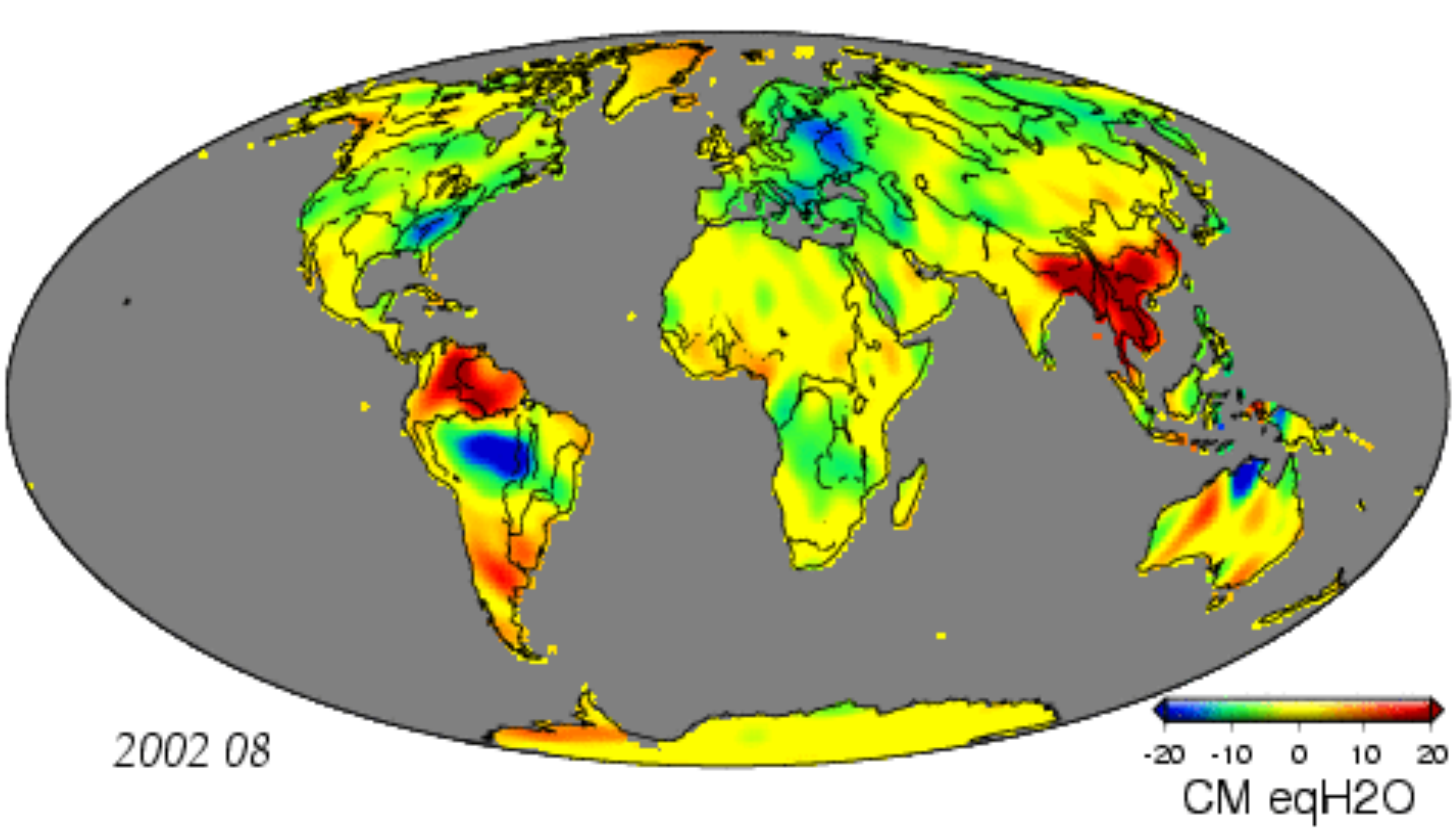
Amelung et al., 1999

Monitoring Small Changes



GRACE: Gravity Recovery And Climate Experiment
Spatial scales: > 150 km
Temporal scales: 1 day to 1 decade

