Genesis orbit and geodetic parameter estimation based on GNSS: Impact of non-gravitational force model deficiencies

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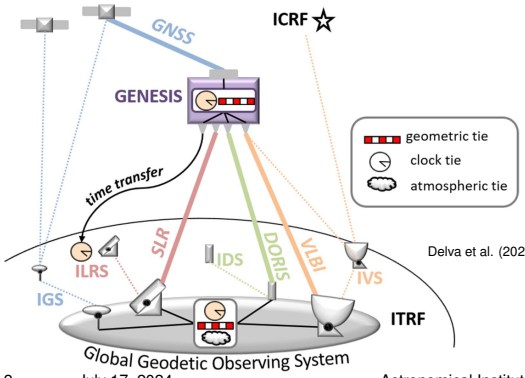
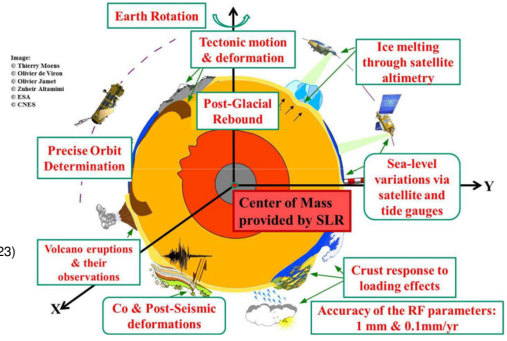
Genesis mission

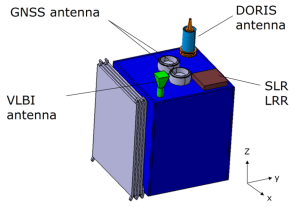
- 1 satellite with instruments for 4 space geodetic techniques GNSS, SLR, DORIS, VLBI, space ties
- Aim: Contribute to an improved International Terrestrial Reference Frame
- Approved at ESA's Ministerial Council in 2022, part of FutureNAV, launch in 2028



Delva et al. (2023)



Genesis satellite and orbit



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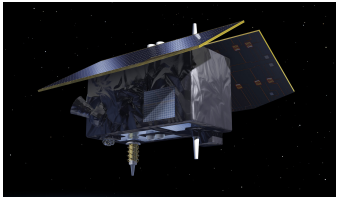
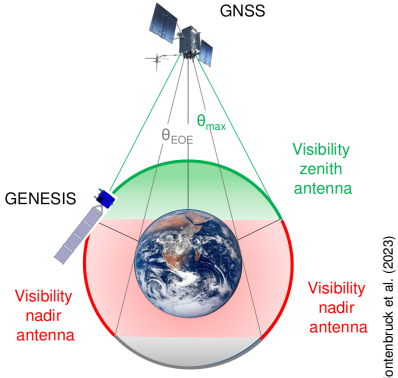


- 6000 km altitude polar orbit (VLBI visibility)

→ rather unfavorable GNSS tracking conditions

→ zenith- and nadir-pointing GNSS antennas



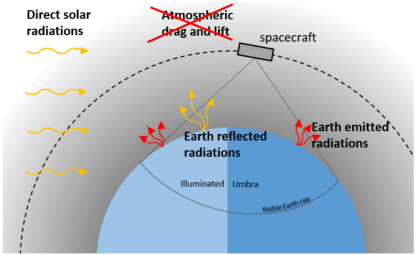
Montenbruck et al. (2023)

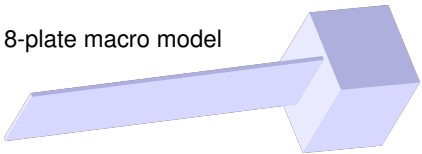
Kur et al. (2024) (DOI 10.1007/s00190-024-01869-8) have recently studied the benefit of Genesis for Galileo orbit and clock determination.

