GENESIS: Collocation in space of four Geodetic Techniques

Dr Javier Ventura-Traveset, Head of Navigation Science Office, ESA Navigation Directorate
Dr Werner Enderle, Head of Navigation Support Office, ESA Operations Directorate

European Space Agency

GENESIS Mission Objective (Proposed for CM 22)

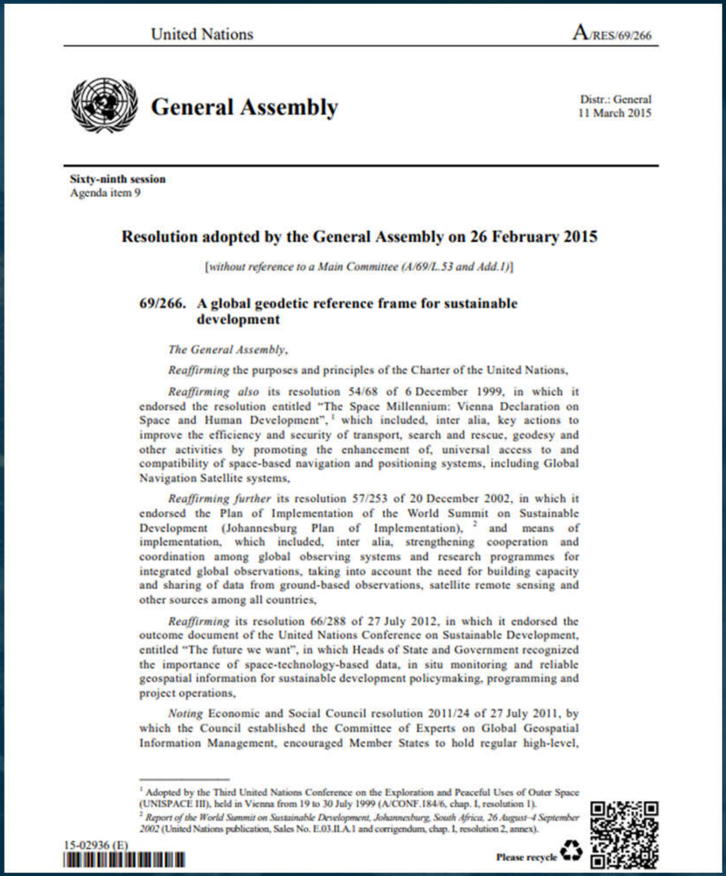
Program Objectives: First ever on-board collocation of **four space GNSS/Geodetic techniques** providing a **major improvement of the Earth International Terrestrial Reference Frame** accuracy/stability **supporting GGOS goals and the UN Resolution** on sustainable development, (A/RES/69/266).

ITRF Targets

- **Accuracy: 1 mm**
- **Stability: 0.1 mm per year**

UN Resolution A/RES/69/266: A global geodetic reference frame for sustainable development

The importance of accurate and stable reference frames is specifically highlighted in the UN resolution on "Global Geodetic Reference Frame (GGRF) for sustainable development" (A/RES/69/266, United Nations General Assembly, 2015), where UN Member States are invited to support the geodetic infrastructures and enhance the global geodetic reference frame, both being at the core of the mission of the GENESIS Programme.



United Nations — A/RES/69/266

General Assembly

Distr.: General
11 March 2015

Sixty-ninth session
Agenda item 9

Resolution adopted by the General Assembly on 26 February 2015

[without reference to a Main Committee (A/69/L.53 and Add.1)]

69/266. A global geodetic reference frame for sustainable development

The General Assembly,

Reaffirming the purposes and principles of the Charter of the United Nations,

Reaffirming also its resolution 54/68 of 6 December 1999, in which it endorsed the resolution entitled "The Space Millennium: Vienna Declaration on Space and Human Development",[1] which included, inter alia, key actions to improve the efficiency and security of transport, search and rescue, geodesy and other activities by promoting the enhancement of, universal access to and compatibility of space-based navigation and positioning systems, including Global Navigation Satellite systems,

Reaffirming further its resolution 57/253 of 20 December 2002, in which it endorsed the Plan of Implementation of the World Summit on Sustainable Development (Johannesburg Plan of Implementation),[2] and means of implementation, which included, inter alia, strengthening cooperation and coordination among global observing systems and research programmes for integrated global observations, taking into account the need for building capacity and sharing of data from ground-based observations, satellite remote sensing and other sources among all countries,

Reaffirming its resolution 66/288 of 27 July 2012, in which it endorsed the outcome document of the United Nations Conference on Sustainable Development, entitled "The future we want", in which Heads of State and Government recognized the importance of space-technology-based data, in situ monitoring and reliable geospatial information for sustainable development policymaking, programming and project operations,

Noting Economic and Social Council resolution 2011/24 of 27 July 2011, by which the Council established the Committee of Experts on Global Geospatial Information Management, encouraged Member States to hold regular high-level,

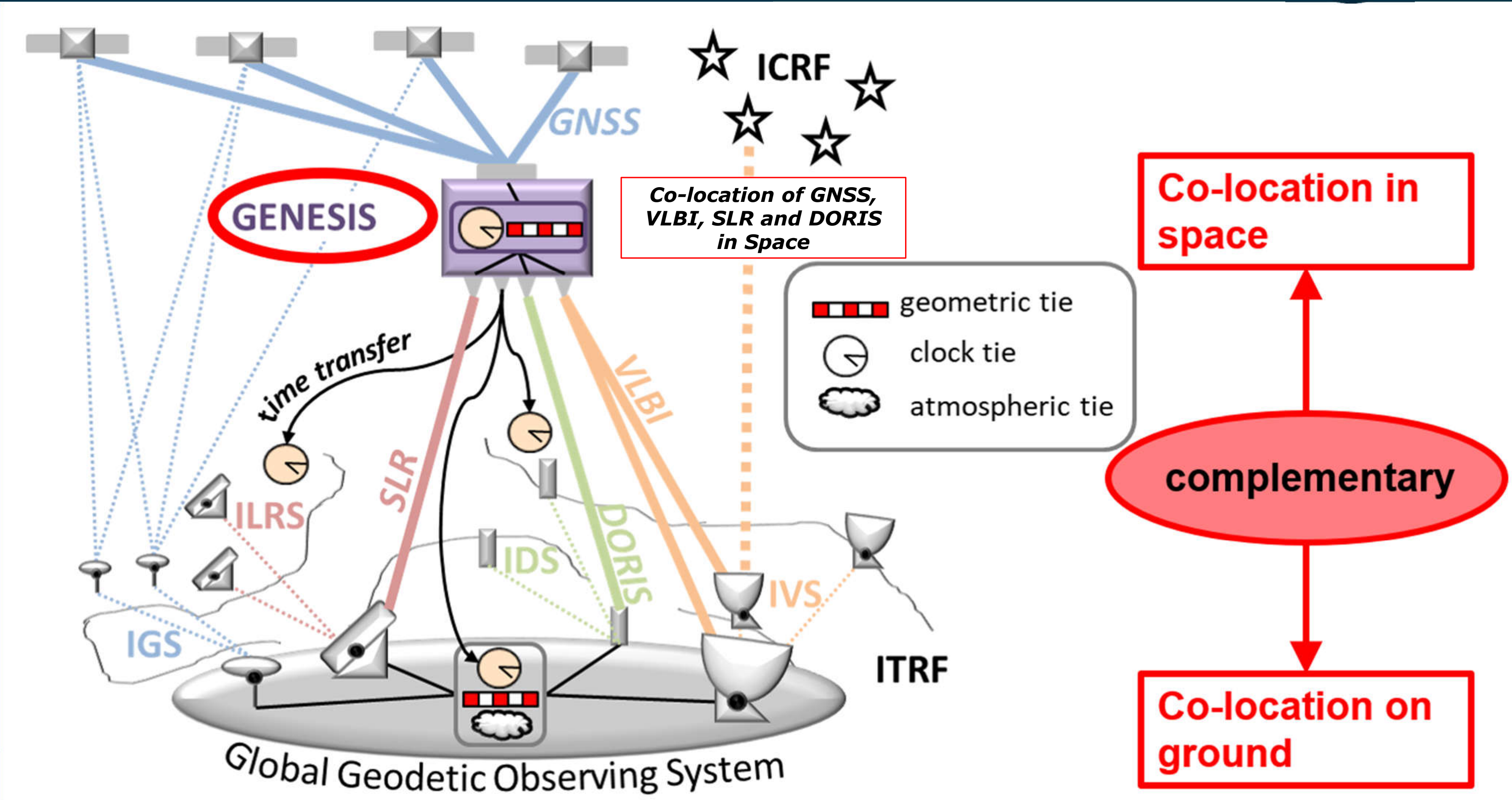
[1] Adopted by the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna from 19 to 30 July 1999 (A/CONF.184/6, chap. I, resolution 1).

