



ESA's Genesis Data PROcessing, Archiving and Distribution facility (PROAD)



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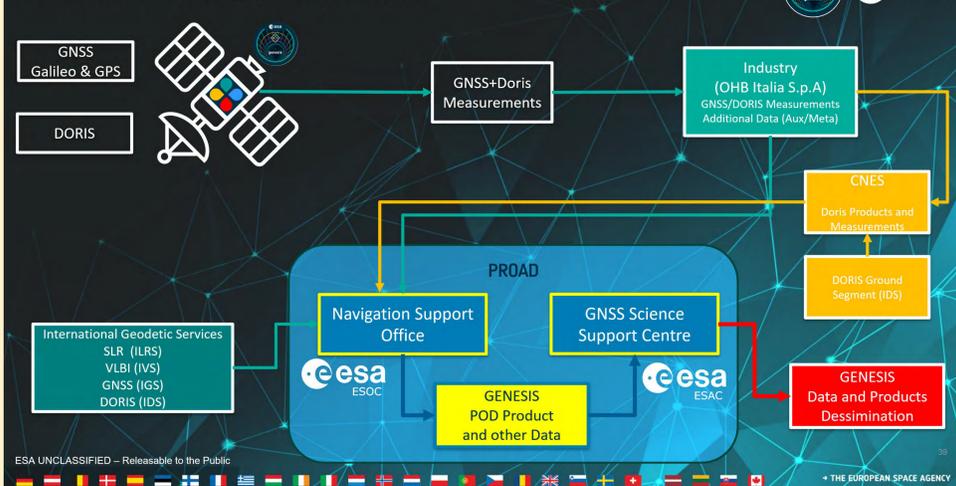
Introduction

The Genesis scientific mission data will be processed, archived, and distributed by ESA's Data PROcessing, Archiving and Distribution facility (PROAD) in close collaboration with the scientific community.

The Genesis data PROcessing part of PROAD is under the responsibility of the ESA Navigation Support Office (NavSO) at ESOC, the European Space Operations Centre in Darmstadt, Germany

The Genesis data Archiving and Distribution part of PROAD is under the responsibility of the GNSS Science Support Centre (GSSC) at ESAC, the European Space Astronomy Centre in Villafranca, Spain.

Genesis – Overall Data Flow



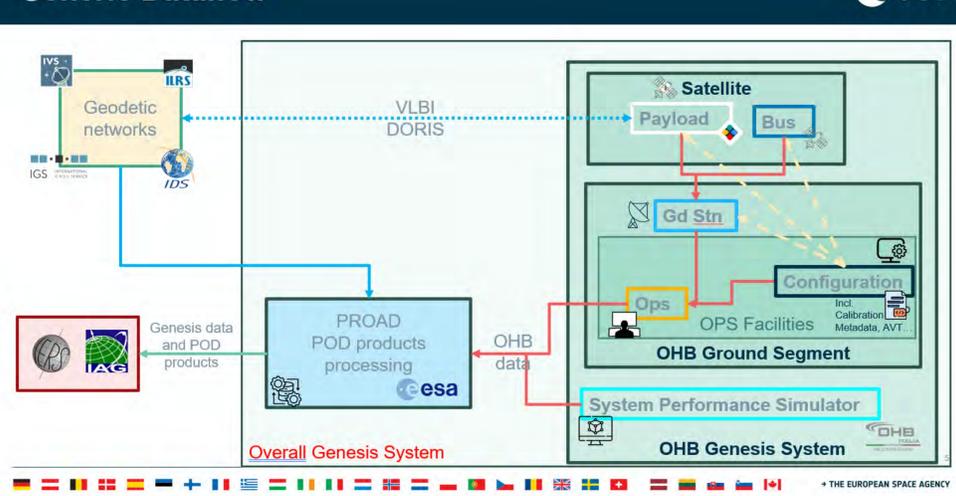
Genesis Data and Products

The ICDs between OHB/CNES and the NavSO, as PROAD data processing part, are being elaborated along the following headers excerpts. The ICD content is exhaustively traced and derived from the Genesis System Requirements Document version 3.

