Genesis orbit and geodetic parameter estimation based on GNSS: Impact of transmit antenna phase pattern errors

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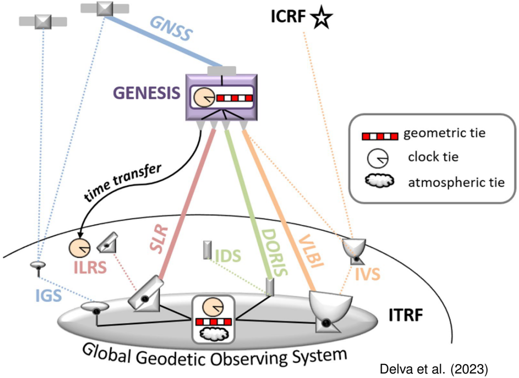
Genesis (or GENESIS?) mission

- 1 satellite with instruments for 4 space geodetic techniques GNSS, SLR, VLBI, DORIS, accurate space ties
- Aim: Contribute to an improved International Terrestrial Reference Frame (towards GGOS goals of 1 mm accuracy / 0.1 mm/yr stability)



Delva et al. (2023)

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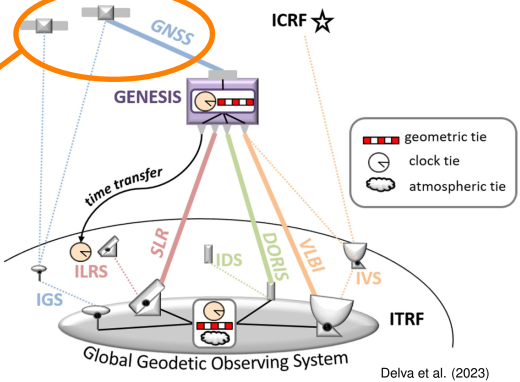
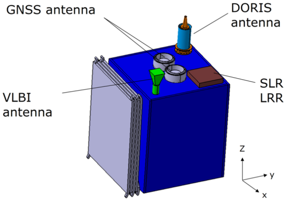


Delva et al. (2023)

This presentation

Kur et al. (2024) have studied the benefit of Genesis for Galileo orbit and clock determination (previous presentation).

Genesis satellite and orbit



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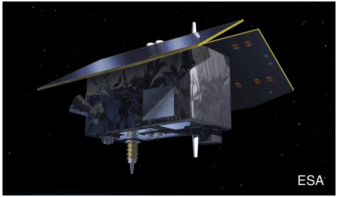

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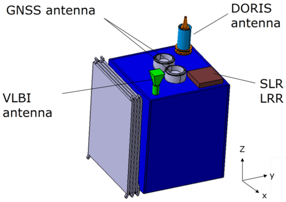

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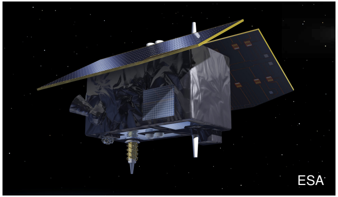

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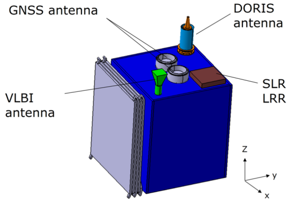
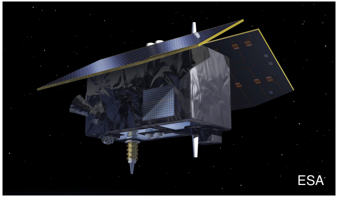


Delva et al. (2023)

Assumed this design for now



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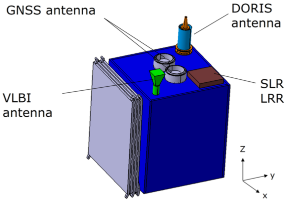