[2] *Report of the World Summit on Sustainable Development, Johannesburg, South Africa, 26 August–4 September 2002* (United Nations publication, Sales No. E.03.II.A.1 and corrigendum, chap. I, resolution 2, annex).

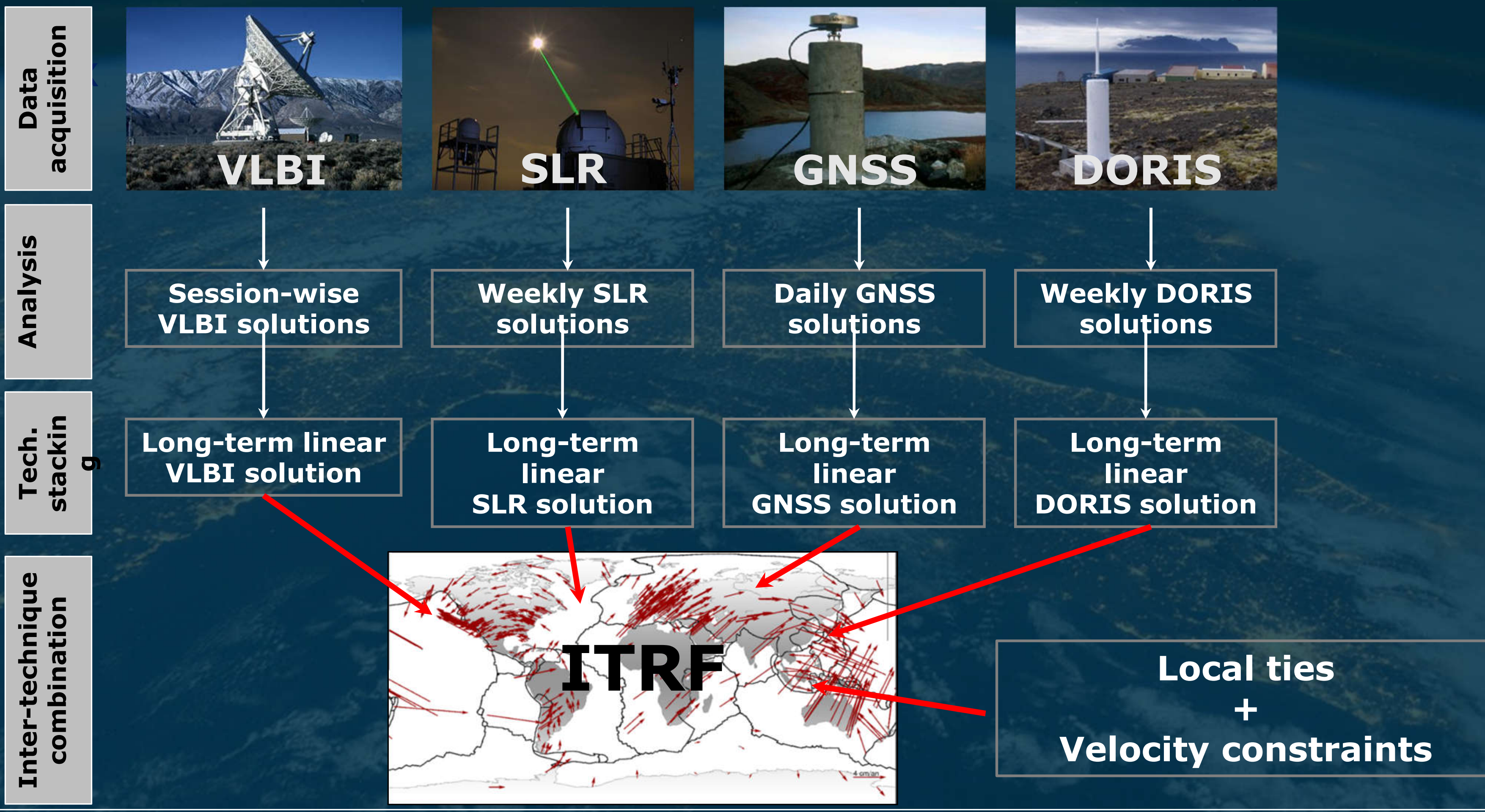
15-02936 (E)

Please recycle

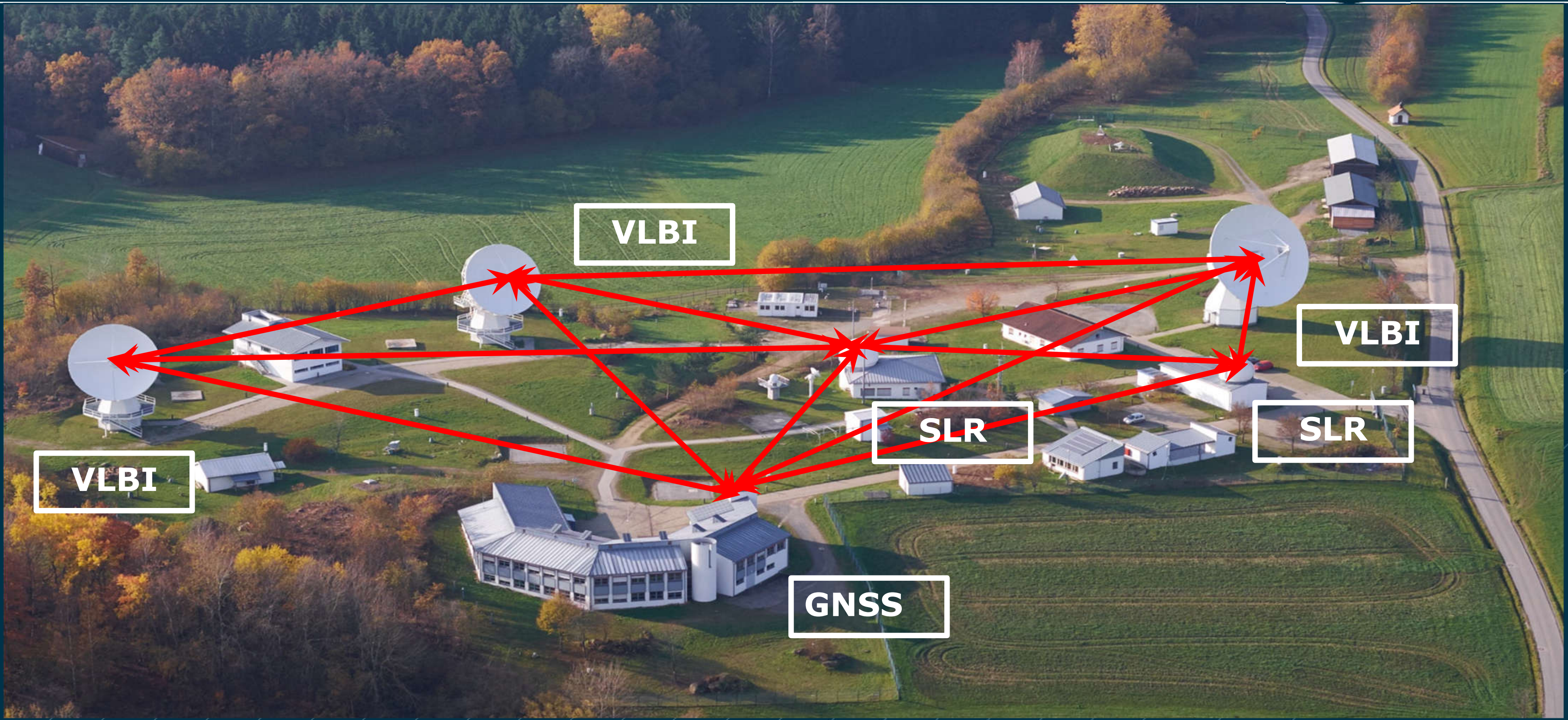
GENESIS MISSION: GEODESY AND GEOPHYSICS



International Terrestrial Reference Frame (ITRF) elaboration



Example of multi-geodetic reference site (Wettzell)

