GENESIS

Co-location of geodetic techniques in space

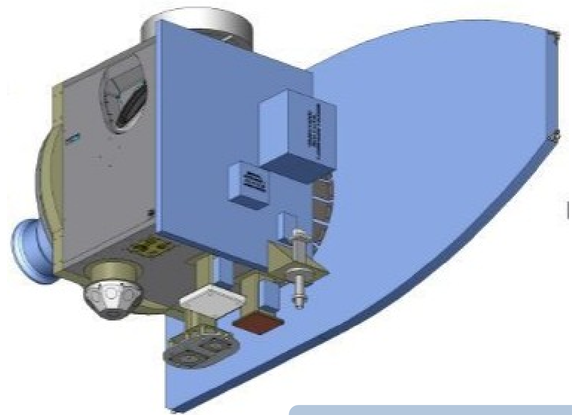
Pacôme DELVA

SYRTE, Paris Observatory-PSL, Sorbonne Université, CNRS, LNE

Former member of the Galileo Scientific Advisory Committee (ESA)

On behalf of the white paper contributors

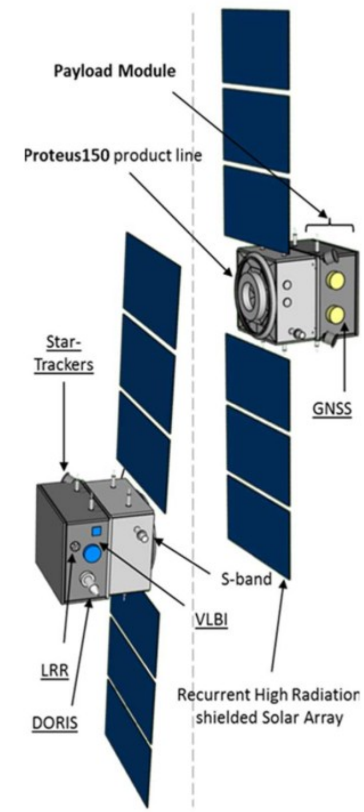
History: from GRASP to GENESIS



GRASP (2011, 2015) – proposals to NASA

850 x 1350 km Sun-Synchronous Orbit

4 geodetic techniques co-location

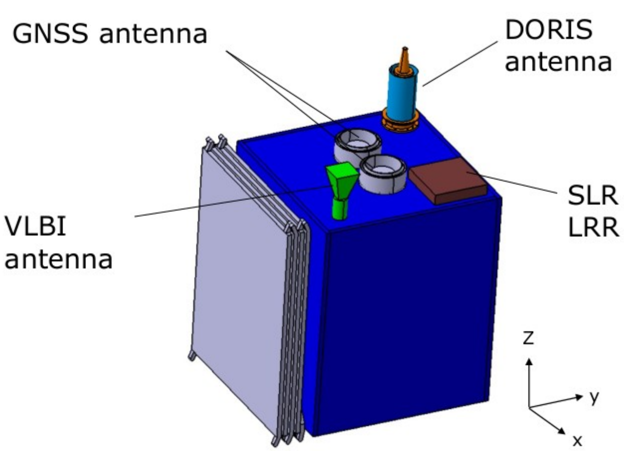


E-GRASP (2016, 2017) – proposals to ESA

762 x 7472 km highly eccentric Orbit

4 geodetic techniques co-location

Add. payloads: accelerometer and atomic clock



GENESIS (2022) – funded in ESA FutureNAV programme

6000 km circular MEO Orbit

4 geodetic techniques co-location

Add. payloads (optional): accelerometer and A-LRR

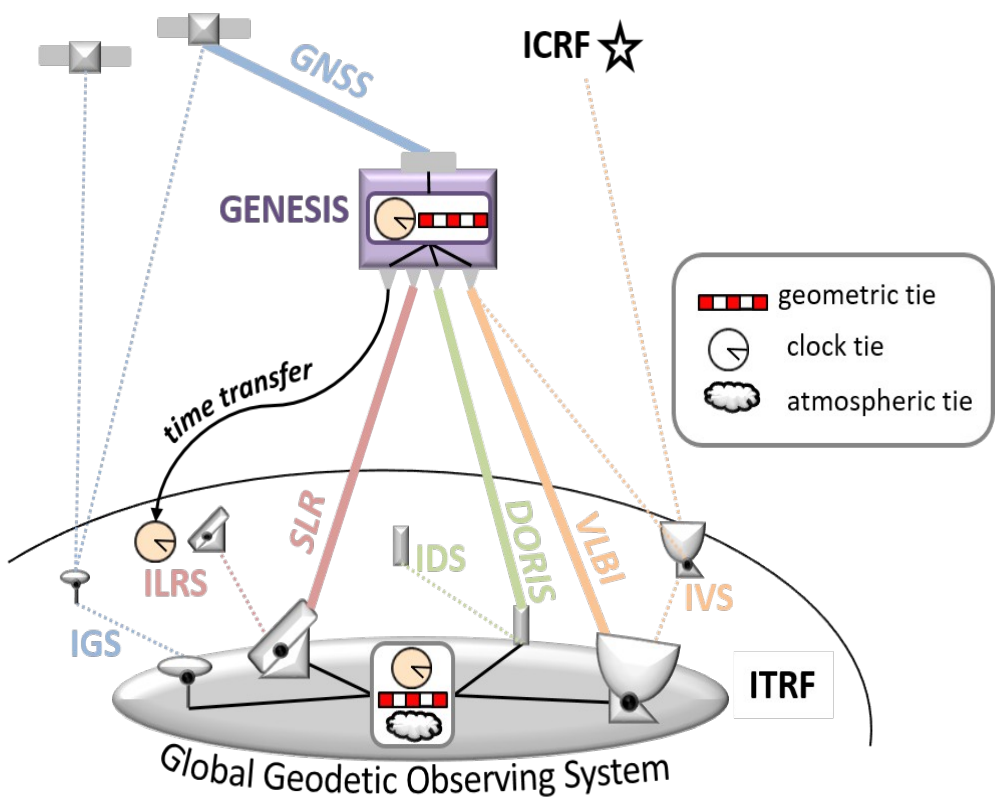
GENESIS: mission concept

Obj. 1

Improve ITRF (International Terrestrial Reference Frame) **accuracy and stability**, aiming for a parameter accuracy of 1 mm and a stability of 0.1 mm/year