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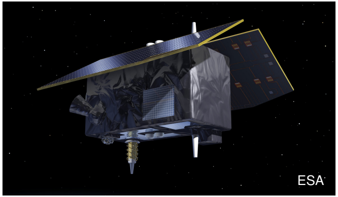
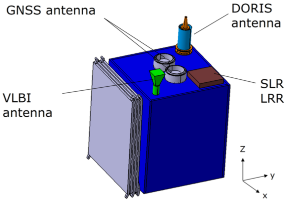


For next analyses

Genesis satellite and orbit



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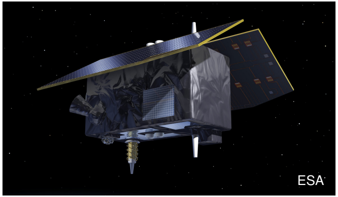
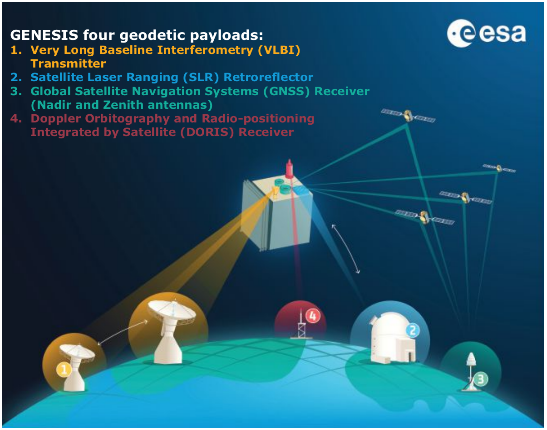
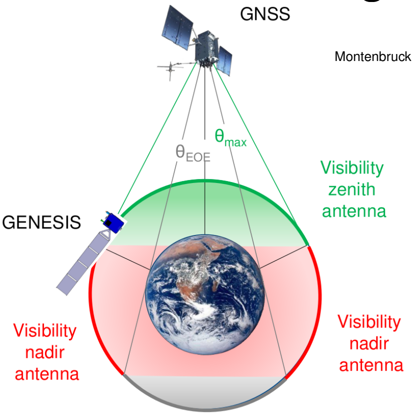


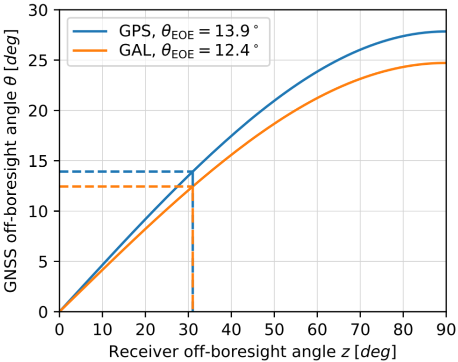
– 6000 km altitude near-polar orbit (VLBI visibility)



GNSS challenges (1)

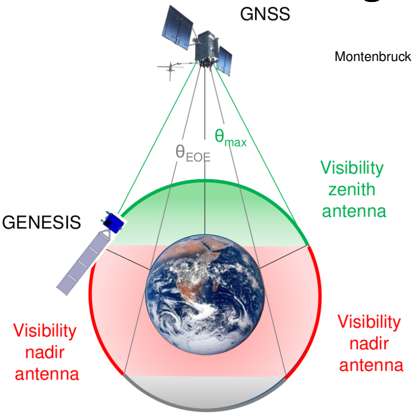


Montenbruck et al. (2023)



Zenith- and nadir-pointing GNSS antennas

GNSS challenges (1)



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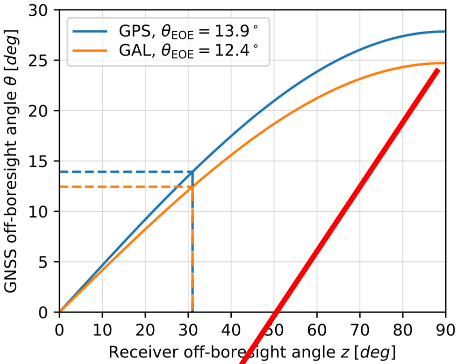
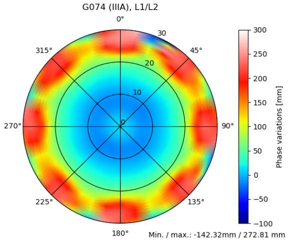
Zenith- and nadir-pointing GNSS antennas



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

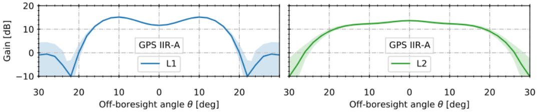
GNSS challenges (2)



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.