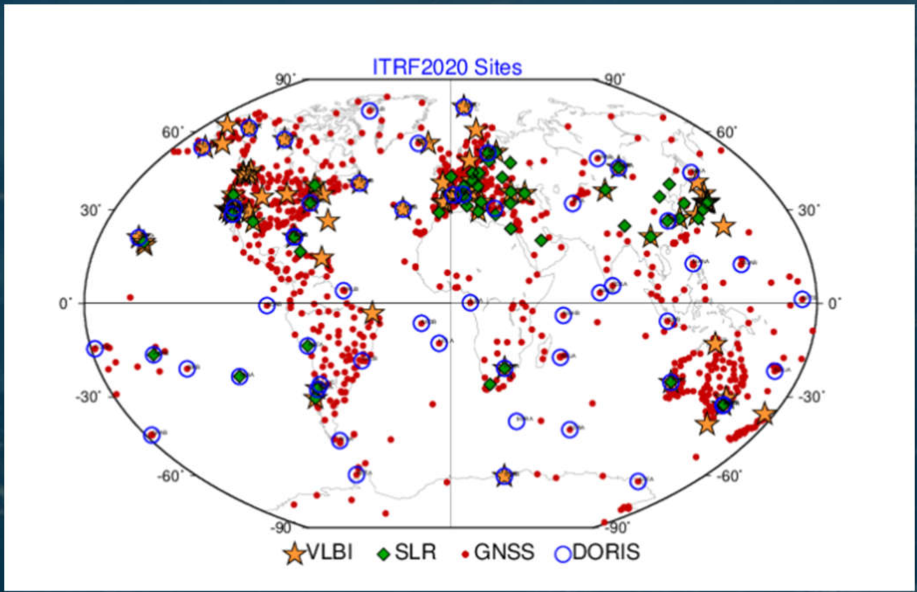


Co-location fundamental station Wettzell, Bavaria

< 1 mm required

Terrestrial (local) Ties and systematics modelling challenges

ITRF 2020



Source: Dr. Z. Altamimi, GENESIS Science Workshop, April 2022

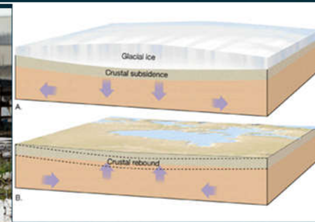
1. ITRF **affected by accuracy of local ties measurements and systematic errors. (e.g. In ITRF 2020 more than 50% measured ties have discrepancies > 5 mm)**
2. In addition**, the number and distribution of these sites over the globe is Inhomogeneous and Unfrequently updated**

PROPOSAL: With GENESIS we will co-locate and combine **for the first time ever** the four space-geodetic techniques GNSS, SLR, VLBI, and DORIS aboard a single fully-calibrated satellite, establishing precise and stable ties between the key geodetic techniques.

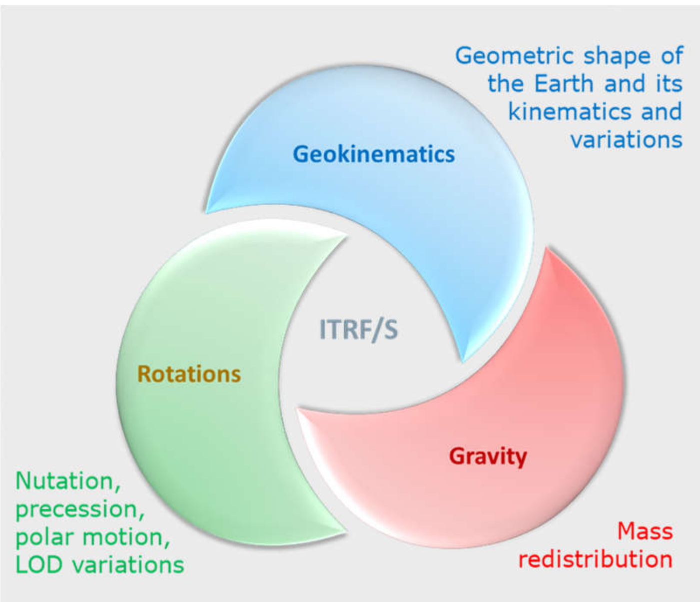
A dynamic space geodetic observatory which will contribute to determine all the instrumental biases inherent to the different Geodetic observing techniques simultaneously

ITRF The foundation for all space- and ground-based observations in Navigation and Earth Science



Credits: UNGGRF http://www.unggrf.org/



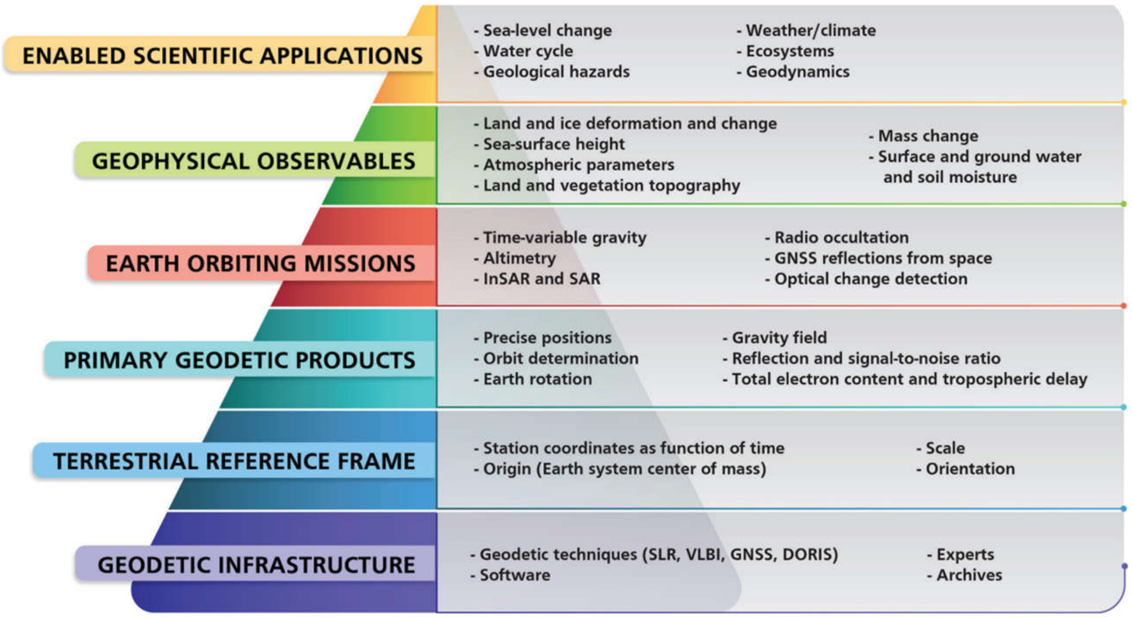
Adapted from: Global Geodetic Observing System. Meeting the requirements of a global society on a changing planet, Plag and Pearlman Eds, 2009

All navigation and positioning applications rely on accurate and reliable ITRF. The ITRF provides the foundation for all space- and ground-based observations in Earth Science. The ITRF is the unique framework is needed for monitoring and ultimately understanding the Earth system as a whole.

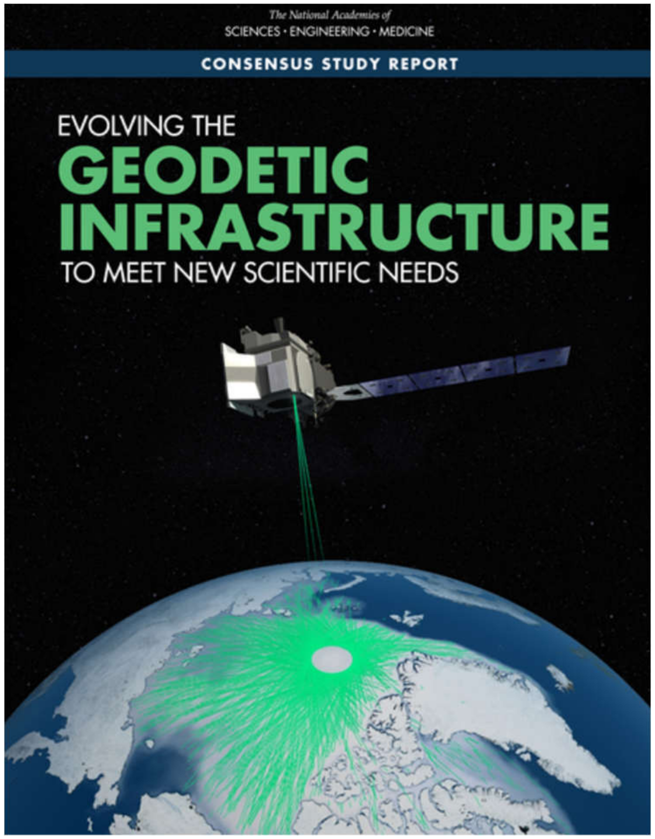
Scientific applications drive the requirements for the realization of the frame parameters (supporting GGOS goals and UN Resolution on sustainable development,(A/RES/69/266).

Accuracy: 1mm
Stability: 0.1 mm/year

ITRF The foundation for all space- and ground-based observations in Navigation and Earth Science



"The International Terrestrial Reference Frame (ITRF) underpins high priority science questions and associated space observational requirements for atmosphere and climate, weather, hydrology, ecosystems, and solid earth science."