Non-gravitational force modeling

For Genesis, a dynamic orbit modeling is desired, as empirical orbit parameters might correlate significantly with specific geodetic parameters

→ requires detailed explicit modeling of non-gravitational (radiation-induced) forces
→ requires proper description of satellite geometry and optical surface properties

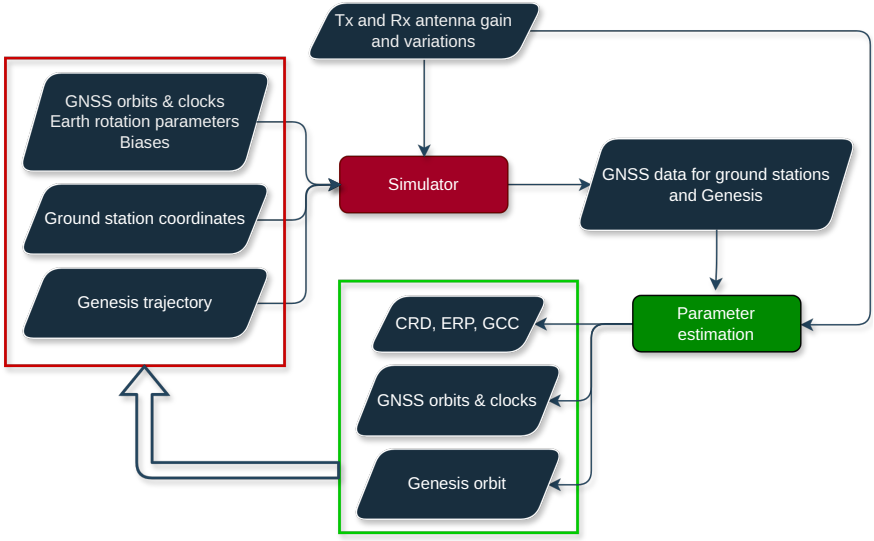




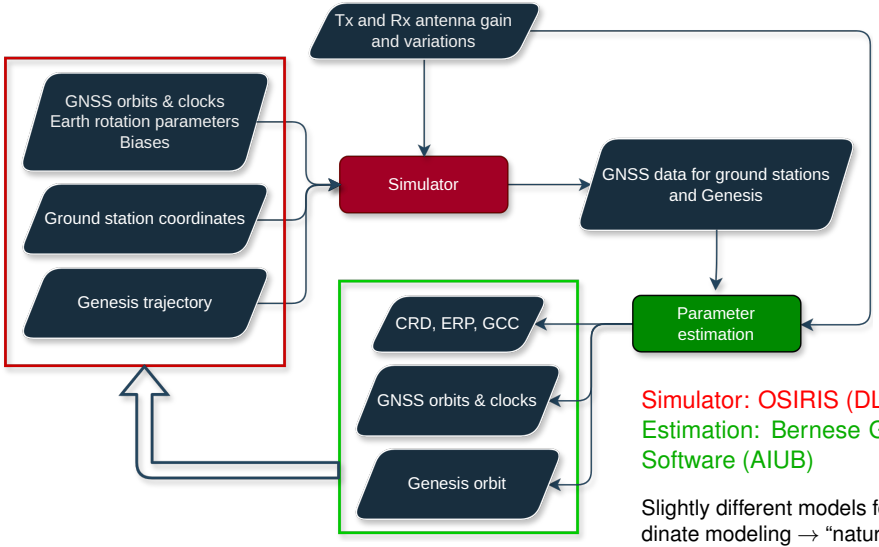
Question

How do uncertainties in the Genesis macro model affect the contribution of Genesis to global TRF solutions?

