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GENESIS-1: Co-location of Geodetic Techniques in Space

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Overview

- Introduction / History
- Motivation
- Unification of Reference Frames
- Science Objectives
- Benefits
- Conclusions

Introduction / History

- **GRASP** proposals to NASA (2011, 2015) have, unfortunately, not been selected (though, 2nd best mission proposal)
- **E-GRASP** proposal for Earth Explorer Opportunity Mission EE-9 submitted in June 2016 (17 proposals, 5 evaluated, none selected)
- Revised Call for Proposals issued by ESA in December 2016
- **Updated E-GRASP** proposal resubmitted in June 2017 by the E-GRASP/Eratosthenes team, very good evaluation, but not selected
- **E-GRIP** satellite mission proposal in 2016 in Switzerland (Call for small satellite mission), relativity tests and co-location, too expensive
- **NanoGEM, NanoX:** micro-satellite proposals with co-location idea of GFZ with partners
- **APOD:** Chinese cubesat mission was realized in 2015 with SLR, GNSS, VLBI: problems with some instruments, limited resources

Co-location of Geodetic Techniques in Space exists already now

- **Satellite altimetry:** Topex/Poseidon, Jason-1 etc. missions with GPS, DORIS and SLR onboard
  - Extreme improvements in LEO orbit determination
  - Missing: VLBI
- **GNSS:** GLONASS, Galileo, Beidou, (GPS) with SLR retro-reflectors
  - Interesting co-location studies
  - Missing: VLBI, DORIS
- **LEO satellites:** GPS (now GNSS) and SLR on many geodetic LEO satellites
  - Missing; VLBI, mostly also DORIS
- **APOD** (Atmospheric density detection and Precise Orbit Determination): Chinese cubesat mission with VLBI, SLR, GNSS
  - Missing: DORIS

→ **no dedicated mission with all techniques**

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Motivation for GENESIS-1

- **GGOS requirements (1 mm accuracy, 0.1 mm/y stability) are far from been met (presently rather on the 1 cm level)**

- **Two main limiting factors of the ITRS realization:**

  (1) Difficulty to accurately measure the **local ties** between the reference points (intersection of axes of large instruments, phase centers of antennas)

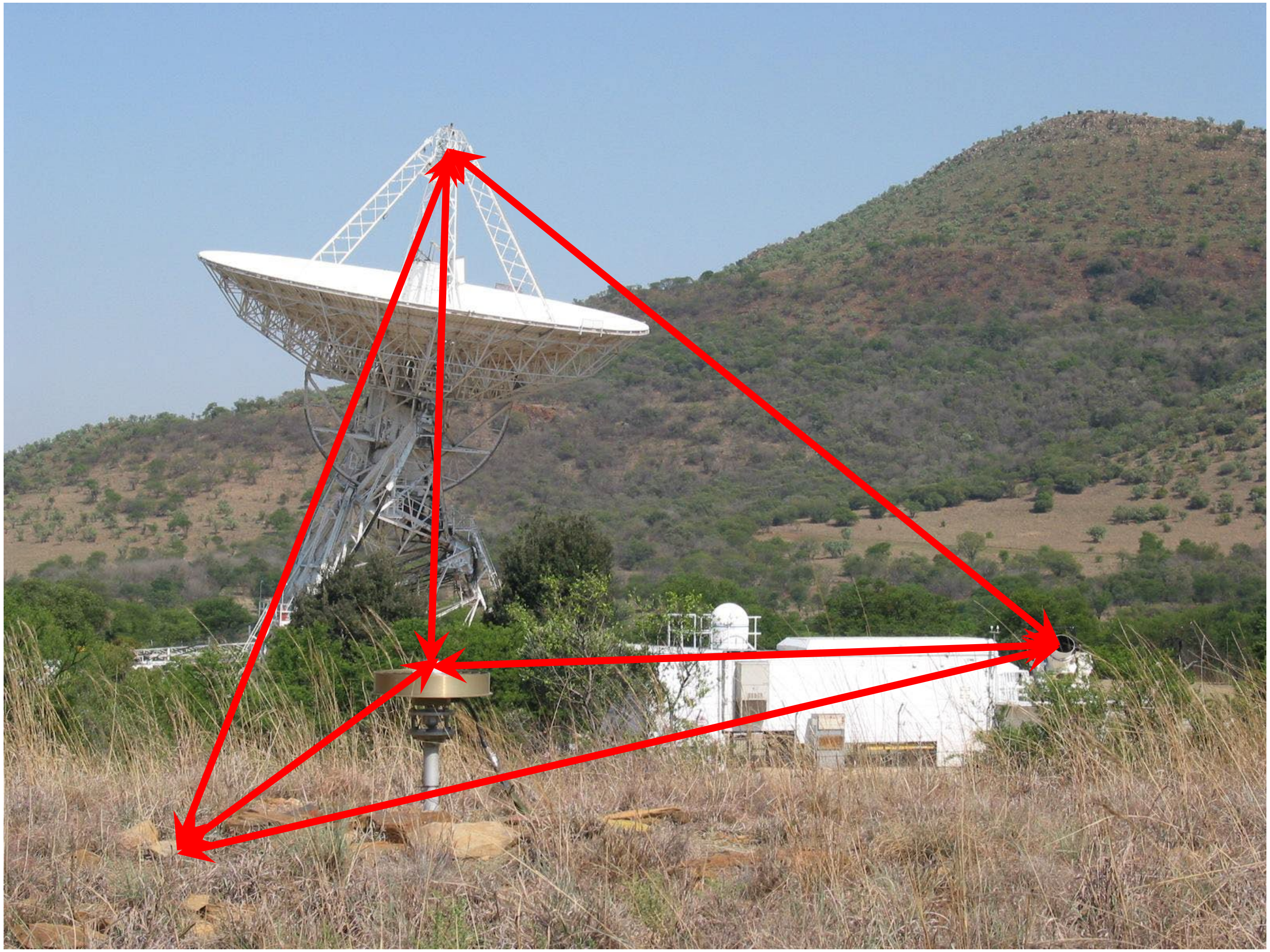
  (2) Each space geodetic technique suffers from its own **systematic effects** (range biases, phase centers, multipath, gravitational sag, tropospheric refraction, quasar structures, …)

- **Fundamental improvement with GENESIS-1:**

  (1) Complementary, highly accurate co-location of all four space geodetic techniques in space, on the same satellite platform

  (2) Particular attention paid to the time and space metrology on board

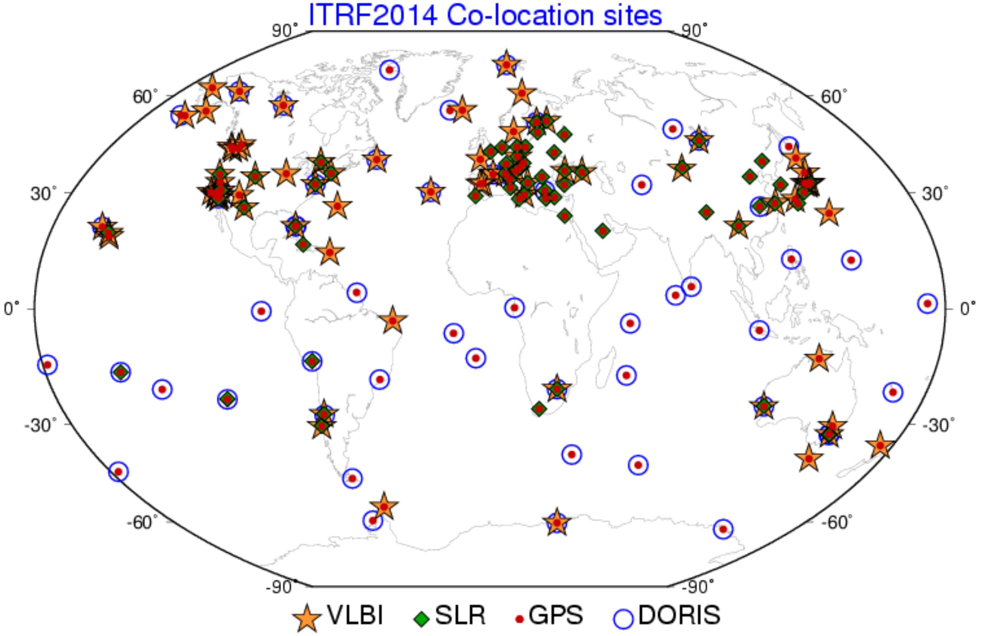
Measurement of Local Ties at Ground Stations