Any IAG Services specific needs (e.g. format adaptation, specific parameter/data, IAG Service specific Genesis product/format, tracking campaigns coordination...) shall be channeled to Navigation-Office@esa.int for integration into

| | | | |
|---|--|---|---|
| <p>I. GENESIS OPERATIONS CONCEPT</p> <p>A. DAILY OPERATIONS</p> <ol style="list-style-type: none"> 1. TIME SCHEDULES 2. RAW TM FORMAT 3. GNSS OBSERVATIONS 3. VLBI OBSERVATIONS 4. DORIS OBSERVATION 5. AOC'S DATA <p>B. ANOMALY REPORTING AND HANDLING</p> <p>C. INTERFACE MAINTENANCE PROCEDURES</p> <p>D. SCHEDULED OUTAGES AND NOTIFICATIONS</p> <p>E. CHANGE MANAGEMENT PROCESS</p> | <p>II. CONFIGURATION</p> <ol style="list-style-type: none"> 1. SATELLITE 2. GROUND SEGMENT 3. NETWORK <p>III. CALIBRATIONS</p> <ol style="list-style-type: none"> 1. ON-GROUND CALIBRATION <ol style="list-style-type: none"> i. CENTRE OF MASS ii. STAR TRACKER REFERENCE 2. IN FLIGHT CALIBRATION <ol style="list-style-type: none"> i. POST-LAUNCH STAR TRACKER ALIGNMENT | <p>IV. PRODUCTS SPECIFICATIONS</p> <ol style="list-style-type: none"> 1. GENERIC SPECIFICATIONS <ol style="list-style-type: none"> 1. FILE NAMING CONVENTION 2. FILES FORMAT 3. DATA TYPES 4. UNITS 5. TIME IN GENESIS PRODUCTS <ol style="list-style-type: none"> i. TIME FORMAT ii. ONBOARD TIME SCALE iii. APPLIED TIME OFFSETS iv. TIME SAMPLING RATES 2. RAW TM 3. HK TM FORMAT 4. PAYLOAD TM FORMAT <ol style="list-style-type: none"> 1. GNSS <ol style="list-style-type: none"> i. GNSS LEVEL 0 ii. GNSS LEVEL 1 2. SLR RETROREFLECTOR 3. DORIS:RINEX/DORIS 4. VLBI 5. GNC TM <ol style="list-style-type: none"> i. AOC'S ii. COMMAND AND CONTROL TM 6. EVENT TM | <p>V. PRODUCT PACKAGING</p> <ol style="list-style-type: none"> 1. PACKAGE STRUCTURE 2. PACKAGE COMPONENTS <p>VI. PRODUCT DELIVERY AND NOTIFICATION</p> <p>VII. INTERFACE VERIFICATION AND VALIDATION</p> <p>VIII. PERFORMANCE MEASUREMENTS</p> <p>VIII. SECURITY</p> |
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Generic Dataflow

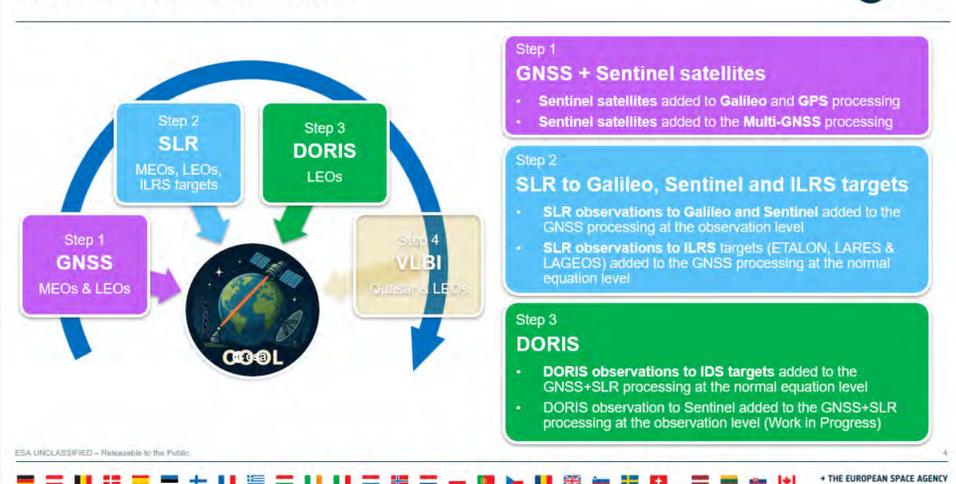


PROAD Data Processing

Based on the data provided by the Genesis industrial operator, the NavSO will:

- Perform input data quality checks ⇒ format, gap, validity, matching IAG services data...
- Compute geodetic technique specific solutions ⇒ based on NavSO official AC tools and experience
- Generate Genesis POD products ⇒ for Genesis, Galileo, GPS and EOP data ⇒ incl. pre-launch calibrated space ties validation
- Apply its COmbination at Observation Level (COOL) ⇒ processing data in one run ⇒ NEQ stacking allows detection and treatment of technique-specific systematic behaviour
- Include LEO/MEO ⇒ incl. e.g. Sentinel, LAGEOS in the combined solution
- Structure and package the data ⇒ incl. synchronised auxiliary/ancillary/metadata
- Validate the output data/products packaging ⇒ incl. synchronised auxiliary/ancillary/metadata
- Deliver the output data/product package to GSSC ⇒ validation of the processed data/products quality

COOL – Current Status



PROAD Data Archiving and Distribution

The Genesis data will be accessible on GSSC Archive.