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

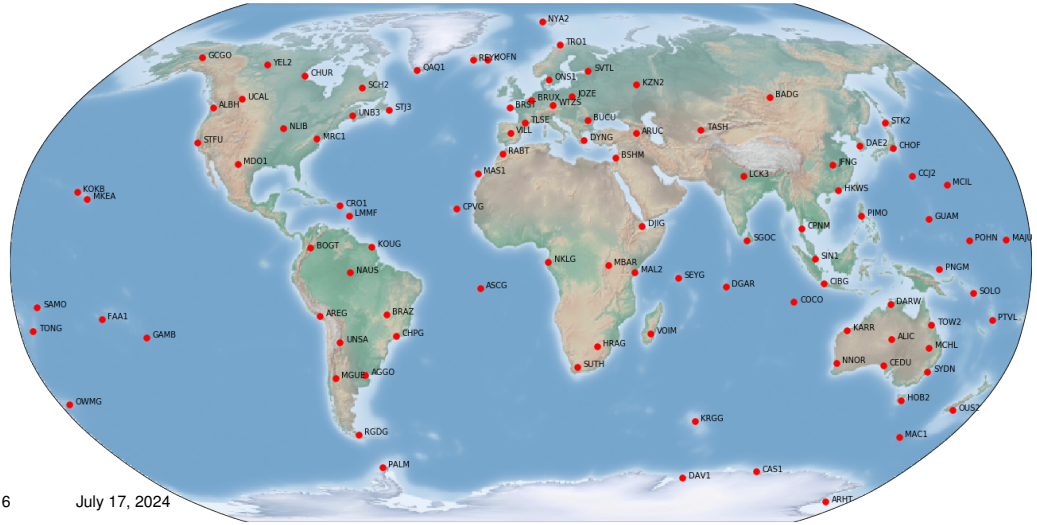


Simulator: OSIRIS (DLR)
Estimation: Bernese GNSS Software (AIUB)

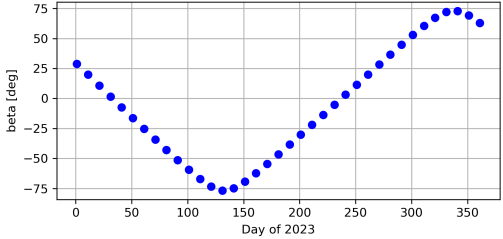
Slightly different models for station coordinate modeling → "natural" uncertainty

Ground stations

Selection of 100 IGS ground stations:



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

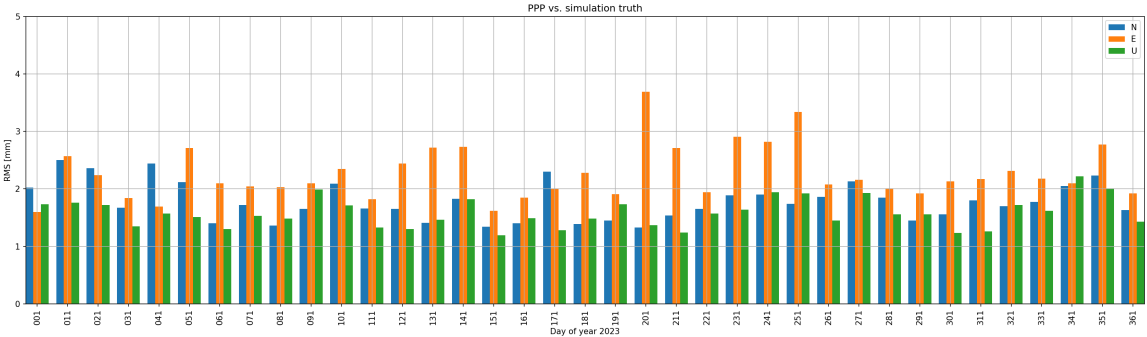
Estimation

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

- 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., no scaling)
  - 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)