Hartebeesthoek (HRAO)

Quality of ITRF2014 Co-locations on Ground

- 1499 stations located in 975 sites
- 91 co-location sites with 2 or more instruments which were or are currently operating
- Co-locations:
  - 40 GNSS – VLBI
  - 33 GNSS – SLR
  - 46 GNSS – DORIS
- "Tie discrepancies" means differences between terrestrial ties and space geodesy estimates



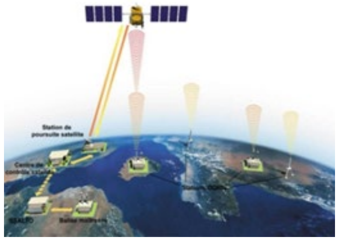
Percentage of tie discrepancies

	< 5 mm	> 5 mm
GNSS – VLBI:	42 %	58 %
GNSS – SLR:	29 %	71 %
GNSS – DORIS:	23 %	77 %

Altamimi et al., Review of IDS contribution to ITRF2014, *IDS workshop 2016*

Technique-specific Systematic Effects

DORIS

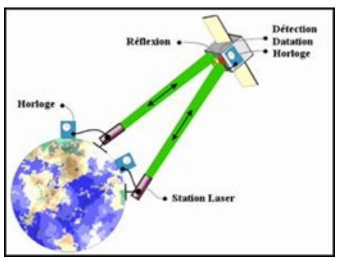


- Uncalibrated phase center pattern of beacons
- Suffering from South Atlantic Anomaly
- Effects of solar radiation pressure (e.g. Z-geocenter component)

GNSS

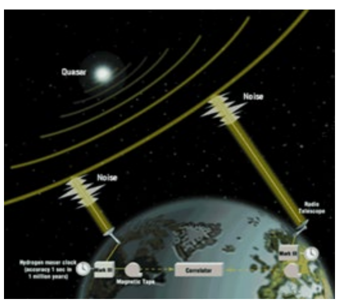
- Phase center offsets and variations of receiver and satellite antennas (affecting TRF scale)
- Extreme number of discontinuities in the position time series due to equipment changes
- Orbit modeling deficiencies (draconitic effects)

SLR



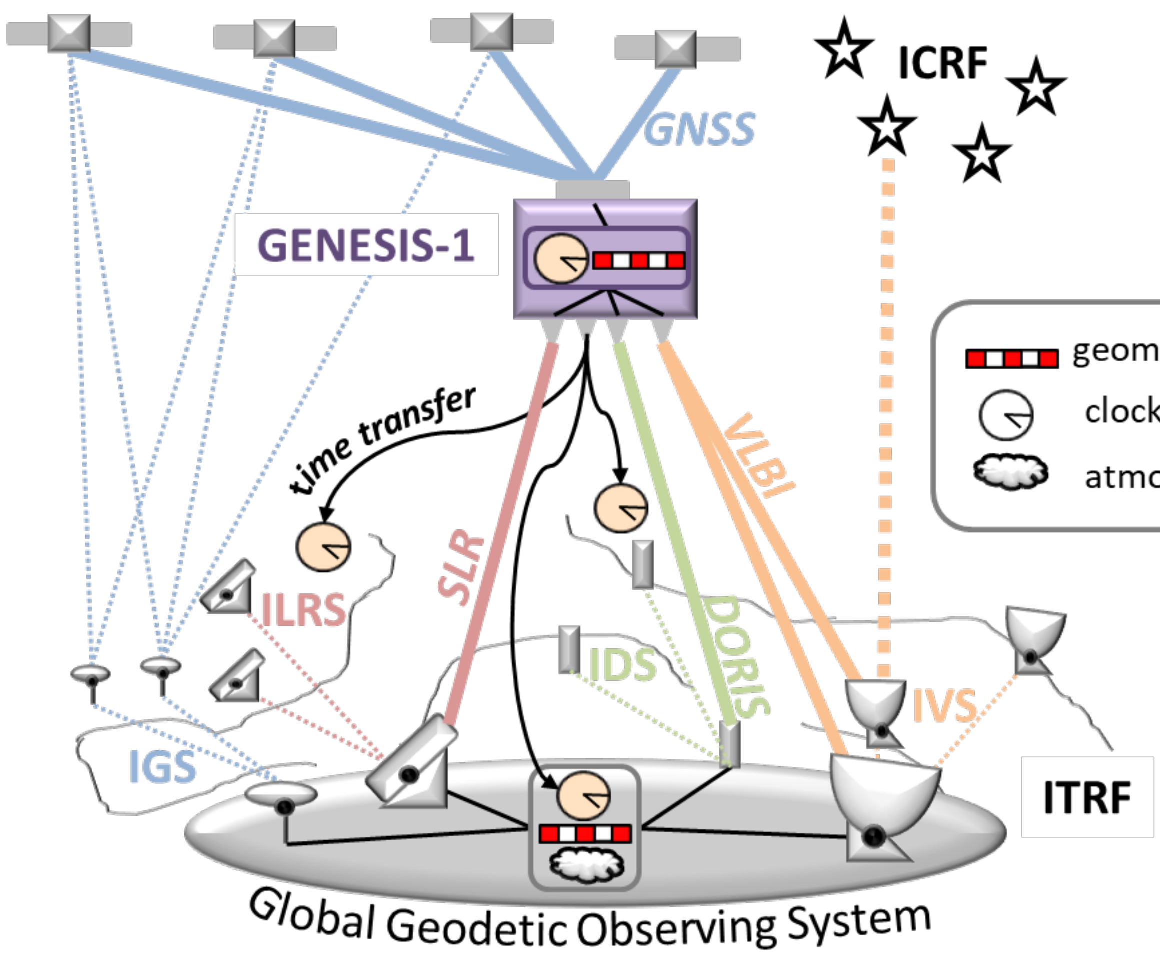
- Inhomogeneous network geometry
- Station and satellite range biases
- Station time biases

VLBI



- Sparse network
- Gravitational sag of telescope
- Thermal deformation of telescope
- Quasar structures

Unification of Space and Time Reference Systems



Co-location in space

complementary

Co-location on ground

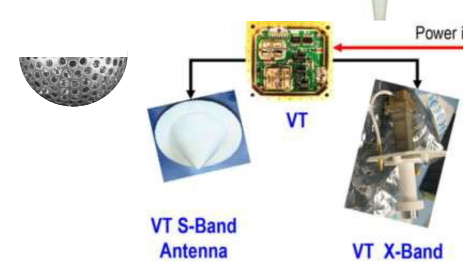
Unification in Parameter Space

co-location in space

co-location on ground

Classification	Type	Parameter	VLBI	GNSS	SLR	DORIS	LLR
common, global	Satellite orbits	GNSS orbits	(√)	√	√		
		LEO orbit		√	√	√	
		LEO clock		√	(√)		
		GENESIS-1 orbit	√	√	√	√	
		GENESIS-1 clock	√	√	√	√	
	EOP	Pole coordinates	√	√	√	√	√
		UT1	√				
		LOD (Length of Day)	(√)	√	√	√	√
		Nutation	√				√
		Nutation rates	√	√	√	√	√
	Gravity field	Earth's center of mass		(√)	√	(√)	
		Low-degree coefficients		√	√	√	(√)
	TRF	Scale	√	(√)	√	(√)	√
common, local	Atmosphere	Ionospheric parameters	√	√	(√)	√	(√)
		Tropospheric parameters	√	√		√	
	TRF	Station positions	√	√	√	√	√
		Station velocities	√	√	√	√	√
	Time & Frequency	Station clocks	√	√	√	√	√
technique-specific	CRF	Quasar positions	√				
		Moon orbit					√
	Instrumental	GNSS clock		√			
		Range biases			√		√

