GNSS-based orbit and geodetic parameter estimation by means of simulated Genesis data

D. Arnold[1] O. Montenbruck[2] P. Steigenberger[2] A. Miller[1] C. Kobel[1] A. Jäggi[1]

[1] Astronomical Institute, University of Bern, Switzerland
[2] German Space Operations Center, Weßling, Germany

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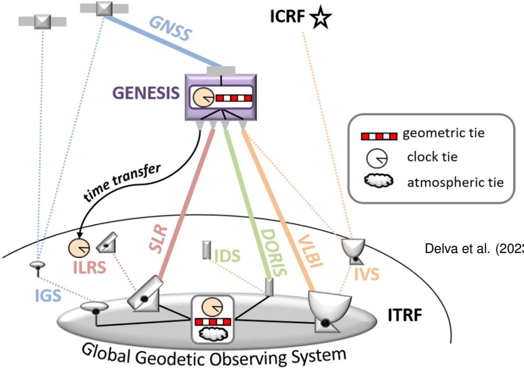
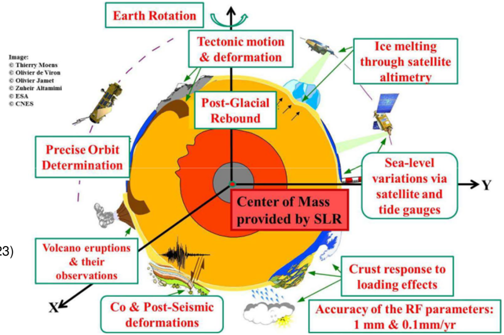
Genesis mission

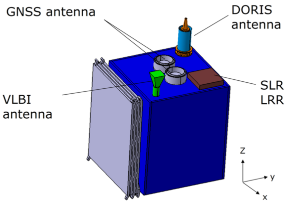
- 1 satellite with instruments for 4 space geodetic techniques GNSS, SLR, DORIS, VLBI, space ties
- Aim: Contribute to an improved International Terrestrial Reference Frame
- Approved at ESA's Ministerial Council in 2022, part of FutureNAV, launch in 2028



Delva et al. (2023)



Genesis satellite and orbit



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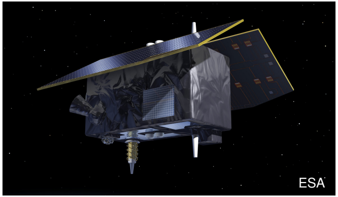
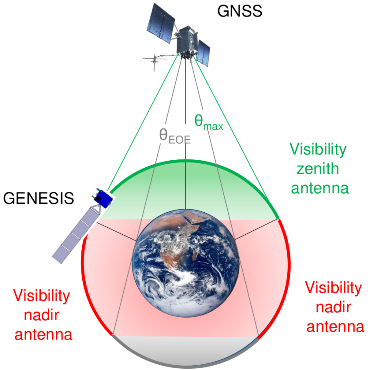


- 6000 km altitude polar orbit (VLBI visibility)

→ received signals emitted at nadir angles up to 28° (max. 14° on ground, 17° in LEO)

- Zenith- and nadir-pointing GNSS antennas



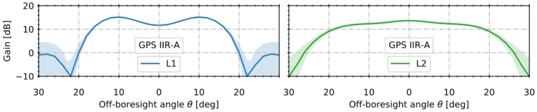
Montenbruck et al. (2023)

GNSS challenges & aim of the study

At nadir angles as large as 28°

- only limited information (gain, phase and pseudo-range variations) on GNSS transmit antennas available
- the GNSS signal strength might be problematic (drop of gain)

Montenbruck et al. (2023)* have analyzed the GNSS visibility for Genesis and presented comprehensive link budget simulations to simulate realistic GNSS data.