Obj. 2

Obtain a **direct link between the ITRF and the ICRF** (International Celestial Reference Frame)



In-orbit co-location of the 4 space geodetic techniques on a highly calibrated and stable platform: GNSS, SLR, DORIS and VLBI

- Circular orbit at 6000 km altitude and quasi-polar inclination (preliminar)
- Maximum development time of 4 years, small satellite platform
- 2-3 year mission duration (4 years nominal lifetime for the satellite)

Geodetic infrastructure including GENESIS

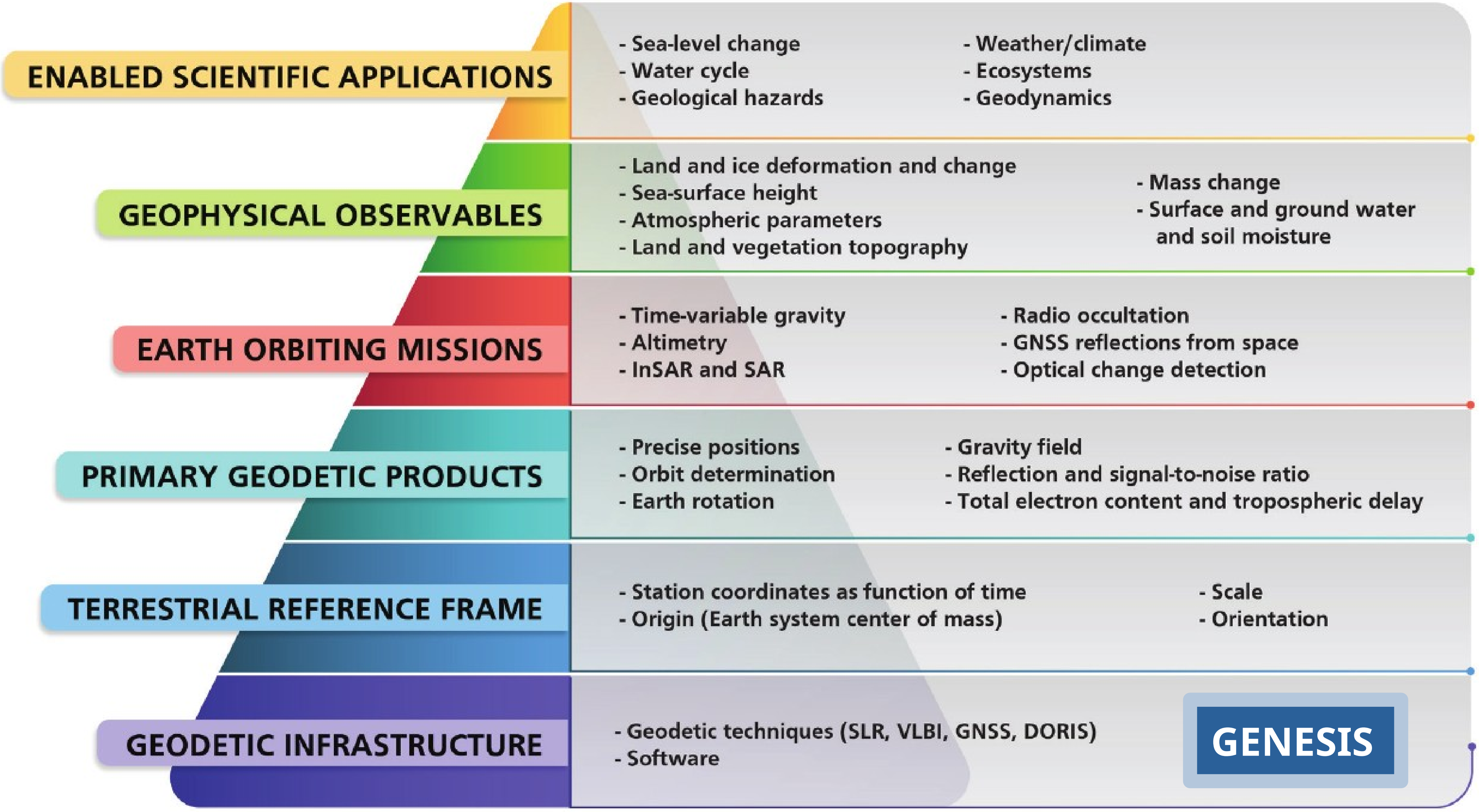


Illustration of how the geodetic infrastructure is connected to enabled scientific applications (National Academies of Sciences, U.S., 2020).

GENESIS Science Objectives

P. Delva et al., Earth, Planets and Space, vol. 75, no. 1, p. 5
open access

Reference Frames and Earth Rotation

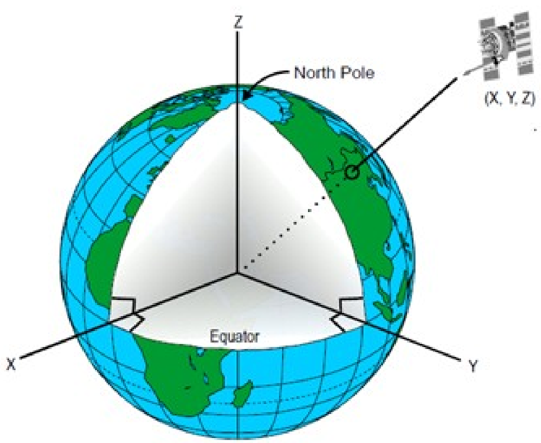
- Improvement of the ITRF
- Unification of reference frames and Earth rotation

