Genesis Orbit And Geodetic Parameter Estimation Based On GNSS: Impact Of Transmit Antenna Phase Pattern Errors

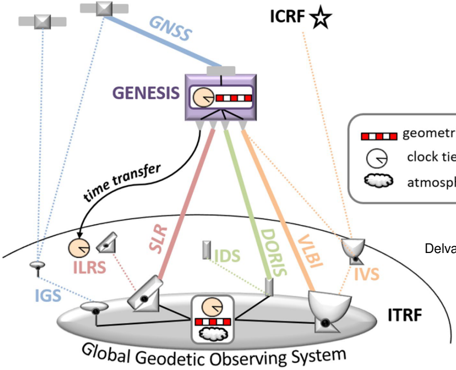
D. Arnold[1] A. Miller[1] O. Montenbruck[2] P. Steigenberger[2] R. Dach[1] A. Jäggi[1]

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

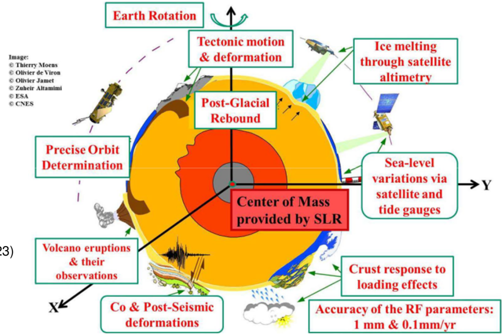
IGS Symposium & Workshop 2024, Bern, Switzerland
Session 2
July 02, 2024

Genesis mission

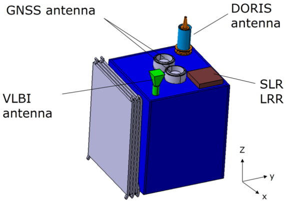
- 1 satellite with instruments for 4 space geodetic techniques GNSS, SLR, DORIS, VLBI, space ties
- Aim: Contribute to an improved International Terrestrial Reference Frame
- Approved at ESA’s Ministerial Council in 2022, part of FutureNAV, launch in 2028



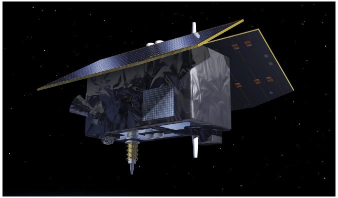
Delva et al. (2023)



Genesis satellite and orbit



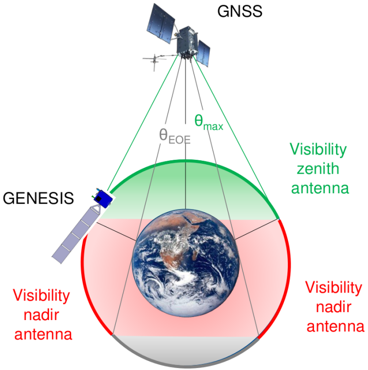
Delva et al. (2023)



- 6000 km altitude polar orbit (VLBI visibility)

→ received GNSS 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)

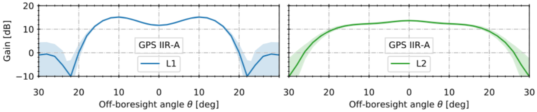
Kur et al. (2024) (DOI 10.1007/s00190-024-01869-8) have studied the benefit of Genesis for Galileo orbit and clock determination.

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.