Mission Characteristics

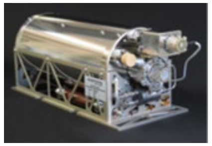


On-board co-location of DORIS, GNSS, SLR, VLBI

→ aiming at determining intersystem biases < 1 mm

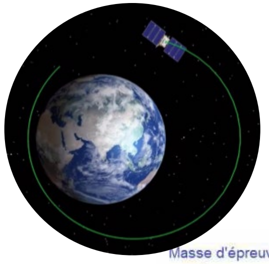
Precise clock (USO) for synchronization

→ on-board synchronization of GNSS-DORIS-VLBI-SLR data (common clock)



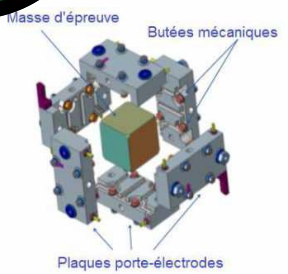
High circular orbit for long baseline visibility

→ 6000 km altitude



Possible additional payload for precision

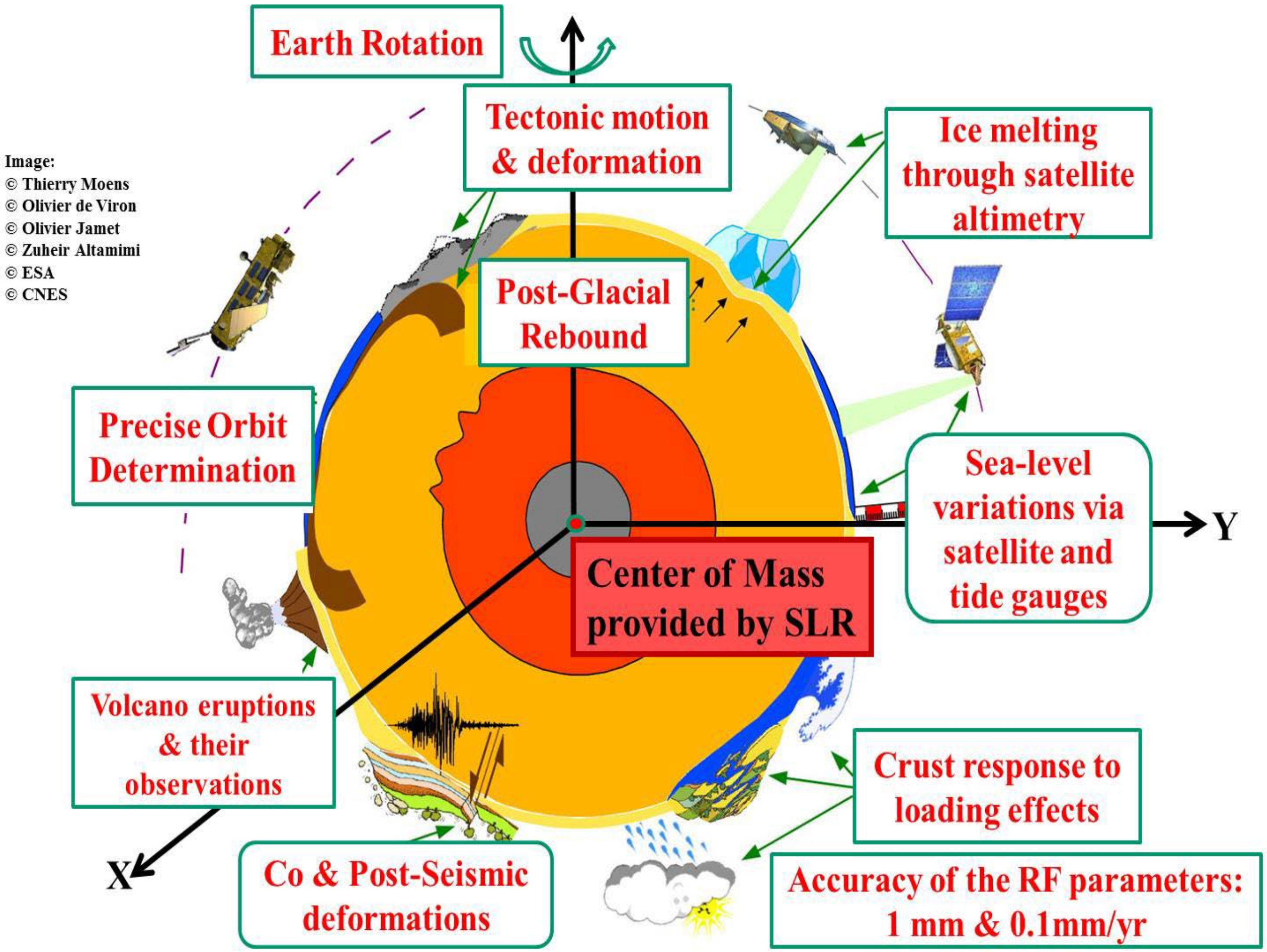
→ accelerometer to measure surface accelerations to 10^{-11} m/s²/√Hz (linear acc.) and the center of mass position to 0.1 mm (angular acc.)



The whole for TRF objectives

→ global accuracy of 1 mm and stability of 0.1 mm/yr improved by a factor 5 w.r.t current knowledge

Science Objectives in Earth Sciences



Science Objectives

Reference Frames and Earth Rotation

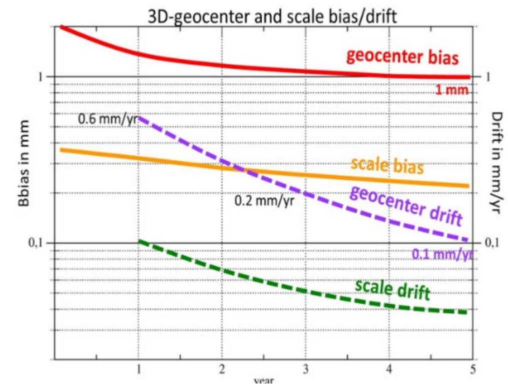
- Unification of reference frames and Earth rotation
- Geocenter and scale

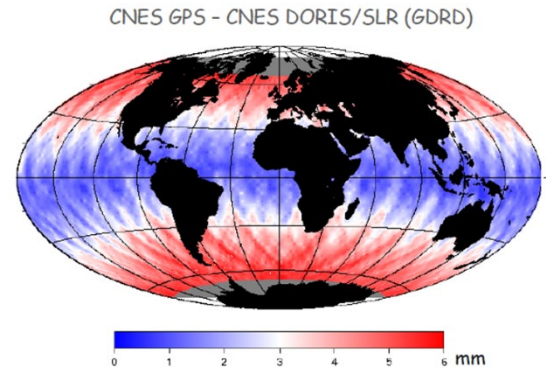
Earth Sciences

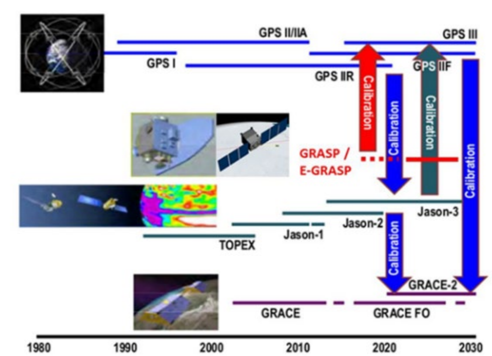
- Long-wavelength gravity field
- Altimetry and sea level rise
- Determination of ice mass loss
- Geodynamics, geophysics, natural hazards
- Thermospheric density measurements, improvements in the Earth radiation budget