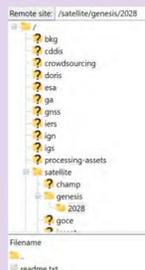
The GSSC Archive is accessible via FTP, SFTP, HTTPS, NTRIP Caster, FTP web client and a REST API

The GSSC FTP and SFTP servers are both accessible using the hostname "gssc.esa.int"
The FTP server operates on port 21, while the SFTP server uses port 2200

Public users can log in to either server by

- entering "anonymous" as the username and
- leaving the password field blank.

GSSC ICD to users

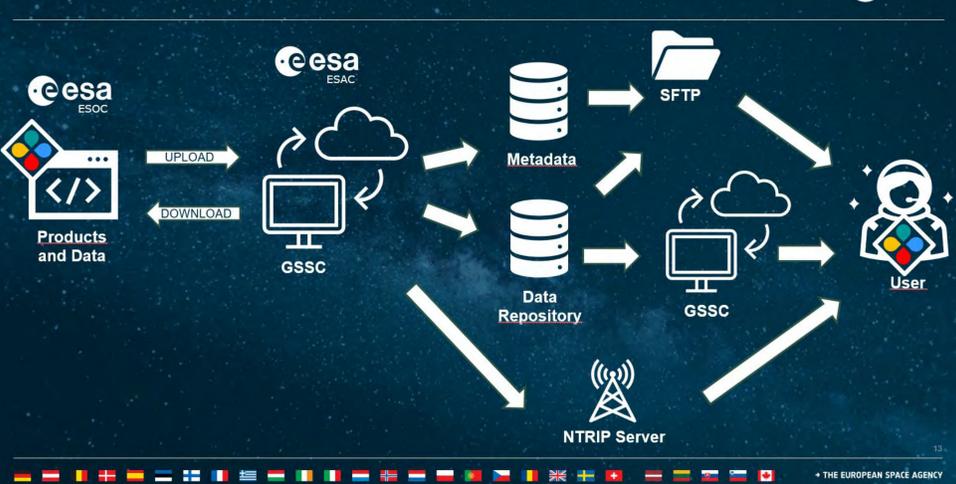


Should the Genesis scientific community request this capability to the Genesis project, the GSSC portal (<https://gssc.esa.int/portal/>) could also be extended to provide a secure web interface for registered users to various services and data tools, in particular metadata-based search and Datalabs (interactive datasets analysis, processing, plotting, exploring and visualization tools, free-of-charge workspace and 10Gb extendable persistent storage, user data upload).

Contact point: gssc.admin@esa.int
Our webpage: gssc.esa.int



Genesis PROAD / GSSC – Dissemination Services



Genesis GNSS Instrument and Processing Aspects

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Overview

During the WG2 kickoff meeting the preparation of an ideal list of *Genesis GNSS Instrument and Processing Aspects* was agreed among the WG2 members. This document was sent to ESA in July 2024 and is summarized on this poster. It has to be noted that the document was drafted without access to the GENESIS system requirements or design studies and does not reflect constraints due to project organization, design requirements, or budgetary limitations. The following colleagues contributed to this document: P. Axelrad, L. Grunwaldt, U. Hugentobler, T. Junique, F. Lemoine, S. Loyer, B. Männel, F.-X. Marmet, F. Mercier, G. Möller, O. Montenbruck, F. Perosanz, H. Peter, C. Siemes, P. Steigenberger.

GNSS System Concept

- The Genesis GNSS receiver shall support concurrent tracking with a nadir and a zenith antenna.
 - Nadir antenna provides better GNSS coverage at the orbital altitude and associated observations are required to compute a standalone navigation solution.
 - Zenith antenna required to observe the inner part ($\theta < 14^\circ$) of the transmit antenna diagram to link Genesis to available terrestrial GNSS observations.
- Signals from both antennas shall be jointly tracked and processed in a single receiver to minimize possible bias variations between data from the two antenna strings.
- Genesis shall provide a redundant and fully independent pair of dual-antenna GNSS receivers with associated antennas to protect against hardware failure.

Antenna System

- The antenna(s) shall offer a minimum gain of -1 dBi (tbd) in all frequency bands for off-boresight angles of less than 60° .
- Phase and Group delay variations shall be calibrated with an accuracy of 1 mm and 1 cm; over the entire field of view in each frequency band.
- The antenna(s) shall be equipped with a choker for multipath mitigation.
- The GNSS subsystem shall support collection of temperature data for the antennas and low noise amplifiers for monitoring of potential bias variations.