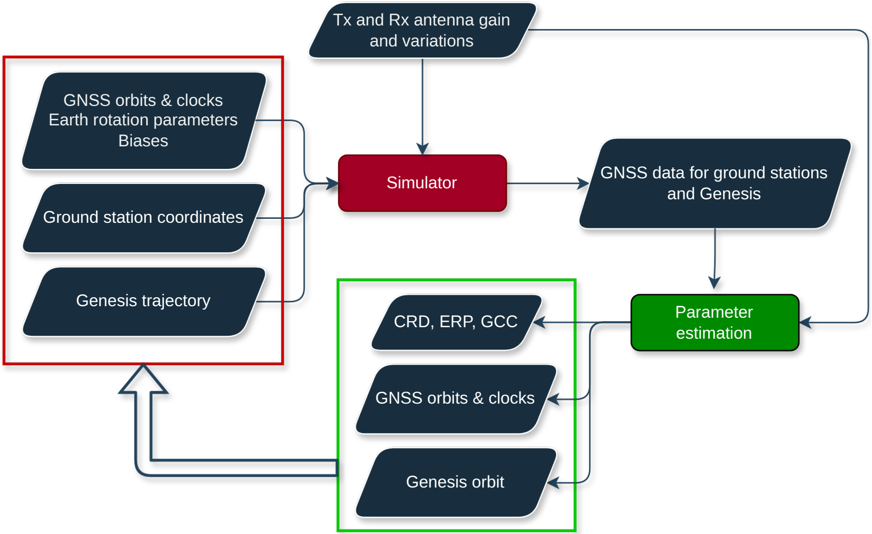
*: DOI 10.1007/s00190-023-01784-4

Question

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

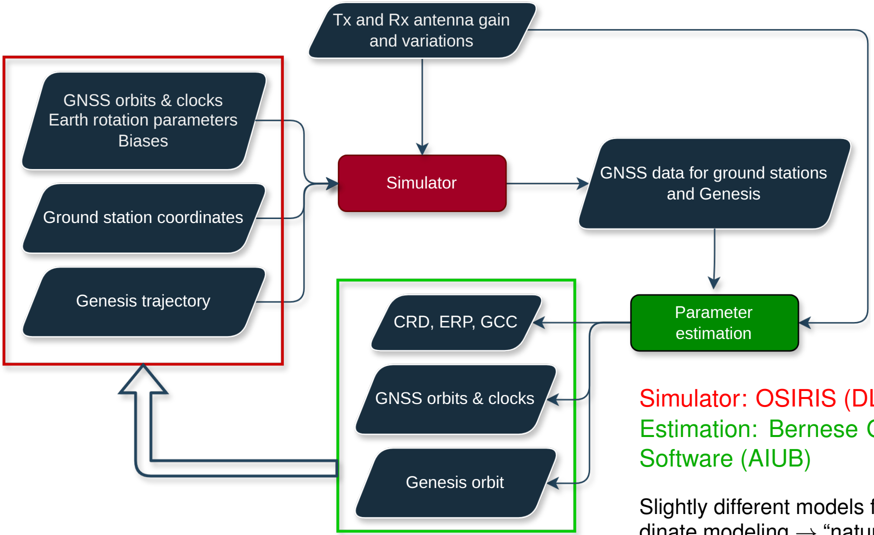
N.b.: In-flight calibrations weaken GNSS contribution to TRF realization!

