Ground Based Space Geodesy Networks Required to Improve the ITRF

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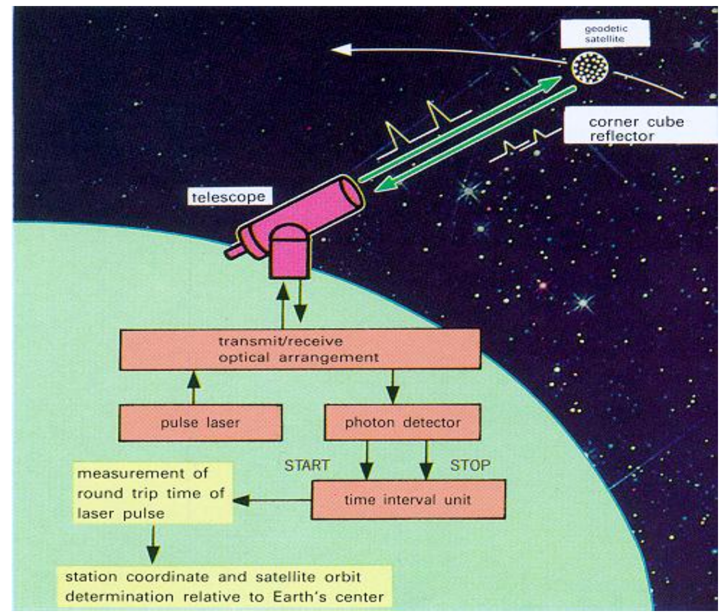
Workshop on Satellite, Lunar, and Planetary Laser Ranging:
Characterizing the Space Segment
Frascati, Italy
November 5 - 9, 2012

Satellite Laser Ranging Technique

Precise range measurement between an SLR ground station and a retroreflector-equipped satellite using ultrashort laser pulses corrected for refraction, satellite center of mass, and the internal delay of the ranging machine.

- Simple range measurement
- Space segment is passive
- Simple refraction model
- Night / Day Operation
- Near real-time global data availability
- Satellite altitudes from 400 km to synchronous satellites, and the Moon
- Cm satellite Orbit Accuracy
- Able to see small changes by looking at long time series



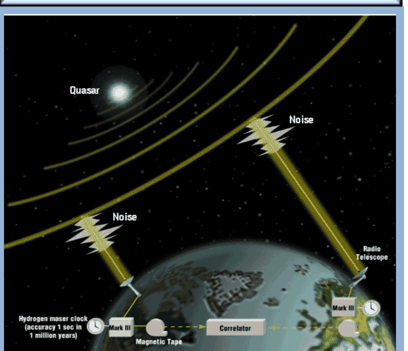
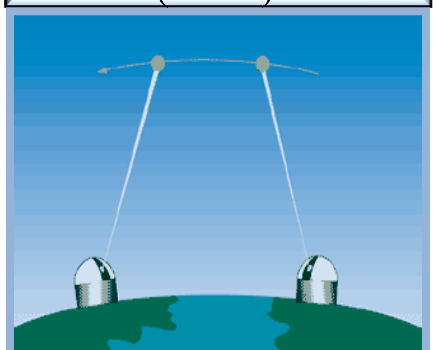
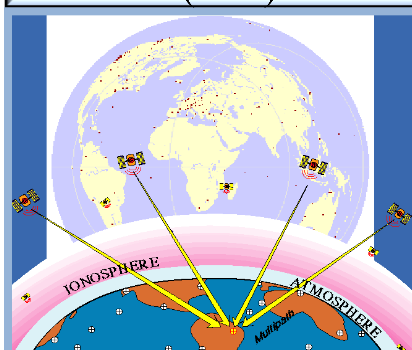
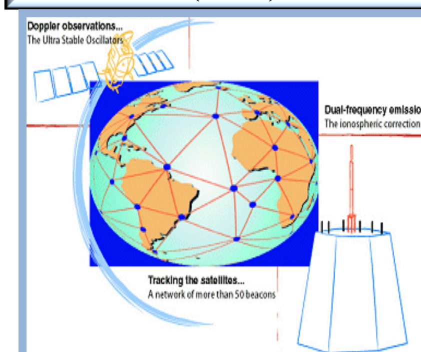
- Only Space Geodesy Technique that measures range directly
- Unambiguous centimeter accuracy orbits
- Long-term stable time series

Space Geodetic Techniques / products (1)

International Terrestrial Reference Frame (ITRFxx)

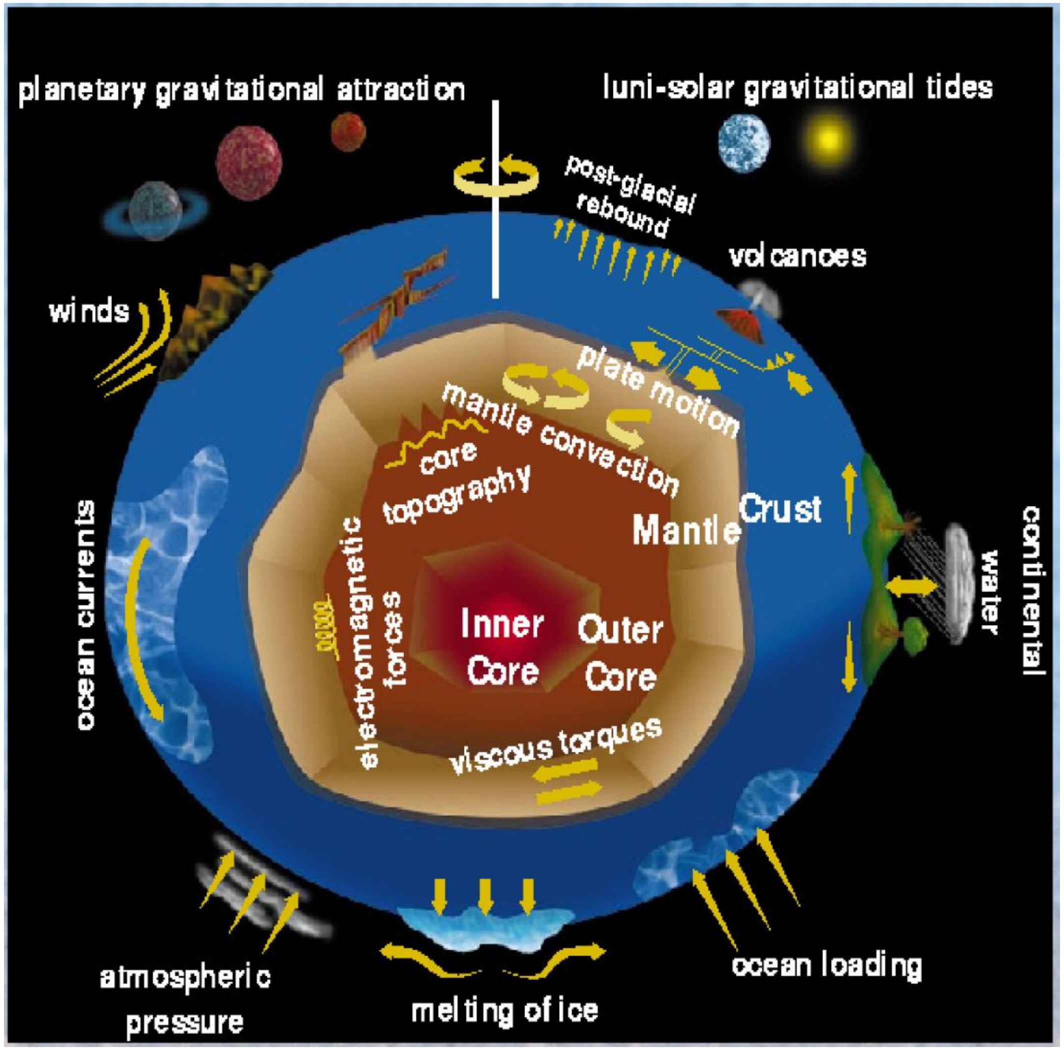
International Earth Rotation and Reference Systems Service (IERS)