Signals and Tracking

- Concurrent tracking of the following signals:
 - GPS L1 C/A, L2C, L5,
 - Galileo E1 O/S, E5a,
 - BeiDou-3 B1C/B2a.
- The receiver shall enable concurrent tracking of all supported signals for:
 - Zenith: >8 satellites per constellation
 - Nadir: >11 satellites
 - Receiver with 114+ channels.
- The Genesis GNSS receiver shall use the pilot component of modernized signals for measurement generation and the data channel for navigation data extraction.



Fig. 2 Genesis design published after closing the Preliminary Design Review (copyright: ESA).

Clock System

- The GNSS receiver shall support use of an external oscillator.
- No interference between the internal and external oscillator. Clock variations due to oscillator cross-talk shall be less than 0.2 mm.
- The receiver shall enable generation of different receiver time scales.
 - Signal biases between antenna pairs of individual receivers shall exhibit variations of less than 1 mm over a 24 h interval.

Ambiguities

- The receiver shall resolve the 180° phase ambiguity of GPS L1 C/A based on the sign of the navigation data.
- The receiver shall make use of a 4-quadrant discriminator to provide carrier phase measurements free of 180° biases for all pilot signals.
- The receiver shall indicate the occurrence of cycle slips in carrier phase observations.
- Carrier phase measurements shall exhibit integer satellite-satellite and receiver-receiver double-differences in a zero-baseline configuration.

Data

- The GNSS receiver shall provide pseudorange, carrier phase, Doppler and carrier-to-noise density ratio (C/N_0) measurements with minimum resolutions of 1 mm, 0.001 cy, 0.01 Hz, 0.1 dB-Hz. The specified observation types are required for POD (pseudorange and phase), pre-processing and coarse navigation (Doppler), as well as observation weighting, multipath analysis, and link budget analyses (C/N_0).
- The GNSS receiver shall provide decoded navigation data for all tracked signals and satellites upon changes of the respective raw message content.
- The Level 1 GNSS observation and navigation data shall be provided in the latest version of the RINEX format.
- Data from individual antennas shall be provided in distinct RINEX files to unambiguously connect the observation with the respective antenna in the GNSS processing.
- The GNSS receiver shall output the onboard navigation solution (position, velocity, and clock offsets) at a sampling rate commensurable with the GNSS observables as the navigation solution is required as a starting point for coarse orbit determination and for proper interpretation of the measurement time tags and clock steering.

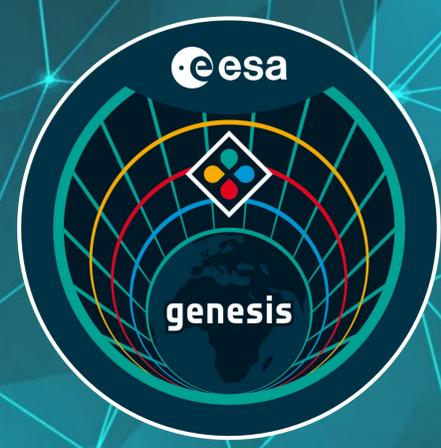
Sensitivity, Noise, and Interference

- The receiver shall be able to acquire signals at a C/N_0 of 30 dB-Hz and track signals down to 25 dB-Hz (35 and 30 dB-Hz for GPS L1 C/A) to ensure a sufficient number of satellites and overlapping arcs of continuous tracking.
- The receiver shall provide a C/N_0 of at least 40 dB-Hz (tbd) for a received flux of -160.6 dB-W/m² (tbd) with a passive 0 dBi RHCP antenna gain (tbd) for all frequency bands.
- The GNSS system needs to be adequately protected against interference.

Tests and Preparation

- Test data from ground campaigns should be shared with the community.
- A zero-baseline test using the two antenna inputs shall be performed to characterize inter-channel biases and noise properties.
- A zero-baseline test using a single antenna to compare the flight receiver to a standard geodetic receiver to characterize any differences.
- The Genesis project shall provide a comprehensive set of level-0 instrument data and full access to GNSS and auxiliary data.

ESA GSET WG-3 (VLBI)



WG-3 participants:

Simone Bernhart – BKG/MPIfR, DEU; Johannes Böhm – TU Vienna, AUT; Patrick Charlot – CNRS Bordeaux, FRA; Christophe Craeye – UCL, BEL; Thibault Deleu – RoB, BEL; Pablo de Vicente – IGN, ESP; Claudia Flohrer – BKG, DEU; Susana Garcia-Espada – Kartverket, NOR; Luciano Garramone – ASI, ITA; Jakob Gruber – BEV Wien, AUT; Rüdiger Haas – Chalmers, SWE; Robert Heinkelmann – GFZ, DEU; Masafumi Ishigaki – GSI, JAP; Lucia McCallum – UTas Hobart, AUS; Alexander Neidhardt – TU München, DEU; Axel Nothnagel – TU Vienna, AUT; Almine Özyildirim – RoB, BEL; Christian Plötz – BKG, DEU; Chet Ruszczyk – MIT Haystack, USA; Matthias Schartner – ETH Zürich, CHE; Harald Schuh – GFZ Potsdam, DEU; Gino Tuccari – INAF & MPIfR, ITA/DEU; Rimsky Wolfs – Chalmers, SWE; **Ex-officio (ESA GSET coordinator & co-coordinator)** Özgür Karatekin – RoB, BEL; Francesco Vespe – ASI, ITA; **ESA:** Sara Bruni – ESOC, DEU; Gaia Fusco – ESTEC, NLD; Erik Schönemann – ESOC, DEU; Pierre Waller – ESTEC, NLD; Frank Zimmermann – ESOC, DEU