(Source: US National Academy of Science- Engineering- Medicine)

GENESIS: A huge Number of Scientific Benefits

Geodesy

- Improvement of the International Terrestrial Reference Frame (ITRF)
- Improvement of Earth rotation parameters (EOP)
- Unification of reference frames

Navigation

- Improvement on GNSS orbits and GNSS positioning (incl. Galileo HAS)
- GNSS antenna phase centre calibration
- Improvement on the POD of LEO satellites

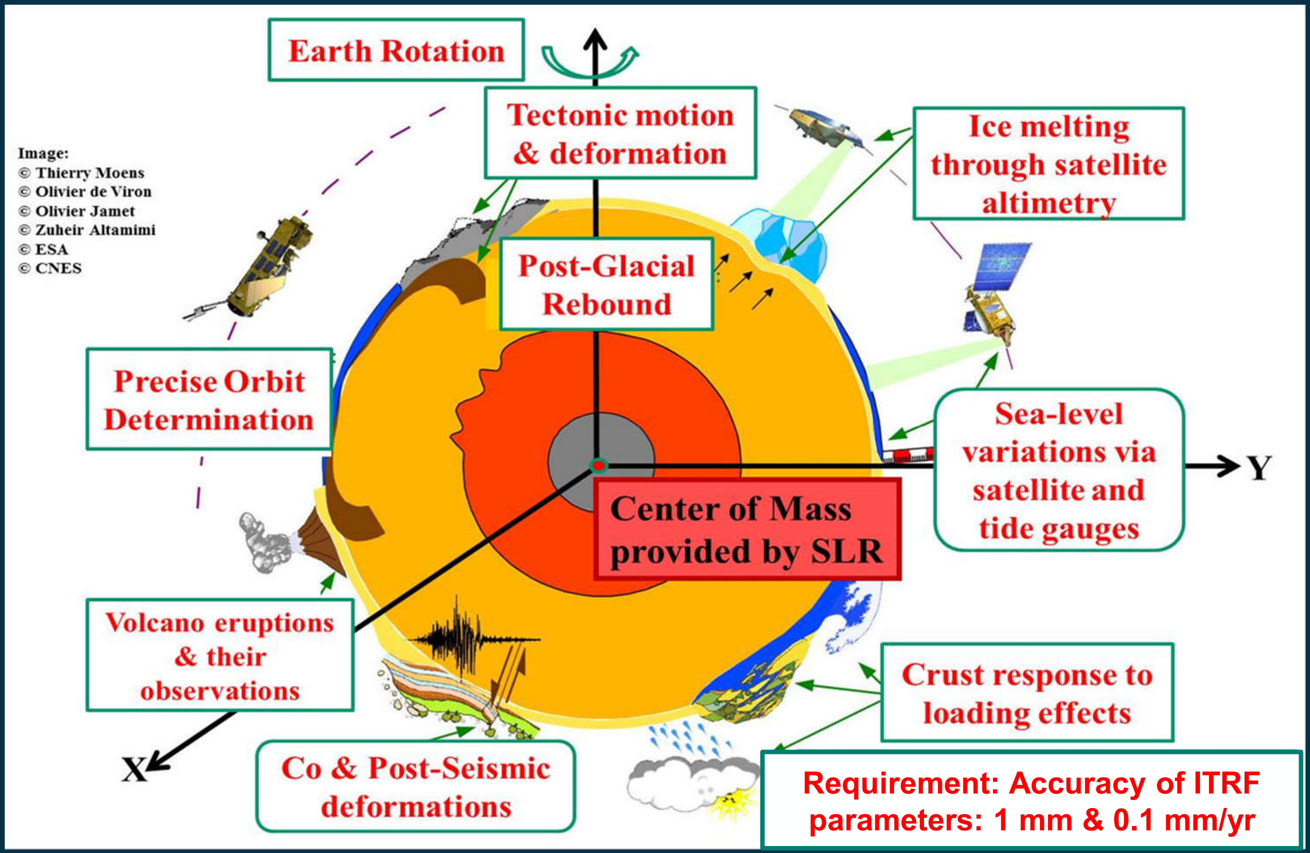
Metrology

- Time transfer demonstration over inter-continental level (with ALR)

Earth Sciences

- Improvements in sea level change measurements
- Improvement of ice mass losses
- Gravity field improvement (Long-wavelength)
- Improvement of Earth radiation budget, etc

A major impact on Earth Sciences and climate change space-based measurements



GENESIS Mission: Key Technical drivers

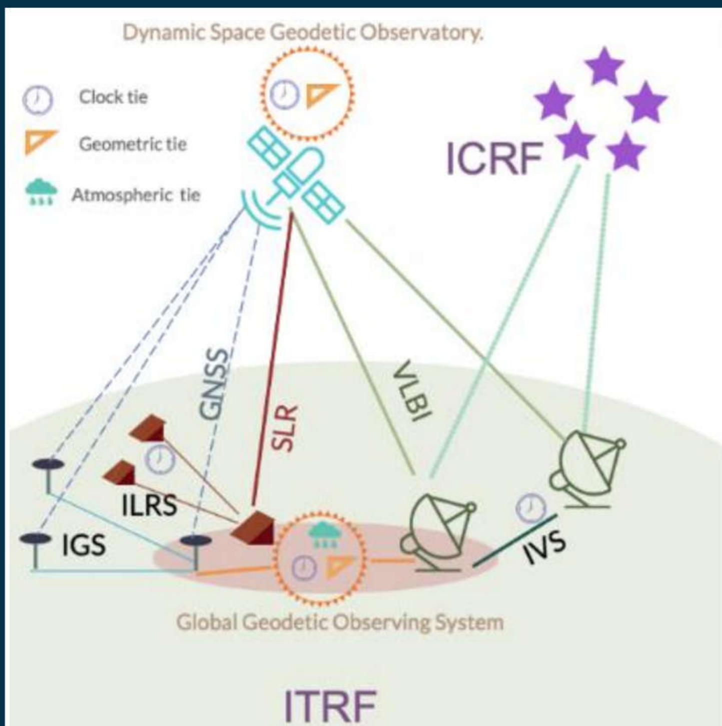
1. **The need of a Very Precise on-Board Metrology (calibrated ties)**: The offset between each payload and the satellite CoM shall be known with accuracies below 1 mm and shall remain within 1 mm-level during the whole duration of the mission. (adequate thermoelastic materials, extremely accurate on-ground calibration tests).

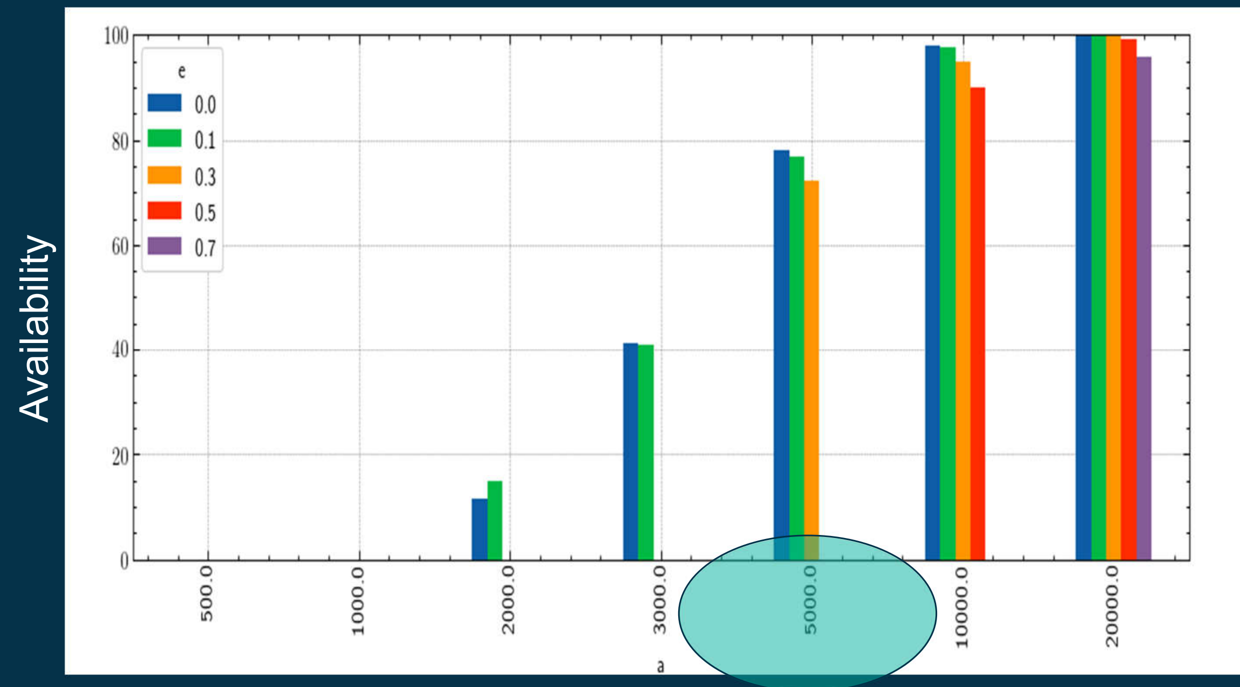
2. **Highly accurate Precise Orbit Determination**: GENESIS-1 will have to be able to determine the orbit with mm-order accuracies (best ever GNSS POD – requiring a high success rate Integer cycle ambiguity resolution and very accurate radiation pressure model of the GENESIS-1 satellite

3. **A common time reference for all on-board instruments (all geodetic instruments shall be referenced and duly synchronized to each other)**

4. **Simultaneous operation/visibility of Geodetic techniques**: leads to MEO or HEO orbit selection, driven by VLBI long baseline observability.

