Ground Based Space Geodesy Networks Required to Improve the ITRF

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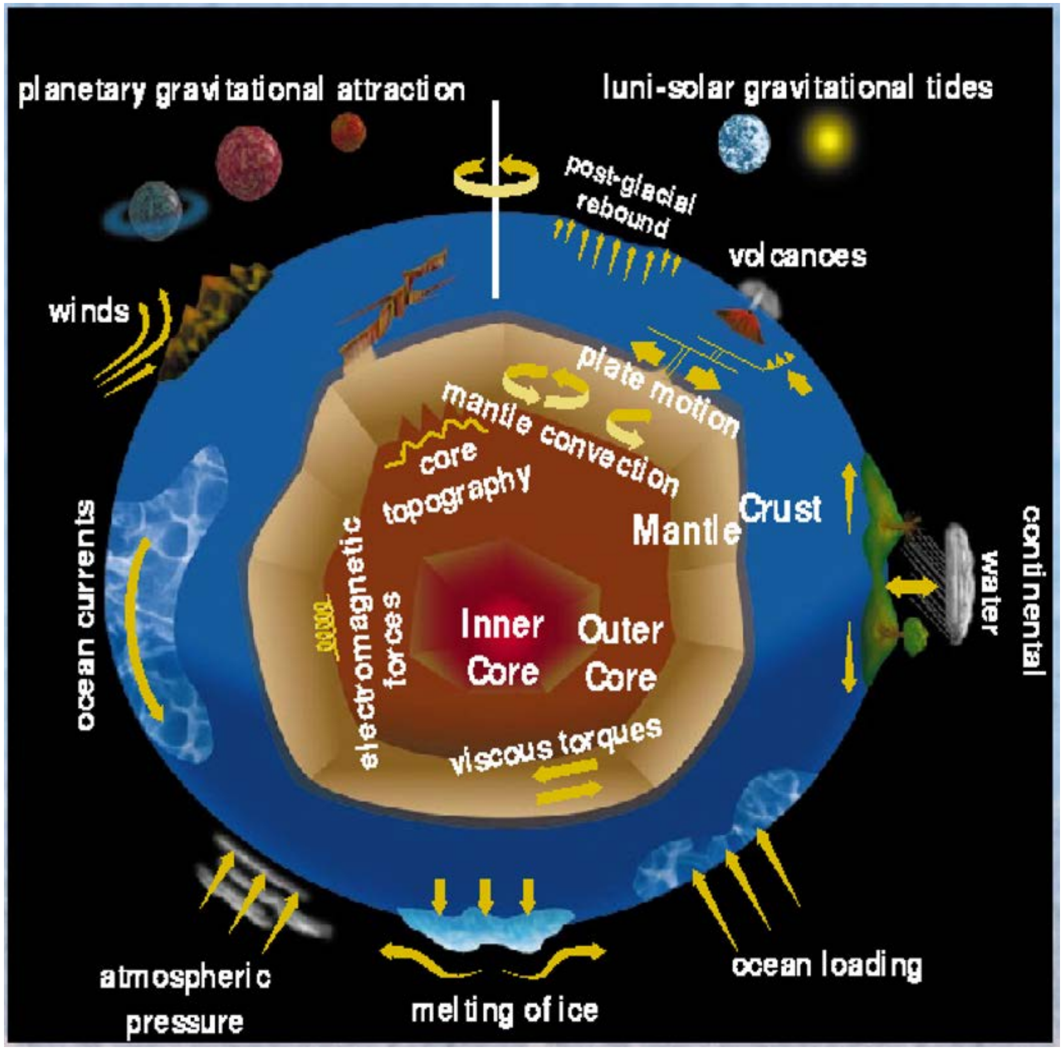
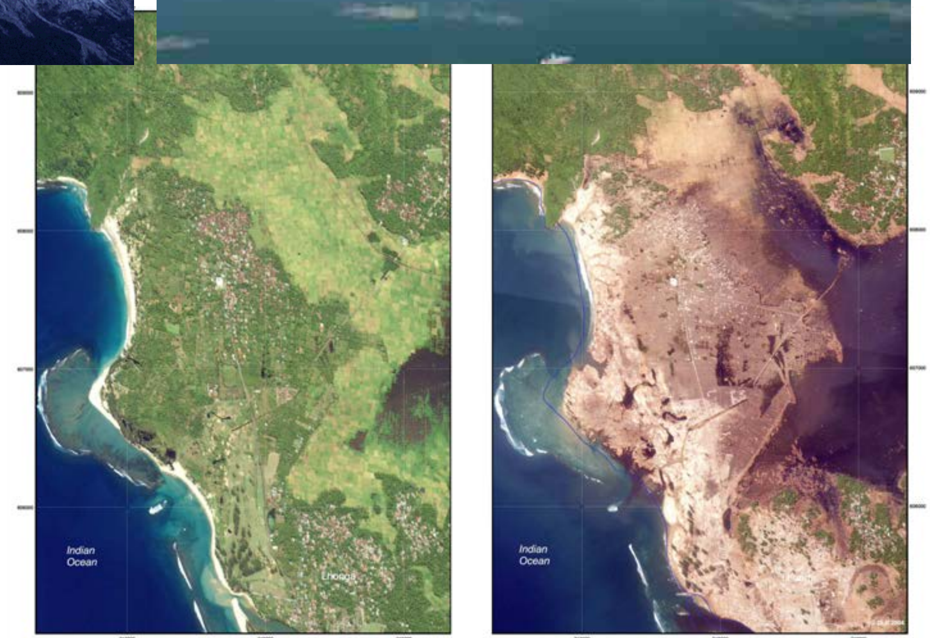
Some people think the Earth looks like this:

But really it looks like this:



Motivation: Monitoring the Earth System



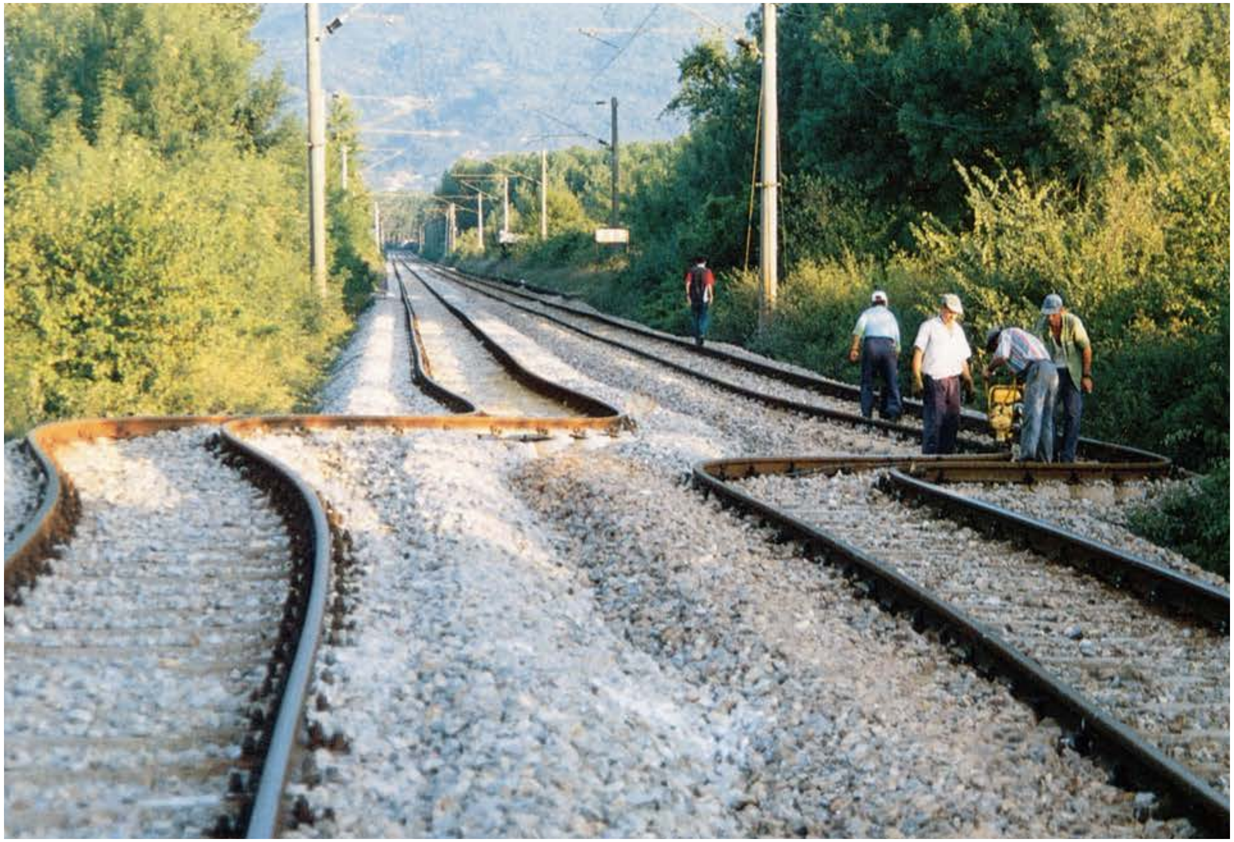
Pillar 1: Geometry and Deformation of the Earth

- Problem and fascination of measuring the Earth:

Everything is moving !