Radio source positions, precise GNSS orbits and clocks, Earth orientation parameters (EOP), station coordinates and velocities

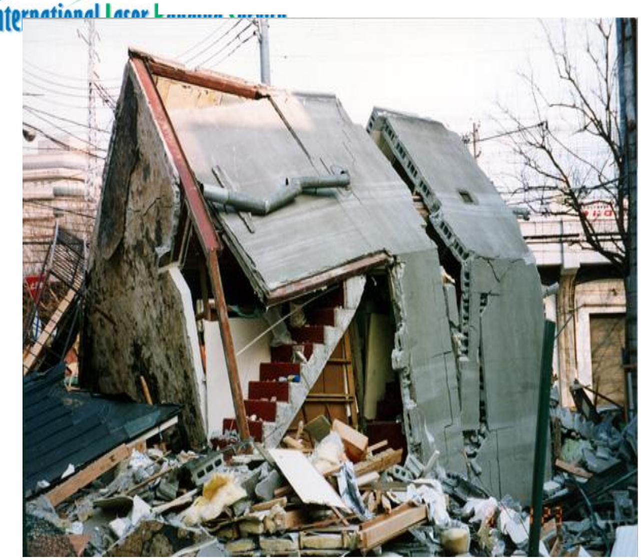
Very Long Baseline Interferometry (IVS)	Satellite Laser Ranging (ILRS)	Global Navigation Satellite Systems (IGS)	Doppler Orbit Determination and Radiopositioning Integrated on Satellite (IDS)
			

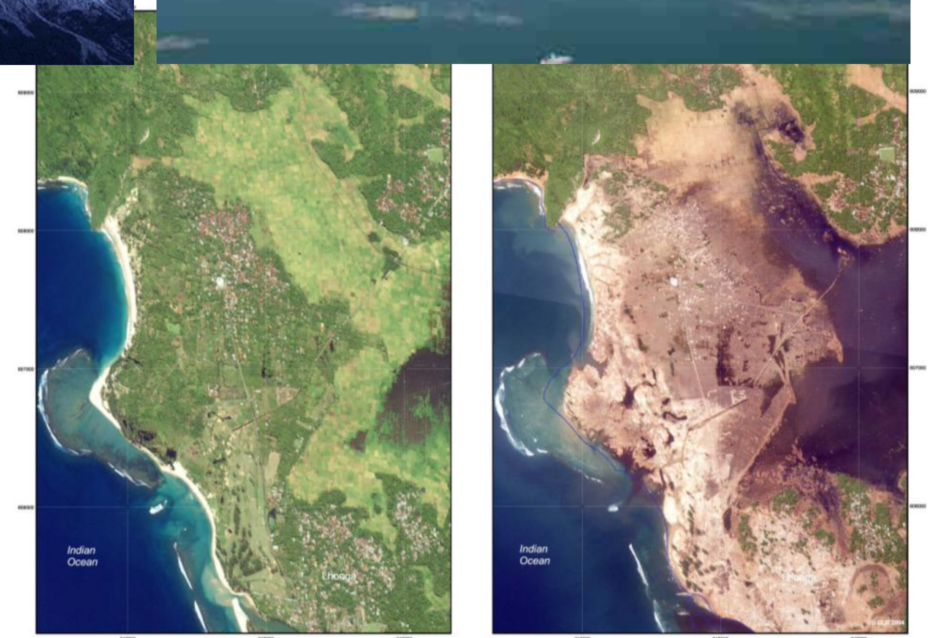
Some people think the Earth looks like this:

But really it looks like this:



Motivation for Monitoring the Earth System





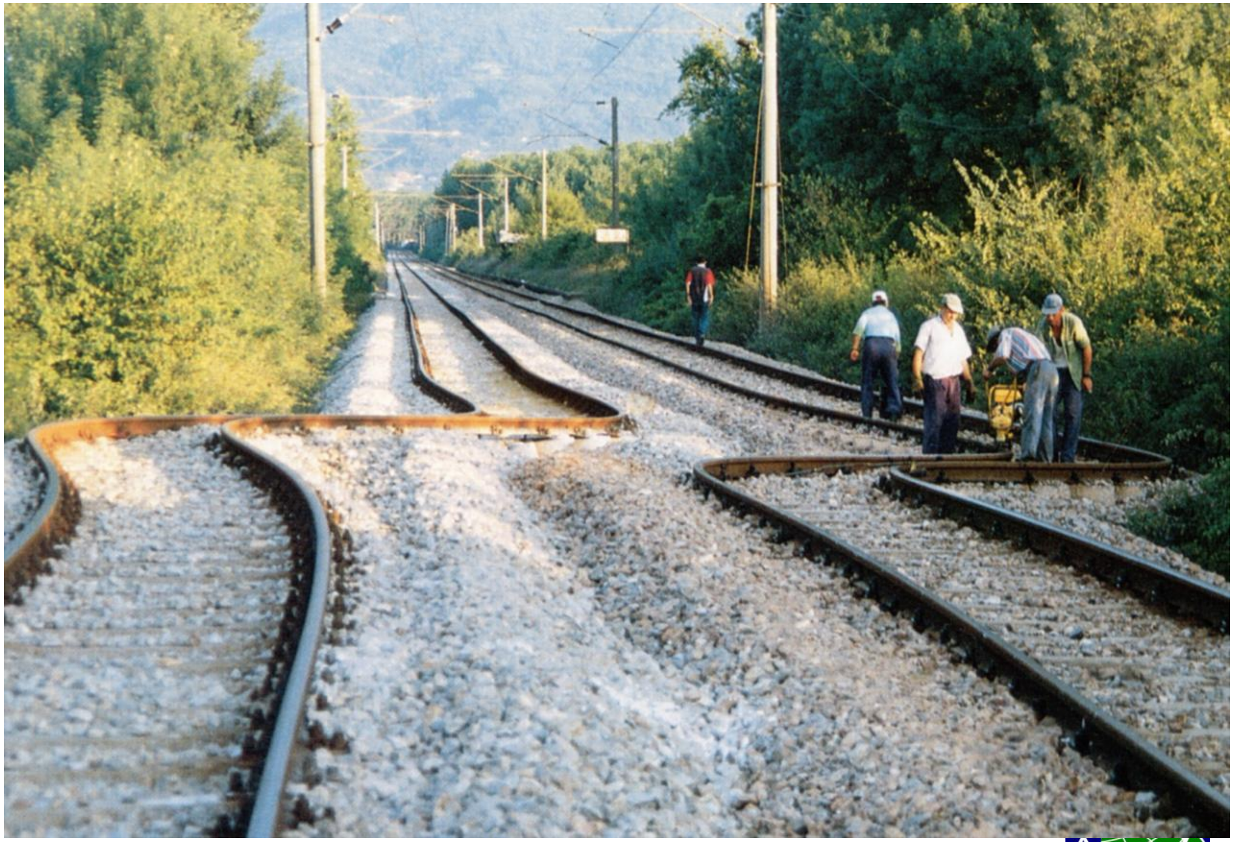
Geometry and Deformation of the Earth

- Problem and fascination of measuring the Earth:

Everything is moving !

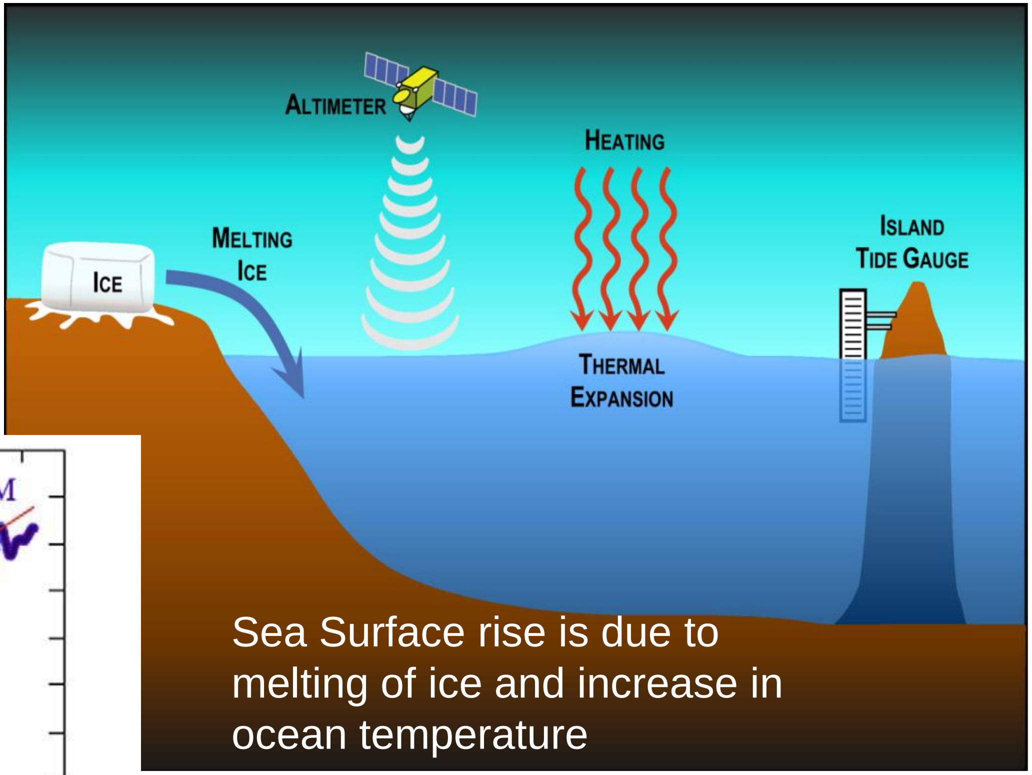
- Monitoring today mainly by GPS permanent networks

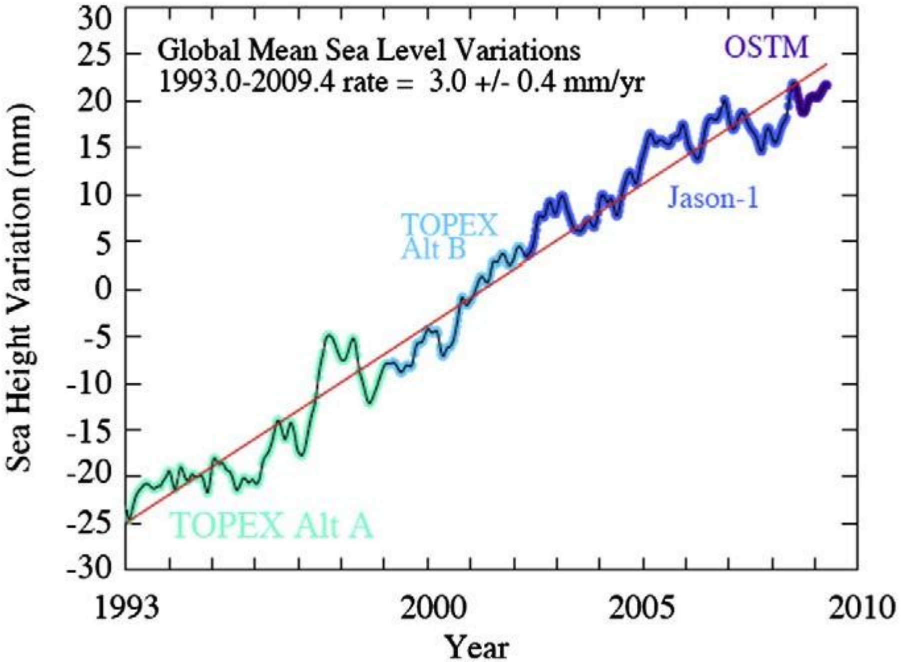
- Examples:
  - Plate motions
  - Solid Earth tides (caused by Sun and Moon)
  - Loading phenomena (ice, ocean, atmosph.)
  - Earthquakes …
- **Continuous monitoring is absolutely crucial**



Measuring Sea Surface Height with Altimetry

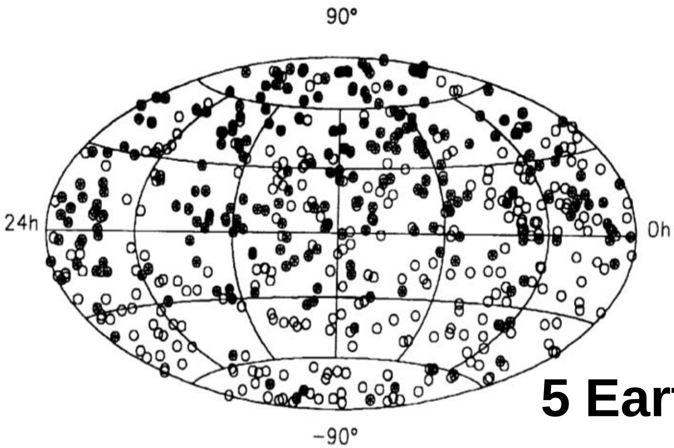
- What kinds of things effect Sea Level?
  - –Water Volume
  - –Water temperature
  - –Tides
  - –Currents
  - –Tsunamis
  - –Weather
  - –Coast Line. etc