Ensuring VLBI Long-Baseline Observability (> 70% time)

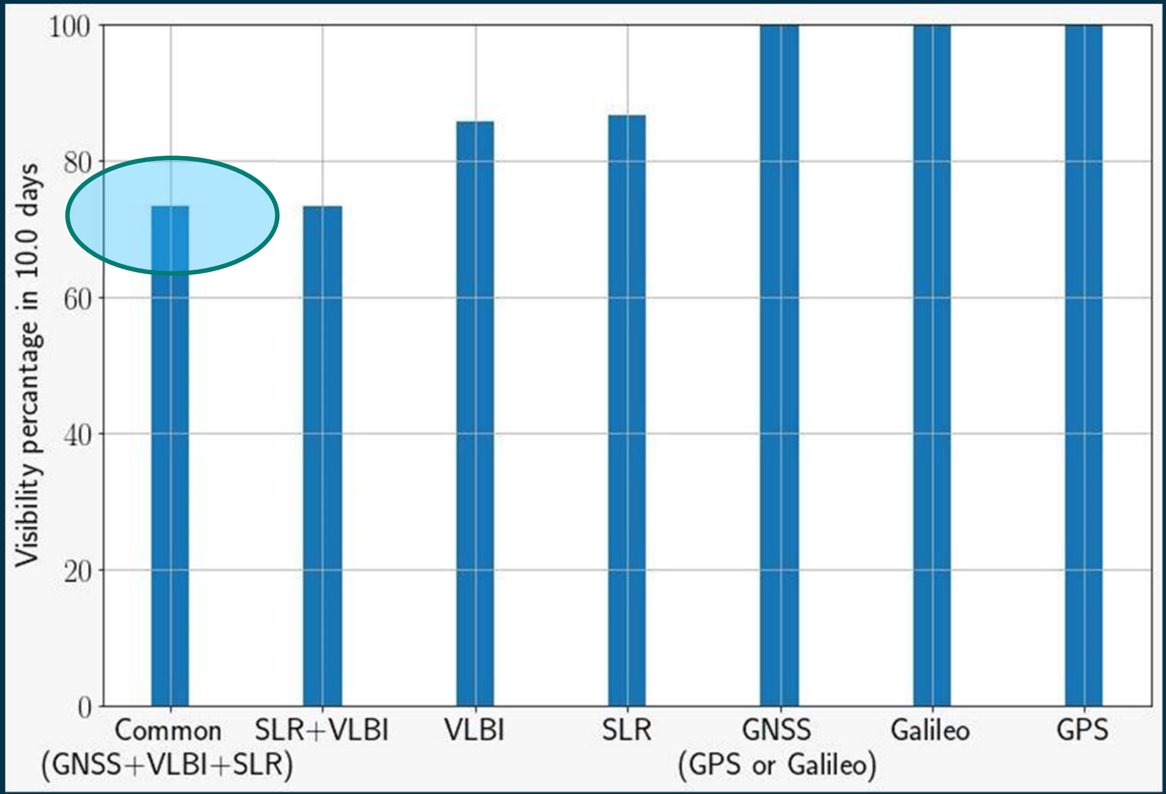




Satellite altitude

Region of Interest

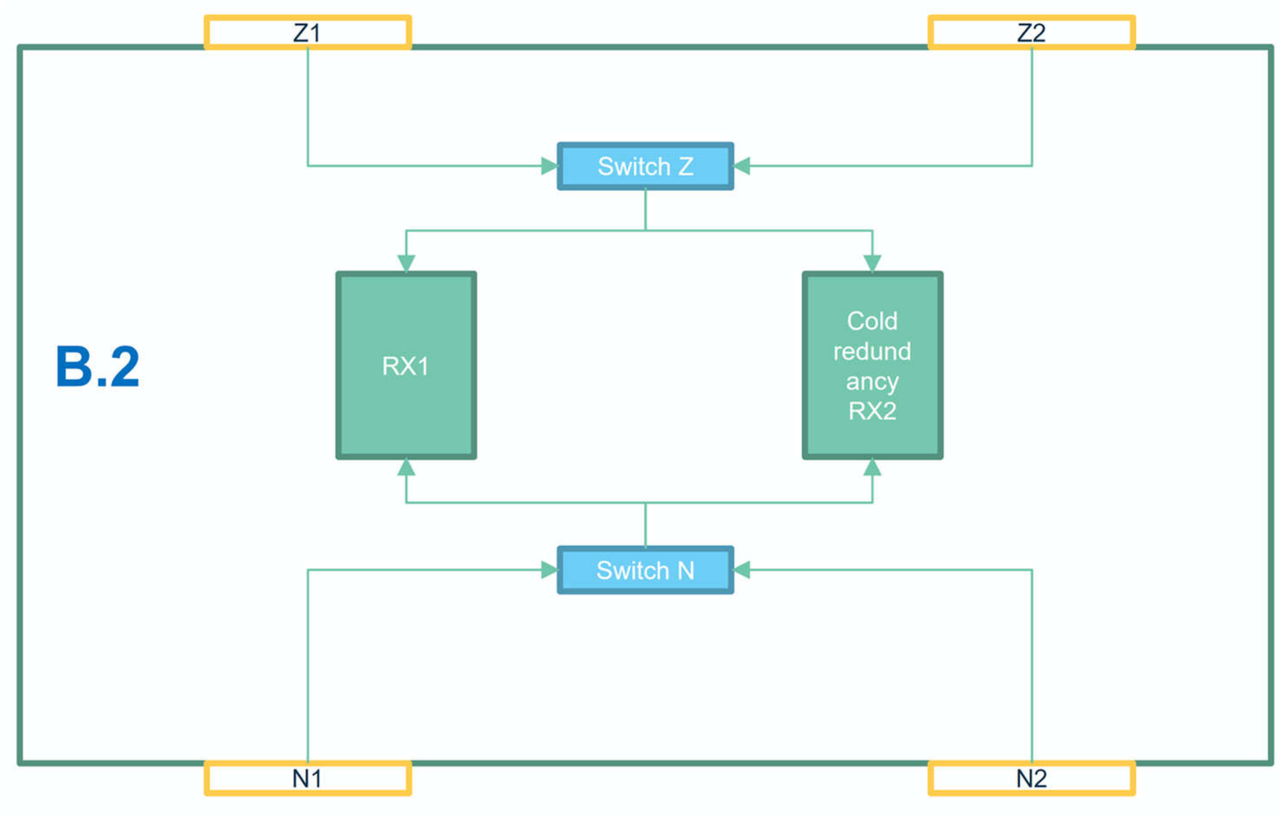
Visibility Percentage of all Geodetic techniques (MEO orbit selected 6000 Km height)



Common Visibility of GNSS, VLB, DORIS and SLR around 75% of the time (10 days simulation)

Note: Results computed by the Royal Observatory of Belgium (ROB)

GNSS on-Board Configuration (Baseline)