Monitoring Small Changes

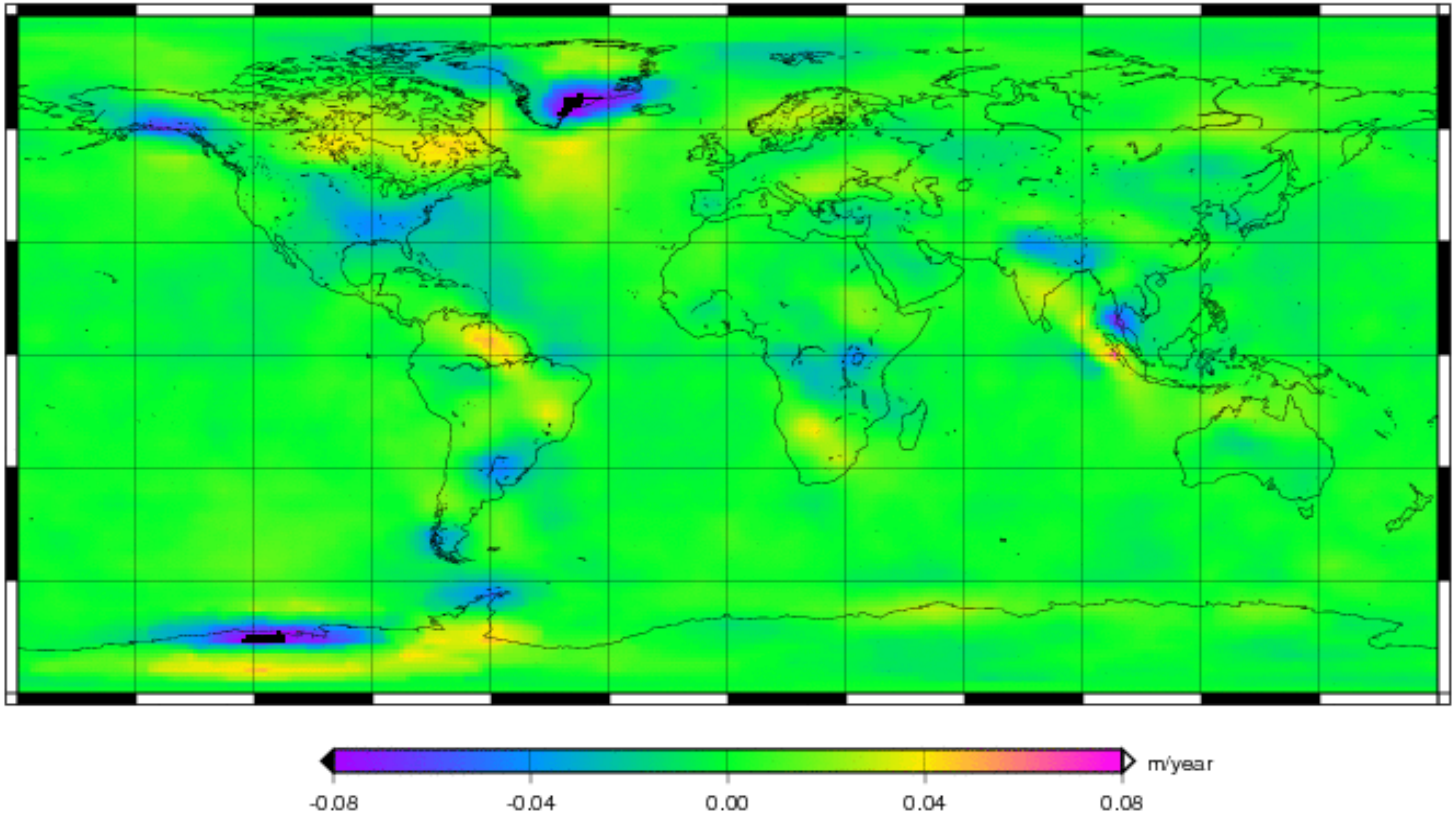


http://grace.jpl.nasa.gov/information/

Satellite Gravity Missions (GRACE)