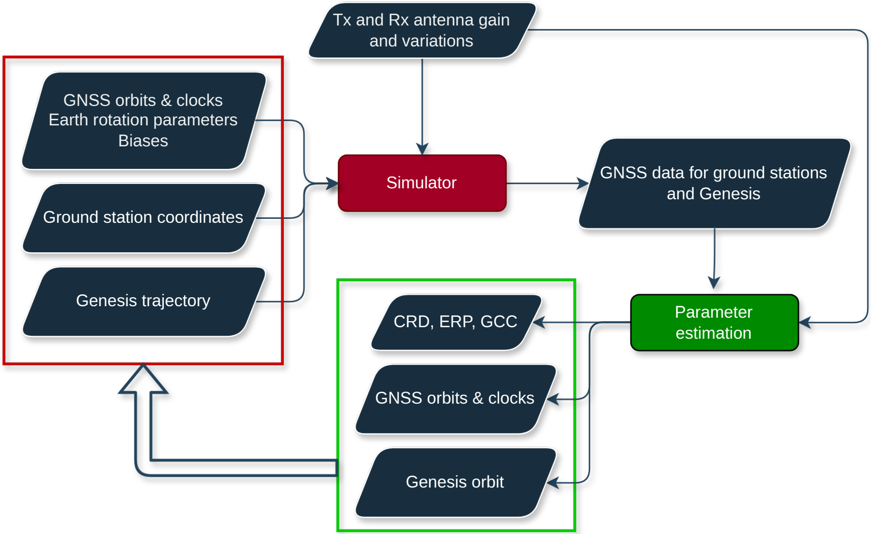


Question

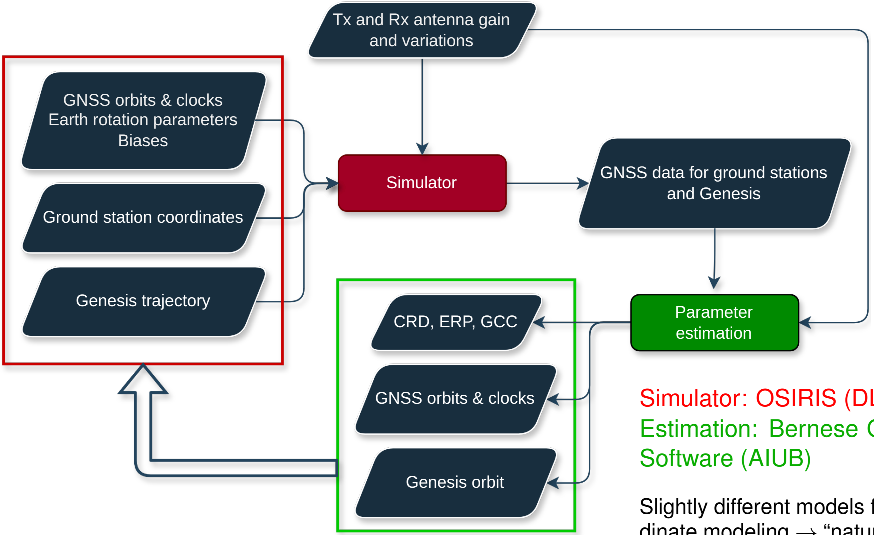
How do uncertainties in GNSS transmit antenna phase variations (PVs) at large nadir angles affect the contribution of Genesis to global TRF solutions?