Positioning and Navigation

- Improvement in global positioning
- GNSS antenna phase center calibration
- Positioning of satellites and space probes
- Time transfer over intercontinental distances







UN - Global Geospatial Information Management (UN-GGIM)

Resolution on the global geodetic reference frame for sustainable development:

Goals: natural hazard and disaster

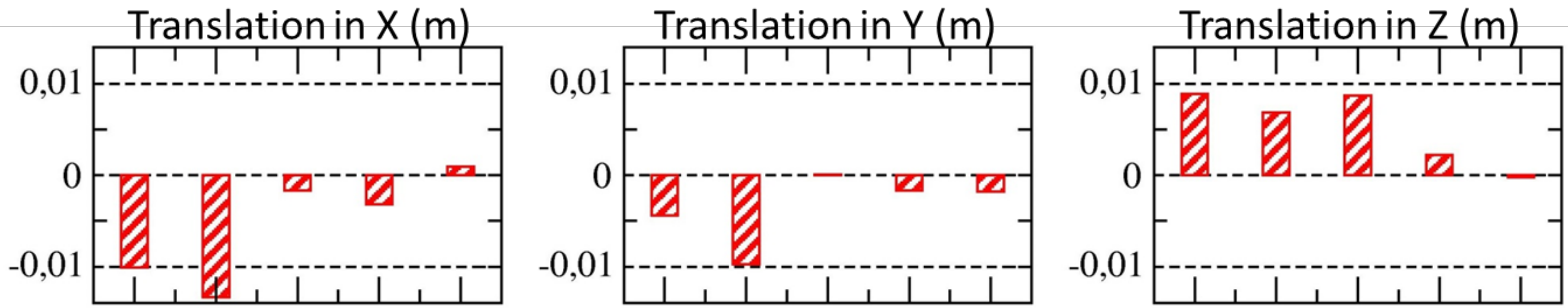
To make good decisions for the future, information is needed about sea level changes, plate movements, land uplift and ice sheet and glacier changes.
The global geodetic reference frame provides the basis for such decisions. Without this system, it would be difficult to identify areas under threat of flooding, earthquakes or drought and to adopt preventive measures to protect them.

Needs: more precise observations

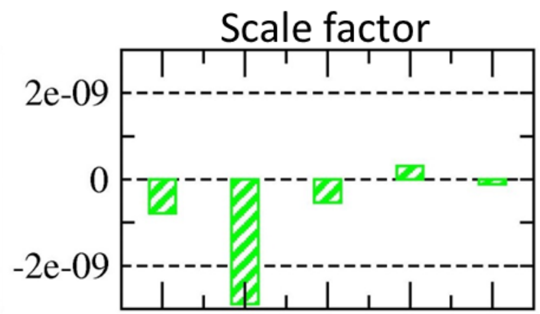
Earth observations must become more precise. We require information about current trends at a scale measured in millimeters to detect changes of the Earth system with sufficient precision, to meet society's future needs.

Report of the UN expert committee on "Global Geospatial Information Management" (2014)

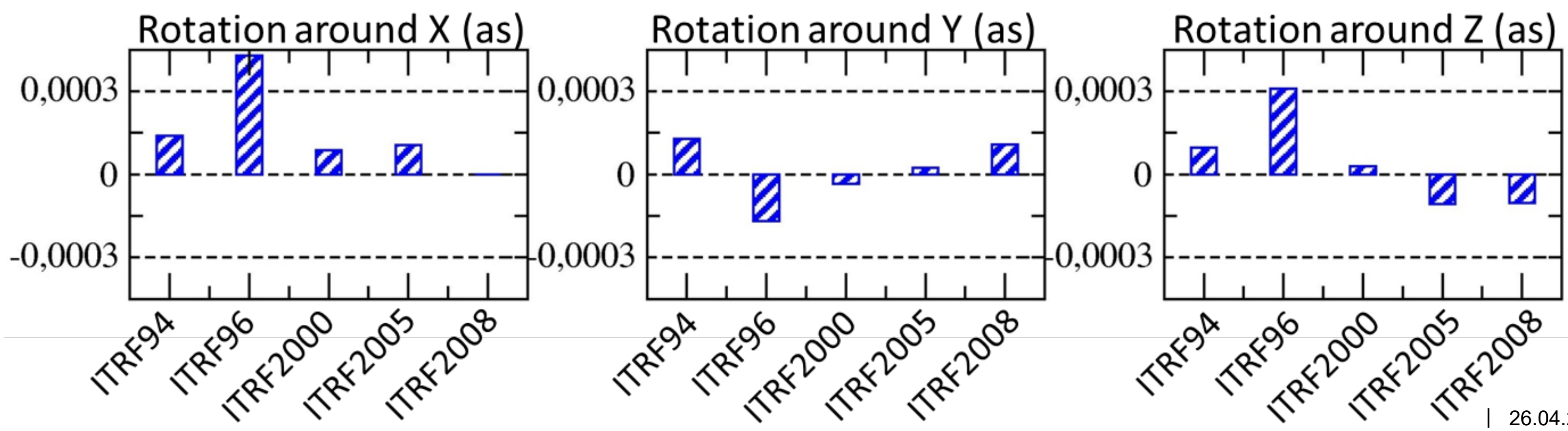
Transformation parameters w.r.t. ITRF2014



ITRFs are aligned within the cm level in translation, scale and rotation, even much better for last realizations.

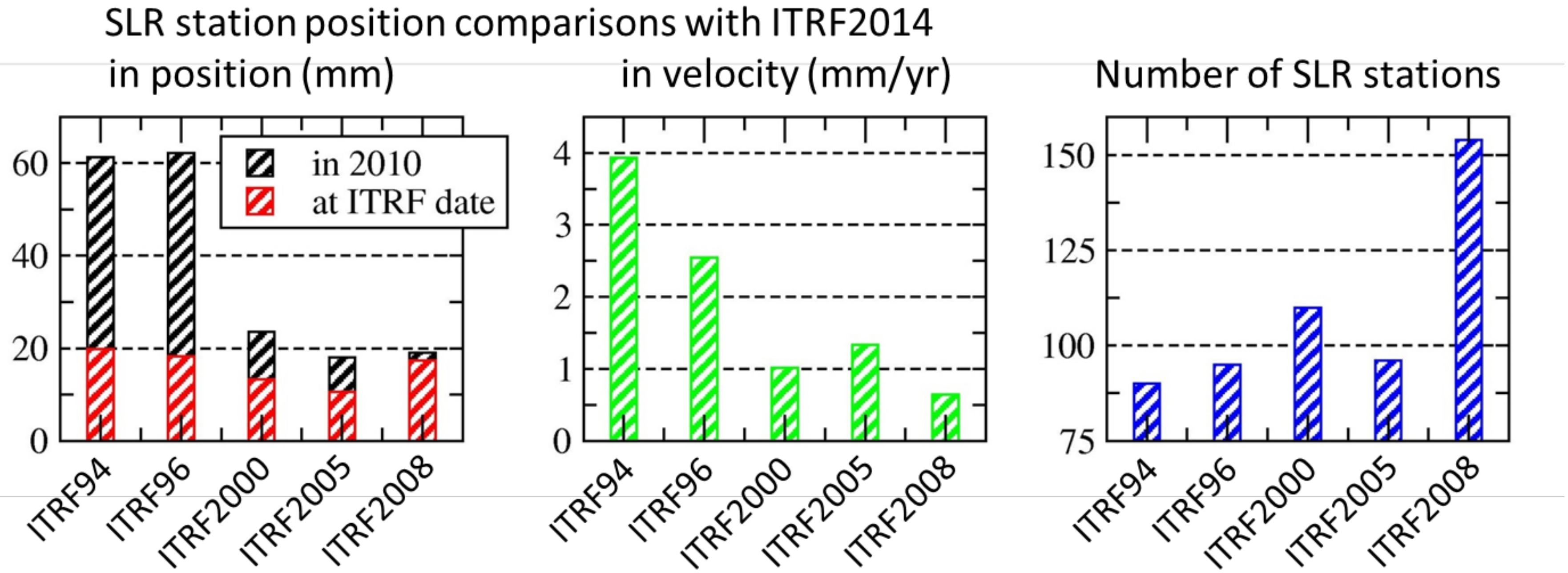


3 ppb ⇔ ~2 cm
.3 mas ⇔ ~1 cm



ITRF comparisons on SLR stations

Evolution of some ITRF realizations in terms of SLR station positions and velocities