Monitoring Small Changes

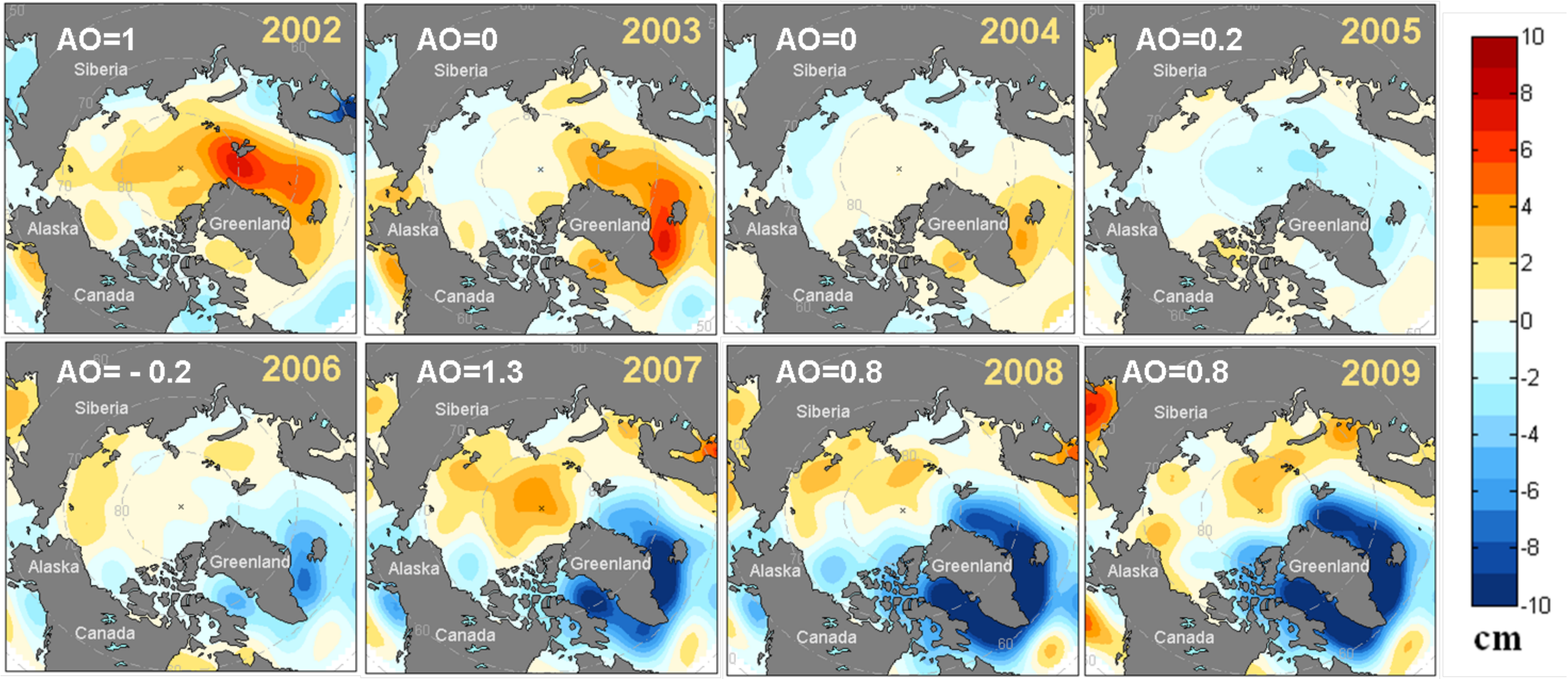
Hydrology: Secular trends in Land Water storage



JPL MASCON, secular trends 2003-2007, Watkins, 2008

GRACE Reveals Changes in Arctic Ocean Circulation Patterns

Variations in the Arctic Ocean circulation are associated with clockwise and counterclockwise shifts in the front between salty Atlantic-derived and less salty Pacific-derived upper ocean waters. Orientation of the front is climatically important because it impacts sea ice transport.