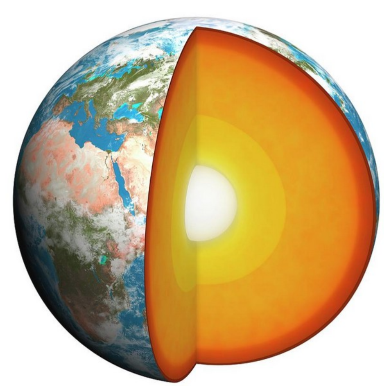
Earth Sciences

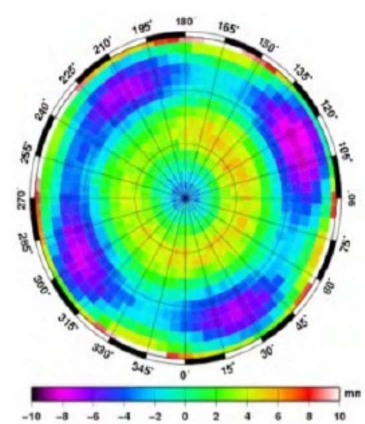
- Gravity field
- Altimetry
- ice mass losses
- Geodynamics, geophysics, natural hazards
- Earth's energy imbalance
- atmosphere

Positioning and Navigation

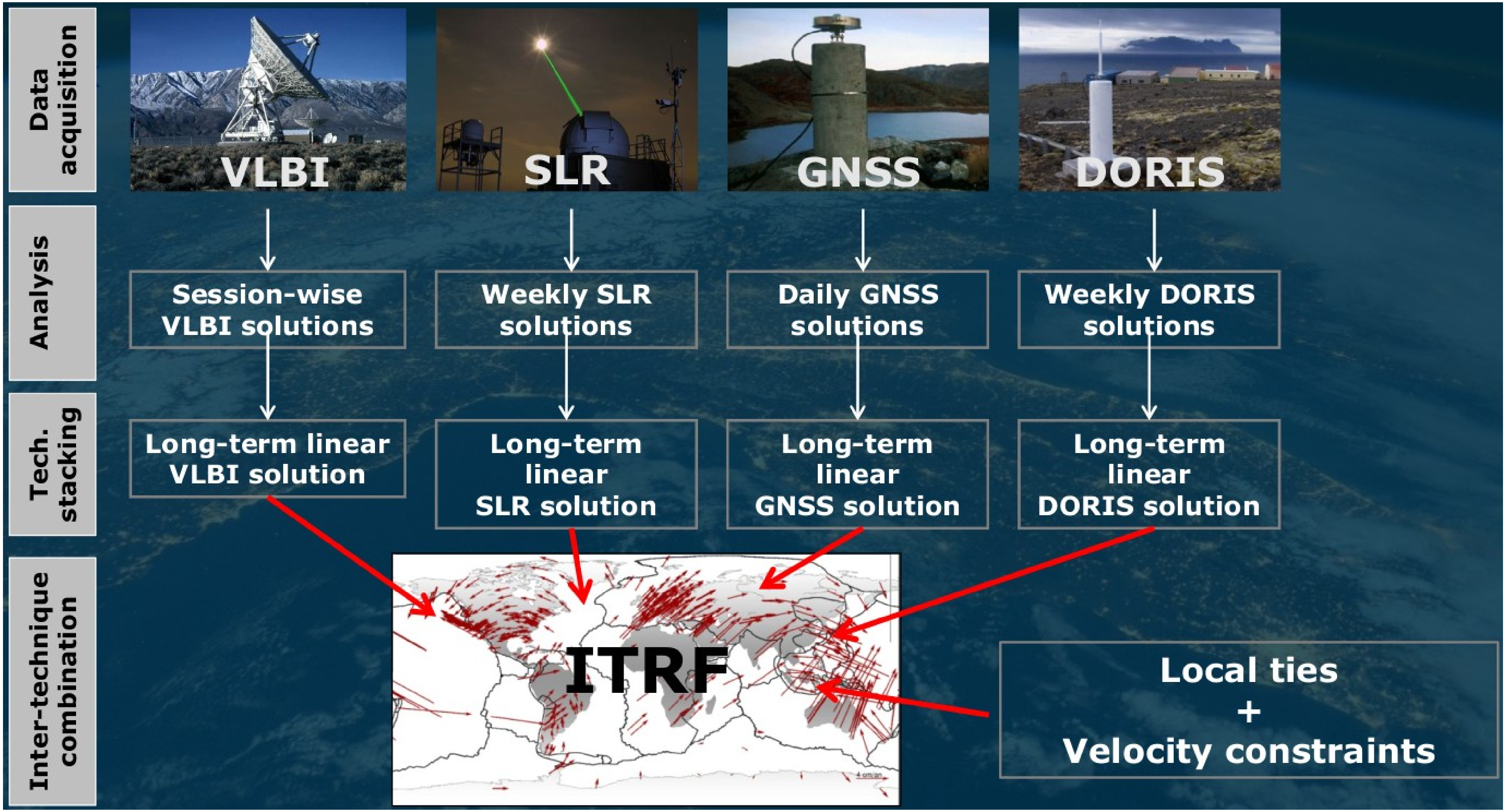
- GNSS orbits and positioning
- GNSS antenna phase center calibration
- Positioning of satellites and space probes