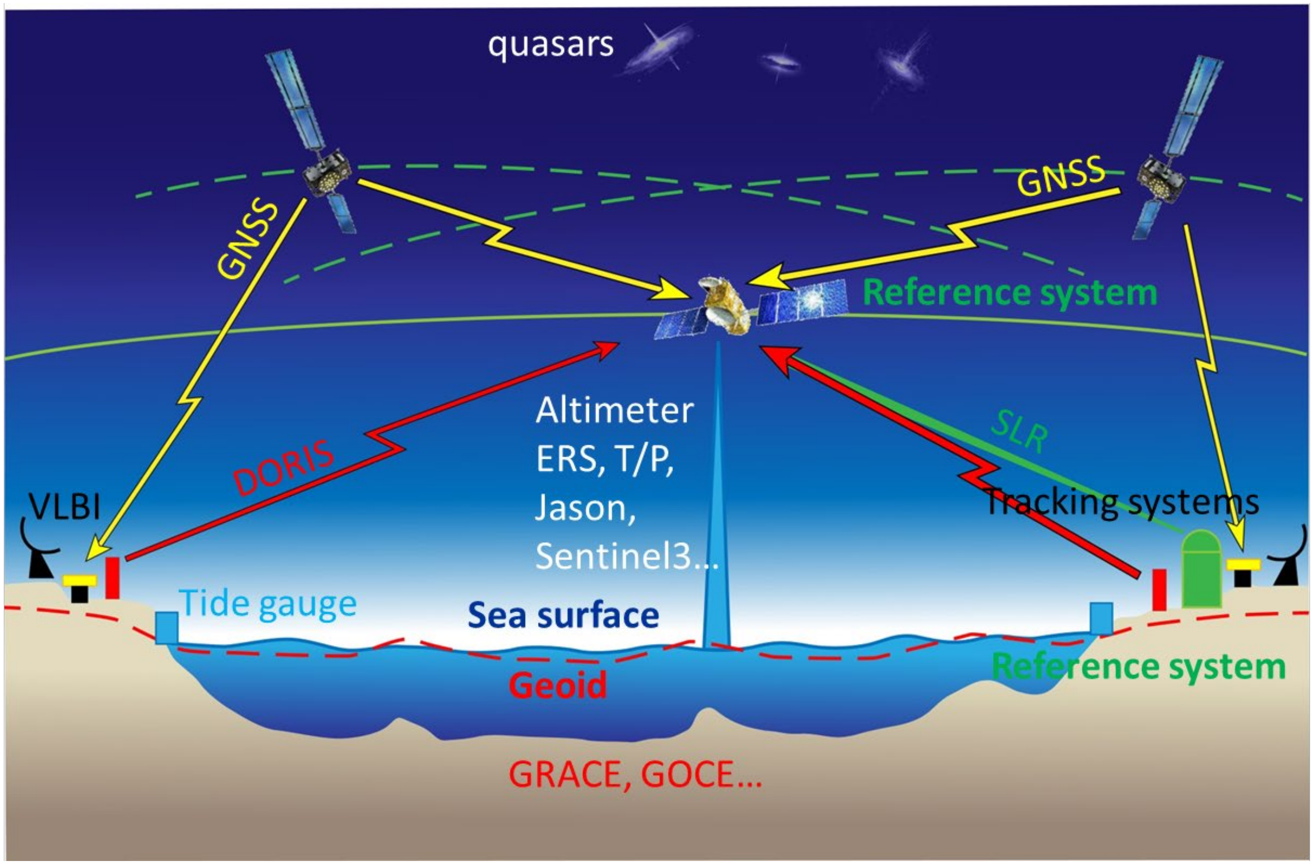


Comparisons of station positions more consistent when using ITRF2014 velocities. The global standard deviation on coordinate differences remains within 1 to 2 cm.

Velocity standard deviations improve by a factor of ~6 over 20 years (1994-2014) up to **~.6 mm/yr.**

Connection: Geometry, Gravimetry, Altmetry

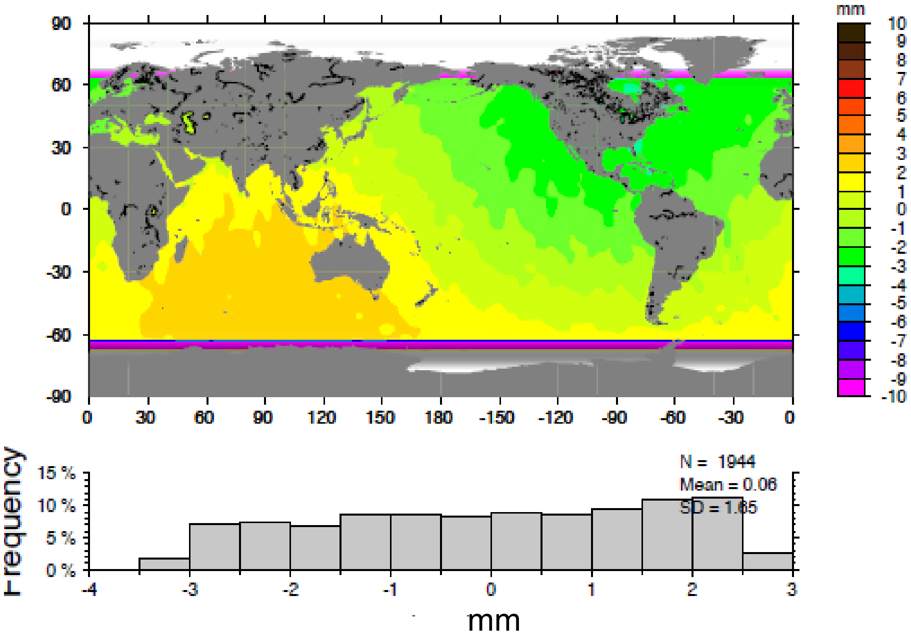
Mission types…	provide
Geometry	Reference system and orbit
Gravimetry	Geoid
Altimetry	Topography and sea surface



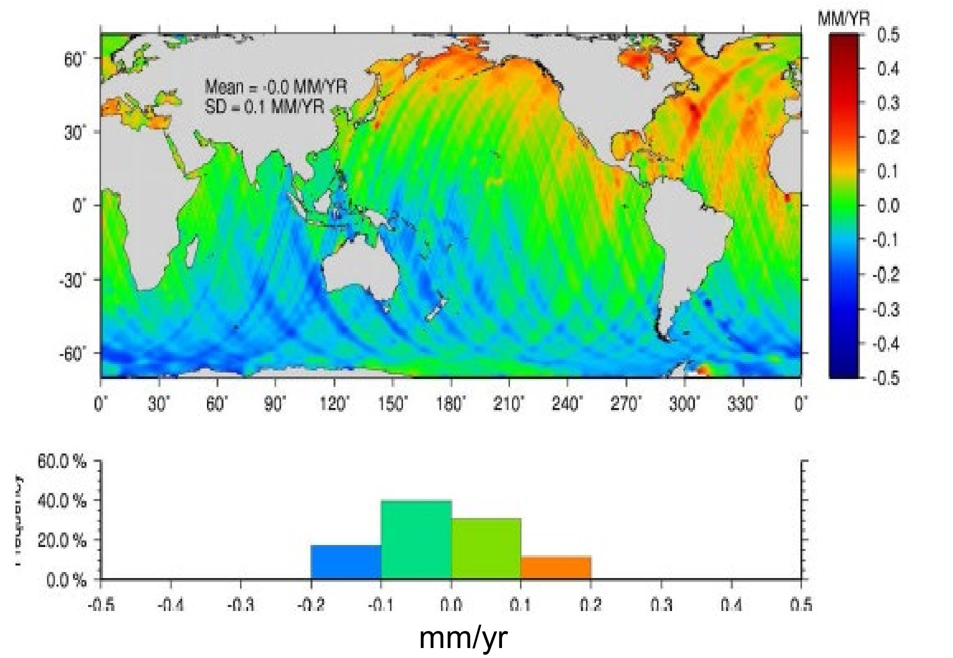
Impact of TRF on sea level height from altimetry