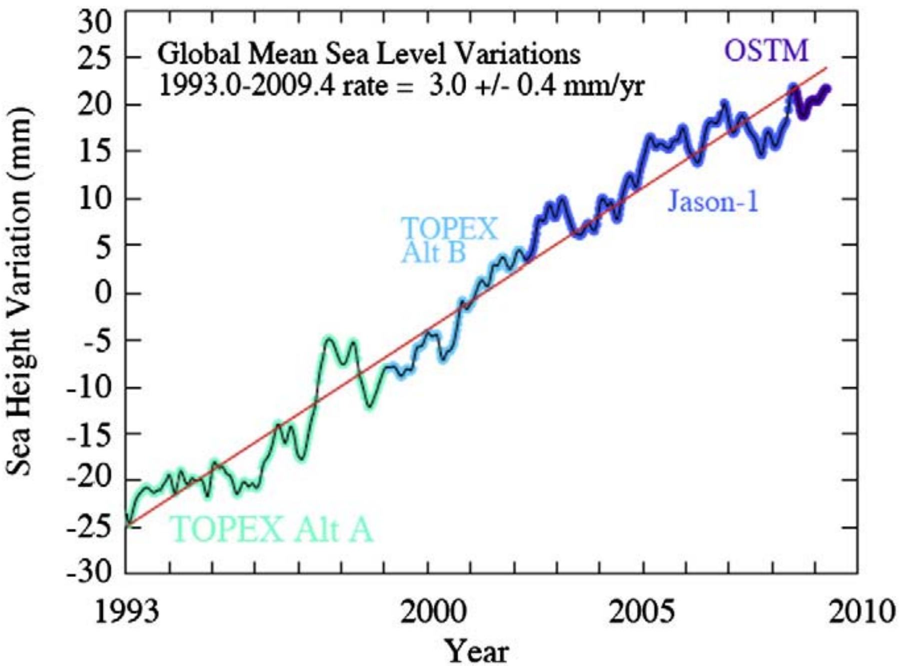
- Monitoring today mainly by GPS permanent networks

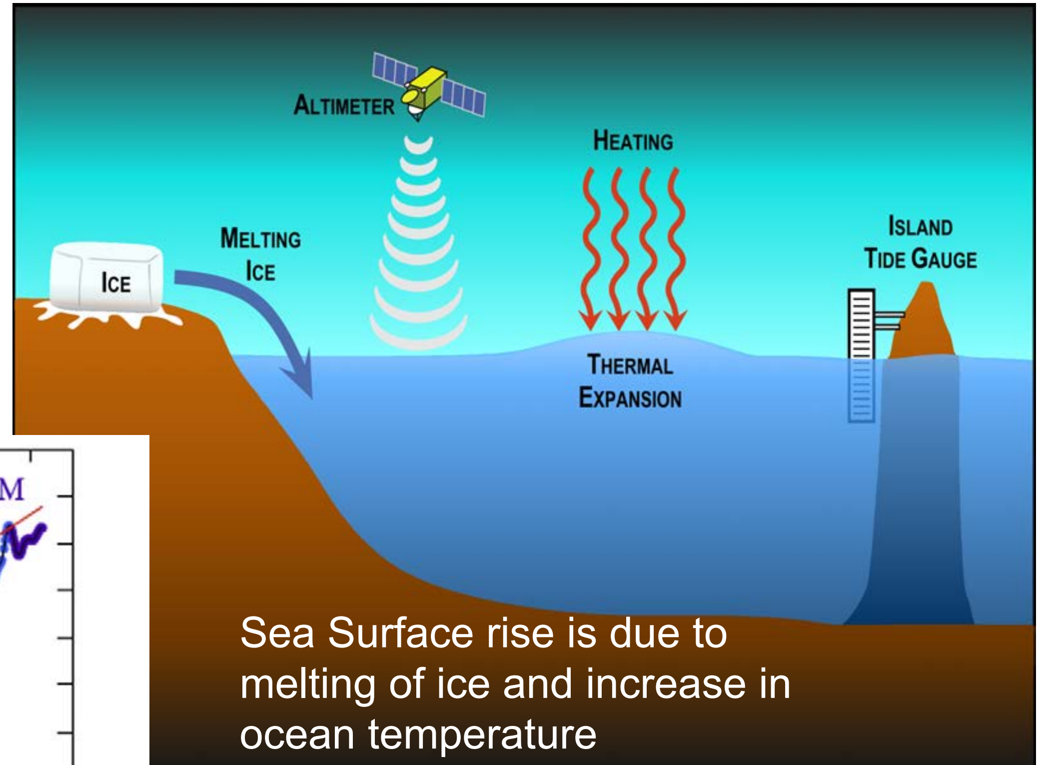
- Examples:
  - Plate motions
  - Solid Earth tides (caused by Sun and Moon)
  - Loading phenomena (ice, ocean, atmosph.)
  - Earthquakes …
- **Continuous monitoring is absolutely crucial**



Measure Sea Surface Height with Altimetry

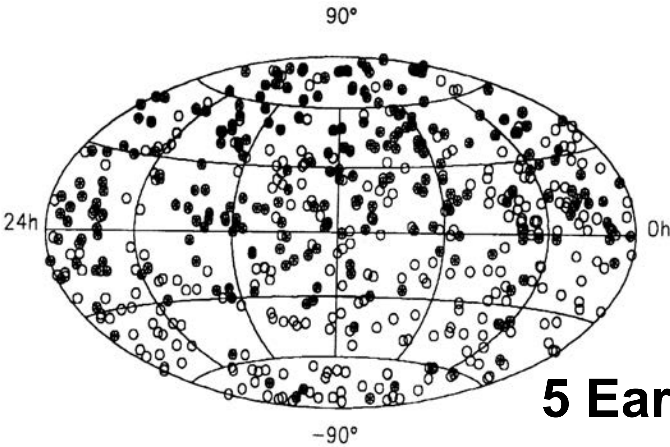
- What kinds of things effect Sea Level?
  - –Water Volume
  - –Water temperature
  - –Tides
  - –Currents
  - –Tsunamis
  - –Weather
  - –Coast Line. etc

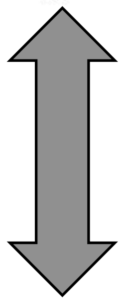


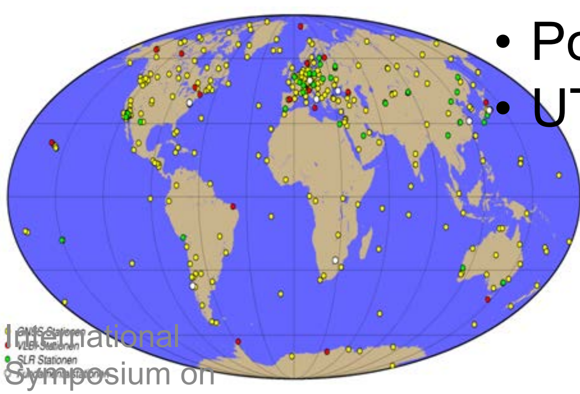


Source: Lemoine, F.G., et al. Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2. J. Adv. Space Res. (2010), doi:10.1016/j.asr.2010.05.007