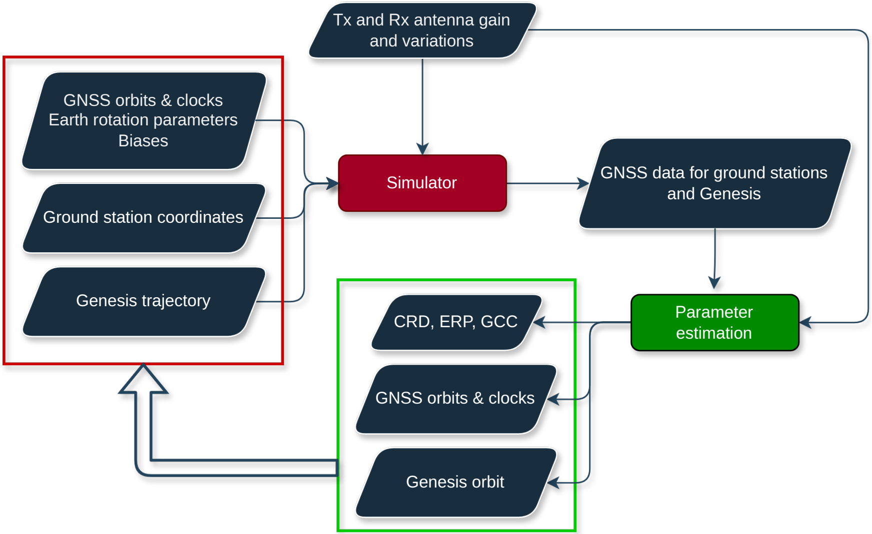
*: DOI 10.1007/s00190-023-01784-4

Question

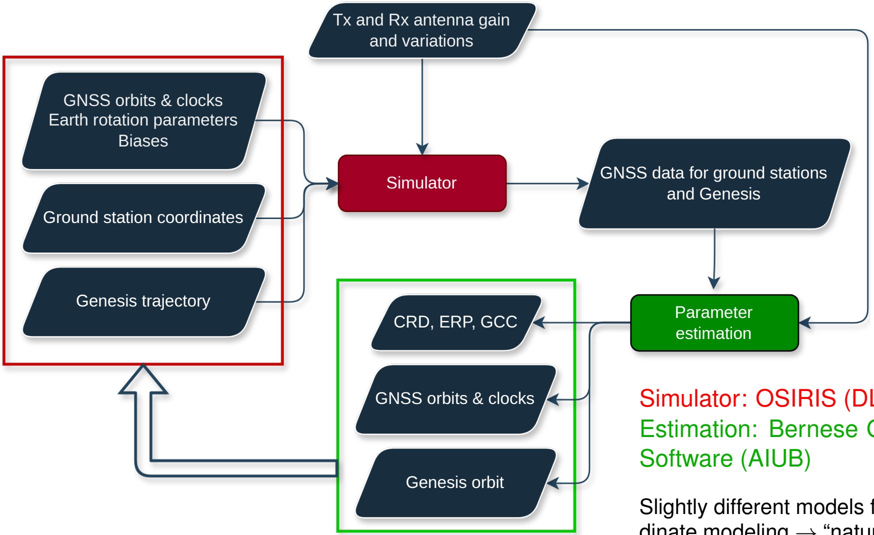
How do uncertainties in GNSS transmit antenna phase patterns at large nadir angles affect the contribution of Genesis to global TRF solutions?

N.b.: In-flight calibrations weaken GNSS contribution to TRF realization!

Methods


Tx and Rx antenna gain and variations
GNSS orbits & clocks
Earth rotation parameters
Biases
Ground station coordinates
Genesis trajectory
Simulator
GNSS data for ground stations and Genesis
Parameter estimation
CRD, ERP, GCC
GNSS orbits & clocks
Genesis orbit