Effect of reference frame difference between ITRF2014 and ITRF2008:

Jason-3 radial orbit difference (cycle 1-22 / 2016)



Jason-2 regional sea level trend (2008 - 2016)



Radial orbit differences exhibit a degree 1 pattern with a **3 mm amplitude**

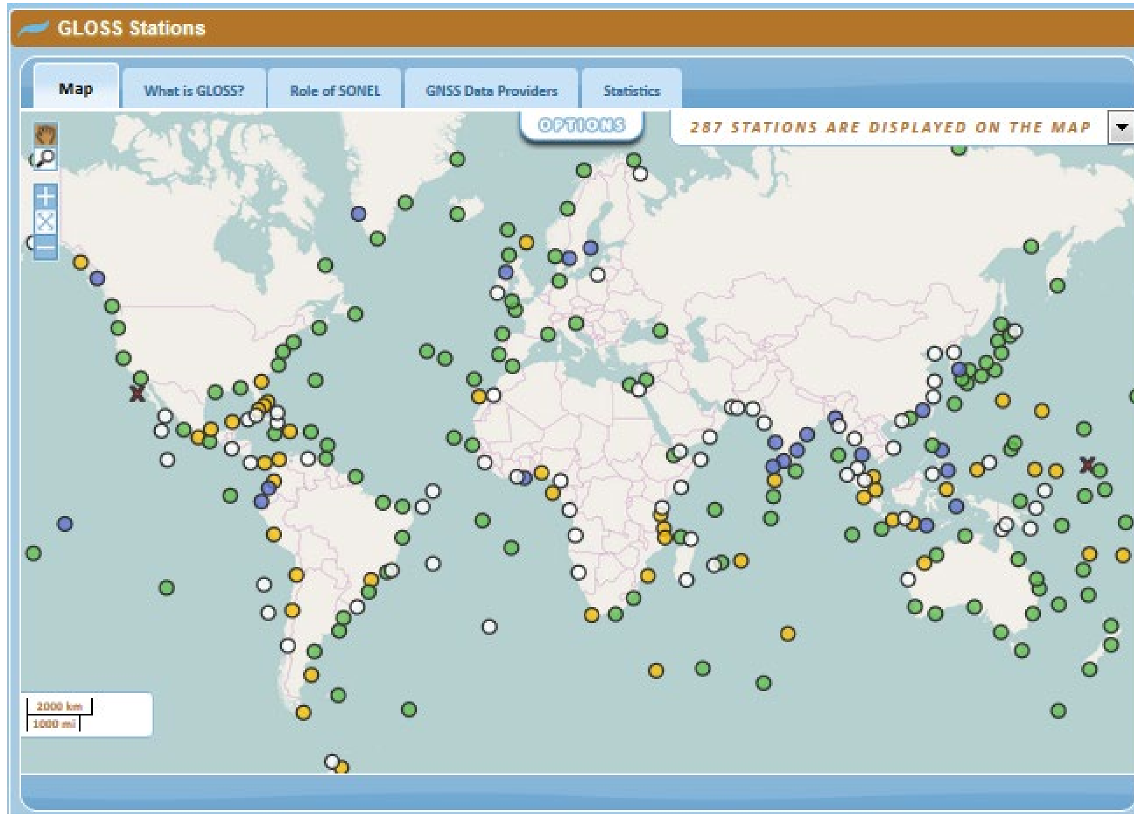
Zonal bias and peak differences reach **0.2 mm/yr at high latitudes**

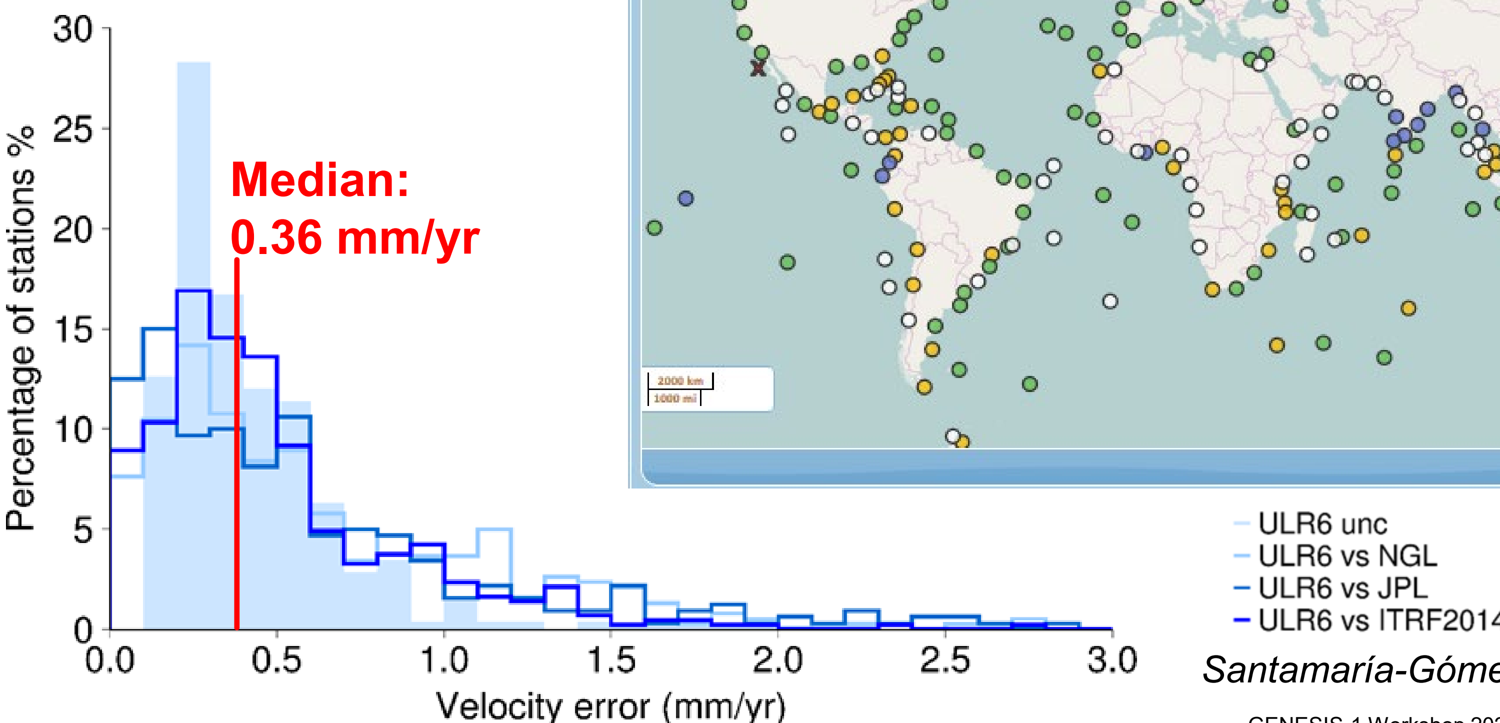
Lemoine et al., Status of POD for Altimeter Satellites at GSFC, OSTST 2016