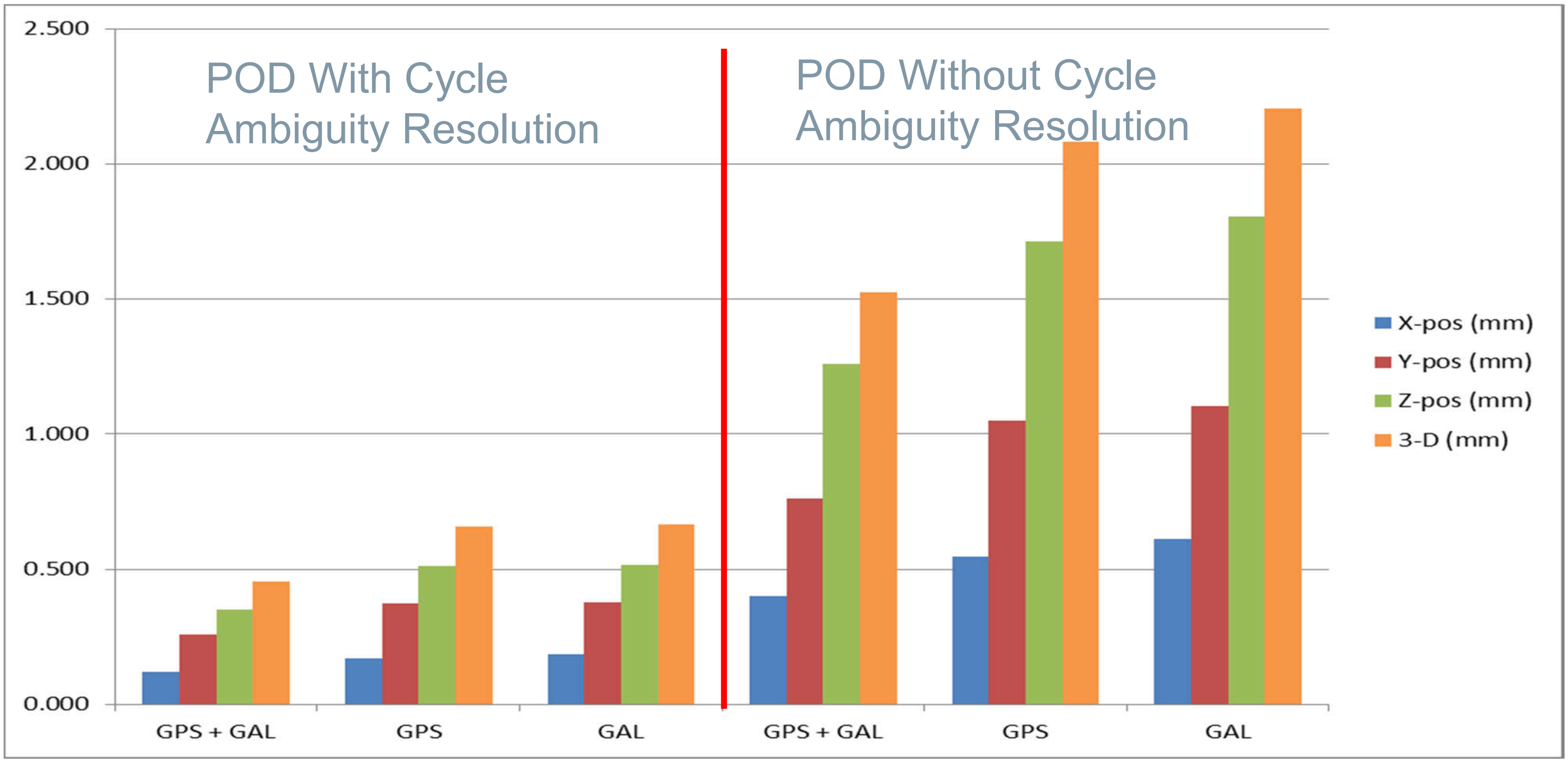
With redundant GNSS Zenit and NADIR antennas

Multifrequency and multi-GNSS receiver (redundant)

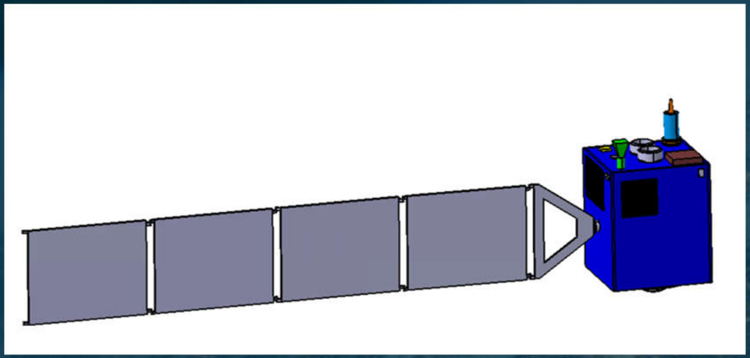
GNSS Receiver SW shall provide a high success rate Integer cycle ambiguity resolution

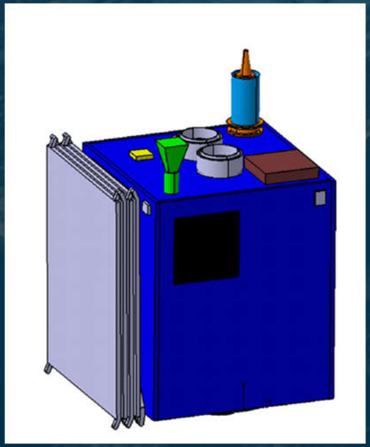
GNSS visibility and POD accuracy Analysis

POD Analysis - Main Results: Satellite Position Formal Errors (mm)



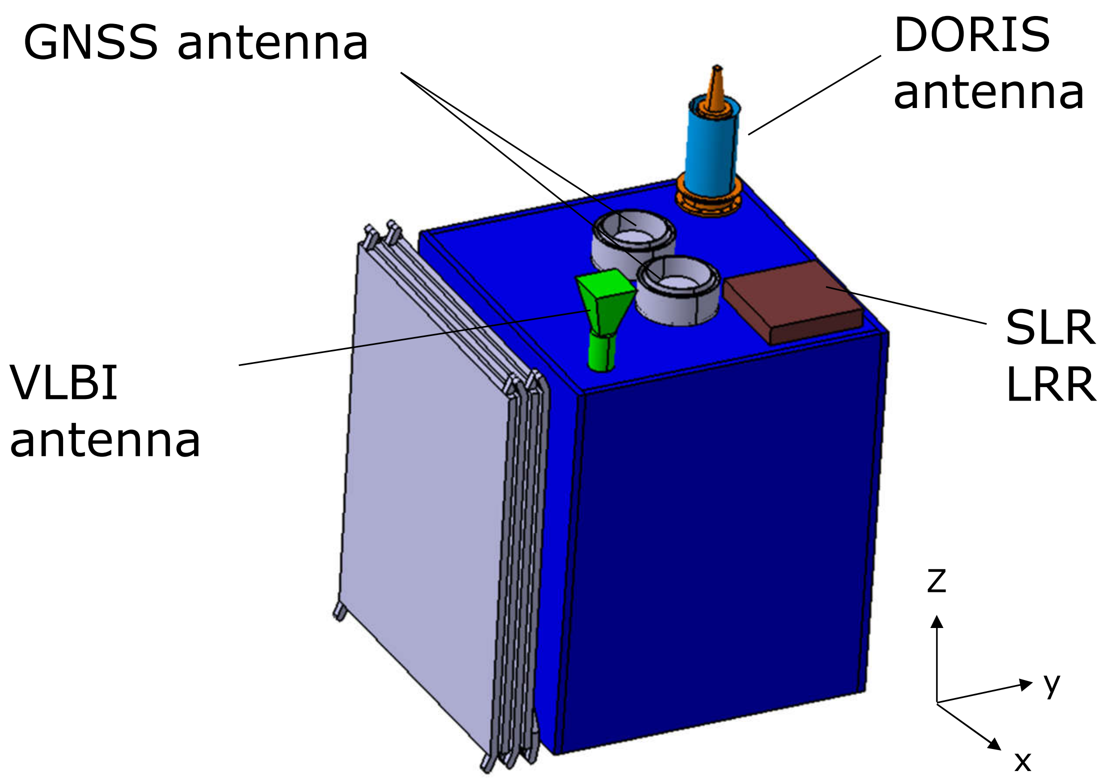
GENESIS Direct Orbit Injection – Preferred Solution
(ESA CDF Study confirmed mission feasibility)





Orbit	6000km circular 95.5° inclination Direct Injection Harsh Radiation environment	
Wet Mass w/ system margin	**220 kg incl. adapter**	
Power w/system margin	**190 W** during nominal mode	
Dimensions Stowed	Max Height	1460mm
	Max Width	950mm
	Max Depth	1015mm
Payloads Mass & power w/maturity margin **(~ 40 Kg and 75 W)**	GNSS 12.2kg, 21W VLBI 2.4kg, 17.4W SLR 1.6kg, passive DORIS 21kg, 26.3W USO 1.8kg, 12W	
Communication/GSO	S-Band used for TT&C LGA Ground station: ESTRACK Station	

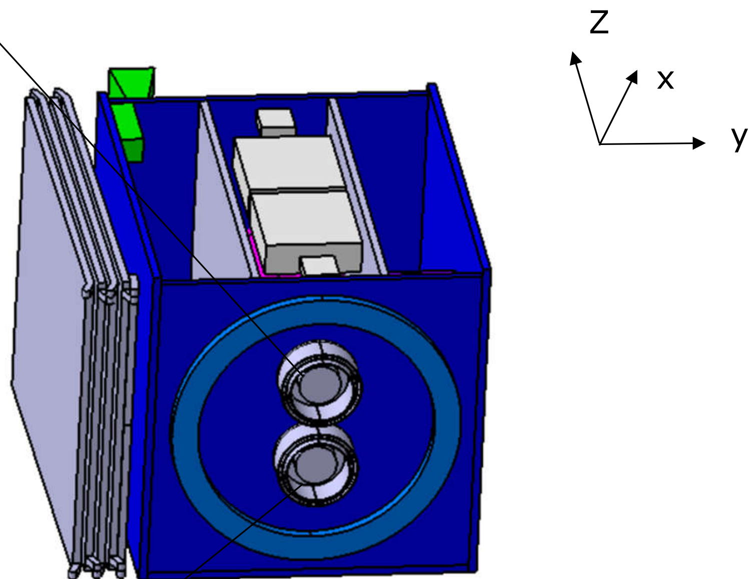
Instruments nadir (ESA CDF Study)