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

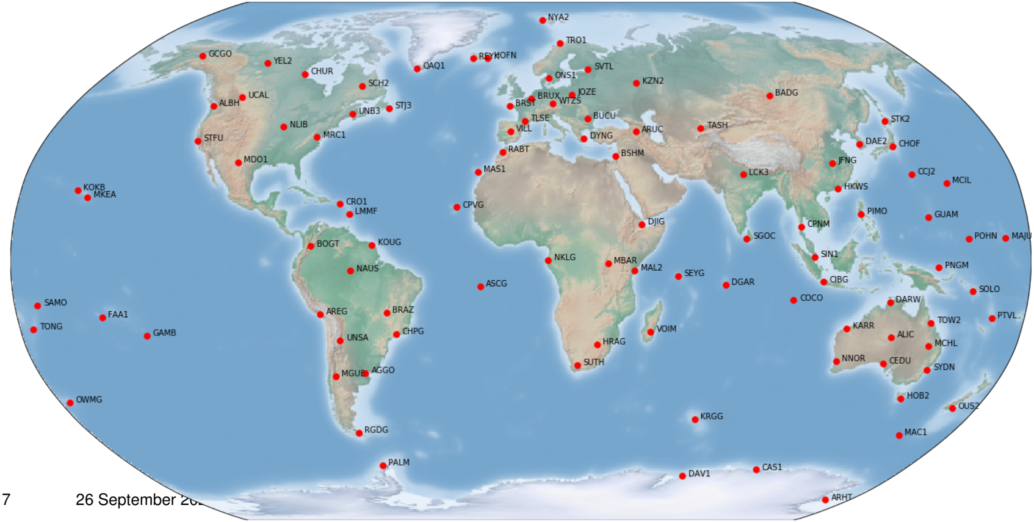


Simulator: OSIRIS (DLR)
Estimation: Bernese GNSS Software (AIUB)

Slightly different models for station coordinate modeling → "natural" uncertaintly

Ground stations

Selection of 100 IGS ground stations:

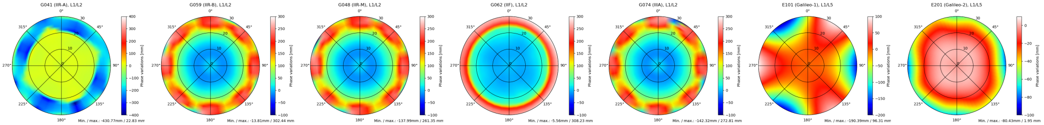


Antenna phase patterns

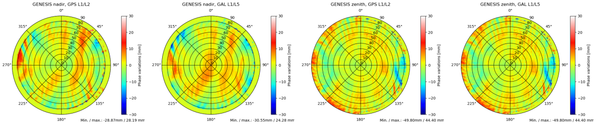
Ground stations: IGS20.ATX

GNSS satellites:

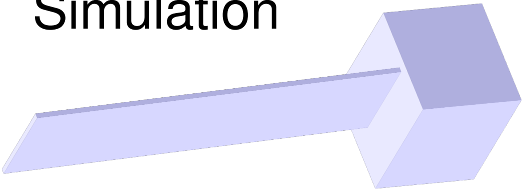
- GPS: LMB20 antenna model (Montenbruck et al., 2024)
- Quadratic extrapolation of published patterns from 20° to 30° nadir angle for Galileo

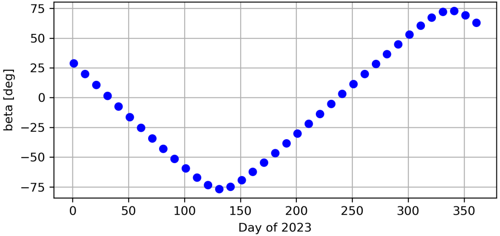


Genesis: Sentinel-6A patterns



Simulation





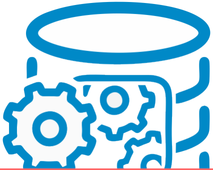
- Day 001, 011, ..., 361 of 2023 (37 days)
- Genesis orbit (5957 km, 95.5°): Dynamic orbit propagated using radiation pressure models based on 8-plate macro model for box and wing and nominal yaw attitude
- GNSS products: CODE final orbits, clocks, ERPs, biases
- Station coordinates: IGS cumulative SINEX, 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 ($\rightarrow$ about 1’800’000 observations/day)