GGOS and the EOP

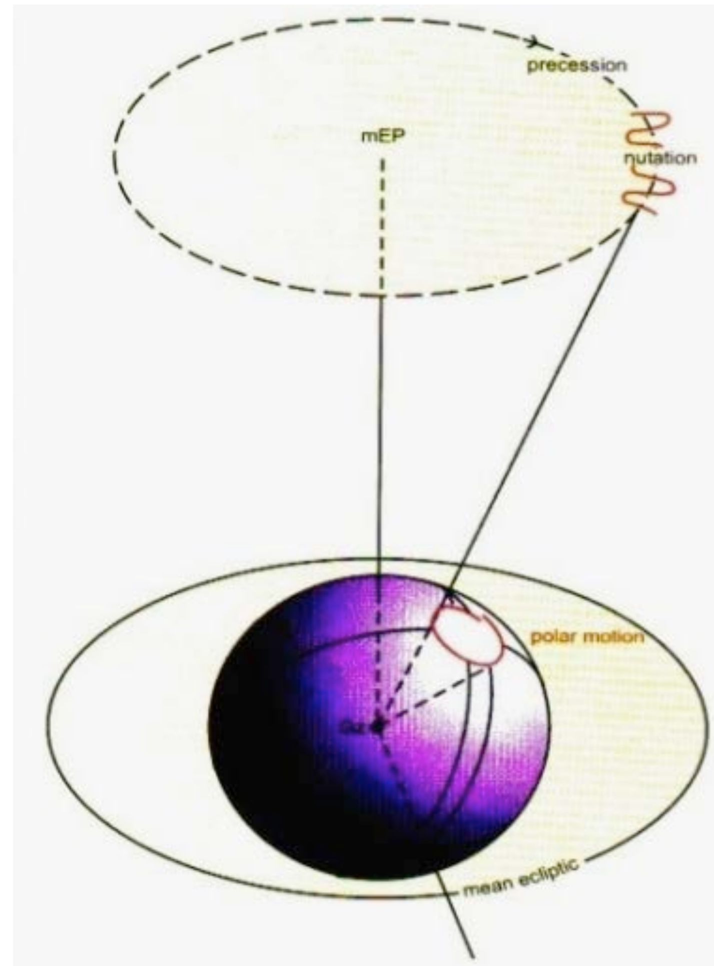




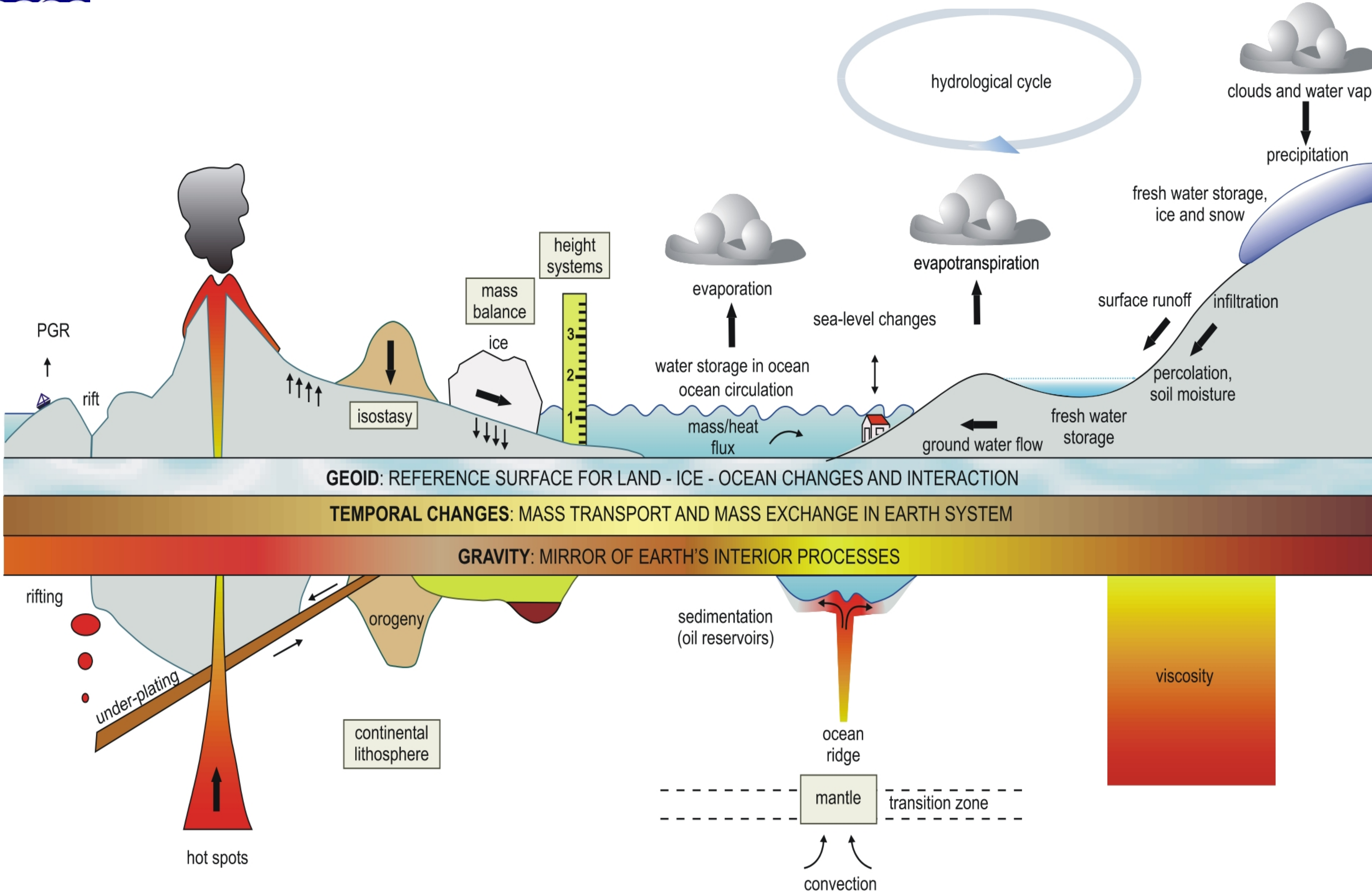


5 Earth orientation parameters (EOP) required for any positioning and navigation:

- Precession/nutation
- Polar motion
- UT1 - UTC (or lod)



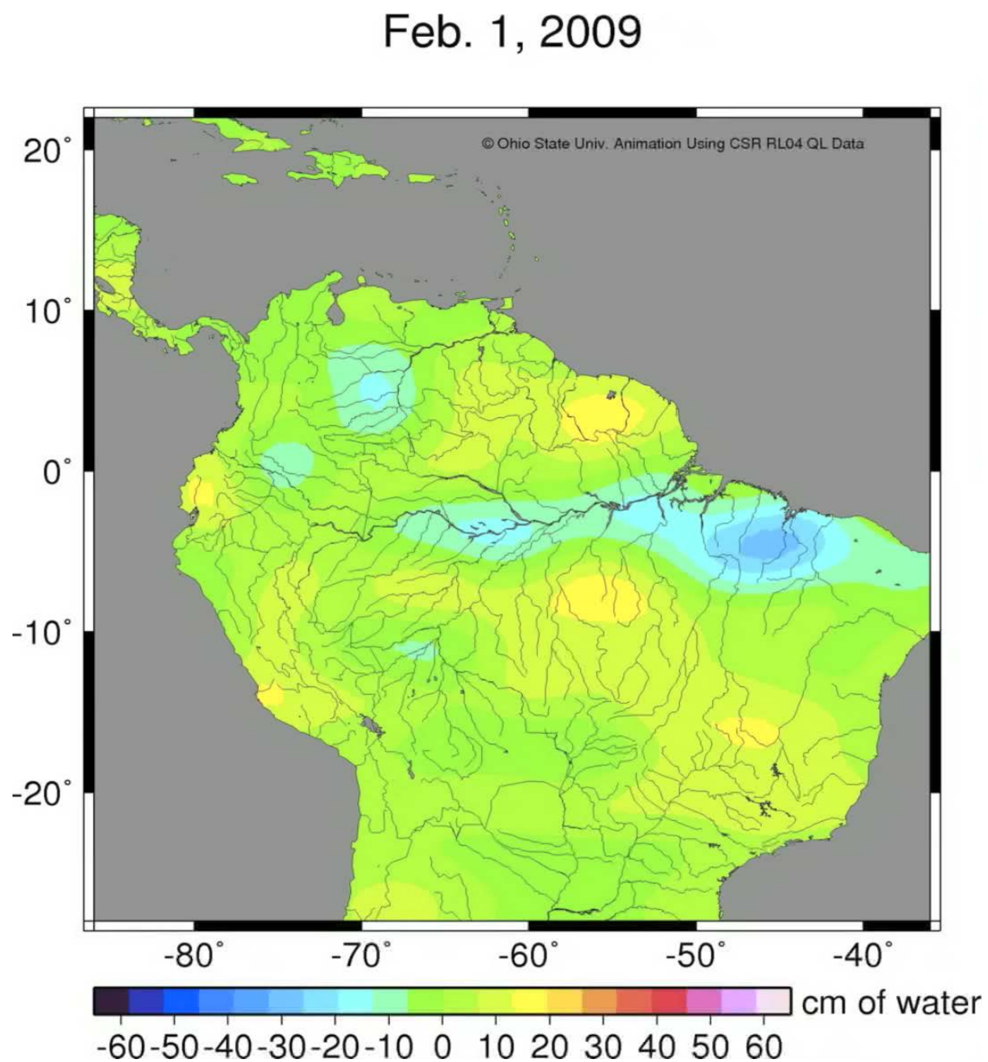
Pillar 3: Gravity Field, Mass Transport

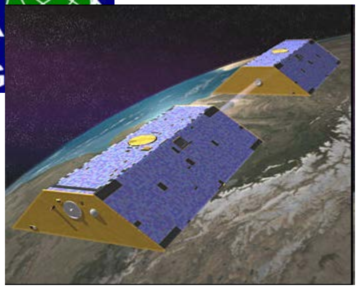


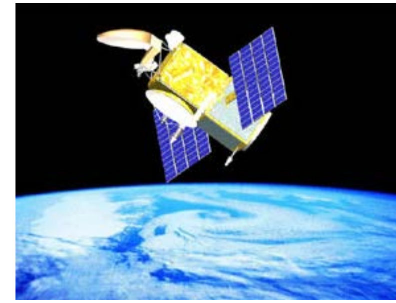
Ilk et al. (2005) Mass Transport and Mass Distribution in the Earth System, 2nd Edition, SPP1257 DFG