Tide Gauge Vertical Motions

Availability of GPS@TG results: www.sonel.org

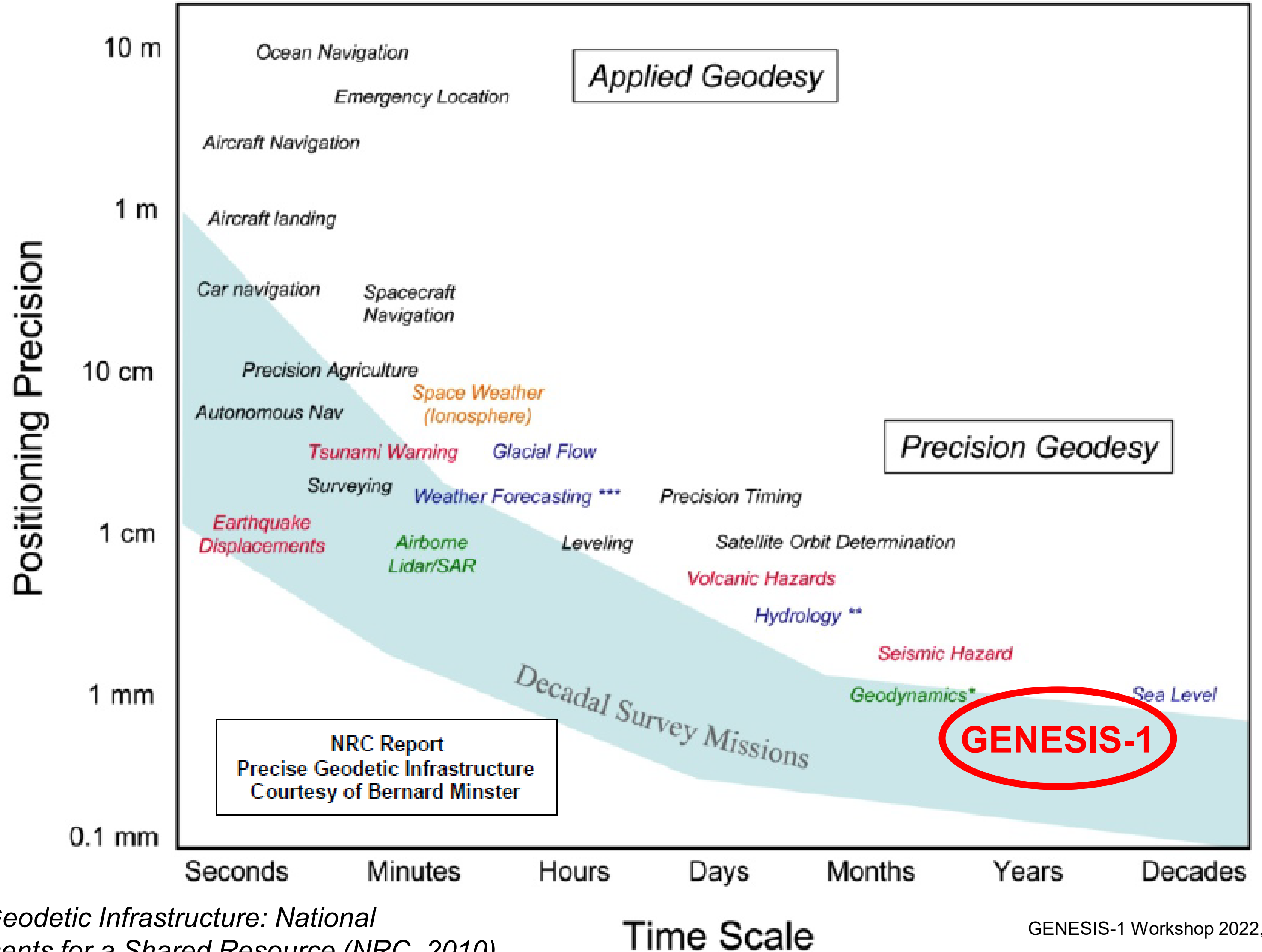
The University of La Rochelle (ULR6) solution





Santamaría-Gómez et al., 2016

GENESIS-1: new step to quantify sea level rise



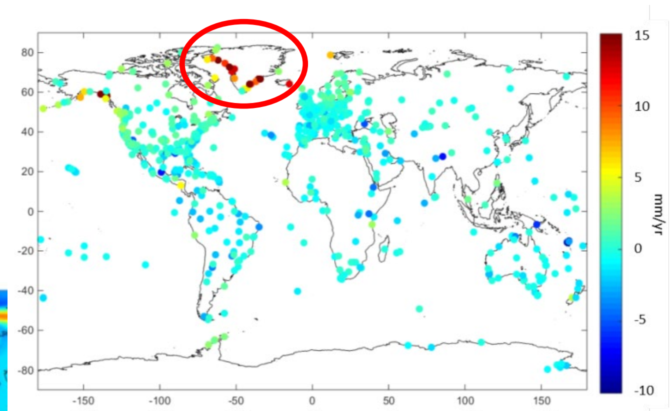
Precise Geodetic Infrastructure: National Requirements for a Shared Resource (NRC, 2010)

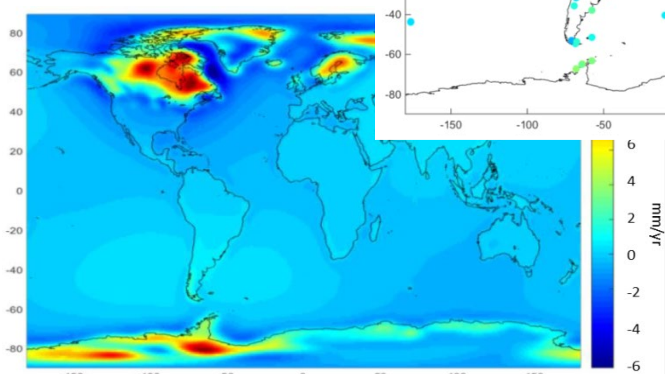
ITRF and GIA model comparison

Geophysical processes affect TRF velocities:
- plate tectonics
- glacial isostatic adjustment
- present ice melting (loading)

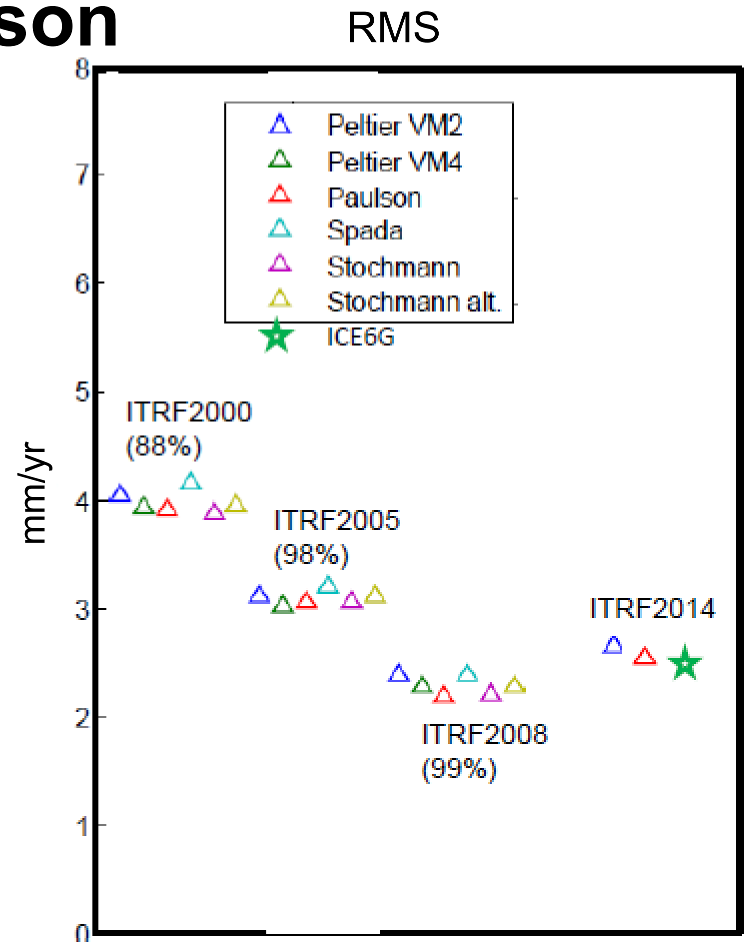
ITRF2014 – GNSS vertical velocities:
- merge past and present climatic signatures