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

Estimation



- Undifferenced GNSS data processing
- Carrier phase ambiguities fixed in PPP-AR
- Estimated parameters:

Macro model

For the reconstruction, the “true” Genesis macro model was used. To see how macro model errors affect the Genesis contribution, check out poster 38: **Miller et al., Impact of non-gravitational force model deficiencies for Genesis orbit and geodetic parameter estimation based on GNSS**.

  - GNSS satellite clocks
  - Genesis orbit (initial cond. and constrained 30’ piecewise-const. acc.)
  - Station and Genesis receiver clocks
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- Data sampling: 180 s (→ about 83’000 parameters/day)
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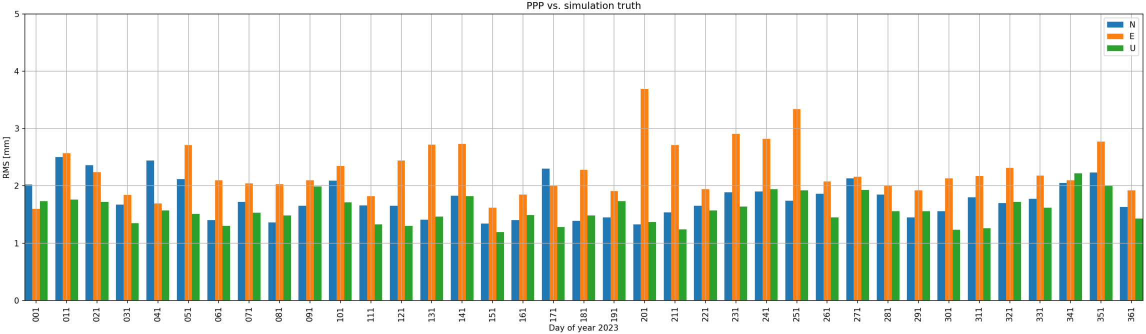
“Zero” test: Coordinates

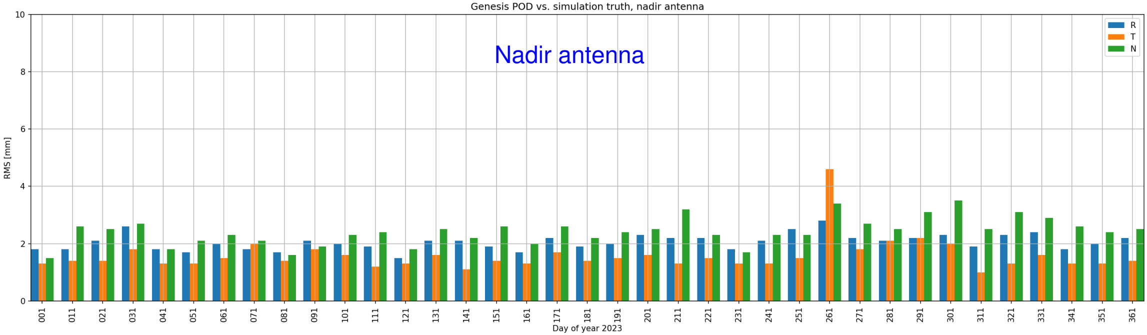
PPP (only estimate station-related parameters) using CODE final GNSS products and the correct transmit PVs. Differences to “true” coordinates:



Same order of magnitude as differences between different IGS ACs (e.g., 4.10/3.32/2.76 mm for CODE vs. ESA for day 23/001) → realistic model uncertainties