2009 Amazon Flooding

From Prof. C. K. Shum, OSU

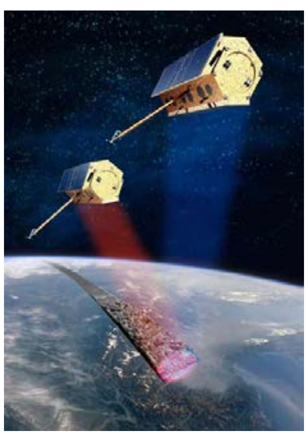


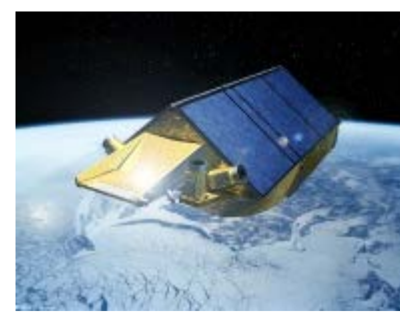


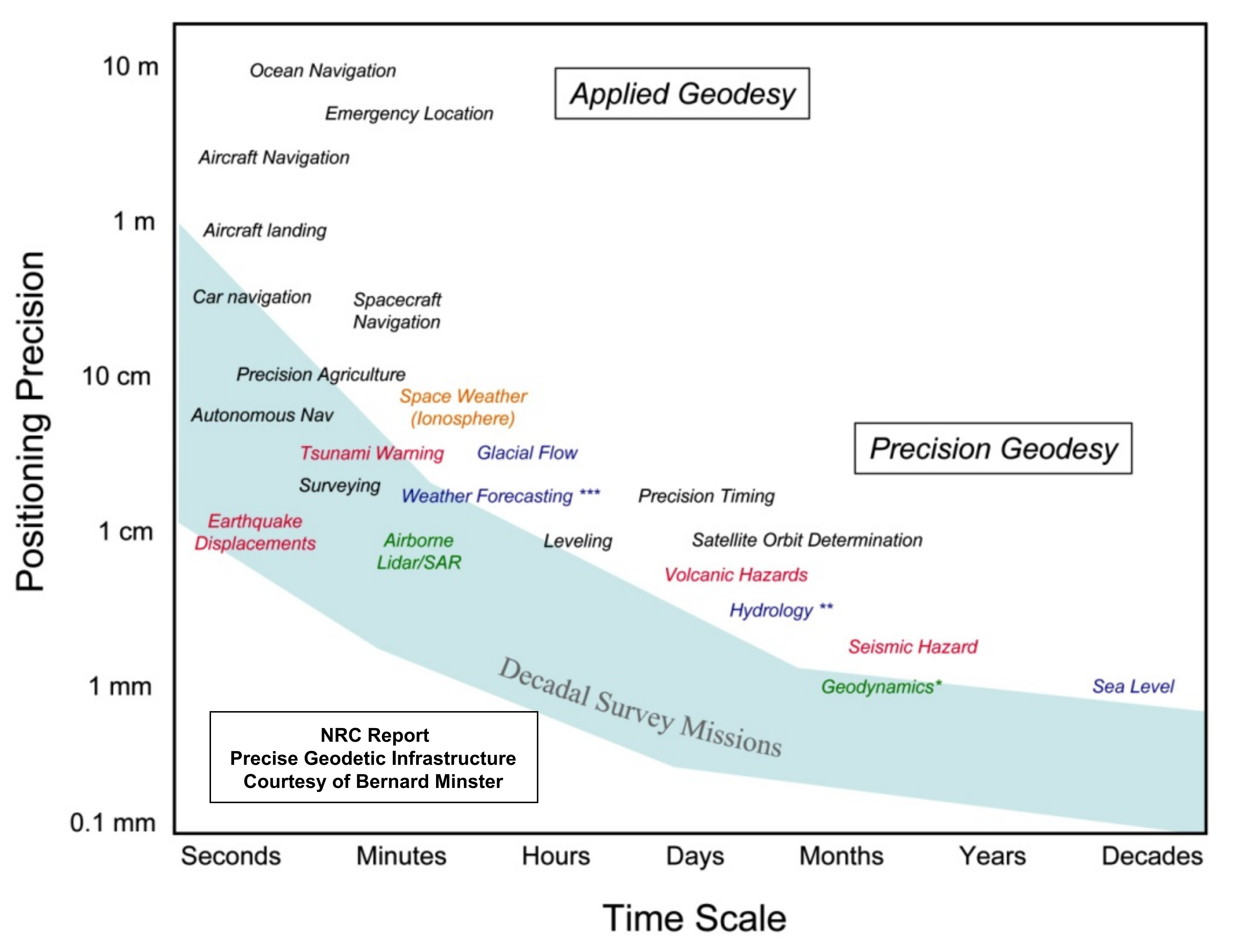


Common Thread:

- Reference Frame
- Precision Orbit Determination



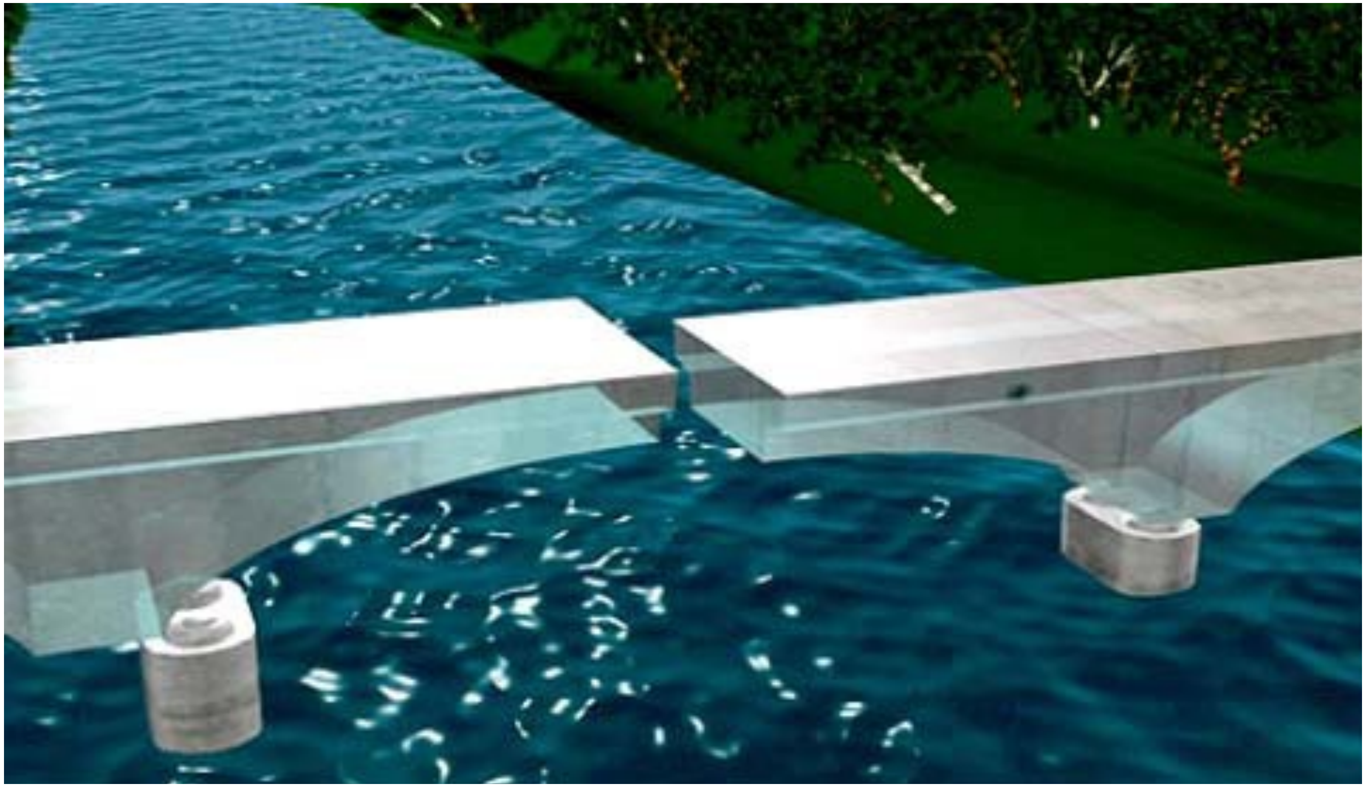




Courtesy of Bernard Minster

http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954

When National Reference Frames are not integrated!

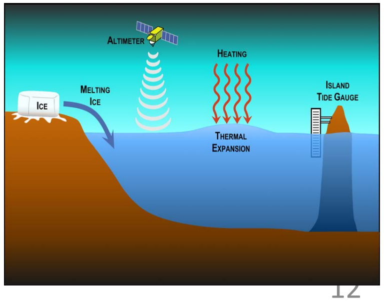


Design error at bridge construction in Laufenburg (2003): During the construction of the bridge across the Rhine river in Laufenburg, a control showed that a height difference of 54 centimeters exists between the bridge built from the Swiss side and the roadway of the German side. Reason of the error is the fact that the horizons of the German and Swiss side are based on different reference frames. Germany refers to the sea level of the North Sea, Switzerland to the Mediterranean.

Courtesy of Hermann Drewes/DGFI

International Terrestrial Reference Frame (ITRF)

- Provides the stable coordinate system that allows us to measure change (link measurements) over space, time and evolving technologies.
- An accurate, stable set of station positions and velocities.
- Foundation for virtually all space-based and ground-based metric observations of the Earth.
- Established and maintained by the global space geodetic networks.
- Network measurements must be precise, continuous, robust, reliable, and geographically distributed (worldwide).
- Network measurements interconnected by co-location of the different observing techniques at CORE SITES.