Difference between ITRF2014 vertical velocities and ICE6G velocities





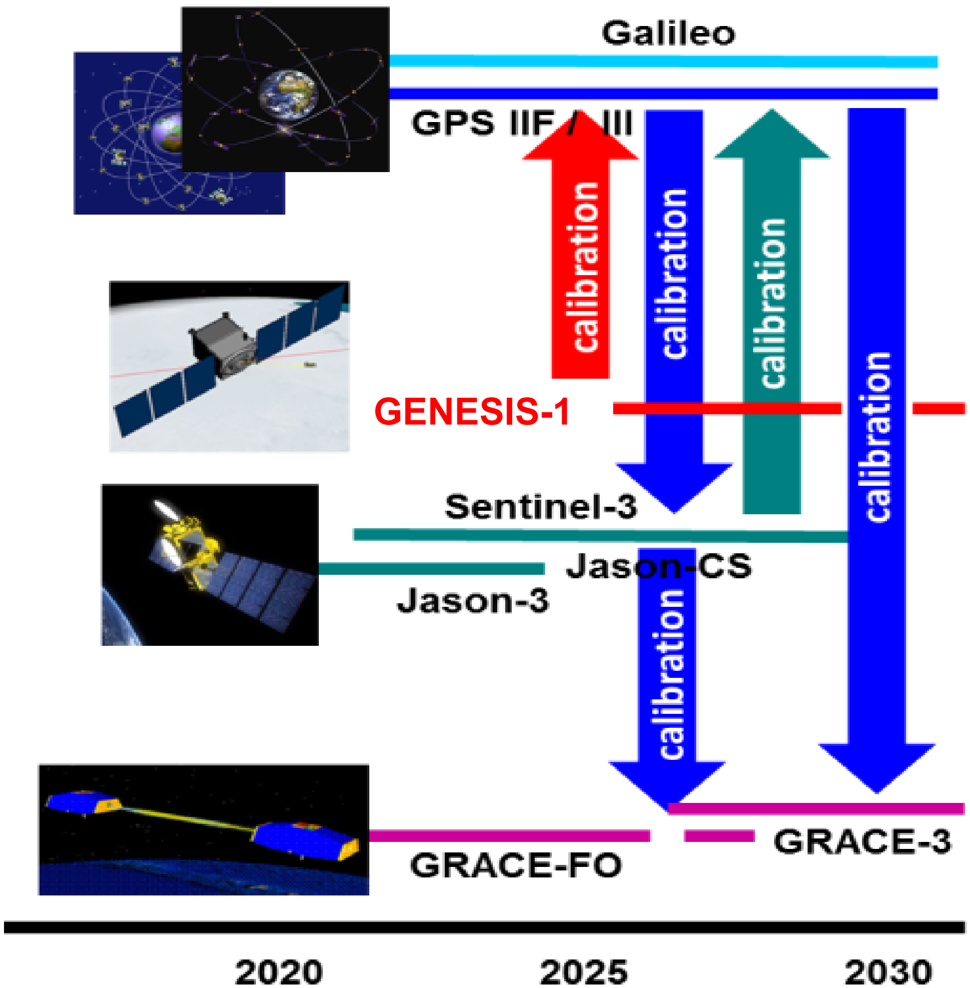
Vertical velocities induced by the post-glacial rebound (ICE6G ; Peltier et al., 2016)

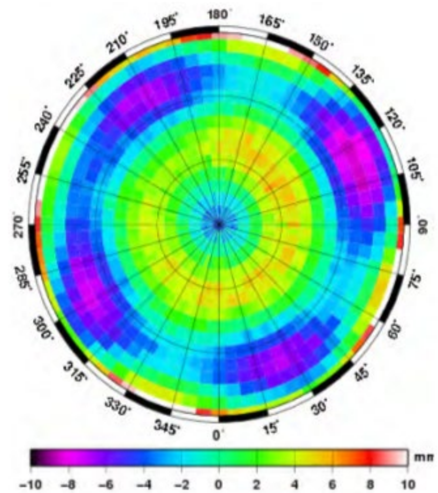


Quadratic means between modelled and observed vertical velocities for different ITRF solutions

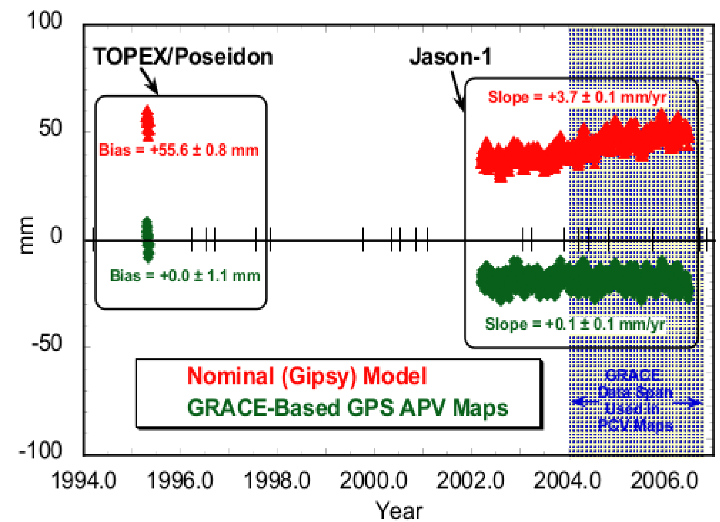
Métivier et al., 2016

Calibration of GNSS antennas for better positioning





GNSS antenna pattern calibration



Improving radial biases in altimetry

GENESIS-1: Conclusions

- Improving the TRF precision by a unique system, integrating all space geodetic techniques on one platform, with orbit and calibration optimized, in order to meet the present-day science requirements. The TRF available today needs an improvement by a factor of about 5, as a minimum (recent ITRF2020 results).
- The accuracy of the TRF impacts directly the orbit quality of altimetry satellites and land motion estimation at tide gauges and consequently the quantification of the sea level variations in space and time.
- More generally, global studies on the mass budget of the earth-ocean-atmosphere system and on global tectonics require an accurate TRF.
- “Earth observations must become more precise. We require information about current trends at a scale measured in millimeters to detect changes of the Earth system with sufficient precision, to meet society’s future needs”, *Report of the UN expert committee on "Global Geospatial Information Management“, 2014.*

Remarks concerning the GENESIS-1 Science

- Stress the benefits for the radar and laser altimetry satellite missions and for the various Sentinel missions (e.g. Sentinel-1, 3, 6)
- Mention the usefulness for the SAR missions (e.g. absolute positioning, earthquakes, volcanoes)
- Mention the term "fundamental site in space" (if not done yet) connecting all the sites
- Argue that GENESIS-1 is the only feasible way to reach the required improvement of the TRF
- Mention the Living Planet Scientific Challenges GENESIS-1 will be contributing to (C2-C5, L2, L3, O1, O2, O5, G1-G4)
- Mention tide gauges with GNSS and GNSS leveling, as they are also profiting from GENESIS-1
- Discuss the issue of systematic errors between the techniques (e.g. VLBI and SLR scale, local ties, etc.)