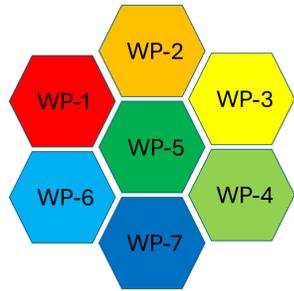
Working group meetings:

- Online WG meetings every 4–6 weeks
- 2024: 5 WG meetings; 2025: 9 WG meetings; 2026: so far 1 WG meeting

Work packages:

WG-3 has seven work packages (WPs):

- WP-1: frequencies, signals etc.
- WP-2: ground station fidelity, etc.
- WP-3: delay resolution and correlation, etc.
- WP-4: scheduling
- WP-5: end-to-end simulations
- WP-6: test observations
- WP-7: PRN-option



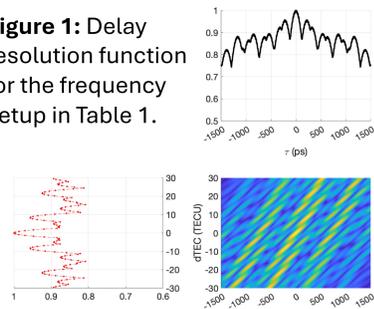
WP-1: some examples

The Genesis VLBI signals will be transmitted in four VGOS-compatible frequency bands. These are 3.1–3.3, 5.25–5.57, 8–8.4, and 9.3–9.8 GHz. Table 1 presents the proposed frequency setup for VGOS observations of Genesis with 5-8-8-8 channels of 32 MHz each in the four bands, spreading in total 6624 MHz. Figure 1 depicts the corresponding delay resolution function.

Table 1: Proposed frequency setup for VGOS observations of Genesis.

| Band-A | | Band-B | | Band-C | | Band-D | |
|--------|--------|--------|--------|--------|--------|--------|--------|
| start | stop | start | stop | start | stop | start | stop |
| 3110 | 3290 | 5260 | 5560 | 8010 | 8390 | 9350 | 9750 |
| (MHz) |
| 3096.4 | 3128.4 | 5272.4 | 5304.4 | 8024.4 | 8056.4 | 9368.4 | 9400.4 |
| 3128.4 | 3160.4 | 5304.4 | 5336.4 | 8056.4 | 8088.4 | 9400.4 | 9432.4 |
| 3160.4 | 3192.4 | 5336.4 | 5368.4 | 8184.4 | 8216.4 | 9432.4 | 9464.4 |
| 3192.4 | 3224.4 | 5400.4 | 5432.4 | 8216.4 | 8248.4 | 9528.4 | 9560.4 |
| 3224.4 | 3256.4 | 5432.4 | 5464.4 | 8248.4 | 8280.4 | 9624.4 | 9656.4 |
| 3256.4 | 3288.4 | 5464.4 | 5496.4 | 8280.4 | 8312.4 | 9656.4 | 9688.4 |
| 3288.4 | 3320.4 | 5496.4 | 5528.4 | 8312.4 | 8344.4 | 9688.4 | 9720.4 |
| 3320.4 | 3352.4 | 5528.4 | 5560.4 | 8344.4 | 8376.4 | 9720.4 | 9752.4 |
| 5 | | 8 | | 8 | | 8 | |

Figure 1: Delay resolution function for the frequency setup in Table 1.



The Genesis signal will be LHCP. The signal strength on the earth surface shall not exceed 20 Jy and be tuneable. Figure 2 depicts the proposed tuning scheme with 15 steps of 1 dB. Due to the close distance to the earth surface, the Genesis signals will experience geometry-dependent free-space loss effects. Figure 3 visualizes the geometry where the free-space loss difference between a station in nadir direction and a station at the edge of illumination is 4.5 dB.

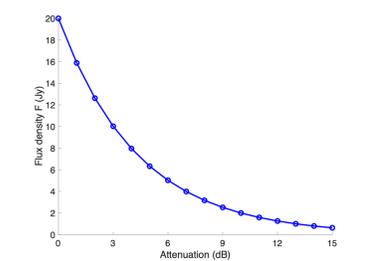


Figure 2: Tunable signals strength.