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

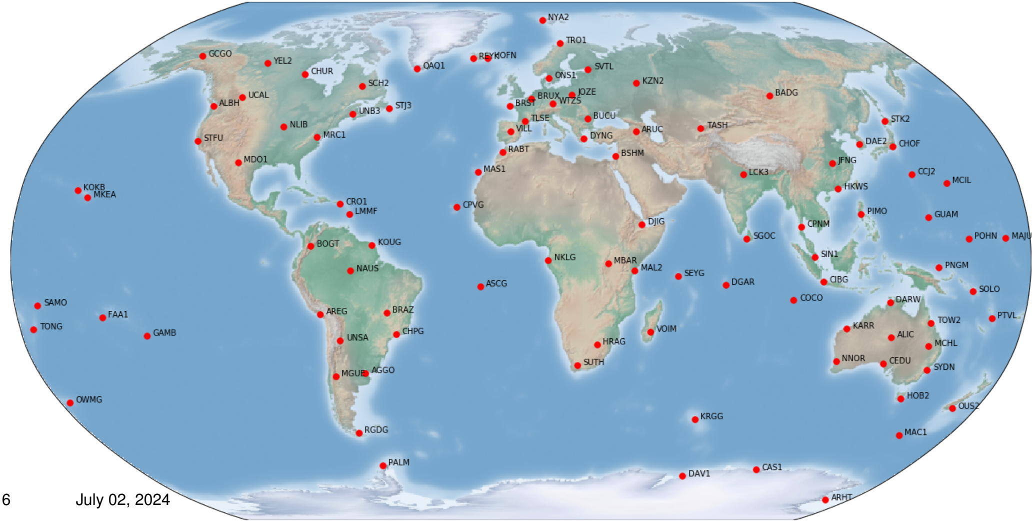


Simulator: OSIRIS (DLR)
Estimation: Bernese GNSS Software (AIUB)

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

Ground stations

Selection of 100 IGS ground stations:

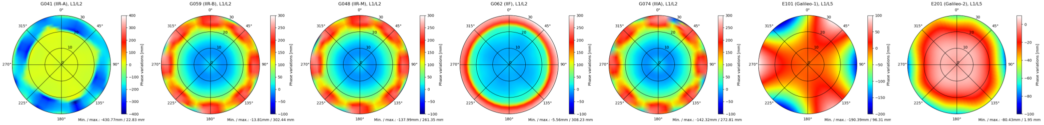


Antenna phase patterns

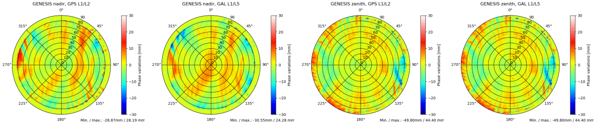
Ground stations: IGS20.ATX

GNSS satellites:

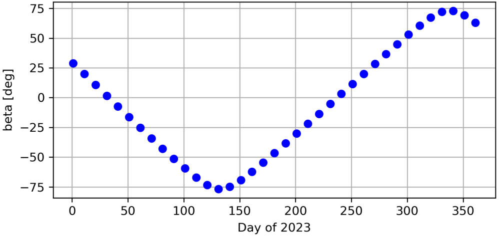
- GPS: LMB20 antenna model (Montenbruck et al., 2024, DOI 10.1007/s00190-023-01809-y)
- Quadratic extrapolation of published patterns from 20° to 30° nadir angle for Galileo



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

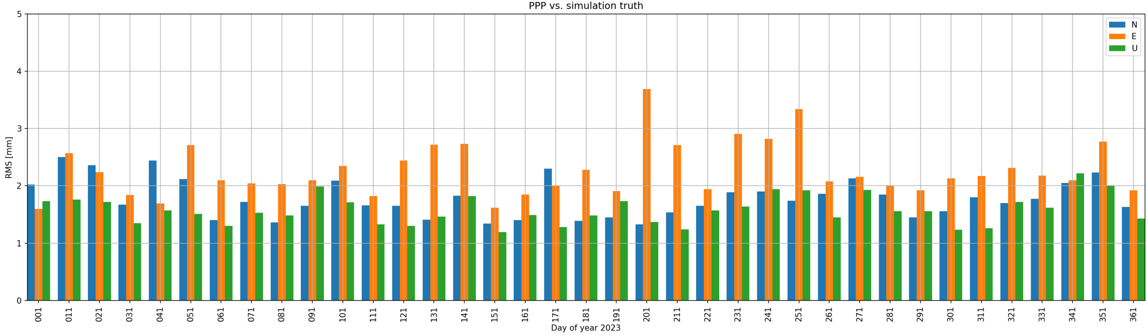
Estimation

- 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 (→ about 83’000 parameters/day)
- Code and phase data for ground stations, only phase data for Genesis (→ about 1’800’000 observations/day)