Global Geodetic Observing System (GGOS)

IAG Bylaws 1(d)

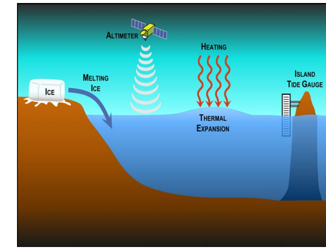
"*The Global Geodetic Observing System is an element of the IAG that works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research.*"

The vision of GGOS is

"*Advancing our understanding of the dynamic Earth system by quantifying our planet's changes in space and time.*"

Major Item: *Provide the infrastructure to maintain and improve the reference frame to meet future needs*

The International Terrestrial Reference Frame is established by the Global Space Geodesy Networks



Requirement (Source GGOS 2020):

<1 mm reference frame accuracy

< 0.1 mm/yr stability

– Measurement of sea level is the primary driver

– Improvement over current ITRF performance by a factor of 10-20.

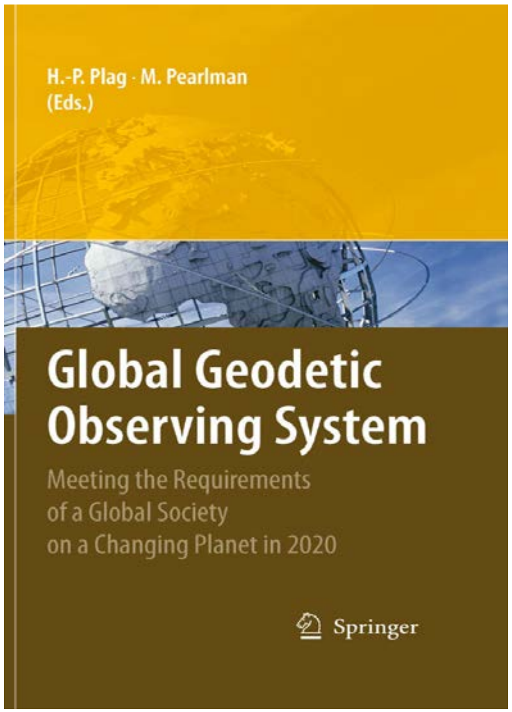
Means of providing the reference frame:

- Global Network of co-located VLBI/SLR/GNSS/DORIS CORE SITES;
- Dense network of GNSS ground stations to distribute the reference frame globally to the users

Requirement: Users anywhere on the Earth can position their measurements in the reference frame at any time

GGOS 2020 Book (2009)

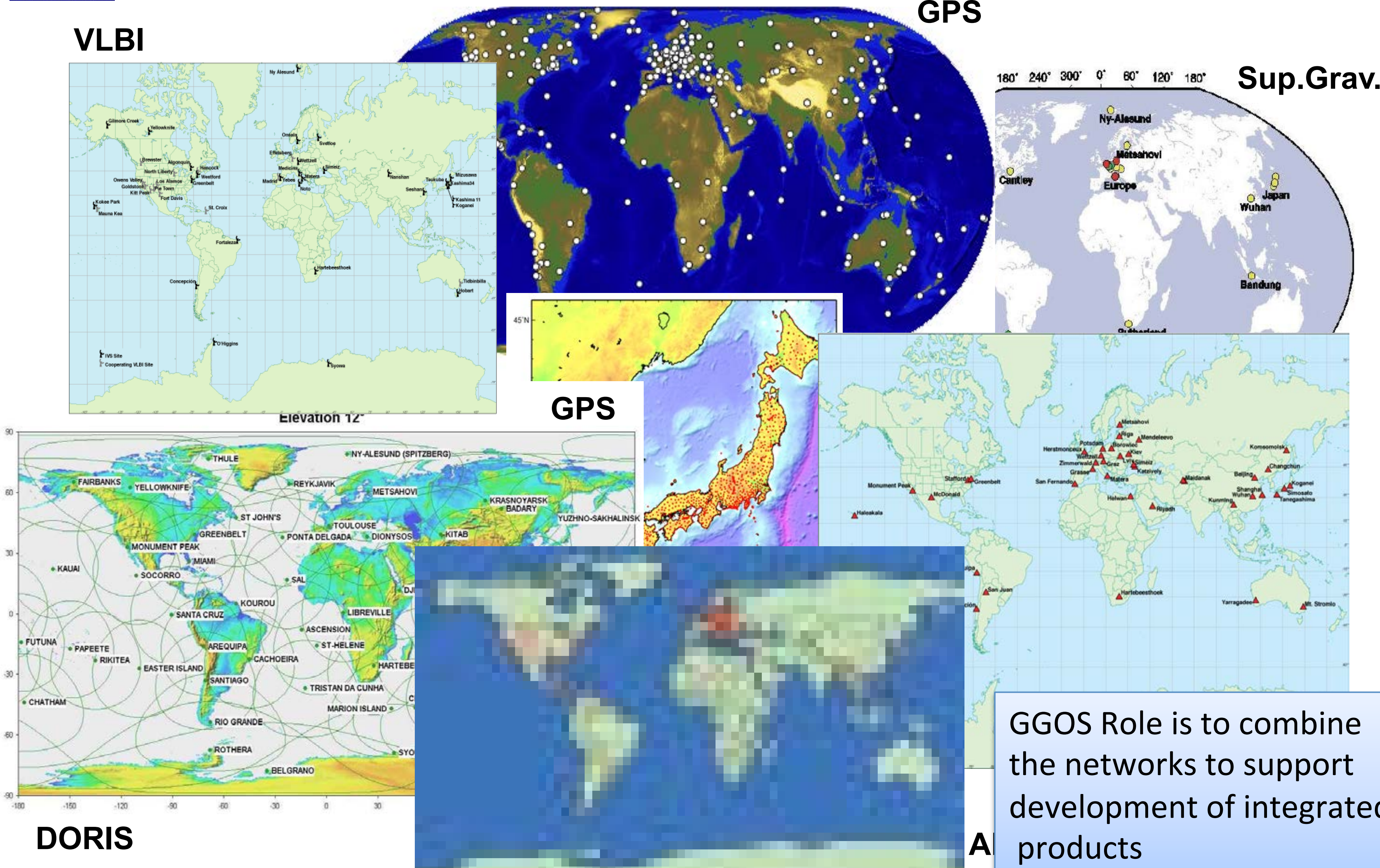
GGOS: Meeting the Requirements of a Global Society on a Changing Planet in 2020. Eds. H.-P. Plag and M. Pearlman. Springer 2009. p. 332



Content: main arguements for GGOS

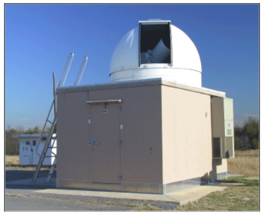
- Goals, achievements and tools of modern geodesy
- Earth science requirements for geodesy
- Maintaining a modern society (9 societal benefit areas)
- Future geodetic reference frames
- Future Global Geodetic Observing System (GGOS)
- GGOS 2020

GGOS: the Ground-Based Component



GGOS Role is to combine the networks to support development of integrated products

What is a Core Site?