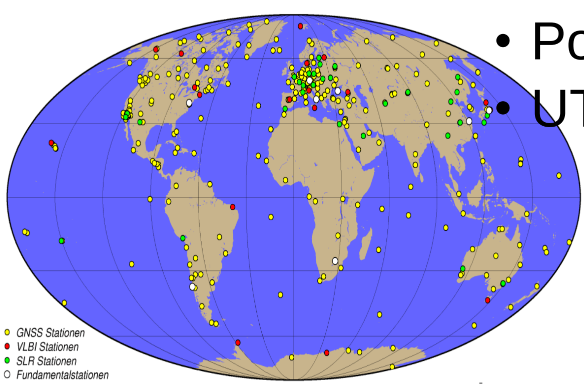




Source: Lemoine, F.G., et al. Towards development of a consistent orbit series for TOPEX, Jason-1, and Jason-2. J. Adv. Space Res. (2010), doi:10.1016/j.asr.2010.05.007

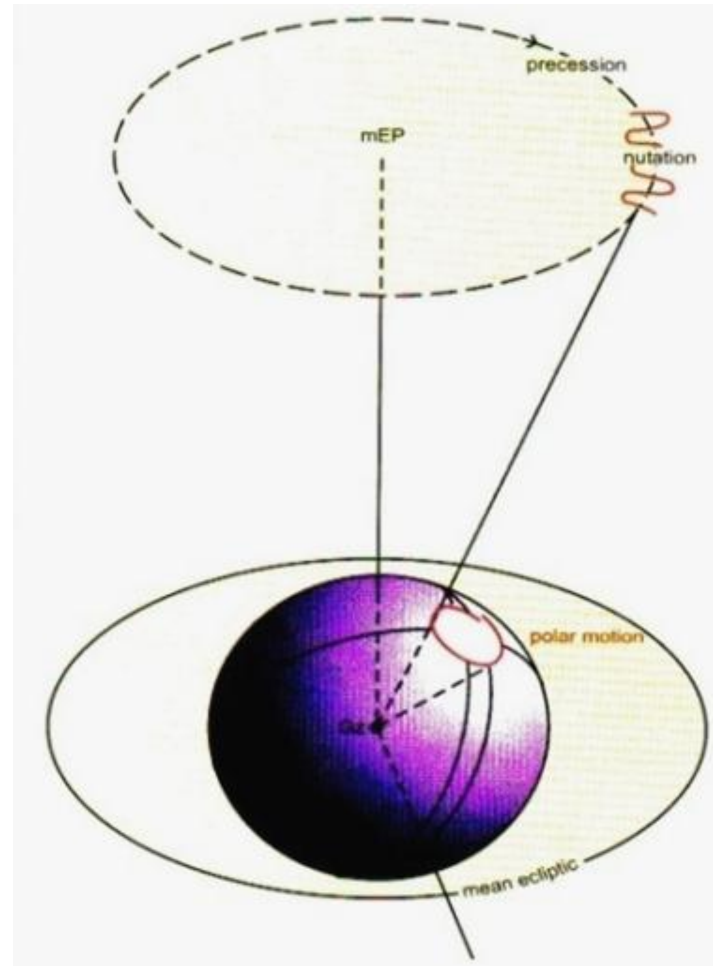
Measuring EOP with Space Geodesy Techniques



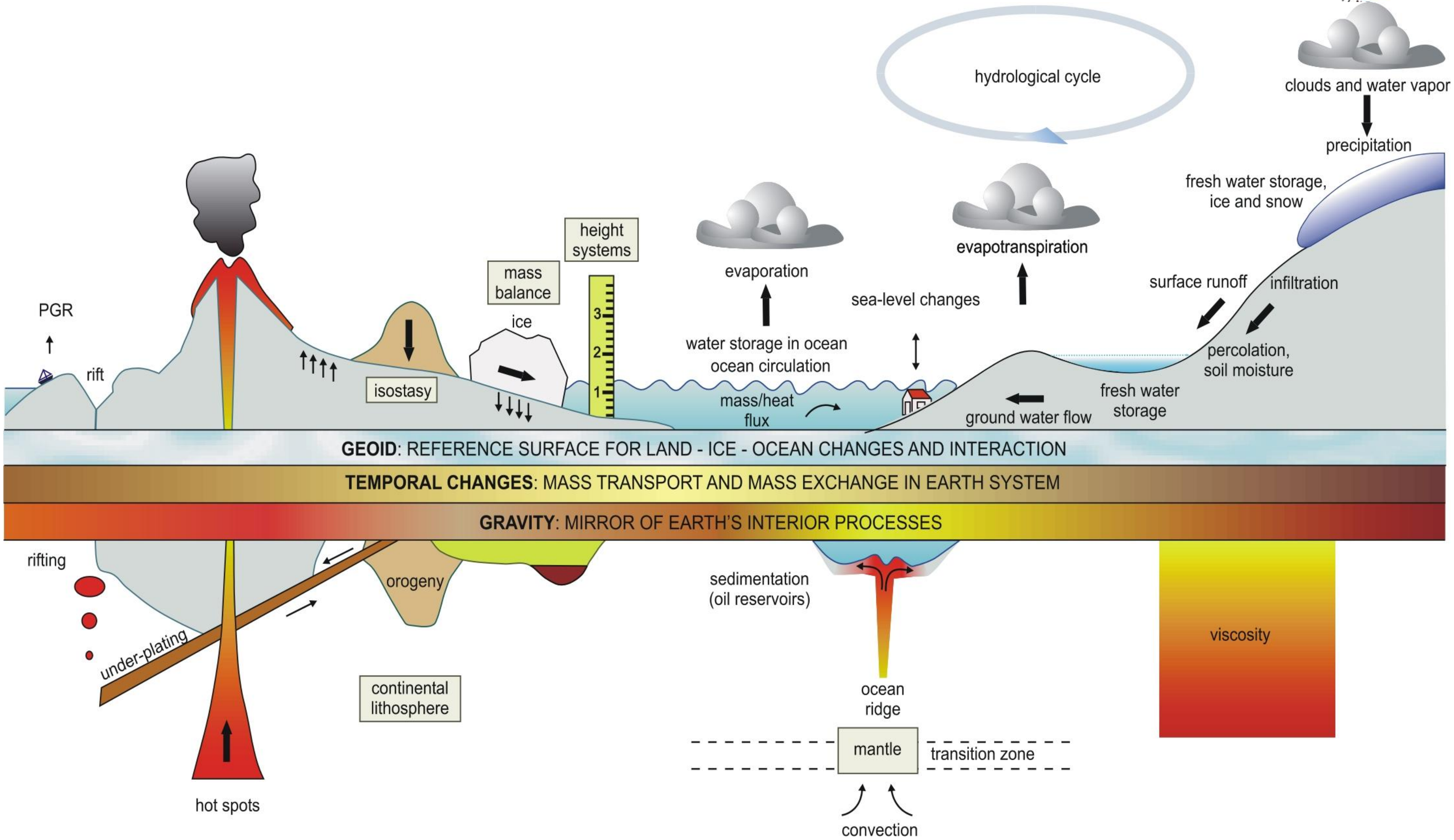


5 Earth orientation parameters (EOP) required for any positioning and navigation:

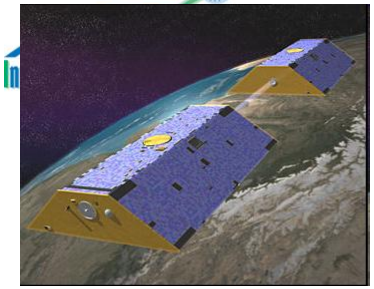
- Precession/nutation
- Polar motion
- UT1 - UTC (or lod)