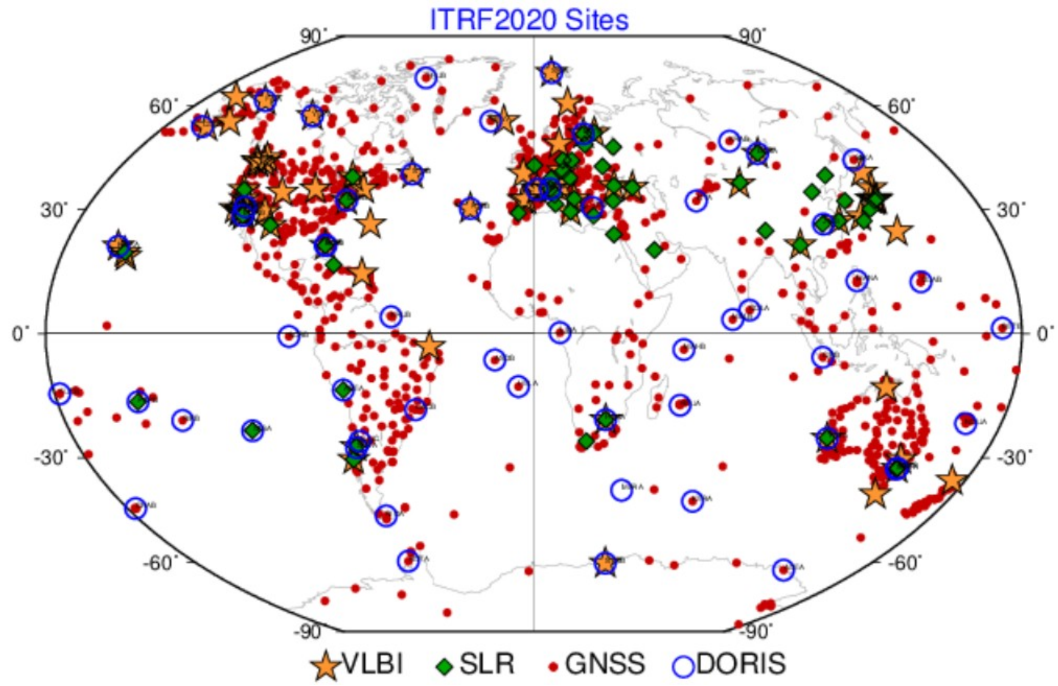


International Terrestrial Reference Frame (ITRF) elaboration



Quality of ITRF Co-locations on Ground

- **ITRF affected by accuracy of local ties measurements**
  - In ITRF 2020 more than 50% measured ties have discrepancies > 5 mm
  - Caused mainly by technique systematic errors
- The **number and distribution of geodetic sites over the globe is inhomogeneous and unfrequently updated**
  - SLR & VLBI co-locations (~ 10 sites) are poorly distributed but fundamental for the frame definition

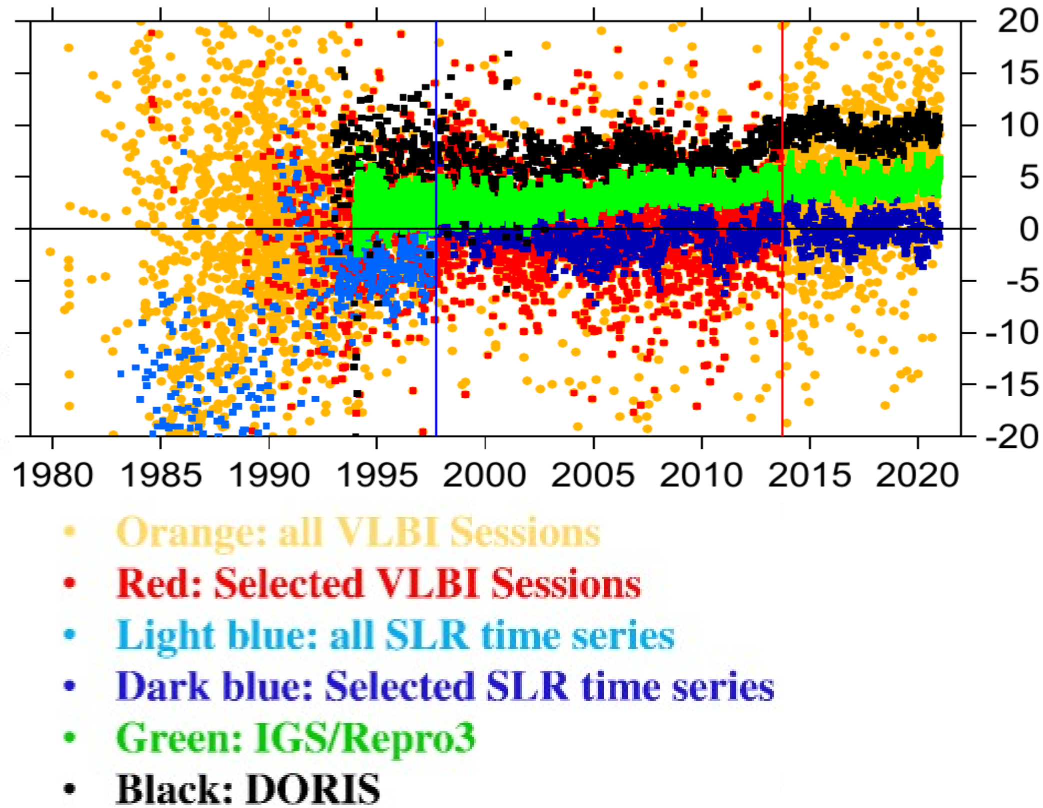


Percentage of tie discrepancies

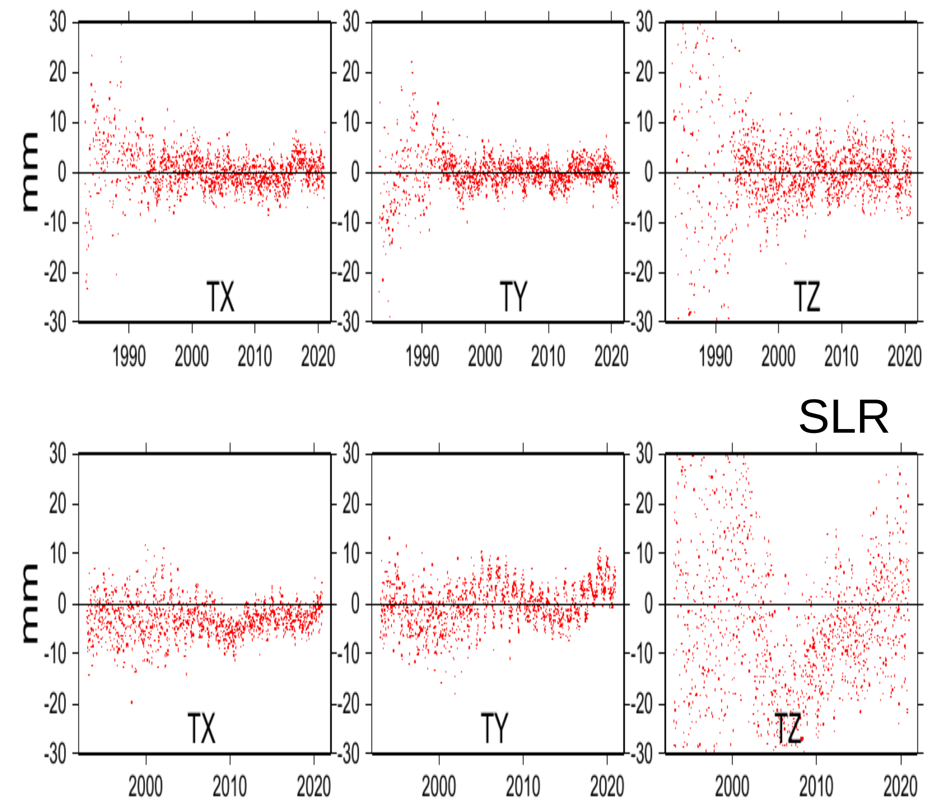
	< 5 mm	> 5 mm
GNSS – VLBI (77)	50 %	50 %
GNSS – SLR (53)	36 %	64 %
GNSS – DORIS (123)	32 %	68 %