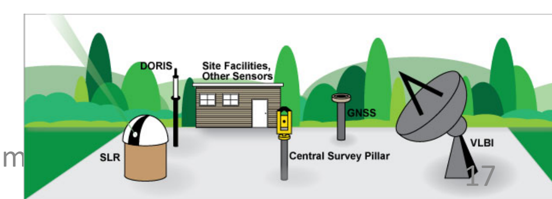
SLR

VLBI

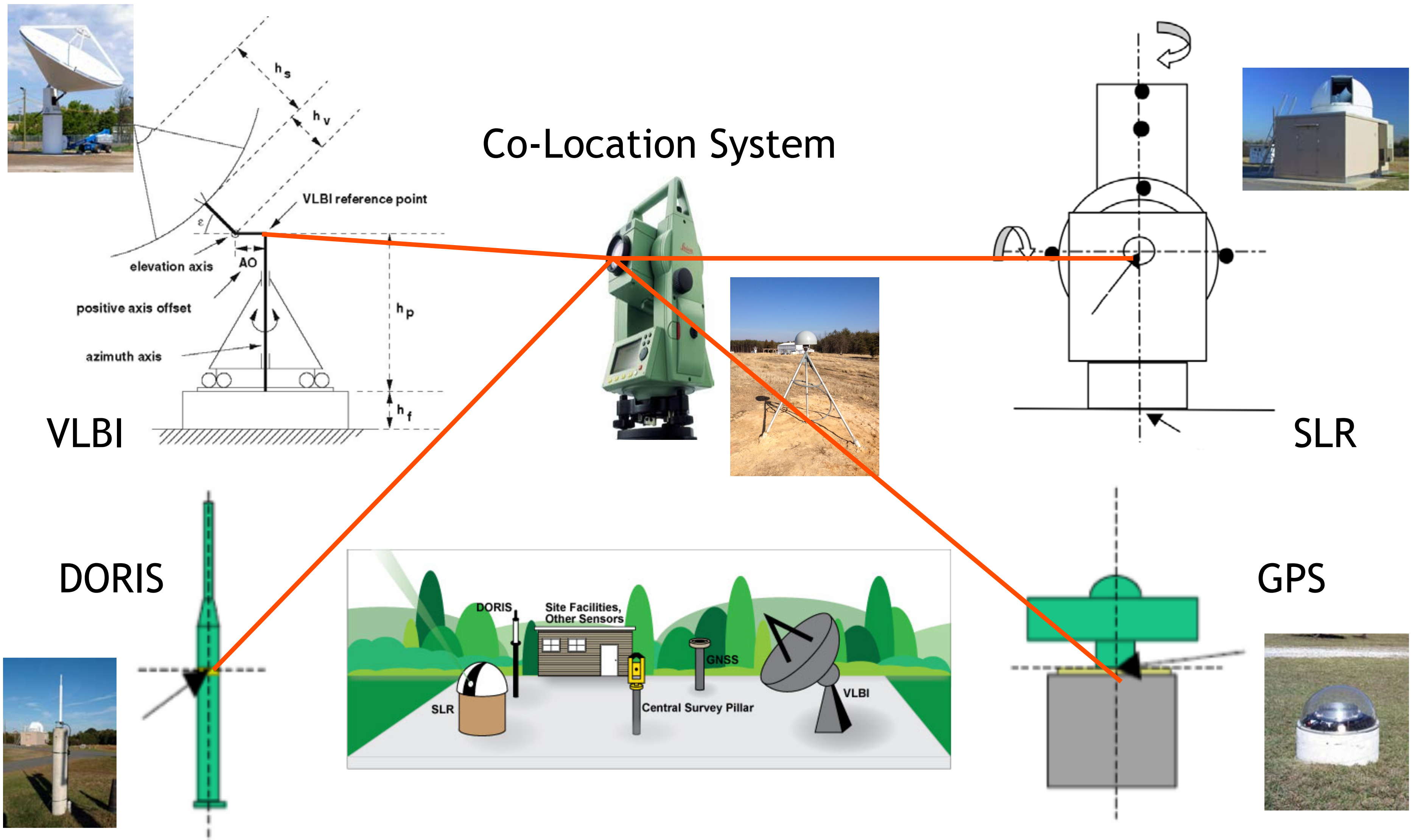
GNSS

DORIS

- A ground site with co-located SLR, VLBI, GNSS and DORIS (where available) so that their measurements can be related to sub-mm accuracy
- Why do we need multiple techniques?
  - Measurement requirements are very stringent
  - Each technique makes its measurements in a different way and therefore each measures something a little different:
    - Terrestrial (satellite) verses celestial (quasar) reference
    - Range verses range difference measurements
    - Broadcast up verses broadcast down
    - Radio verses optical
    - Active verses passive
    - Geographic coverage
  - Each technique has different strengths and weaknesses
  - The combination (Co-location) allows us to take advantage of the strengths and mitigate the weaknesses



Local Ground Survey is an Essential Part of Co-location



Example Core Site

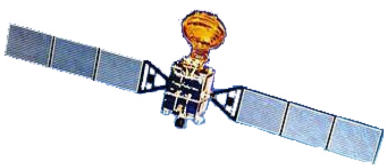
NASA Goddard Space Flight Center, Greenbelt MD, USA

- Goddard Geophysical and Astronomical Observatory (GGAO) has four Co-located techniques on site:

  SLR, VLBI, GPS, DORIS

Concepcion, Chile

Co-location in Space

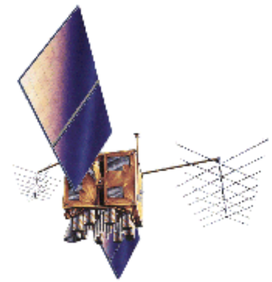


Compass

GNSS/SLR

GLONASS

GNSS/SLR

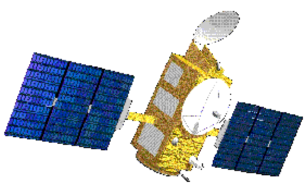


GPS

GNSS/SLR

GIOVE/Galileo

GNSS/SLR

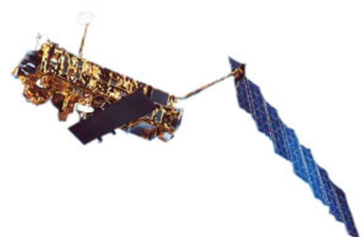


Jason

DORIS/GNSS/SLR

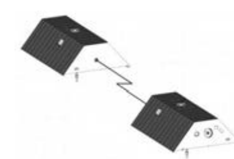
CHAMP

GNSS/SLR



Envisat

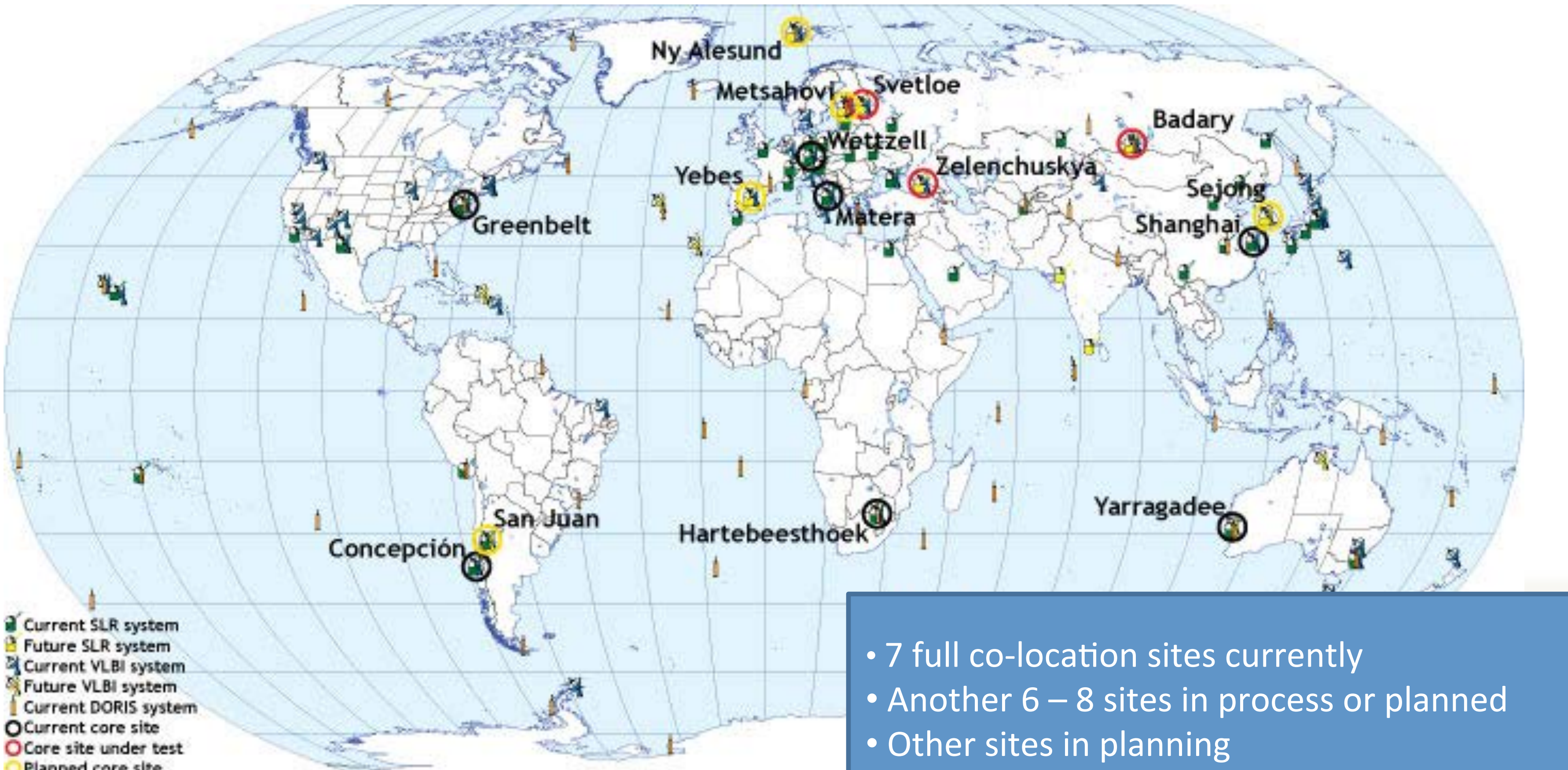
DORIS/SLR



GRACE

GNSS/SLR

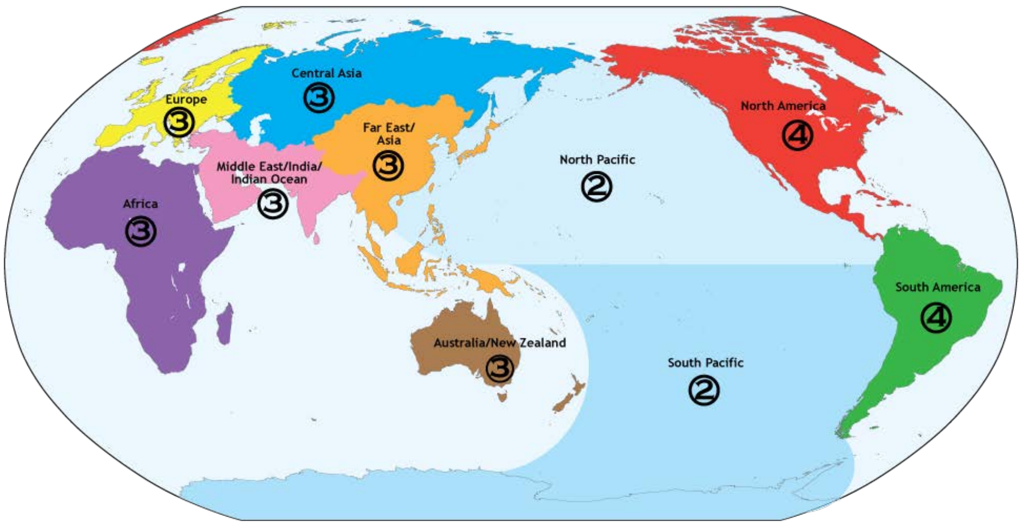
Co-located VLBI, SLR, GNSS
(Some with DORIS)