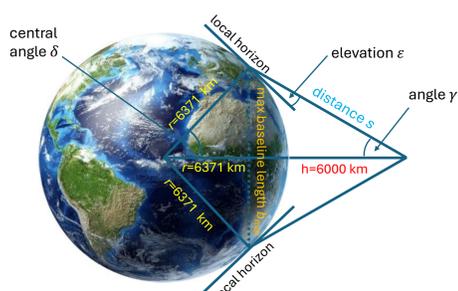


Figure 3: Genesis observation geometry.

WP-2: some examples

Genesis will pass over a VGOS station within 68 minutes from horizon to horizon. For a VGOS antenna of 13 m diameter, Genesis will pass through the telescope beam within 6 s (Fig. 4). Continuous tracking is therefore necessary. A standardized command for satellite tracking will be implemented in the VLBI field system. The radio frequency environment at the VGOS stations needs to be studied. Figure 5 depicts the example of station ONSA13NE.

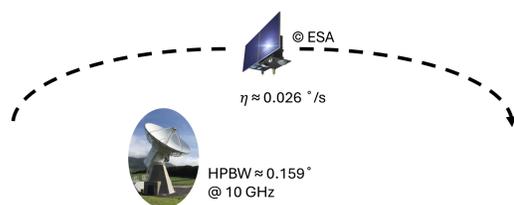


Figure 4: Schematic of a Genesis overpass.

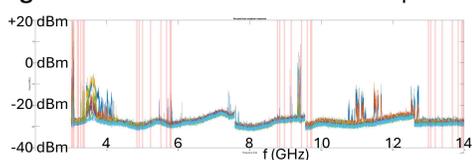


Figure 5: Radio frequency environment at VGOS station ONSA13NE.

WP-3: some examples:

There will be three VLBI transmit antennas, one each for S-band, C-band, and X-band signals (see Tab.1). The antennas will have individual phase center offsets (PCOs) w.r.t. the satellite's center of mass (COM), as well as individual phase center variations (PCVs). These effects, as well as satellite attitude, will affect the interferometric phase measurements and need to be corrected in the VLBI processing chain. It is suggested to do this before fringe fitting.

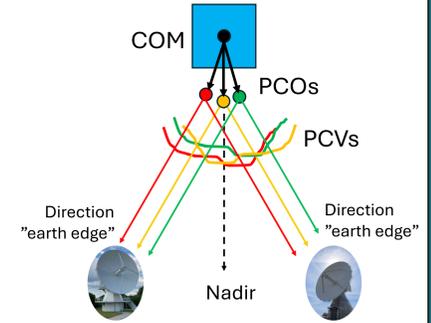


Figure 5: Schematic of VLBI transmit antennas, COM, PCO and PCV.

WP-4: some examples

The possibility to observe the Genesis satellite depends on geometry, i.e. the VGOS ground station network and the satellite orbit. Figure 6 depicts an example satellite orbit and how many stations can see the satellite simultaneously. Eq. 1 describes the necessary observing time T for a pair of VGOS stations to achieve a particular signal-to-noise ratio (SNR). Here, $SEFD_i$ and S_i are the stations sensitivities and signal flux densities, respectively, while BW is the observed bandwidth, $bits$ describes the sampling, and η is the correlator efficiency.

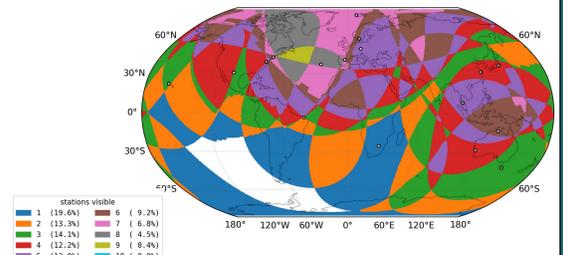


Figure 6: Example of Genesis visibility in the VGOS network (reference: M. Schartner, ETH).

$$T = \frac{1}{2 \cdot BW \cdot bits} \cdot \left(\frac{SNR}{\eta}\right)^2 \cdot \frac{SEFD_1}{S_1} \cdot \frac{SEFD_2}{S_2} \quad (1)$$

WP-5: some examples

A number of end-to-end simulations were performed and published already, see Table 2. The most important outcomes are that (a) Genesis observations can be integrated into IVS observations without influencing the IVS products negatively (b) orbit determination is possible (c) station position repeatabilities are achievable in the mm-range.