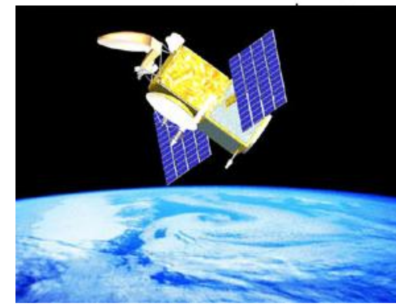


Gravity Field tells us about Mass Transport



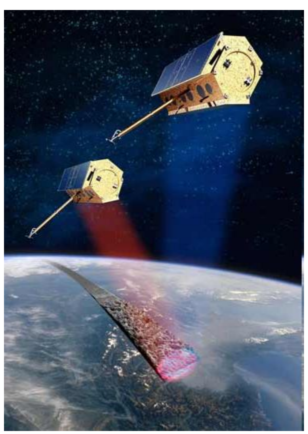
Ilk et al. (2005) Mass Transport and Mass Distribution in the Earth System, 2nd Edition, SPP1257 DFG

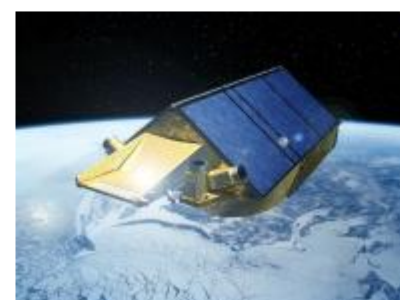


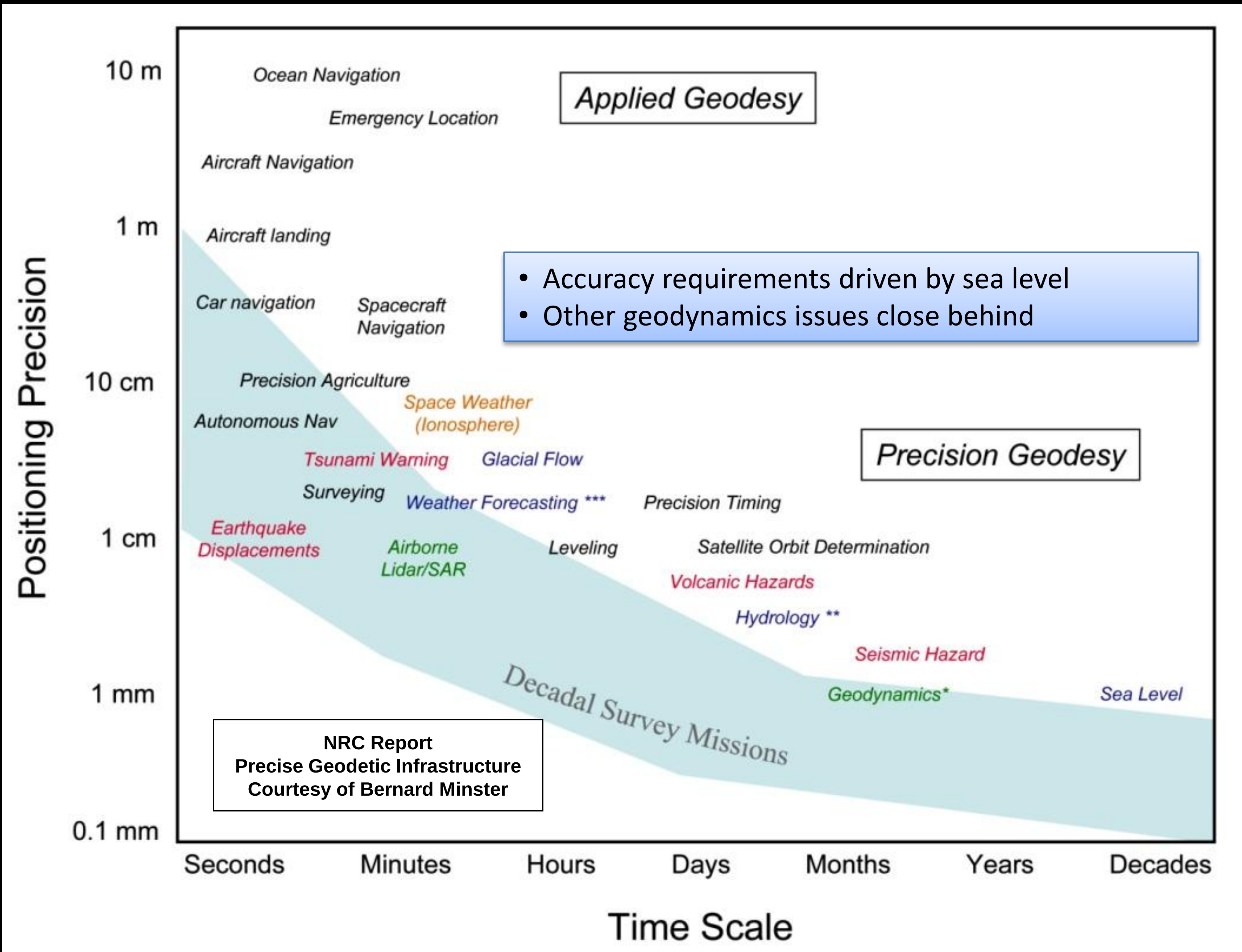


Common Thread for Measurements:

- Reference Frame
- Precision Orbit Determination



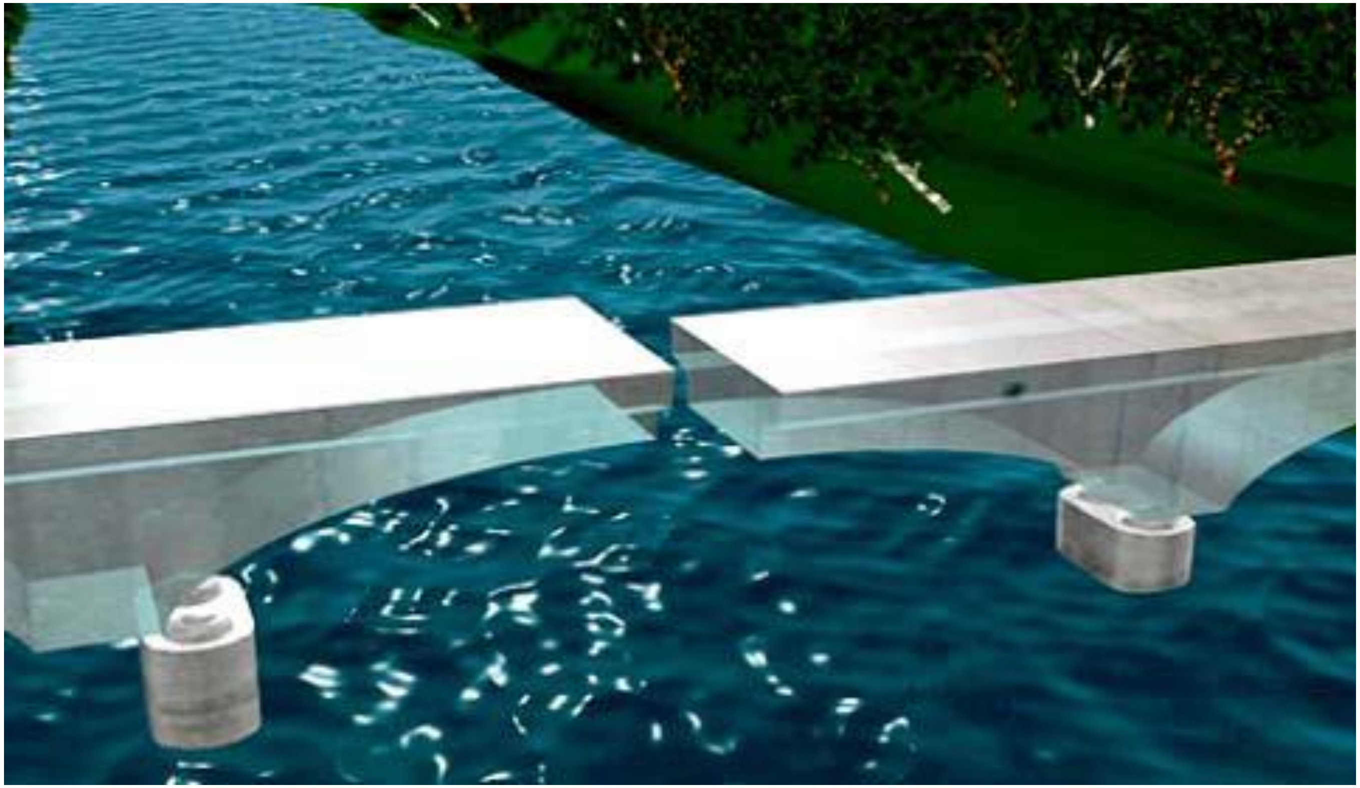




- Accuracy requirements driven by sea level
- Other geodynamics issues close behind

Courtesy of Bernard Minster
http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954

When National Reference Frames are not integrated!

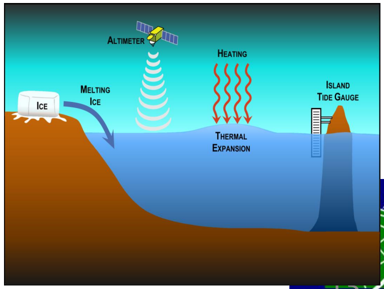


Design error at bridge construction in Laufenburg (2003): During the construction of the bridge across the Rhine river in Laufenburg, a control showed that a height difference of 54 centimeters exists between the bridge built from the Swiss side and the roadway of the German side. Reason of the error 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 <u>the stable coordinate system that allows us to measure change (link measurements) over space, time and evolving technologies</u>.
- 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."

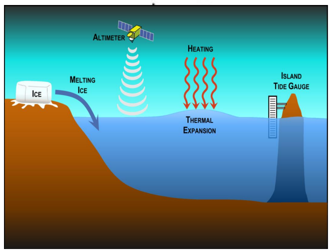
The vision of GGOS is

"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*

International Laser Ranging Service

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:

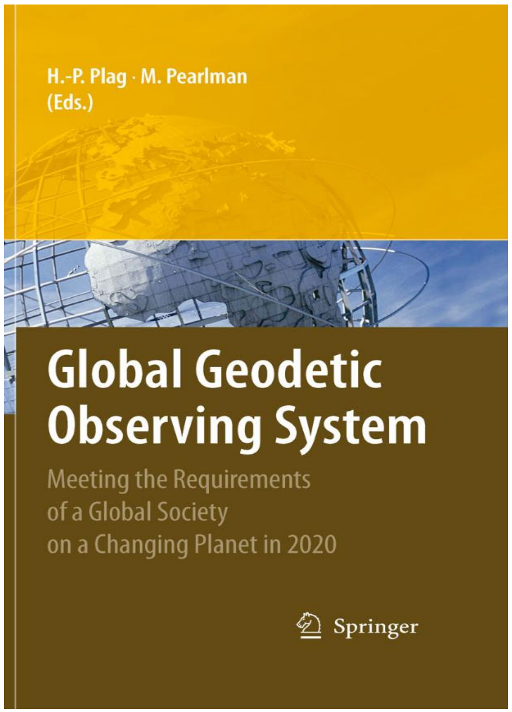
- Global Network of co-located VLBI/SLR/GNSS/DORIS CORE SITES
- Sites with two and three co-located techniques ;
- Dense network of GNSS ground stations to distribute the reference frame globally to the users

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

- **Measurement requirement is very challenging**
- **Connection between SLR and GNSS is critical**

GGOS 2020 Book (2009)