“Zero” test: Coordinates

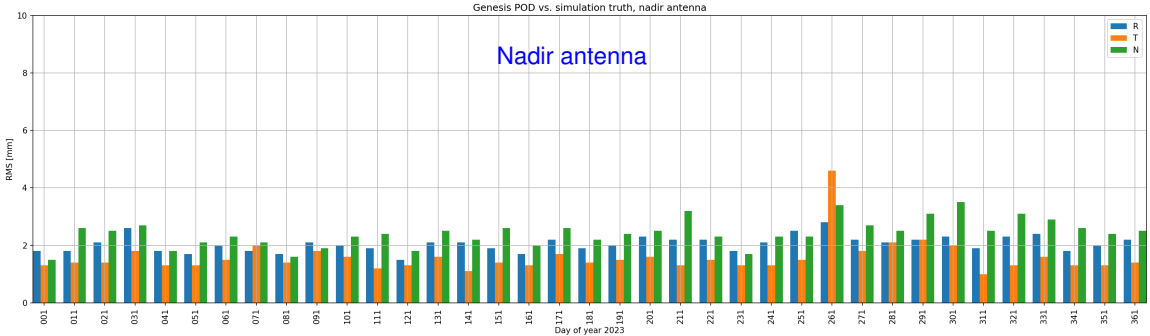
PPP (only estimate station-related parameters) using CODE final GNSS products and the correct macro model. Differences to “true” coordinates:



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 macro model.
Differences to “true” Genesis orbit:



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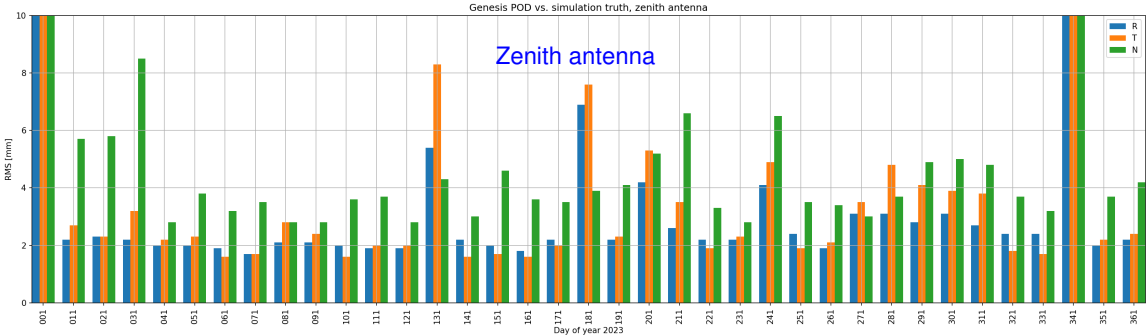
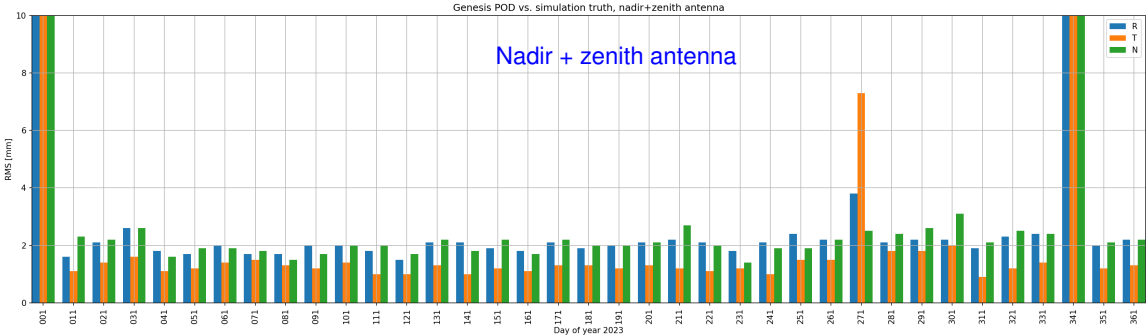