Table 2: Examples of end-to-end simulations.

| |
|---|
| Klopotek G, Hobiger T, Haas R, Otsubo T (2020). Geodetic VLBI for precise orbit determination of Earth satellites: a simulation study. In: <i>Journal of Geodesy</i> (Vol. 94, Issue 6). https://doi.org/10.1007/s00190-020-01381-9 |
| Schunck D, McCallum L, Molera Calvés G (2024). On the Integration of VLBI Observations to GENESIS into Global VGOS Operations. In: <i>Remote Sensing</i> (Vol. 16, Issue 17, p. 3234). MDPI AG. https://doi.org/10.3390/rs16173234 |
| Schunck D, McCallum L, Molera Calvés G (2024). Practical Considerations of VLBI Observations to the GENESIS Mission. In: <i>IAG Symposium</i> . Springer Berlin Heidelberg. https://doi.org/10.1007/1345_2024_245 |
| Wolf H, Kern L M, Steinmetz S, Böhm J (2025). Impact of the Inclination of Genesis on the VLBI Terrestrial Reference Frame. In: <i>Proc. EVGA2025</i> . https://doi.org/10.5281/zenodo.18088484 |
| Sert H, Schartner M, Haas R, Karatekin Ö (2025). SNR simulations for Genesis VT observations. In: <i>Proc. EVGA2025</i> . https://doi.org/10.5281/zenodo.18088484 |

WP-6: some examples

First test observations using the proposed Genesis frequency setup (Tab. 1) were performed successfully in July 2025. A set of natural radio sources was observed, and examples of fringe plots are depicted in Fig. 7. A 24 h observation session with a global VGOS network is planned for spring 2026.

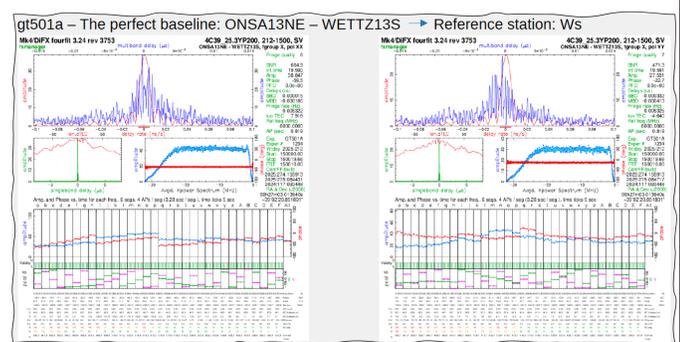


Figure 7: Fringe plots of the first test observations using the proposed Genesis frequency setup (Tab. 1).

WP-7: some examples

The wide bandwidth available with Genesis raised the idea to also have the possibility of sending a pseudo range noise (PRN) code in at least two of the Genesis bands. This could allow one-way ranging measurements with about 15–20 times higher precision than today's GNSS. These could be of interest for time and frequency transfer over long distances. Further work on this interesting topic is ongoing.

Conclusions and outlook:

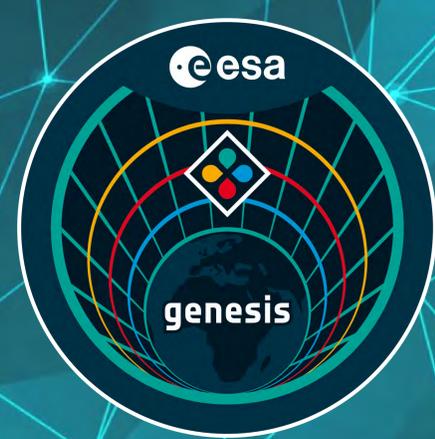
ESA GSET WG-3 (VLBI) is working hard to understand all aspects of future VLBI observations using Genesis signals. The WG works tightly with ESA and gives advice and recommendations. The overriding goal is to be well prepared and to be able to incorporate Genesis observations smoothly into IVS operations, as well as to prepare for combination with the other space geodetic techniques onboard Genesis.



IVS Working Group on Satellite Observations with VLBI (WG7)

L. McCallum¹, D. Schunck¹, and members of WG7*

¹University of Tasmania, *a full list of members appears at the bottom



The International VLBI Service for Geodesy and Astrometry (IVS) is keen to support the Genesis mission. IVS Working Group 7 (WG7) was reconstituted in October 2024 with the aim to study possibilities to observe Earth satellites with the VLBI ground network affiliated with the IVS. **The main focus of WG7 is Genesis, in particular how the IVS can integrate Genesis observations in the IVS observing program.**

The envisaged work packages cover technical issues, ensure station compatibility, as well as work towards an observing plan considering overall resources and regular IVS observing programs.

Terms of Reference (ToR)

Task 1: Station compatibility & IVS resources

1. Station equipment and radio frequency environment
2. VGOS antenna control and steering
3. Mission support by the IVS stations
4. Mission support by other IVS components

Task 2: Technical issues

1. Implementation of a satellite into observing formats
2. Exploring alternative observing modes (e.g. code signal)
3. Compatibility with VGOS (Genesis sends in non-standard VGOS frequencies)
4. How do we deal with an artificial signal?