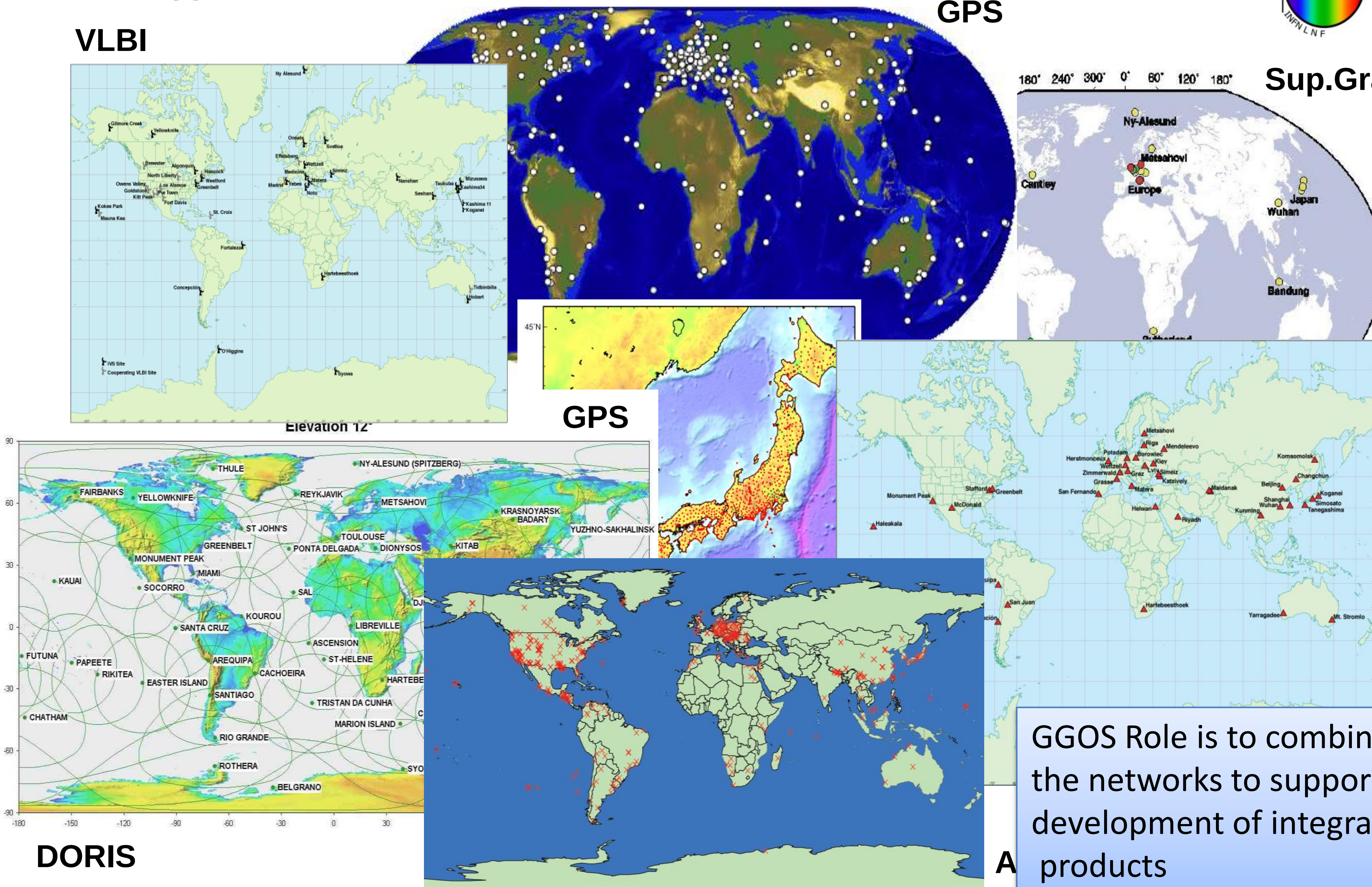
GGOS: Meeting the Requirements of a Global Society on a Changing Planet in 2020. Eds. H.-P. Plag and M. Pearlman. Springer 2009. p. 332