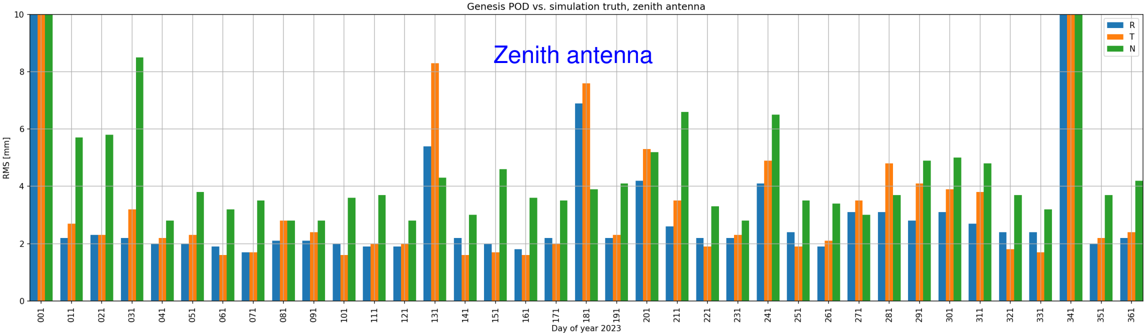
“Zero” test: Genesis orbit

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



“Zero” test: Genesis orbit

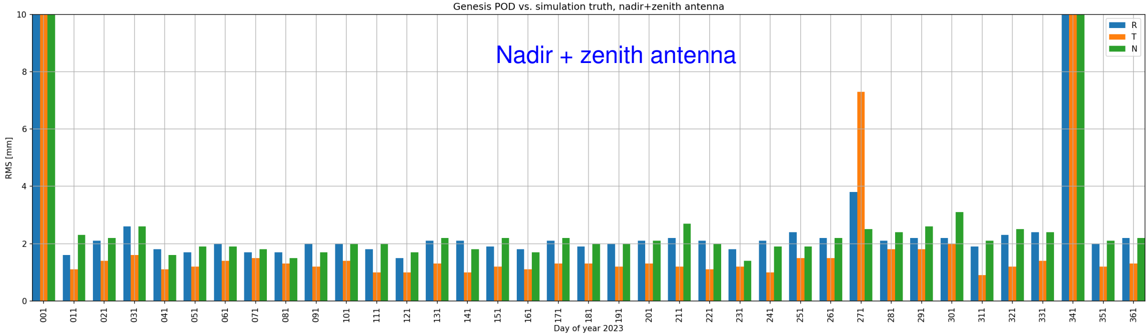
Genesis POD using CODE final GNSS products and the correct transmit PVs.
Differences to “true” Genesis orbit:



Zenith-antenna based POD more challenging

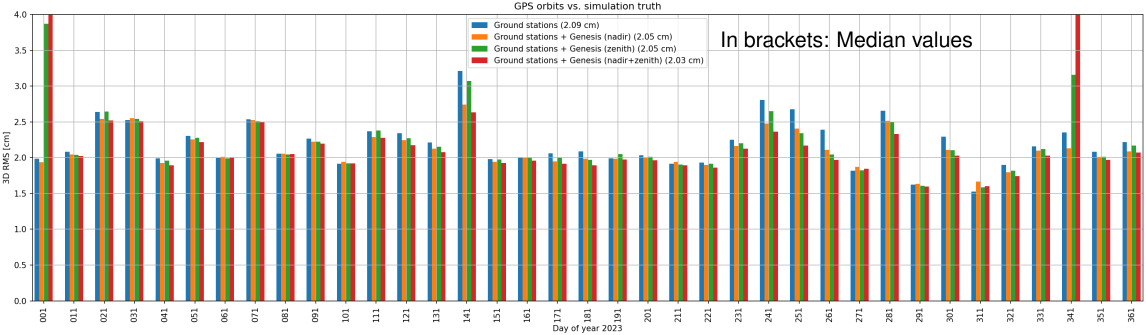
“Zero” test: Genesis orbit

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



Full parameter estimation: GNSS orbits

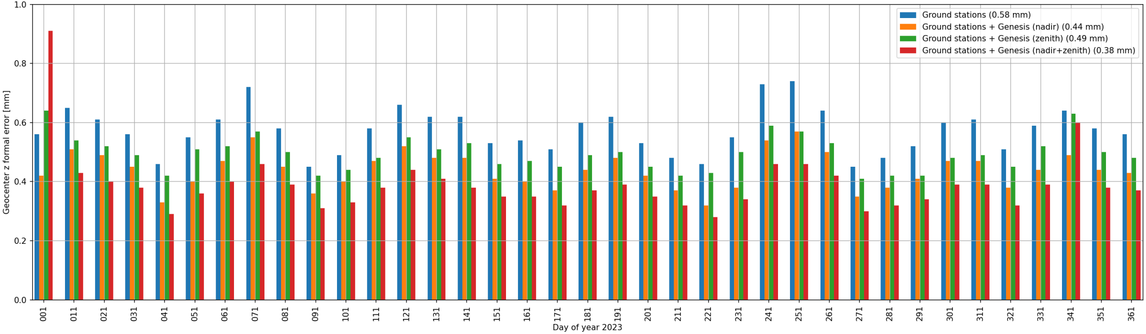
Estimating orbit and geodetic parameters using ground stations and Genesis data and correct transmit PVs. Differences of estimated GPS orbits compared to “true” orbits:



- Notice: The “true” orbits (CODE final) are 3-day orbits, while here only 1-day orbits are computed ($\rightarrow$ slightly degraded comparison).

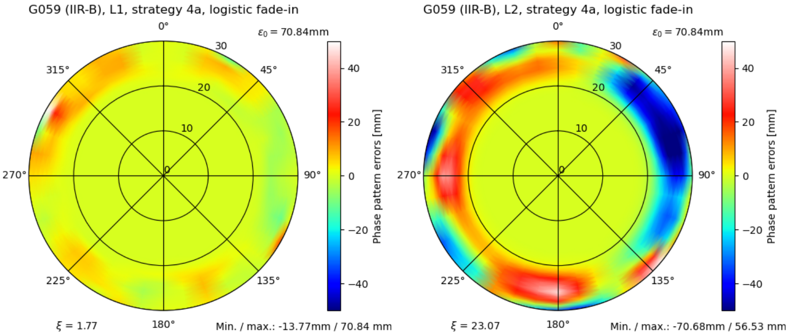
Full parameter estimation: Geocenter

Formal errors of geocenter z coordinates, using correct transmit PVs:



Phase pattern errors

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

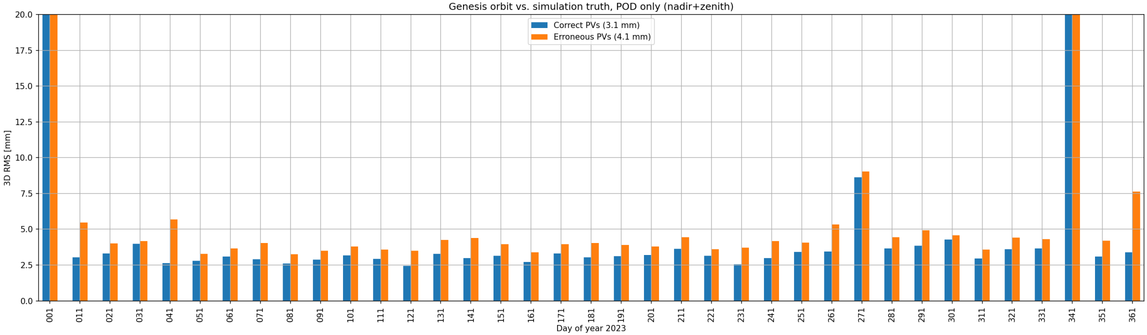


Errors zero for small nadir angles.