Systematic effects in the ITRF

ITRF Scale (in ppb)



ITRF Origin (Geocenter)



SLR

DORIS

Current accuracy and stability of the ITRF long-term origin achievable today using SLR data is at the level of or better that 5 mm in position and 0.5 mm/yr in time variation. A factor of at least 5 will be needed to reach the GGOS goal.

Z. Altamimi et al., Journal of Geodesy (2023) 97:47

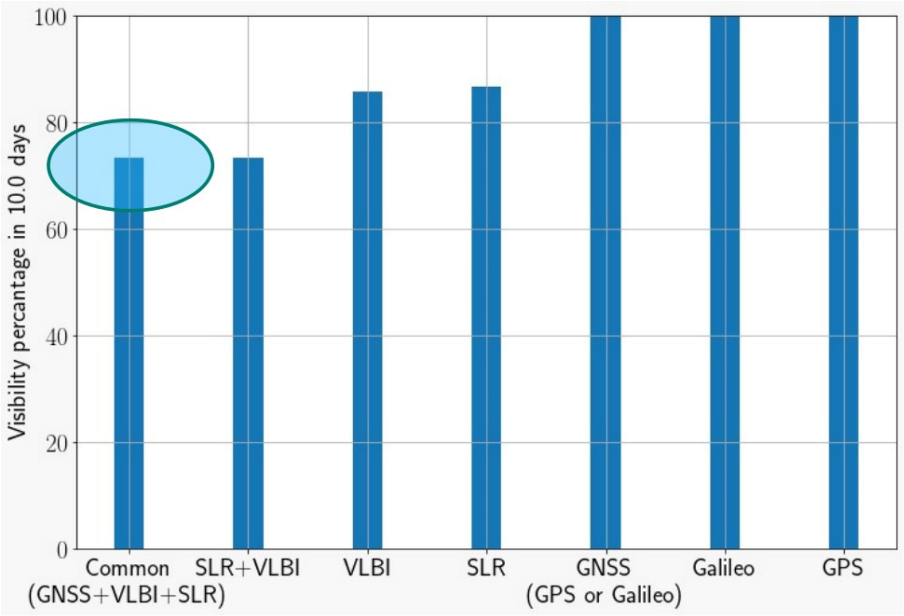
Motivation for GENESIS concerning ITRF

GGOS (Global Geodetic Observing System) requirements for the ITRF (1 mm accuracy, 0.1 mm/yr stability) are far from being met

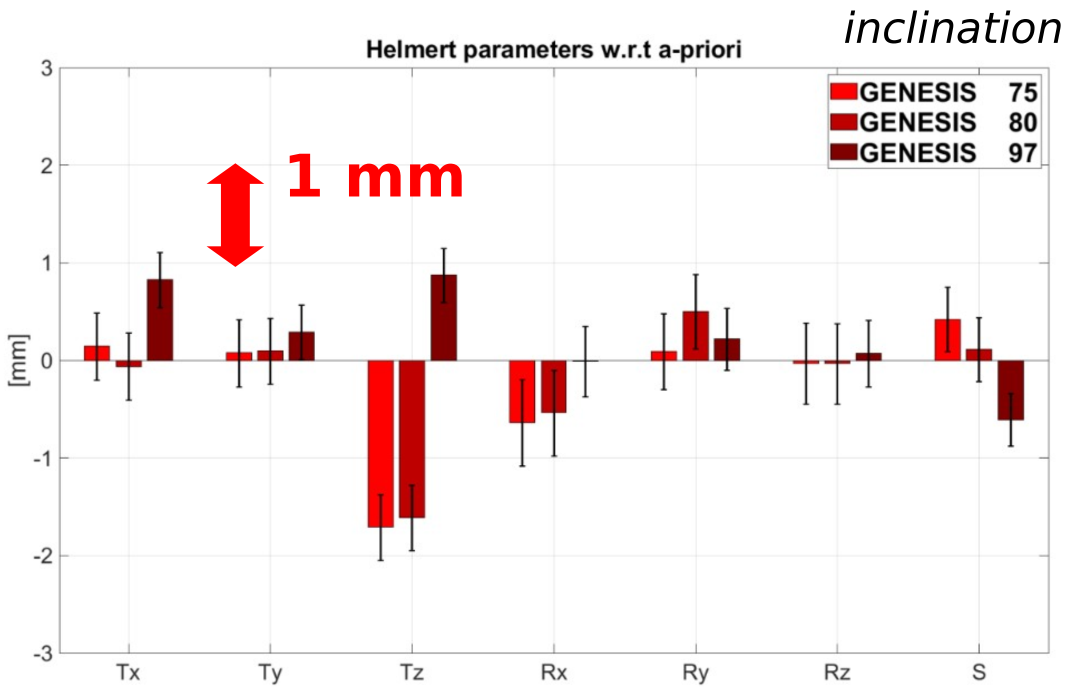
- **Main limiting factors of the ITRS realization:**
  - Number and distribution of **geodetic sites** (SLR and VLBI)
  - Number and accuracy of the measurements of **local ties** between the reference points of different techniques
  - Each space geodetic technique suffers from its own **systematic effects:** range biases, phase centers, multipath, gravitational sag, tropospheric refraction, quasar structures, …
- **Fundamental improvement with GENESIS:**
  - Complementary, highly accurate **co-location** of all four space geodetic techniques in space, on the same satellite platform
  - Particular attention paid to the **time and space metrology** on board