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

“Zero” test: Coordinates

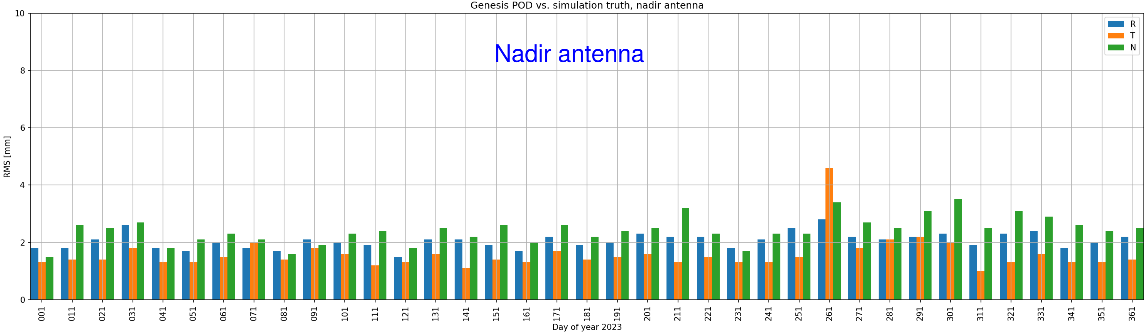
PPP (only estimate station-related parameters) using CODE final GNSS products and the correct transmit PVs. Differences to “true” coordinates:



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

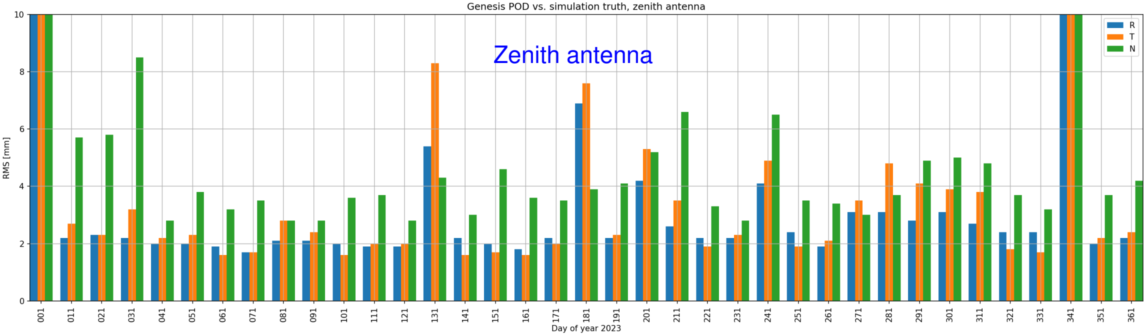
“Zero” test: Genesis orbit

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



“Zero” test: Genesis orbit

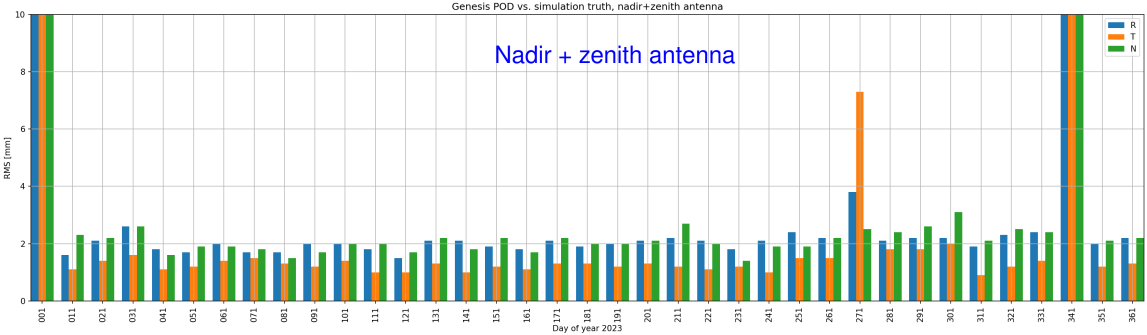
Genesis POD using CODE final GNSS products and the correct transmit PVs.
Differences to “true” Genesis orbit:



Zenith-antenna based POD more challenging

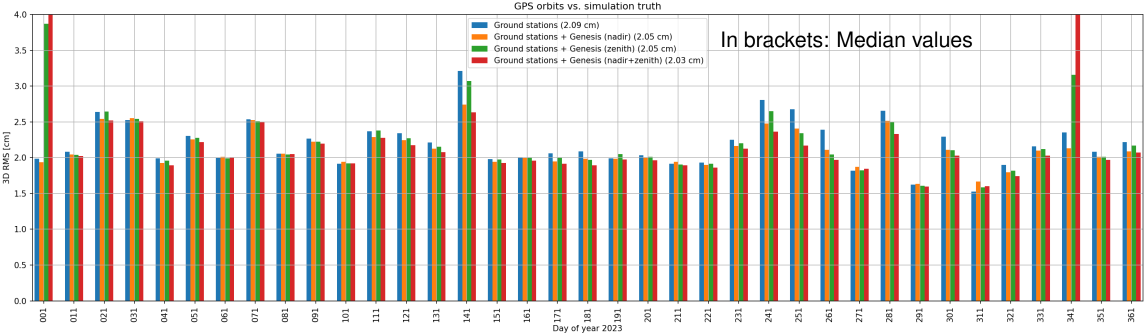
“Zero” test: Genesis orbit

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



Full parameter estimation: GNSS orbits

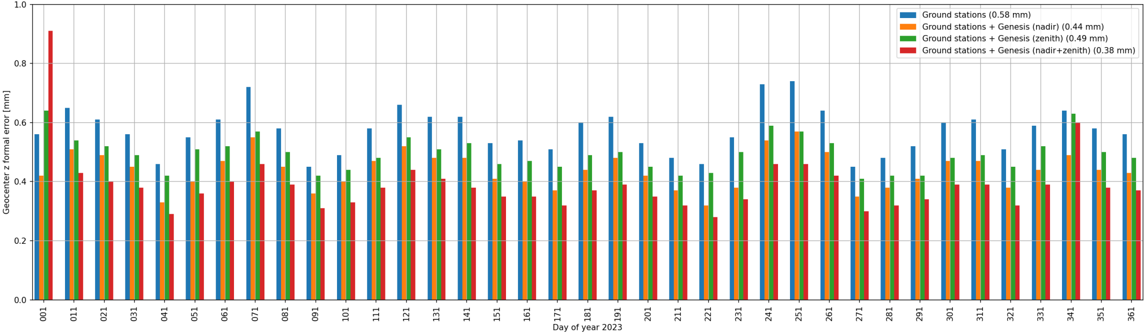
Estimating orbit and geodetic parameters using ground stations and Genesis data and correct transmit PVs. Differences of estimated GPS orbits compared to “true” orbits:



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

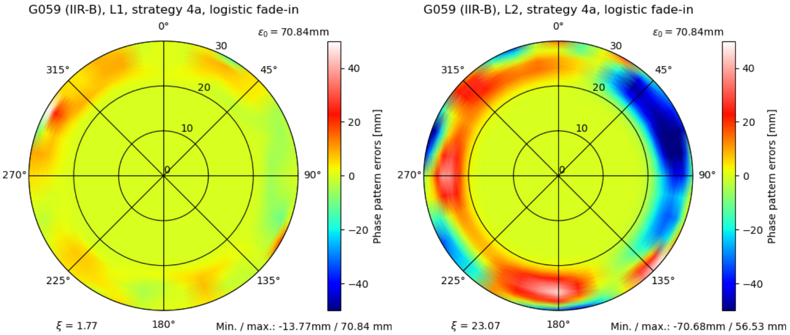
Full parameter estimation: Geocenter

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:

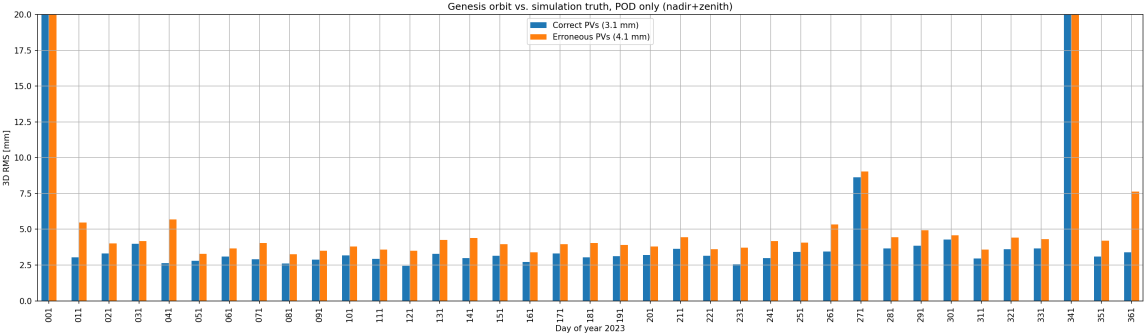


Errors zero for small nadir angles.

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

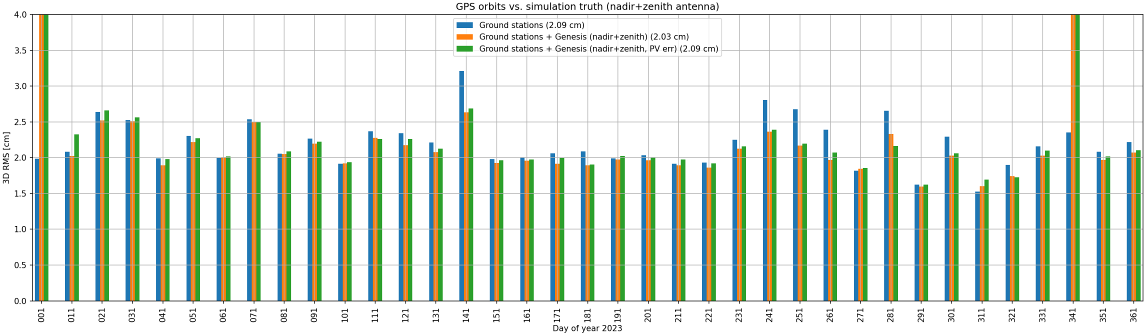
Impact on Genesis orbit

Genesis orbit differences from a POD-only solution:



Impact on GNSS orbits

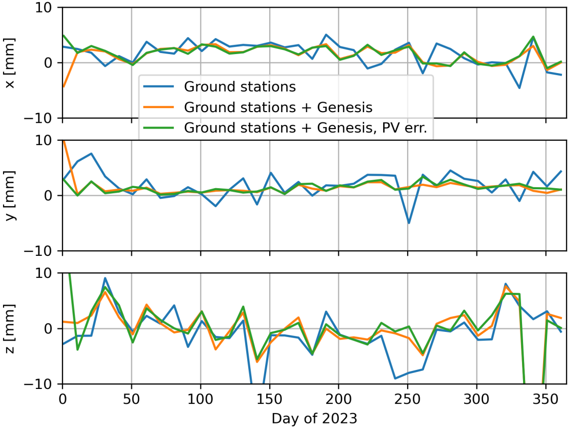
Differences of estimated GPS orbits compared to “true” orbits:



Slight degradation of GNSS orbits, benefit of Genesis reduced

Impact on geocenter coordinates

Estimated geocenter coordinates (nadir+zenith antenna):



Median $\pm$ MAD:

$+2.2 \pm 2.0$ mm
$+1.8 \pm 1.6$ mm
$+1.8 \pm 1.7$ mm

$+2.1 \pm 2.3$ mm
$+1.2 \pm 0.7$ mm
$+1.3 \pm 0.8$ mm

-1.3 ± 3.1 mm
-0.1 ± 2.8 mm
$+0.1 \pm 3.2$ 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!

Thank you!

Contact: daniel.arnold@unibe.ch