Methods



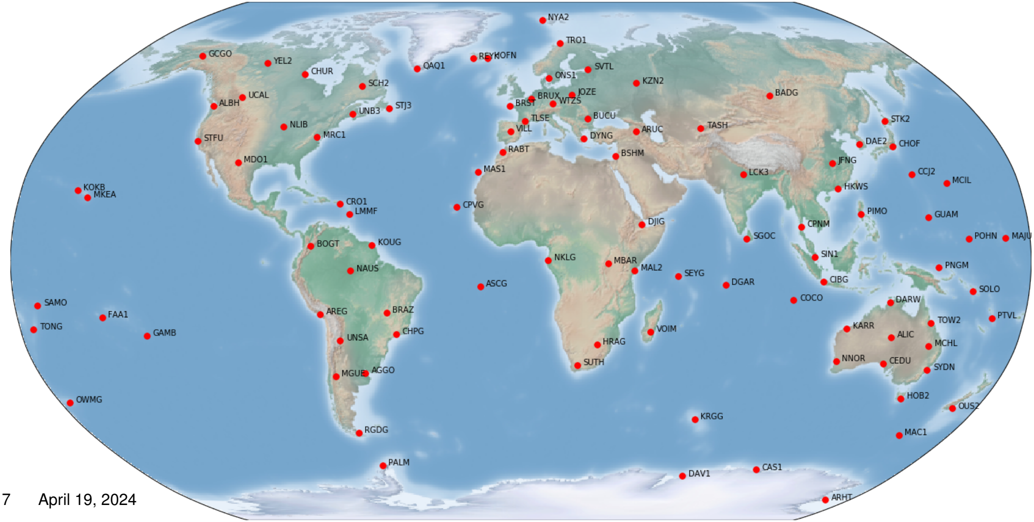
Simulator: OSIRIS (DLR)

Estimation: Bernese GNSS Software (AIUB)

Slightly different models for station coordinate modeling → “natural” uncertaintly

Ground stations

Selection of 100 IGS ground stations:

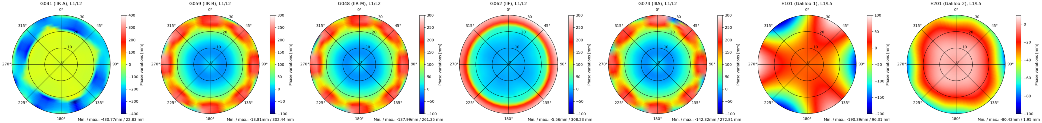


Antenna phase patterns

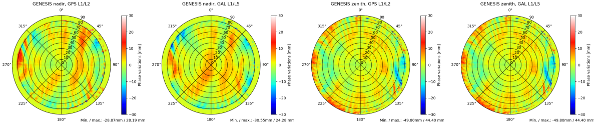
Ground stations: IGS20.ATX

GNSS satellites:

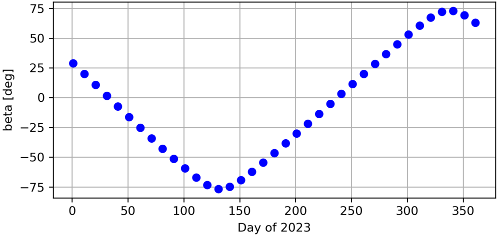
- GPS: LMB20 antenna model (Montenbruck et al., 2024, DOI 10.1007/s00190-023-01809-y)
- Quadratic extrapolation of published patterns from 20° to 30° nadir angle for Galileo



Genesis: Sentinel-6A patterns



Simulation



- Day 001, 011, ..., 361 of 2023 (37 days)
- Genesis orbit (5957 km, 95.5°): Dynamic orbit propagated using radiation pressure models based on 8-plate macro model for box and wing and nominal yaw attitude
- GNSS products: CODE final orbits, clocks, ERPs, biases
- Station coordinates: IGS cumulative SINEX, PSD, ITRF2020 seasonal harmonics, solid Earth tides, pole tides, ocean loading
- Ionosphere: CODE GIMs (ground stations), NeQuick-G (Genesis)
- Troposphere: GPT/GMF model