Zenith-antenna based POD more challenging

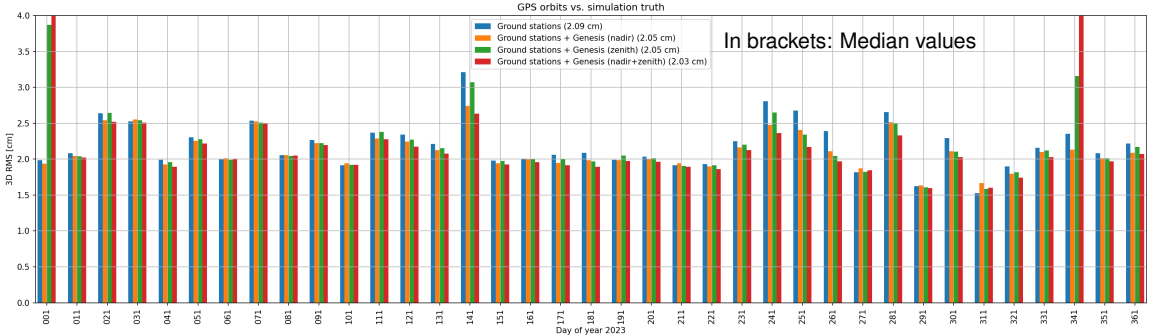
“Zero” test: Genesis orbit

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



Full parameter estimation: GNSS orbits

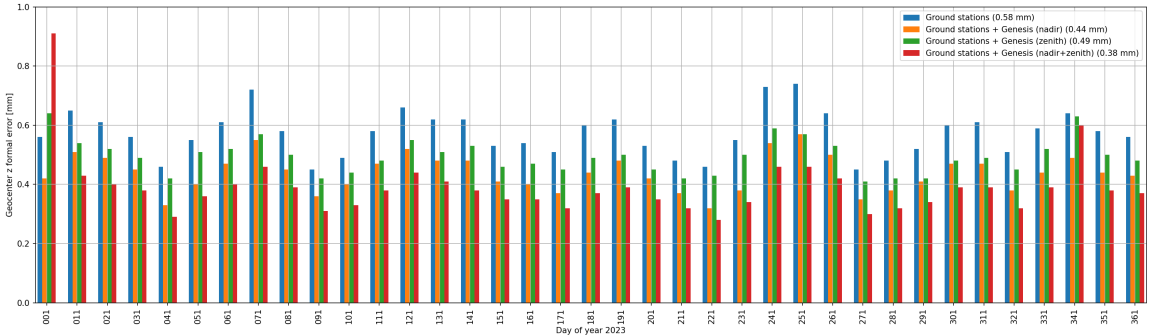
Estimating orbit and geodetic parameters using ground stations and Genesis data and correct macro model. Differences of estimated GPS orbits compared to “true” orbits:



– 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 macro model:



Significant reduction of formal errors due to Genesis

Macro model error 1

Change visual and IR optical properties of satellite body surfaces by 0.1:

Nr	A [m^2]	n1	n2	n3	IRKspec	IRKdif	VIKspec	VIKdif	Comment
1	0.90	1.0	0.0	0.0	0.200	0.040	0.200	0.050	+X
2	0.90	-1.0	0.0	0.0	0.200	0.050	0.250	0.050	-X
3	0.90	0.0	1.0	0.0	0.200	0.040	0.200	0.050	+Y
4	0.90	0.0	-1.0	0.0	0.200	0.050	0.250	0.050	-Y
5	0.64	0.0	0.0	1.0	0.200	0.040	0.200	0.050	+Z
6	0.64	0.0	0.0	-1.0	0.200	0.050	0.250	0.050	-Z
7	3.40	1.0	0.0	0.0	0.310	0.000	0.180	0.000	Solar panel front
8	3.40	-1.0	0.0	0.0	0.000	0.270	0.000	0.190	Solar panel back