- 7 full co-location sites currently
- Another 6 – 8 sites in process or planned
- Other sites in planning
- Many regional voids in the network
- Most sites have older less reliable technology

Simulation Studies to Scope the Network
(impact on the Reference Frame)
(Erricos Pavlis)

- Simulations completed
  - ~30 globally distributed, well positioned, co-location Core Sites with modern technology and proper conditions;
  - 16 of these Core Sites must track GNSS satellites with SLR to calibrate the GNSS orbits;
- Simulations underway
  - Sensitivity to intersystem vector accuracy
  - Phased deployment; evolution of the products
  - Impact of errors and outages;
  - Additional space objects
  - Tracking scenarios



GGOS Site Requirements Document

(http://cddis.gsfc.nasa.gov/docs/GGOS_SiteReqDoc.pdf)

Global Geodetic Observing System (GGOS)

Site Requirements
for
GGOS Core Sites

August 1, 2011

Contributors:

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Curtis Emerson	NASA GSFC

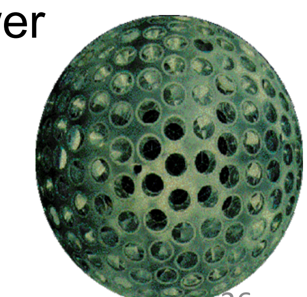
- Introduction and Justification
  - What is a Fundamental Station?
  - Why do we need the Reference Frame?
  - Why do we need a global network?
  - What is the current situation?
  - What do we need?
- Site Conditions
  - Global consideration for the location
  - Geology
  - Site area
  - Weather and sky conditions
  - Radio frequency and optical Interference
  - Horizon conditions
  - Air traffic and aircraft Protection
  - Communications
  - Land ownership
  - Local ground geodetic networks
  - Site Accessibility
  - Local infrastructure and accmmodations
  - Electric power
  - Site security and safety
  - Local commitment

Technology

- The Ground-based Techniques are making progress
- Path Forward on the Technology is pretty much known
- Improvements are being made in the Space Segment

Next Generation
Satellite Laser Ranging System
Basis for the Next Generation System

- Higher pulse repetition rate (KHz) for faster data acquisition;
- Smaller, faster slewing telescope for more rapid target acquisition and pass interleaving;
- Range from LEO to GNSS;
- More accurate pointing for link efficiency;
- Narrower laser pulse width for greater precision;
- Single photon detection for greater accuracy;
- More automation for economy (24/7);
- Greater temporal and spatial filtering for improved signal to noise conditions;
- Modular construction and more off the shelf components for lower fabrication/operations/maintenance cost;



Next Generation VLBI 2010
(Developed within the International VLBI Service (IVS))

- Smaller, faster antennas (~12m) for more rapid target acquisition;
- Unattended operation for expanded temporal coverage;
- Broad continuous frequency range (~2-12 GHz) using multiple bands – smaller observation error;
- Selectable frequency bands RFI avoidance and better accommodation with legacy (S/X) systems;
- Higher speed recording (8 Gbps), for increased sensitivity increased sensitivity – Mark 5C recorder;
- Transfer data with combination of high speed networks and high rate disk systems;
- Standardization and commercial off-the-shelf availability of many parts for lower operating and replicating costs;
- Improved group delay to support ~1 mm position determination;
- Possible use of phase delay for even better precision

Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)

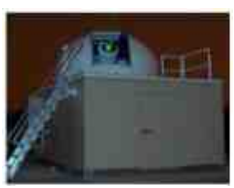
- Global network of ~57 stations.
- DORIS receivers are used on altimeter (TOPEX, Jason1, Jason2, ENVISAT, Cryosat-2) and remote sensing (SPOT) satellites; Future Missions: Jason-3, SWOT & SENTINEL-3.

New Generation GNSS Receiver

- Multi-constellation receiver (GPS, Galileo, GLONAS, COMPASS, etc)
- Installed with deep-drilled brace monuments;
- Registered for the IGS

NASA Space Geodesy Project

- New initiative started at the end of FY11
- Goddard/JPL partnership with participation from Smithsonian Astrophysical Observatory and the University of Maryland.
- The Goddard Geophysical and Astronomical Observatory is one of the current Core Sites (with all four geodetic techniques co-located).
- Goals:
  - Establish and operate a prototype next generation space geodetic site with integrated next generation SLR, VLBI, GNSS (and DORIS) systems, along with a system that provides for accurate vector ties between them.
  - Develop a Project Implementation Plan for the construction, deployment and operation of a NASA network of similar next generation stations that will become the core of a larger global network of modern space geodetic stations.

VLBI	NGSLR	GNSS	DORIS	Vector Tie
				

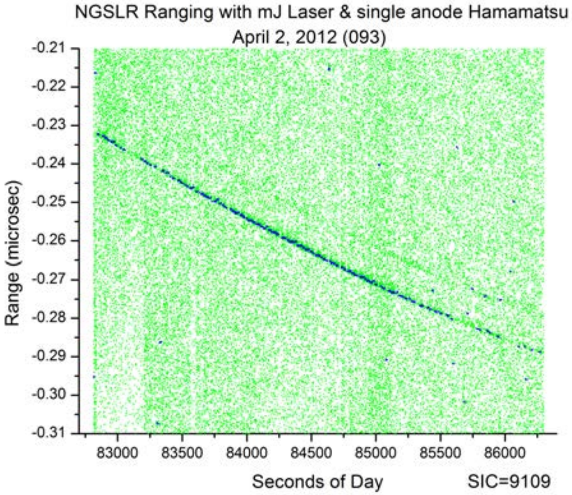
VLBI 2010 Status

- 12m antenna implemented at GSFC with the full VLBI2010 signal chain;
- Demonstrated 5 deg per sec azimuth slew rate
- Demonstrated 60% aperture efficiency
- The Westford 18m implemented with the same electronics but a prototype feed;
- Demonstrated broadband (8 Gbps) data collection and 4 ps group delay on the Haystack-GSFC baseline
- Six hours of geodetic data taken at 3.2, 5.2, and 9.2 Ghz; all bands produced good observations

NASA's Next Generation
Satellite Laser Ranging System (NGSLR)

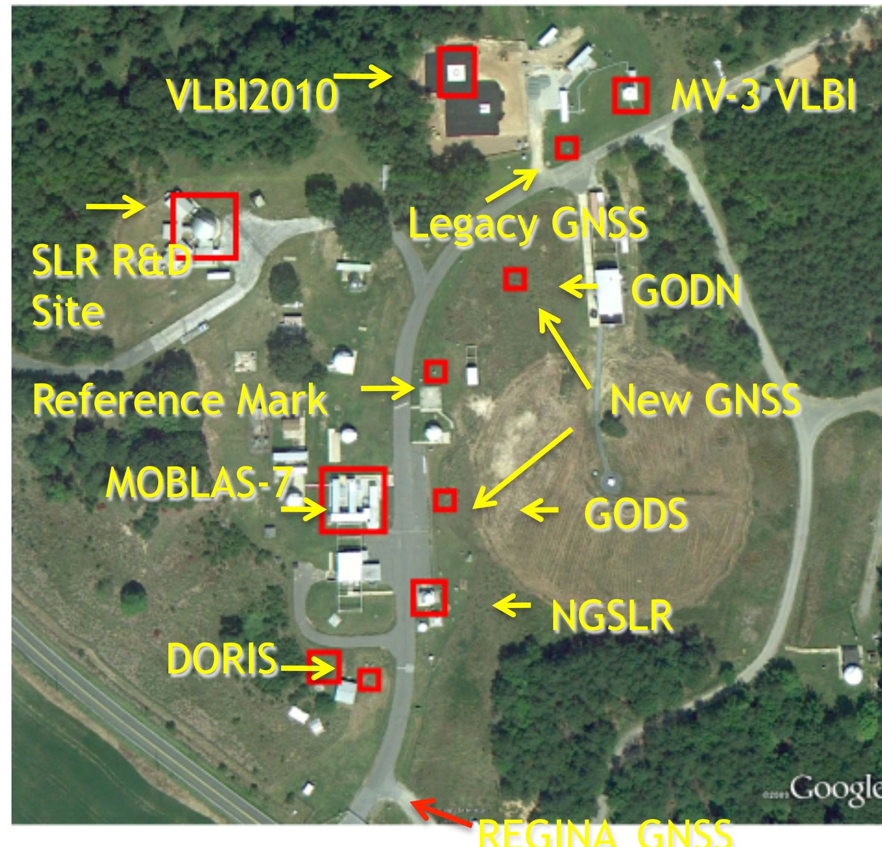
- High repetition rate (2 Khz) laser
- 1 to 2 arcsec pointing/tracking accuracy
- Day and Night-time operation
- Operating on full range of satellites
  (LEO to GNSS)
- Preliminary inter-comparison testing with legacy system shows good stability.
- Still lots to do