Simulations: ITRF objectives

Several institutes assessed the possibility to reach the ITRF objectives with a GRASP like satellite through simulations: JPL (GRASP), IGN/IPGP/CNES/SYRTE (E-GRASP, GENESIS), ROB/GFZ/ESA (GENESIS)

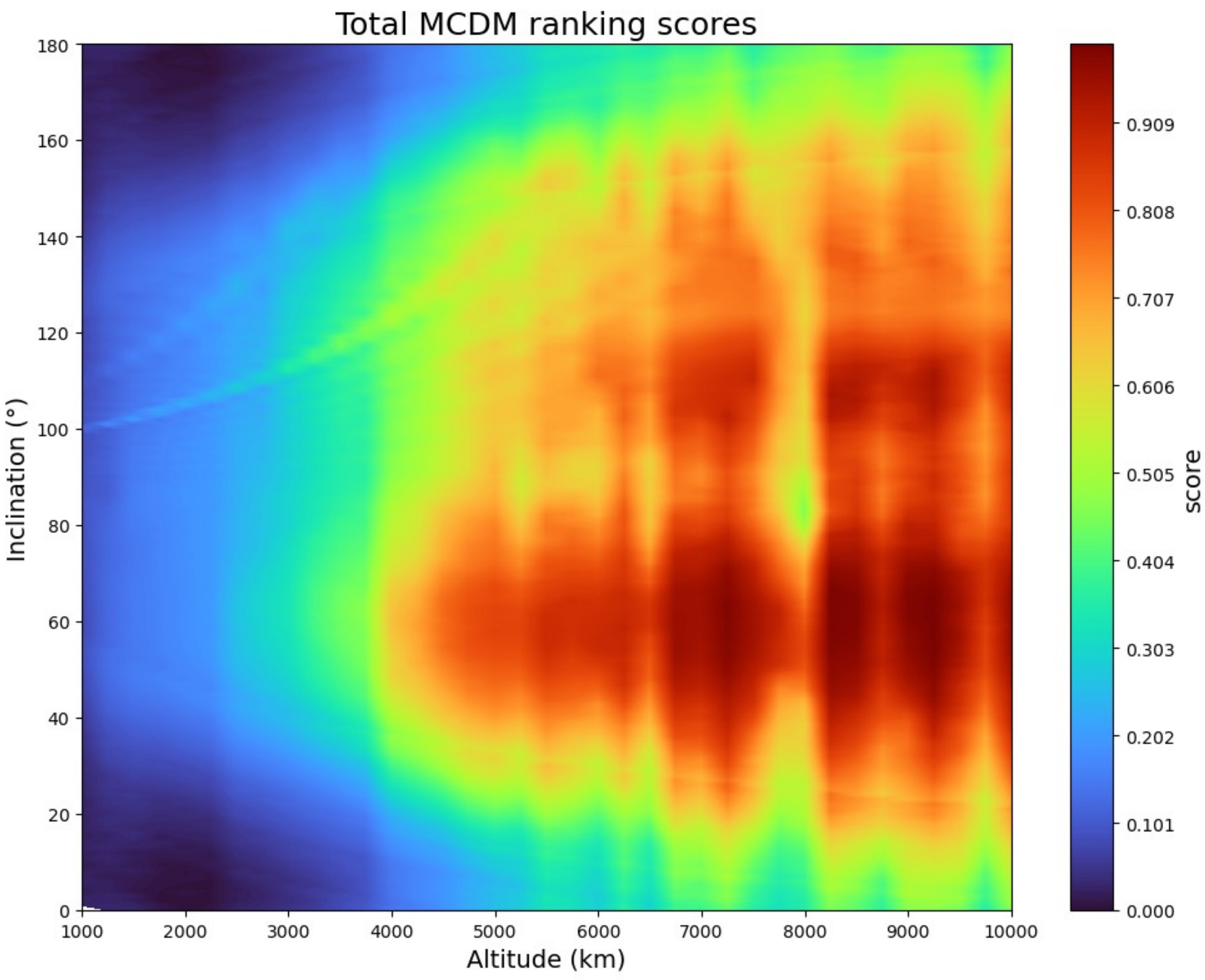


GENESIS common Visibility of GNSS, VLBI, DORIS and SLR around 75% of the time, 10 days simulation (ROB)



GENESIS Helmert parameters of the VLBI-only solution with respect to the a-priori reference frame (GFZ)