Requirements:

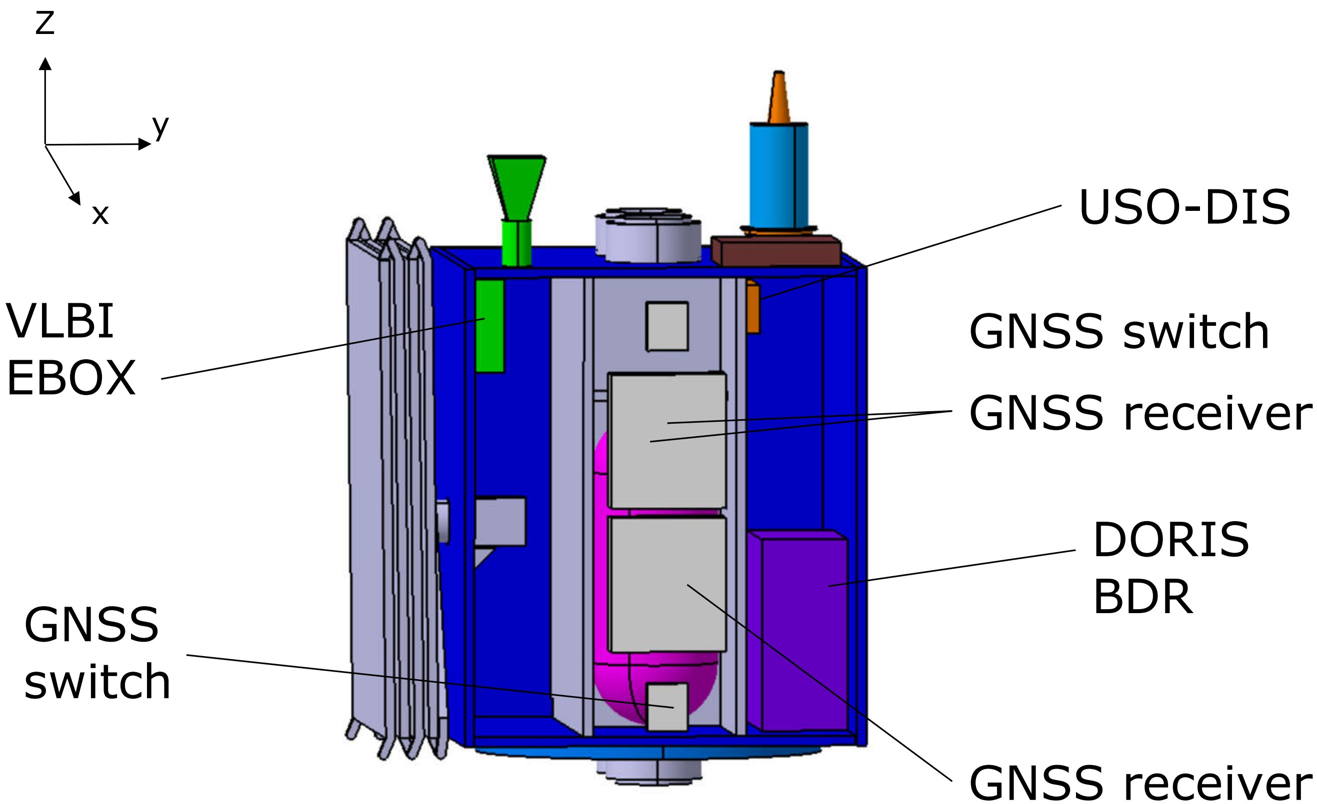
- Nadir-pointing of DORIS, GNSS antenna nadir, SLR and VLBI
- GNSS antennas placed in the middle of the panel
- DORIS and VLBI might have EMC issues – position as far away as possible
- Unobstructed field of view for GNSS, DORIS and VLBI

Instruments zenith (ESA CDF Study)



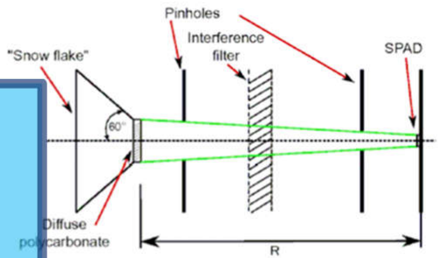
Requirements:
- Zenith pointing of GNSS antenna zenith
- GNSS antennas placed in the middle of the panel
- Unobstructed field of view for GNSS

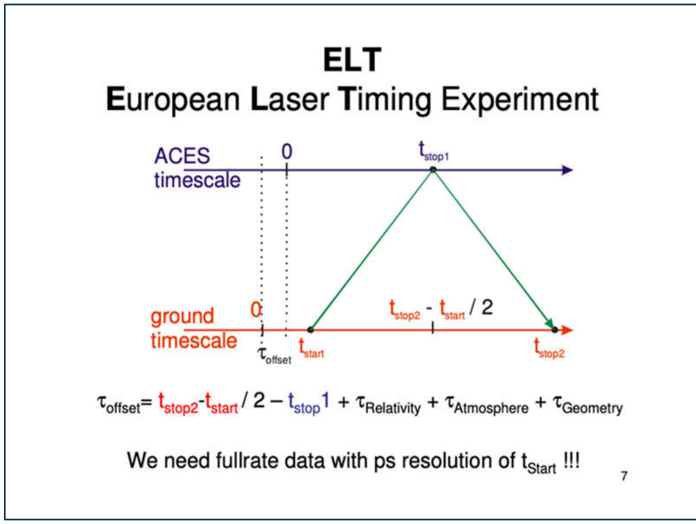
Instruments inside (ESA CDF Study)



Optional Payload 1: Active Laser Ranging (ALR)

An ALR is a highly recommended optional payload for the GENESIS-1 mission which would allow demonstrating (in addition to core Mission objectives) time transfer over inter-continental level and on-board synchronisation with ground clocks. Given its low SWaP (< 1 Kg and < 1 Watt) and scientific interest its integration is highly desirable.

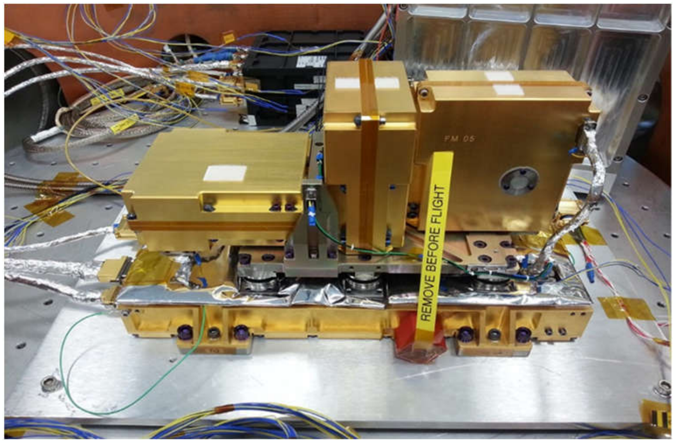




High-TRL but upgrades to adapt to the GENESIS-1 specific mission needs

Optional Payload 2: Accelerometer

Integration of an accelerometer on-board will further support high-precision orbit determination, the modelling of non-conservative forces and would also allow in-orbit determination of the satellite Center of Mass (CoM).