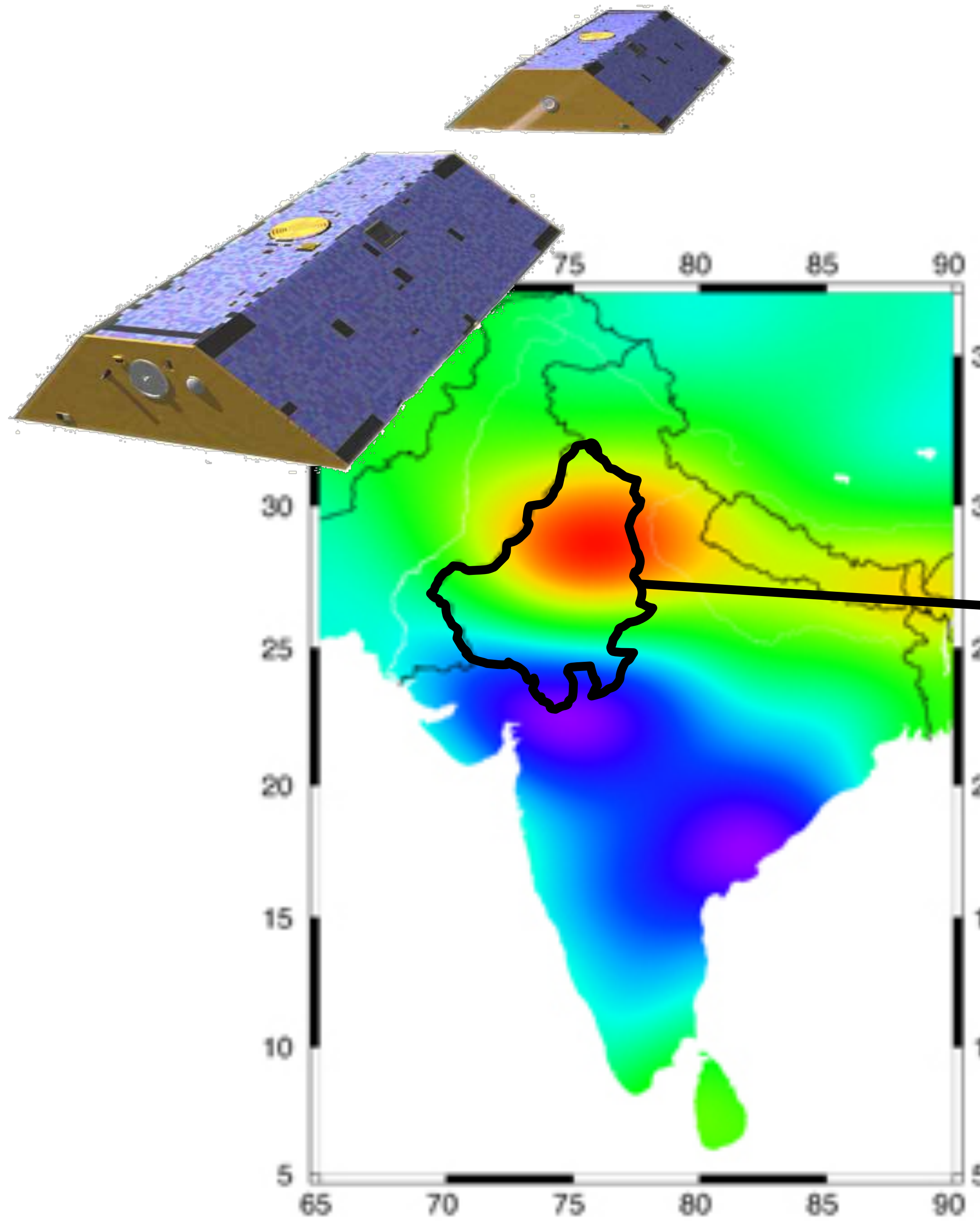
Morrison et al., *GRL*,2007

Monitoring Small Changes

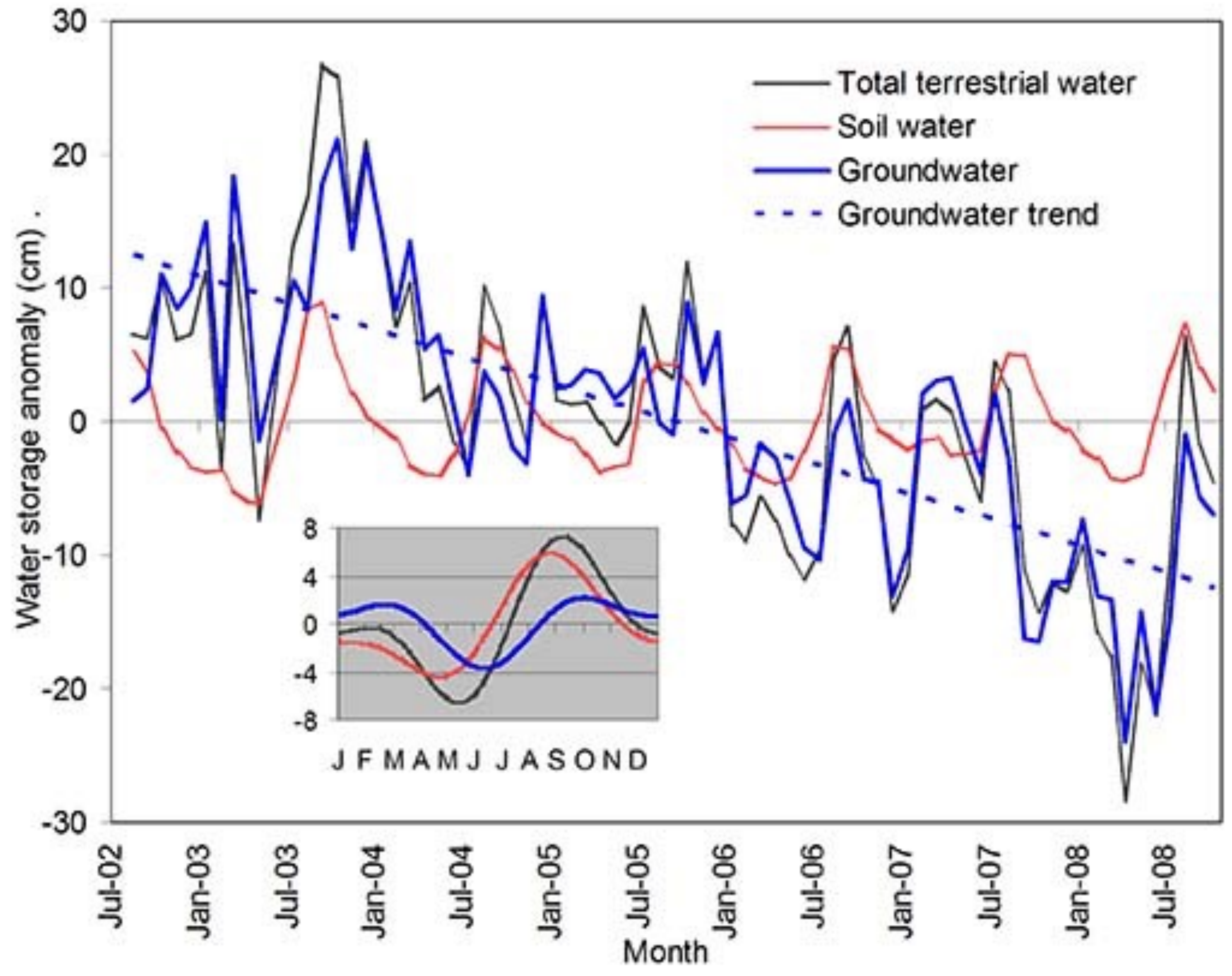
GRACE Quantifies Massive Depletion of Groundwater in NW India

The water table is declining at an average rate of 33 cm/yr

GRACE is unique among Earth observing missions in its ability to monitor variations in all water stored on land, down to the deepest aquifers.



Trends in groundwater storage during 2002-08, with increases in blue and decreases in red. The study region is outlined.



Time series of total water from GRACE, simulated soil water, and estimated groundwater, as equivalent layers of water (cm) averaged over the region. The mean rate of groundwater depletion is 4 cm/yr. Inset: Seasonal cycle.