Simulations: choice of the GENESIS orbit



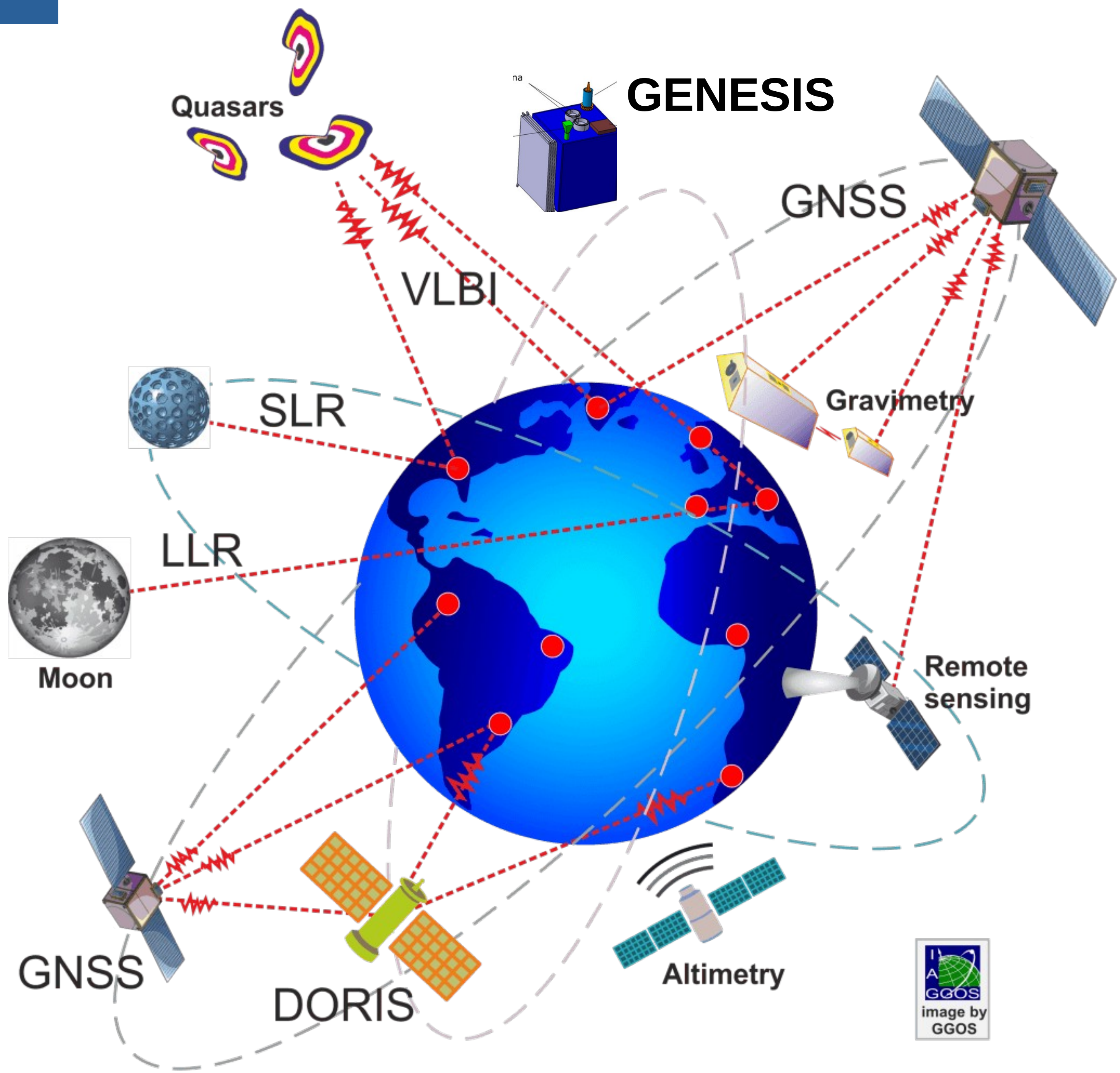
IGN/IPGP/CNES/SYRTE

Scores based on Multi-Criteria Decision Making (MCDM) methods

(preliminary results)

- MCDM gives the best compromise for all chosen criteria
- Orbits at 60° inclination preferred
- For the chosen criteria the best orbit is at 60° inclination and 9250km altitude