For simulation

Nr	A [m^2]	n1	n2	n3	IRKspec	IRKdif	VIKspec	VIKdif	Comment
1	0.90	1.0	0.0	0.0	0.300	0.140	0.300	0.150	+X
2	0.90	-1.0	0.0	0.0	0.300	0.150	0.350	0.150	-X
3	0.90	0.0	1.0	0.0	0.300	0.140	0.300	0.150	+Y
4	0.90	0.0	-1.0	0.0	0.300	0.150	0.350	0.150	-Y
5	0.64	0.0	0.0	1.0	0.300	0.140	0.300	0.150	+Z
6	0.64	0.0	0.0	-1.0	0.300	0.150	0.350	0.150	-Z
7	3.40	1.0	0.0	0.0	0.310	0.000	0.180	0.000	Solar panel front
8	3.40	-1.0	0.0	0.0	0.000	0.270	0.000	0.190	Solar panel back

For reconstruction

Macro model error 2

Change visual and IR optical properties of solar panel front by 0.1:

Nr	A [m^2]	n1	n2	n3	IRKspec	IRKdif	VIKspec	VIKdif	Comment
1	0.90	1.0	0.0	0.0	0.200	0.040	0.200	0.050	+X
2	0.90	-1.0	0.0	0.0	0.200	0.050	0.250	0.050	-X
3	0.90	0.0	1.0	0.0	0.200	0.040	0.200	0.050	+Y
4	0.90	0.0	-1.0	0.0	0.200	0.050	0.250	0.050	-Y
5	0.64	0.0	0.0	1.0	0.200	0.040	0.200	0.050	+Z
6	0.64	0.0	0.0	-1.0	0.200	0.050	0.250	0.050	-Z
7	3.40	1.0	0.0	0.0	0.310	0.000	0.180	0.000	Solar panel front
8	3.40	-1.0	0.0	0.0	0.000	0.270	0.000	0.190	Solar panel back

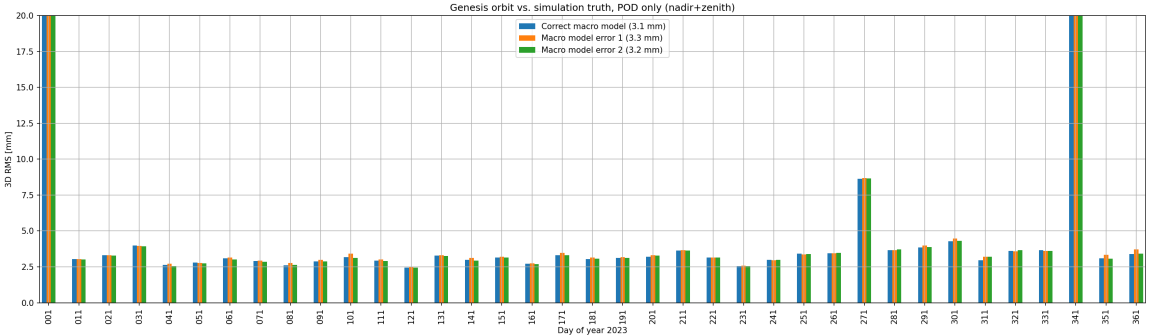
For simulation

Nr	A [m^2]	n1	n2	n3	IRKspec	IRKdif	VIKspec	VIKdif	Comment
1	0.90	1.0	0.0	0.0	0.200	0.040	0.200	0.050	+X
2	0.90	-1.0	0.0	0.0	0.200	0.050	0.250	0.050	-X
3	0.90	0.0	1.0	0.0	0.200	0.040	0.200	0.050	+Y
4	0.90	0.0	-1.0	0.0	0.200	0.050	0.250	0.050	-Y
5	0.64	0.0	0.0	1.0	0.200	0.040	0.200	0.050	+Z
6	0.64	0.0	0.0	-1.0	0.200	0.050	0.250	0.050	-Z
7	3.40	1.0	0.0	0.0	0.410	0.100	0.280	0.100	Solar panel front
8	3.40	-1.0	0.0	0.0	0.000	0.270	0.000	0.190	Solar panel back

For reconstruction

Impact on Genesis orbit (1)