Task 3: Test observations

1. Test Genesis frequencies/mode and processing
2. Test parts of the observing/processing chain with observations to other already existing satellites
3. Field tests in other areas: antenna steering, switching modes, PRN/code signal recording, signal strength etc.
4. Coordinate and provide test observations for frame tie processing

Task 4: Scheduling, Simulations, Analysis

1. Software packages: scheduling, data processing tools, and analysis to include the handling of satellites
2. Simulations: regarding network considerations, session cadence, orbit estimation
3. Work towards an observing plan. How can/will Genesis be supported by the IVS?

Progress

There is great interest in this WG's activities. From initially 13 (+2), members, 12 more colleagues have joined the group as corresponding members. We hold regular online meetings (8 so far) with 20+ participants.

- Support VGOS R&D proposal to observe in Genesis frequencies.
- Handbook (in preparation) to summarise steps for entire chain from scheduling via observations through to analysis.
- A delay comparison campaign for near-field delay models in software is in preparation (led by Helene Wolf and Rimsky Wolfs).
- Test tracking capabilities of stations: work is ongoing with individual IVS stations to enable satellite tracking (lead Alexander Neidhardt, IVS Network coordinator).
- Implementation of satellites into correlation and fringe-fitting routine, as well as standard file formats; first practical experience and exchange of knowledge.
- Sharing of test observations (VLBI observations to GNSS satellites) amongst the group; for software development (VLBI analysis) as well as code solution (ROB Belgium).

Gaps and Open Questions

It shall be emphasised that satellite observations with geodetic VLBI is a novel technique. Multiple aspects are yet to be investigated in order to make the Genesis VLBI observations reach their target accuracies. Some of these open gaps identified by WG7 are:

In-depth technical development of the technique

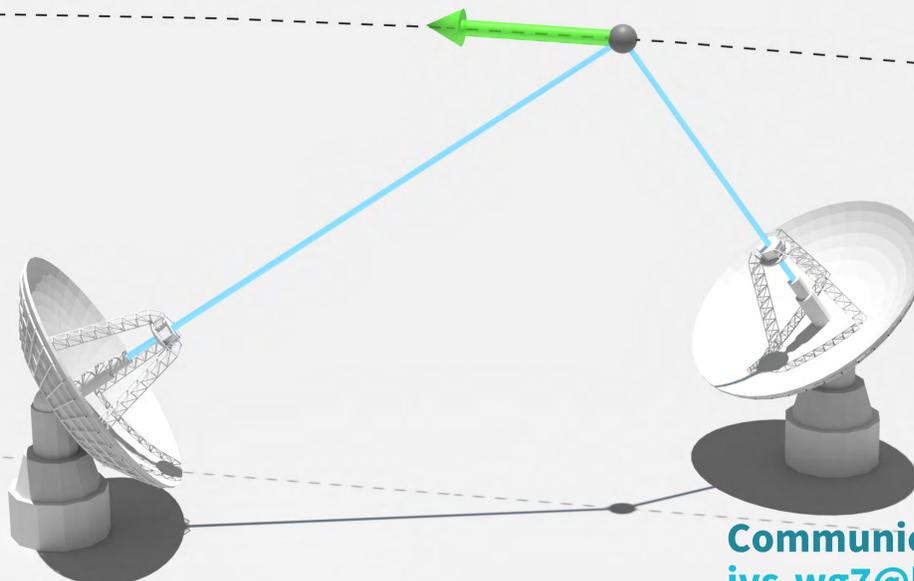
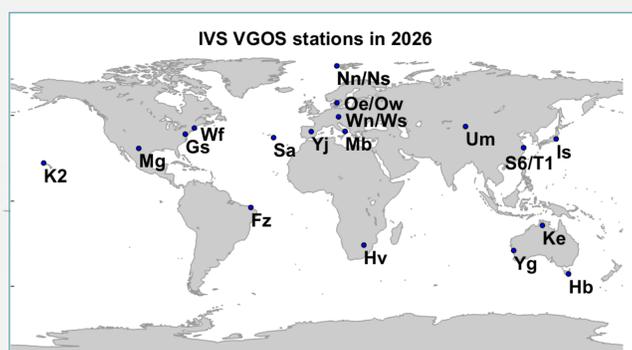
The handling of the artificial signal for VGOS is not standard and will have to be worked on (e.g. applying calibrations at visibility level). There are only very few people working on these questions.

Session cadence

Today, the IVS network observes 1 VGOS 24 h session per week. It is yet to be investigated how Genesis observing can be incorporated into regular IVS observing and how many (Genesis) sessions can be supported.

Correlator and processing resources

A lack of correlator capacity is restricting current IVS VGOS observing efforts. Securing additional correlation and processing resources will be essential for a high observing cadence of Genesis.



Communication
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