INAF, TAS-I (I) – accelerometer

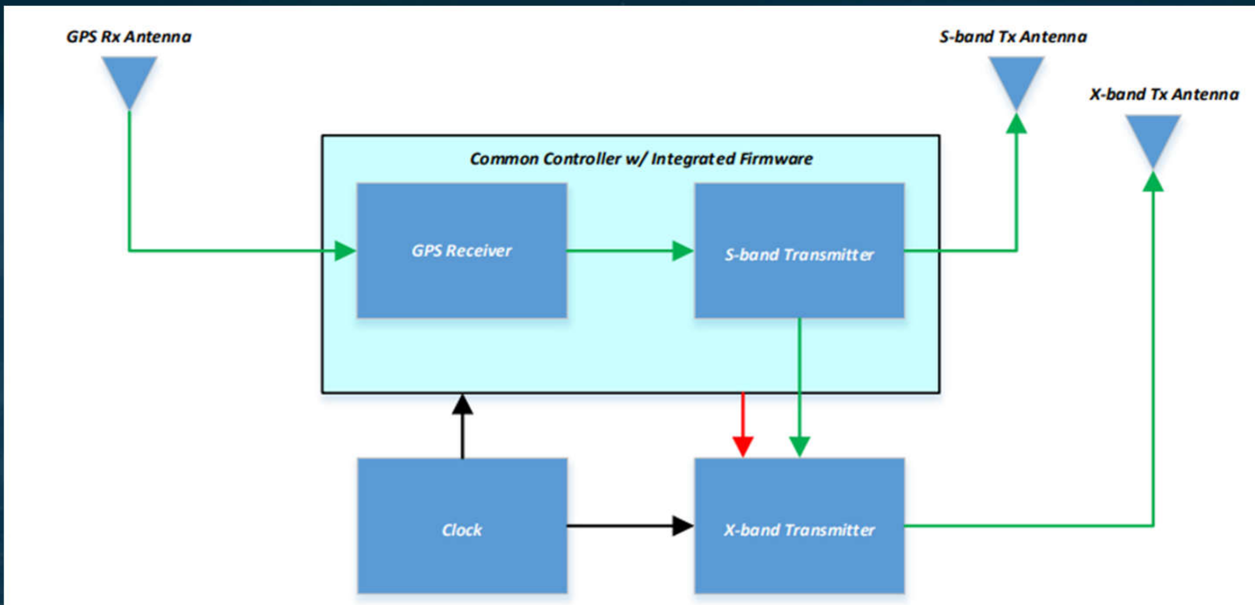
Bepicolombo, JUICE (2023)

ONERA(FR) – accelerometer

GRACE

High-TRL but upgrades to adapt to the GENESIS-1 specific mission needs

POTENTIAL COOPERATION WITH NASA (GRITSS)



NASA GRITSS INSTRUMENT BLOCK DIAGRAM

Transponding GPS to VLBI users over S and X-bands to enhance GNSS/VLBI collocation ties accuracy

National Aeronautics and
Space Administration

Headquarters
Washington, DC 20546-0001

May 2, 2022

Reply to Attn of: SMD/Earth Science Division

Dr. Javier Ventura-Traveset
Head of Galileo Navigation Science Office - NAV-P
ESA Navigation Directorate
European Space Agency

Dear Dr. Ventura-Traveset,

NASA and ESA have a common interest in space geodesy in support of our respective Earth science programs. As the foundation for modern positioning, navigation, and timing applications, the importance of space geodesy to science, commerce, and civilian society is clearly demonstrated on a daily basis, from the navigation of automobiles, ships, aircraft and satellites to the accurate time transfer required by our communication systems. It also enables powerful new techniques for monitoring the Earth system as exhibited in measurements of water resources, sea level rise, ocean circulation, and atmospheric weather.

Of particular importance to NASA is the maintenance and improvement of the International Terrestrial Reference Frame and the daily measurements of the Earth Orientation Parameters that are essential for spacecraft navigation and to geolocate Earth observations. The generation of these geodetic products relies on the Global Geodetic Observing System of geodetic ground stations. NASA is making significant investments in upgrading the NASA Space Geodesy Network and we were excited to learn about the proposed GENESIS program that includes a geodetic observatory for co-location of the geodetic techniques in space. We are interested in exploring potential cooperation in this mission and how it can be used to improve the geodetic products, particularly the International Terrestrial Reference Frame. Please keep us informed on the development of this interesting program.

Sincerely,

Benjamin Phillips
Lead, Earth Surface and Interior Focus Area
NASA Science Mission Directorate, Earth Science Division

cc:
NASA Goddard Space Flight Center/Stephen Merkowitz
NASA Office of International and Interagency Relations/Peyton Blackstock

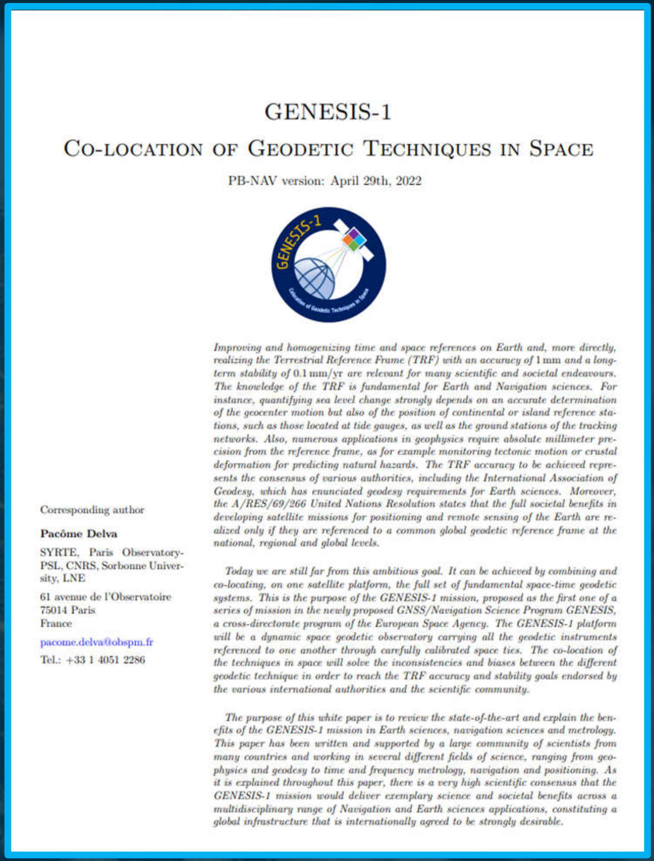
GENESIS High Level Implementation Schedule

GENESIS Mission (4 years development)	Plan
Request for Information - RFI	July/Sept 2022
Ministerial Conference	Nov 2022
Invitation To Tender issued	Dec 2022/Jan 2023
GENESIS Kick-Off	Q2 2023
Design Review	Q3 2024
Integration Readiness Review	Q4 2025
Launch	2027
GENESIS Operations	~ 2-3 years

GENESIS SCIENCE WHITE PAPER

" There is a very high scientific consensus that the GENESIS mission would deliver exemplary science and societal benefits across a multidisciplinary range of Navigation and Earth sciences applications, constituting a global infrastructure that is internationally agreed to be strongly desirable."

A total of **75 specialised Scientists** have contributed or explicitly expressed their endorsement to this White paper



GENESIS-1

CO-LOCATION OF GEODETIC TECHNIQUES IN SPACE

PB-NAV version: April 29th, 2022

Improving and homogenizing time and space references on Earth and, more directly, realizing the Terrestrial Reference Frame (TRF) with an accuracy of 1 mm and a long-term stability of 0.1 mm/yr are relevant for many scientific and societal endeavours. The knowledge of the TRF is fundamental for Earth and Navigation sciences. For instance, quantifying sea level change strongly depends on an accurate determination of the geocenter motion but also of the position of continental or island reference stations, such as those located at tide gauges, as well as the ground stations of the tracking networks. Also, numerous applications in geophysics require absolute millimeter precision from the reference frame, as for example monitoring tectonic motion or crustal deformation for predicting natural hazards. The TRF accuracy to be achieved represents the consensus of various authorities, including the International Association of Geodesy, which has enunciated geodesy requirements for Earth sciences. Moreover, the A/RES/69/266 United Nations Resolution states that the full societal benefits in developing satellite missions for positioning and remote sensing of the Earth are realized only if they are referenced to a common global geodetic reference frame at the national, regional and global levels.

Today we are still far from this ambitious goal. It can be achieved by combining and co-locating, on one satellite platform, the full set of fundamental space-time geodetic systems. This is the purpose of the GENESIS-1 mission, proposed as the first one of a series of mission in the newly proposed GNSS/Navigation Science Program GENESIS, a cross-directorate program of the European Space Agency. The GENESIS-1 platform will be a dynamic space geodetic observatory carrying all the geodetic instruments referenced to one another through carefully calibrated space ties. The co-location of the techniques in space will solve the inconsistencies and biases between the different geodetic technique in order to reach the TRF accuracy and stability goals endorsed by the various international authorities and the scientific community.

The purpose of this white paper is to review the state-of-the-art and explain the benefits of the GENESIS-1 mission in Earth sciences, navigation sciences and metrology. This paper has been written and supported by a large community of scientists from many countries and working in several different fields of science, ranging from geophysics and geodesy to time and frequency metrology, navigation and positioning. As it is explained throughout this paper, there is a very high scientific consensus that the GENESIS-1 mission would deliver exemplary science and societal benefits across a multidisciplinary range of Navigation and Earth sciences applications, constituting a global infrastructure that is internationally agreed to be strongly desirable.

Corresponding author

Pacôme Delva

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

61 avenue de l'Observatoire
75014 Paris
France

pacome.delva@obspm.fr

Tel.: +33 1 4051 2286

GENESIS: A great opportunity for Europe !