Content: main arguments 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

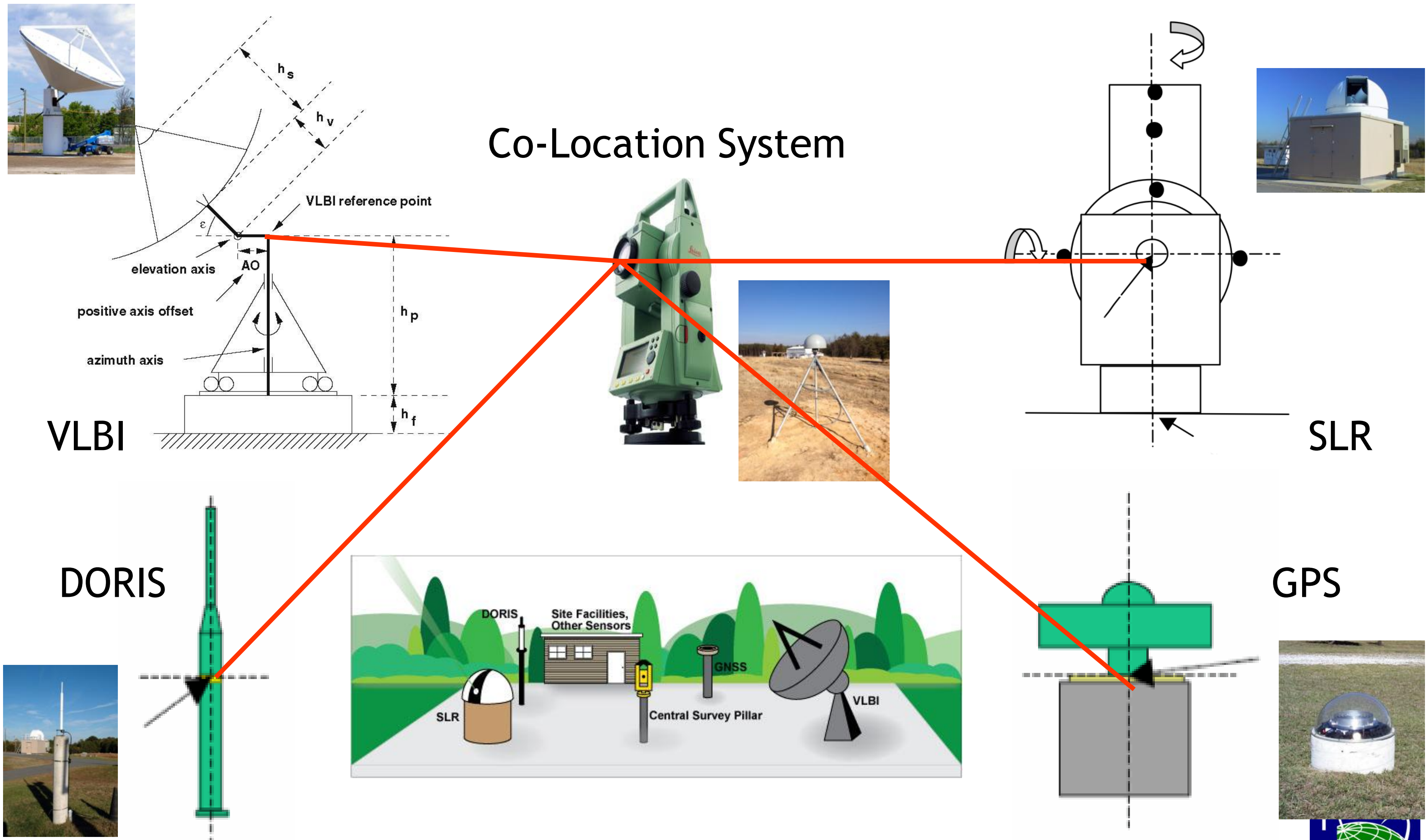
GNSS

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

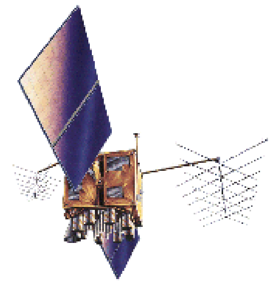
Co-location in Space

Compass

GNSS/SLR

GLONASS

GNSS/SLR

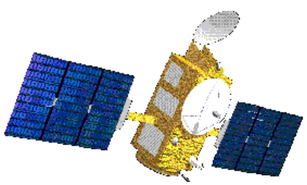


GPS

GNSS/SLR

GIOVE/Galileo

GNSS/SLR



Jason

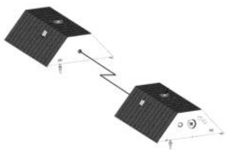
DORIS/GNSS/SLR

CHAMP

GNSS/SLR

Envisat

DORIS/SLR



GRACE

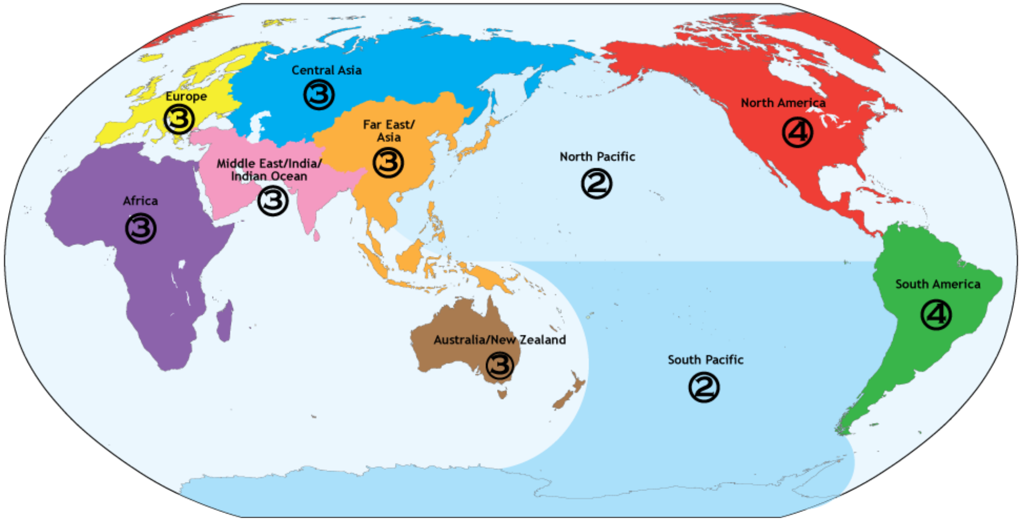
GNSS/SLR

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

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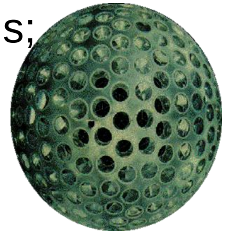
- Introduction and Justification
  - What is a Fundamental Station?
  - Why do we need the Reference Frame?
  - Why do we need a global network?
  - What is the current situation?
  - What do we need?
- Site Conditions
  - Global consideration for the location
  - Geology
  - Site area
  - Weather and 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

Current trends in the Laser Ranging Ground Systems

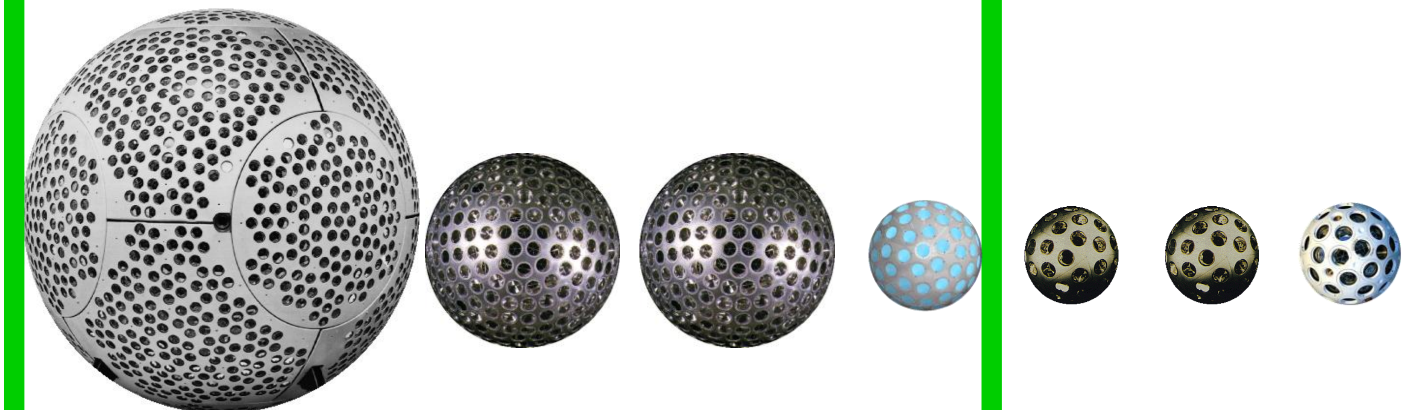
- Higher pulse repetition rate (0.1 – 2 KHz) for faster data acquisition;
- Smaller, faster slewing telescope for more rapid target acquisition and pass interleaving;
- Ranging from LEO to GNSS;
- Ranging to Space-born receivers
- More accurate pointing for link efficiency;
- Narrower laser pulse width for greater precision;
- New detection systems 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;



- Path forward to improve performance is known
- Important issues with calibration, validation, etc still exist

SLR Geodetic Satellite Constellation

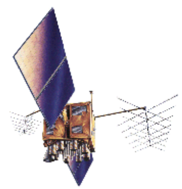
ITRF Constellation

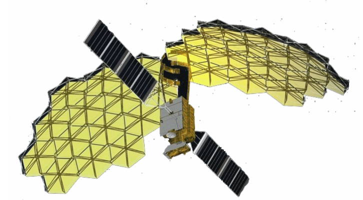


	Etalon-I & -II	LAGEOS-1	LAGEOS-2	LARES	Starlette	Stella	Larets
Inclination	64.8°	109.9°	52.6°	69.5°	50°	98.6°	98.2°
Perigee ht. (km)	19,120	5,860	5,620	1450	810	800	691
Diameter (cm)	129.4	60	60	36	24	24	24
Mass (kg)	1415	407	405.4	387	47.3	47.3	23.3

$LARES_{A/m}$ = 0.36 x LAGEOS

Retroreflector Arrays on High Constellation Satellites

	GLONASS	GPS	COMPASS	Galileo	ETS-8
Inclination	65˚	64.8˚	55.5˚	56˚	0˚
Perigee ht. (km)	19,140	20,195	21,500	23,920	36,000
Mass (kg)	1,400	930	2,200	600	2,800

Regarding the Space Segment

Currently

- LARES added to the Geodetic Constellation in 2012
- Smarter about the way we build our arrays
- Facilities that can do a much better job of measuring array properties, examine different options, optimize designs, and setting specifications
- More groups building arrays
- Many new satellites with arrays coming along
- We have a “loose” ILRS Standard for GNSS (effective cross section)

What to we need?

- More standardization on how we treat our data
- More definitive GNSS array specification based on our analyses and laboratory testing.