Daylight Ranging to GNSS



GNSS Installation at GSFC

- Pair of multi-constellation GNSS (GPS, GLONASS, Galileo) receivers (GODN and GODS) installed with deep-drilled brace monuments; data collecting since January 2012

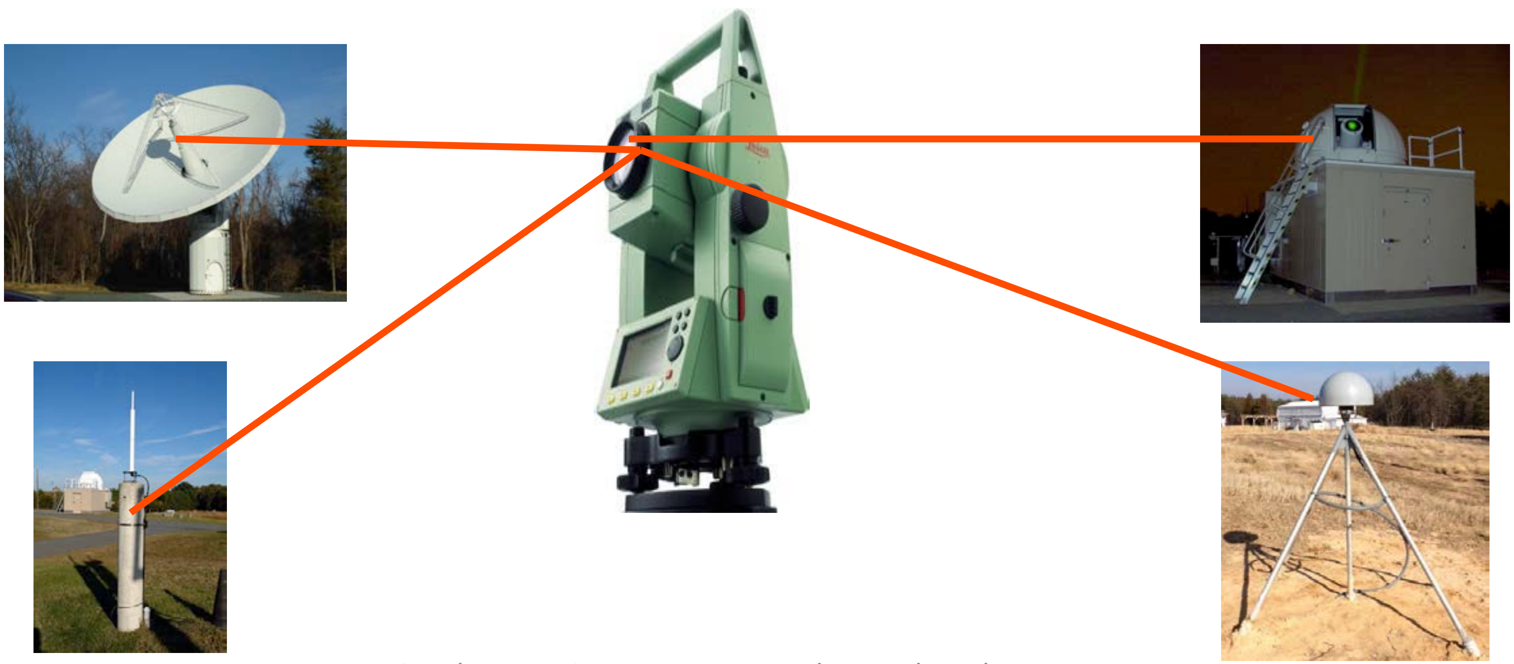


- De-meaned time series of baseline show standard deviation of 0.5 mm East, 0.7 mm North, and 2.7 mm up;
- Existing GPS (GODE) and GPS +GLONASS (GODZ) receivers to remain operational

Major Challenge

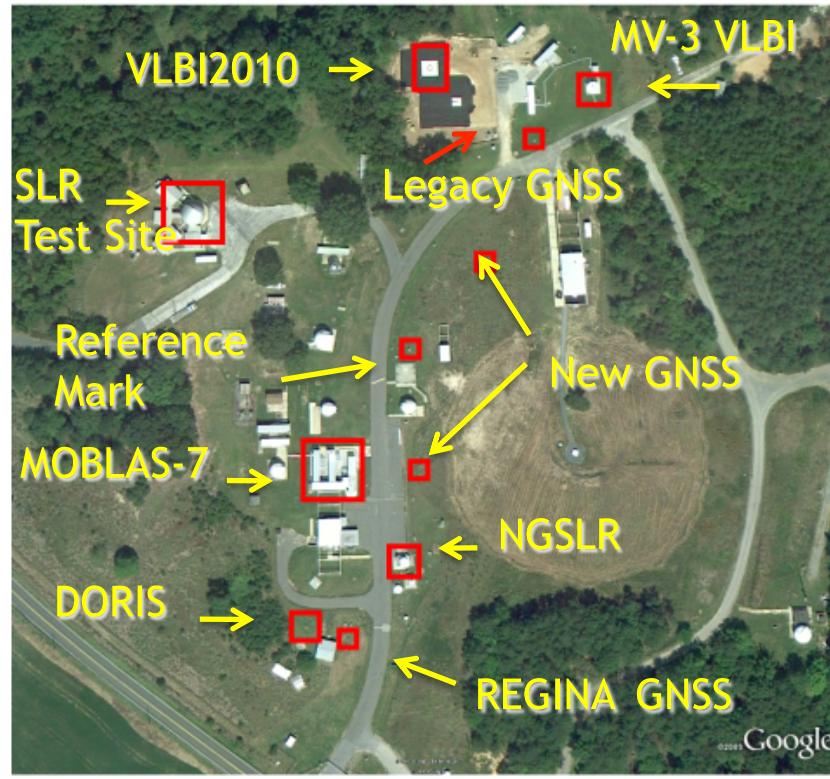
Co-location Intersystem Vectors

- Automated measurement of inter-instrument vectors is an essential aspect of an integrated space geodesy station.
- Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.
- Tests of technologies and currently available systems underway at GGAO.
- <u>BIG CHALLENGE: How do we extrapolate measurements to the "electronic or optical" reference point on each instrument?</u>



Space Geodesy Project Approach to RFI

- Modeling the GGAO environment and VLBI2010 susceptibility before & after tree removal
- Measuring the DORIS Beacon, and the NGSLR radars in South, radar masks & DORIS path loss provide mitigation
- Measuring 12m side lobes with a standard gain horn simulator ≥100m away
- Mitigate RFI with masks, filtering, and shielding



Lots of Instruments on the Site

NASA SGP Project Status Summary

- Simulation studies have scoped the size of the full international network required;
- Site Requirements Document is on line;
- Prototype station is currently on-budget and on-schedule for a July 2013 completion;
- An implementation plan is currently being developed to upgrade the current NASA sites and establish new sites with our international partners;
- Evaluate current NASA Sites as candidate Core Sites;
  - Current year: GSFC, Monument Peak, Mt. Haleakala, Kokee Park, McDonald, Gilmore Creek, Arequipa, Yarragadee, Hartebeesthoek, Tahiti, Fortaleza
- On-going discussions with existing and potential international partners, including Brazil, Columbia, Norway, South Africa, Australia, and France.
- If additional systems are built, they could be deployed as a full station or perhaps as a system contribution in a partnership.

GGOS Call for Participation;
The Global Geodetic Core Network:
Foundation for Monitoring the Earth System

We seek proposals from organizations that would participate in the development, implementation and maintenance of the GGOS Global Geodetic Core Network.

- **To implement and operate core space geodesy stations including:**
  - **existing stations that already have the four techniques implemented and plan for upgrade to the next generation systems;**
  - **existing stations that have one or more techniques operational, are planning for upgrade to the next generation systems and for the implementation of the remaining techniques;**
- **To support the network design and planning activity with analysis, simulations, site research (geology, weather, logistics, personnel, etc). To help design and develop the inter-technique vector systems and operational procedures.**
- **To provide applicable space geodetic instruments for implementation at a GGOS Global Geodetic Core Site in cooperation with a local organization.**
- **To implement and operate core stations offered by others;**
- **Call for Participation has been issued through the Services and the IAG.**

GGOS Call for Participation; The Global Geodetic Core Network: Foundation for Monitoring the Earth System

- 15 Submissions covering 36 sites
- Submissions;
  - Legacy Core Sites
  - Legacy/New Technology Technique Sites
  - Core and Technique Sites being developed
  - Sites offered
- Summary to be posted on the GGOS Website
- Other Groups being approached.

GGOS today

Motivation (GGOS ToR)

"We live on a dynamic planet in constant motion that requires long-term continuous quantification of its changes in a truly stable frame of reference."

The mission of GGOS is:

To provide the observations needed to monitor, map and understand changes in the Earth's shape, rotation and mass distribution.

To provide the global frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.

To benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

GGOS today

The goals of GGOS are:

1. To be the primary source for all global geodetic information and expertise serving society and Earth system science.

2. To actively promote the sustainment, improvement and evolution of the global geodetic infrastructure needed to meet Earth science and societal requirements.

3. To coordinate with the international geodetic services that are the main source of key parameters needed to realize a stable global frame of reference and to observe and study changes in the dynamic Earth system.

4. To communicate and advocate the benefits of GGOS to user communities, policy makers, funding organizations, and society.