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

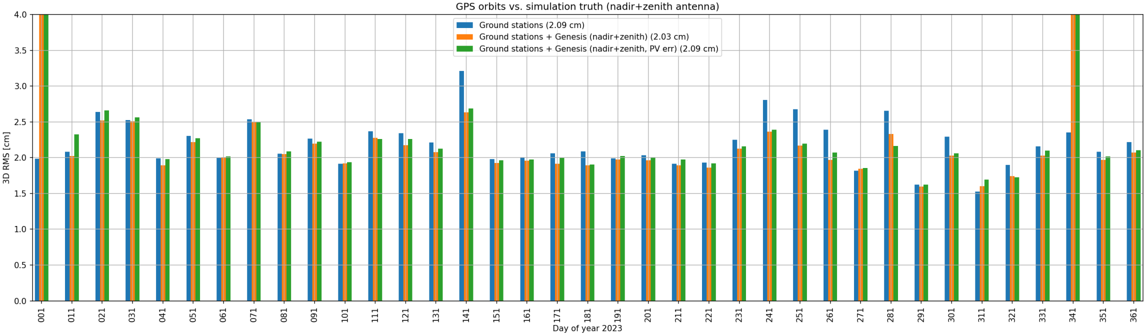
Impact on Genesis orbit

Genesis orbit differences from a POD-only solution:



Impact on GNSS orbits

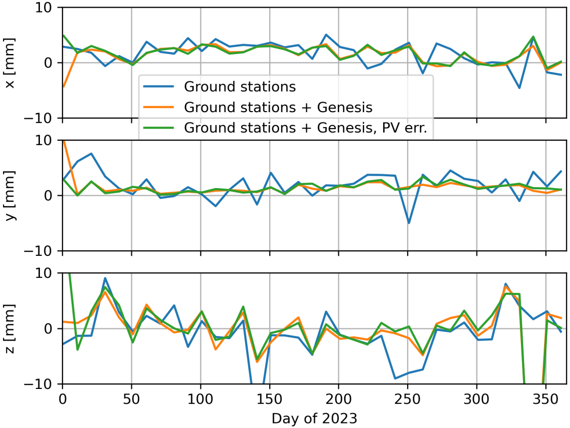
Differences of estimated GPS orbits compared to “true” orbits:



Slight degradation of GNSS orbits, benefit of Genesis reduced

Impact on geocenter coordinates

Estimated geocenter coordinates (nadir+zenith antenna):



Median $\pm$ MAD:

$+2.2 \pm 2.0\,\mathrm{mm}$

$+1.8 \pm 1.6\,\mathrm{mm}$

$+1.8 \pm 1.7\,\mathrm{mm}$

$+2.1 \pm 2.3\,\mathrm{mm}$

$+1.2 \pm 0.7\,\mathrm{mm}$

$+1.3 \pm 0.8\,\mathrm{mm}$

$-1.3 \pm 3.1\,\mathrm{mm}$

$-0.1 \pm 2.8\,\mathrm{mm}$

$+0.1 \pm 3.2\,\mathrm{mm}$

Conclusions

- The GNSS tracking of Genesis is less straightforward than for LEOs (especially zenith antenna).
- Established a simulation framework to study impact of systematic GNSS modeling errors on orbit and global solutions.
- Supposedly realistic GNSS transmit phase pattern errors counteract the potential benefit of Genesis on GNSS orbits and geocenter coordinates.
- To fully exploit Genesis for TRF contributions, characterizations of GNSS transmit antennas up to large nadir angles should be known/made available to the extent possible!
- Check out poster 38: Miller et al., Impact of non-gravitational force model deficiencies for Genesis orbit and geodetic parameter estimation based on GNSS.

Thank you!

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References

Delva, P., Altamimi, Z., Blazquez, A. et al. GENESIS: co-location of geodetic techniques in space. Earth Planets Space 75, 5 (2023).

Kur, T., Sośnica, K. and Kalarus, M., 2024. Prospects of GENESIS and Galileo joint orbit and clock determination. J Geod 98, 51 (2024).

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