During the study period, 2002-08, 109 km^3 of groundwater was lost from the states of Rajasthan, Punjab, and Haryana; triple the capacity of Lake Mead

Rodell, Velicogna, and Famiglietti, *Nature*, 2009

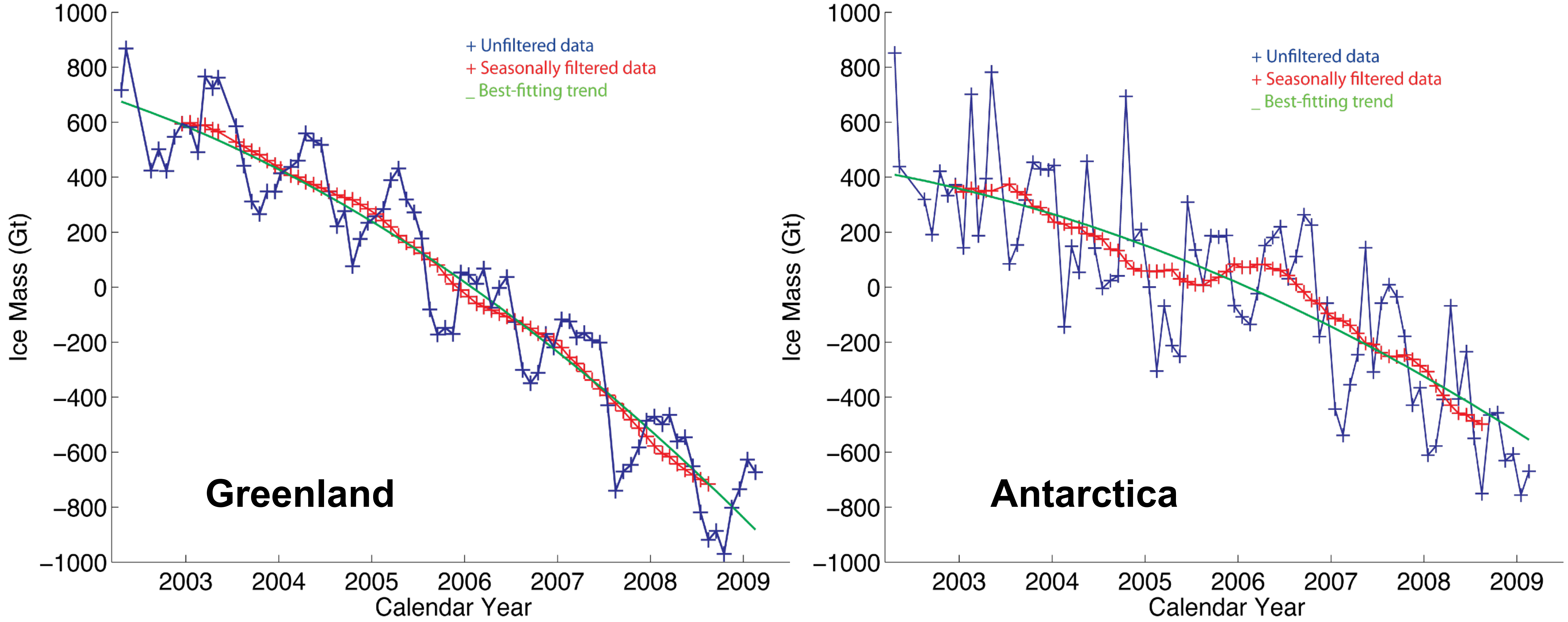
Monitoring Small Changes

GRACE Detects Accelerated Ice Mass Loss in Greenland and Antarctica

During the period of April 2002 to February 2009 the mass loss of the polar ice sheets was not constant but increased with time, implying that the ice sheets' contribution to sea level rise was increasing.

Greenland:
- mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- acceleration of -30 ± 11 Gt/yr^2 in 2002–2009.

Antarctica:
- mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009
- acceleration of -26 ± 14 Gt/yr^2 in 2002–2009.



Velicogna, *GRL*,2009