Earth system observations synergies

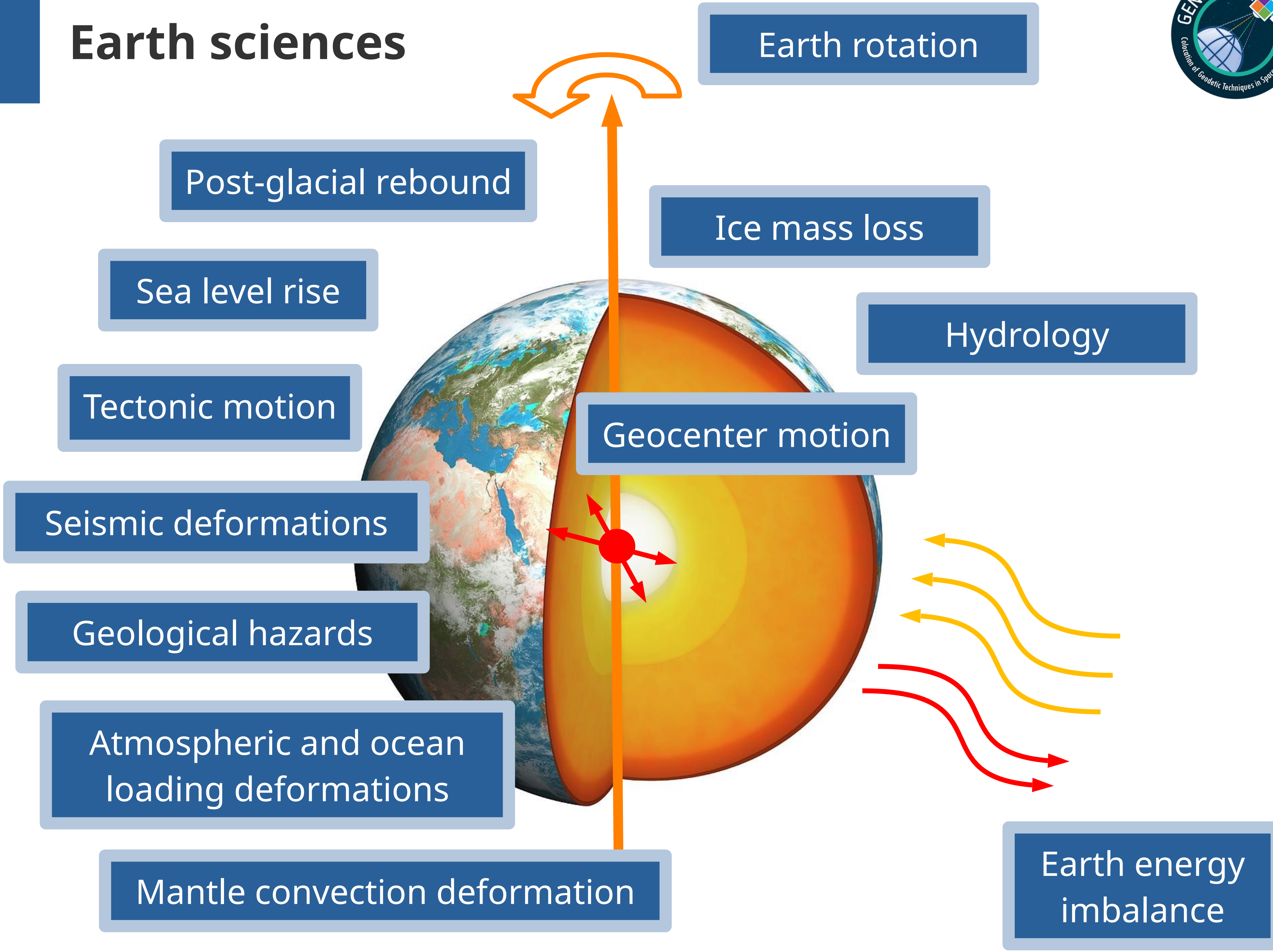


Geometry
reference systems and orbits (VLBI, SLR, GNSS, Doris, GENESIS, …)

Gravimetry
geoid (gravimeters, GRACE-FO, GOCE, …)

Altimetry/InSAR
topography, deformations (Sentinel-x, …)

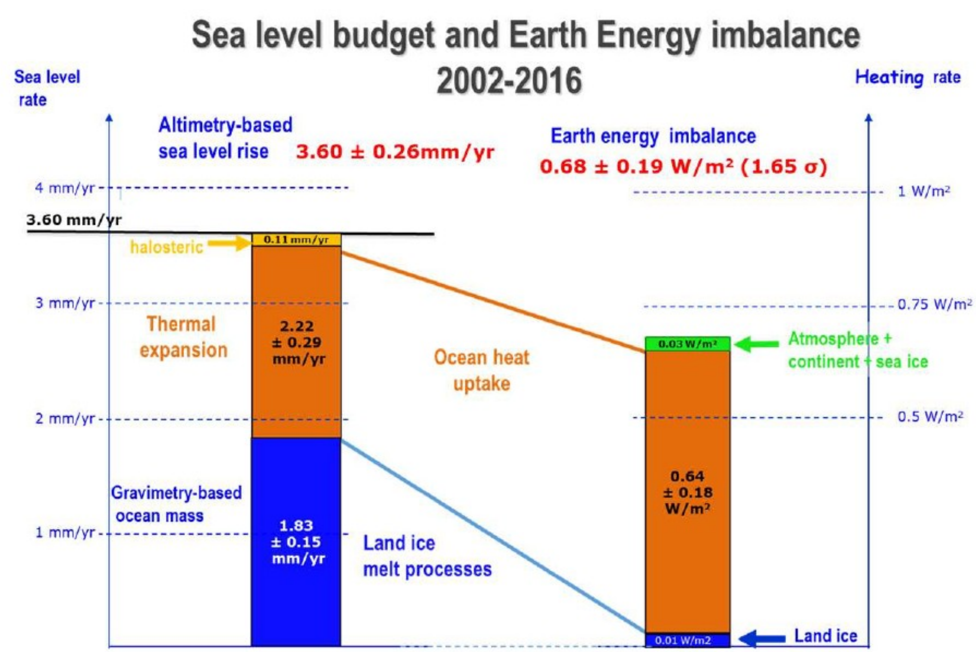
Earth sciences



Effect of uncertainty in the geocenter estimate

The uncertainty in geocenter dominates (GENESIS workshop, April 2022, A. Blazquez & B. Meyssignac) :

- The uncertainty in the gravimetry-based **ocean mass trend** and the Earth global water budget
- The uncertainty in the 20 yr trend of altimetry-based **global-mean sea-level**
- The uncertainty in the geodetic-based **Earth Energy Imbalance (EEI)**



Now: ±0.17 W·m^{-2} in 18-yr mean EEI
Goal: ±0.10 W·m^{-2} in 20-yr mean EEI & trends in EEI

mmSLE/yr	Ocean mass	Greenland	Antarctica	LWS
geocenter	**0.19**	<0.01	0.03	**0.22**
Center	**0.06**	0.01	**0.05**	**0.06**
GIA	0.03	0.03	0.01	0.04
C20	0.01	<0.01	<0.01	0.02
filter	0.01	<0.01	0.02	0.01
TOTAL	0.24	0.03	0.05	0.26

GRACE-based global water budget, Source of the uncertainties in the trends (mm/yr)

Participation of scientific community

June 2023	Oct 2023	Q4 2023	Nov/Dec 2023
GSAC 37	ITT closure	Scientific Exploitation Gap analysis	GENESIS Science Workshop

A **small team of scientists** with a Lead Coordinator will be nominated by ESA

- Participation to **requirements consolidation** in Phase A
- Support ESA in the **follow up of the industrial activities**, with emphasis on instrument and platform developments
- **Analysis of mission performance** and the mission contribution towards target ITRF improvement
- **Preparation of the scientific data exploitation**, covering any gaps in algorithms, tools or ground infrastructure required
- Preparation and execution of required **ground-based campaigns** (VLBI, SLR)

Presentation of Sara Gidlund at the CNES GENESIS workshop 19/19/2023

Conclusions

- Primary objective of the GENESIS mission: **improve the accuracy and stability of the realization of the ITRS** to GGOS requirements (1mm acc. and 0.1mm/year stab.)
- Critical importance of the ITRF and the entire geodetic infrastructure and products for **many scientific applications in Earth and navigation sciences**, in particular in the context of climate change
- These goals are **endorsed by a large community of scientists and industries** as well as various authorities (IAG, UN, ...)
- GENESIS will **improve the products of several other missions** such as gravimetry and altimetry satellites
- CDF of ESA has shown the **feasibility of the GENESIS** mission within the ESA GENESIS defined program boundaries, with a target launch date in 2027