Estimation

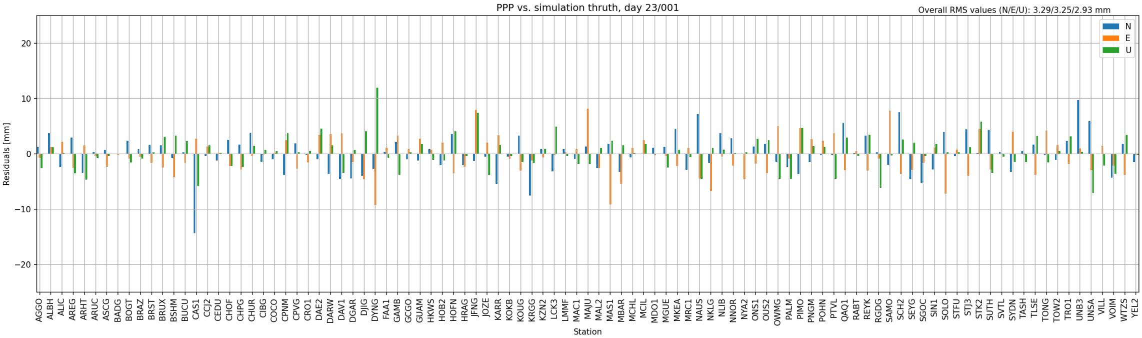
- Undifferenced GNSS data processing
- Carrier phase ambiguities fixed in PPP-AR
- Estimated parameters:
  - Station coordinates
  - Earth rotation parameters
  - Geocenter coordinates
  - Site-specific troposphere parameters
  - GNSS satellite orbits
  - GNSS satellite clocks
  - Genesis orbit (initial cond. and constrained 30’ piecewise-const. acc.)
  - Station and Genesis receiver clocks
  - Observable-specific code biases
- Data sampling: 180 s ($\rightarrow$ about 83’000 parameters/day)
- Code and phase data for ground stations, only phase data for Genesis, currently only nadir antenna ($\rightarrow$ about 1’800’000 observations/day)

Procedures: Kobel et al. (2024), DOI 10.1016/j.asr.2024.04.015

“Zero” test: Coordinates

PPP (only estimate station-related parameters) using CODE final GNSS products and the correct PCVs. Differences to “true” coordinates:

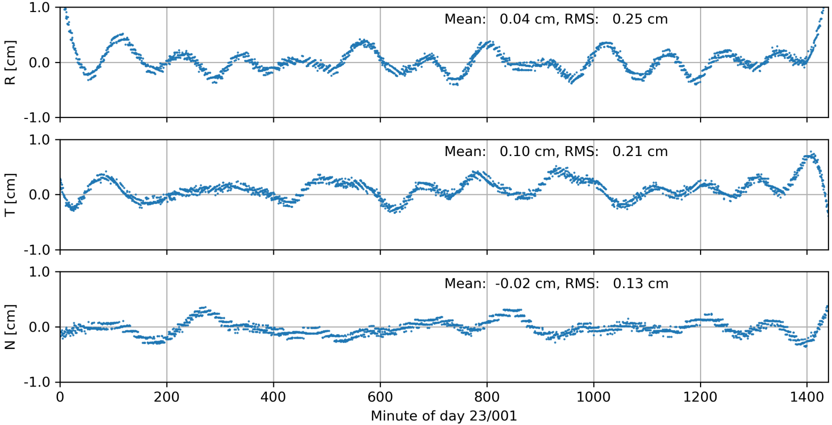
Overall RMS in N/E/U: 3.29/3.25/2.93 mm



Same order of magnitude as differences between different IGS ACs (e.g., 4.10/3.32/2.76 mm for CODE vs. ESA) → realistic model uncertainties

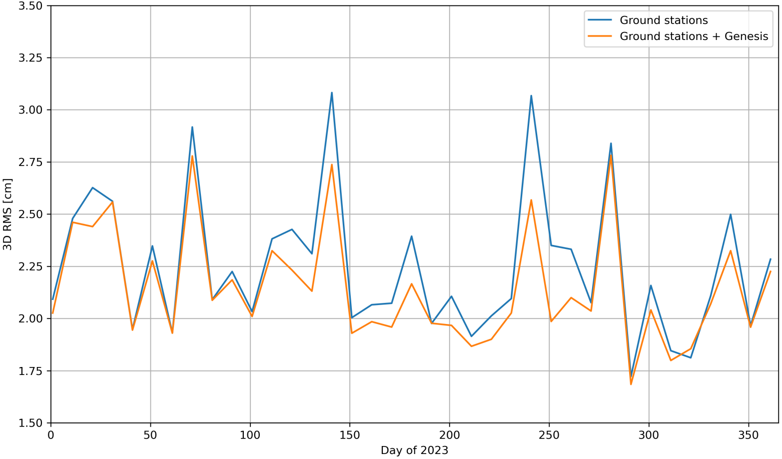
“Zero” test: Genesis orbit

Genesis POD using CODE final GNSS products and the correct PCVs. Differences to “true” Genesis orbit:



Full parameter estimation

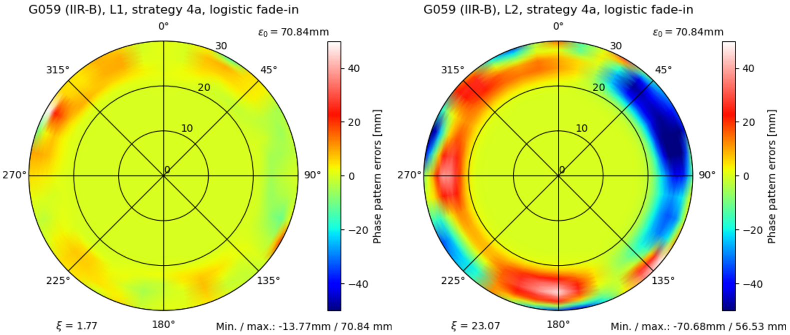
Differences of estimated GPS orbits compared to “true” orbits, using correct PCVs:



Notice: The “true” orbits (CODE) are 3-day orbits, while here only 1-day orbits are computed.

Phase pattern errors

Derive transmitter phase pattern errors by scaling differences of single patterns w.r.t. block-specific mean values:

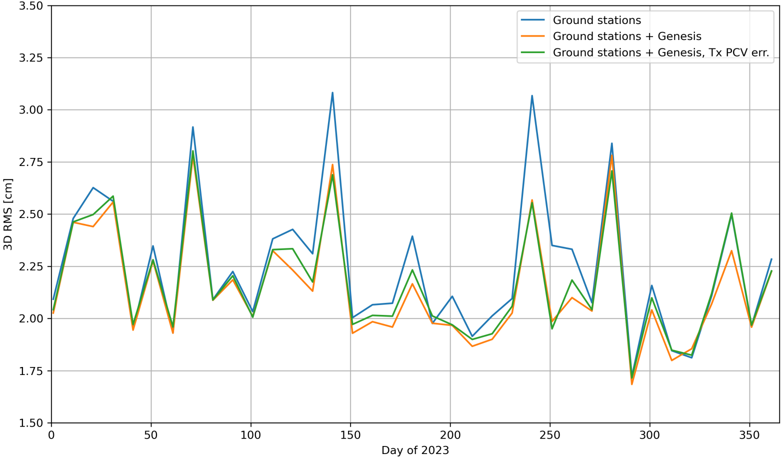


Errors zero for small nadir angles.

Add these pattern errors to the true transmit PCVs in the parameter estimation

Impact on recovered GNSS orbits

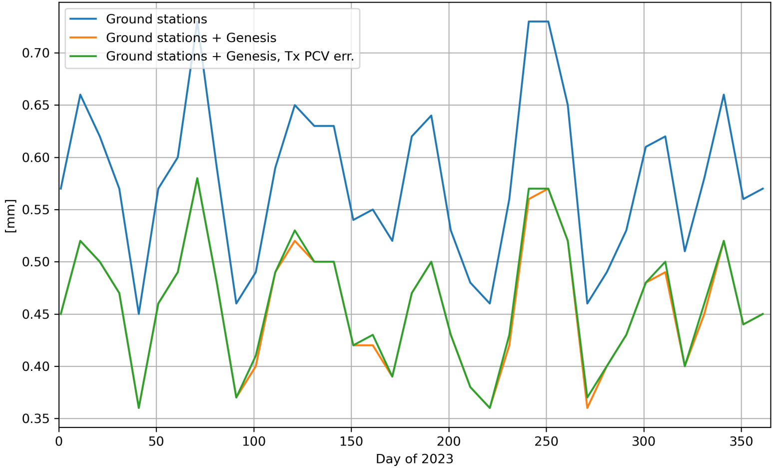
Differences of estimated GPS orbits compared to “true” orbits:



Slight degradation of GNSS orbits

Geocenter formal errors

Formal errors for the geocenter z coordinates:



Adding Genesis helps, transmit phase pattern errors do not have a large impact.

Conclusions

- The GNSS tracking of Genesis is less straightforward than for LEOs
- Established a simulation framework to study impact of systematic GNSS modeling errors on orbit and global solutions
- Realistic GNSS transmit phase pattern errors have a small detrimental effect on GNSS (and Genesis) orbits
- Further systematic analysis for other parameters...

Thank you!

Contact: daniel.arnold@unibe.ch