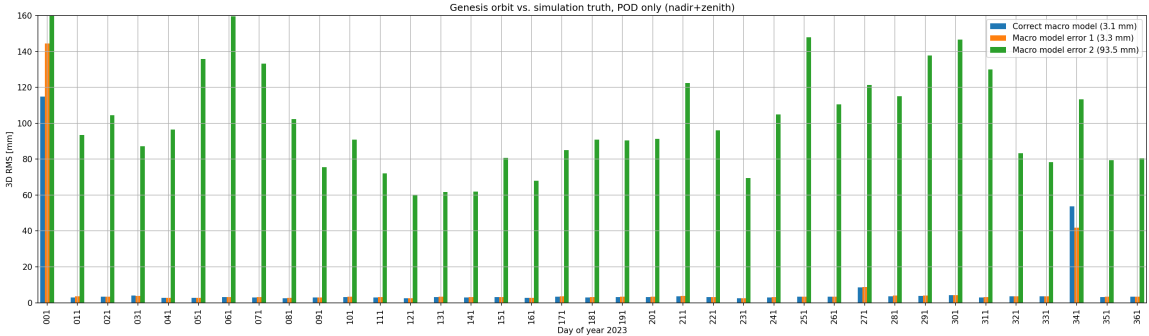
Genesis orbit differences from a POD-only solution, when estimating a scaling factor for solar radiation pressure (SRP):



Only very small impact on POD-only solution

Impact on Genesis orbit (2)

Genesis orbit differences from a POD-only solution, when estimating no SRP scaling:

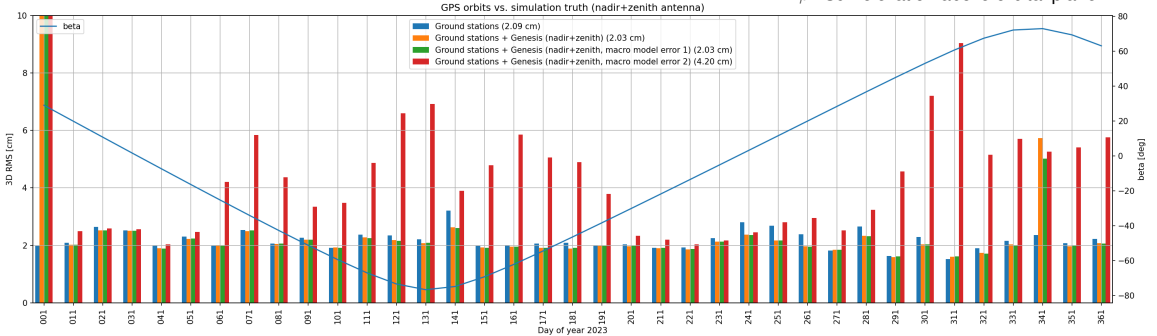


Significant degradation of Genesis orbit for macro model error 2 (solar panel front)

Impact on GNSS orbits

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

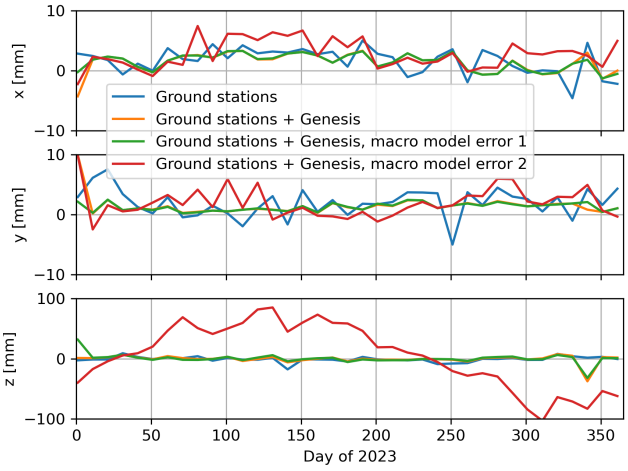
β: Sun elevation above orbital plane



- Macro model error 1: Only small impact
- Macro model error 2: Large, β-dependent impact (no SRP scaling estimated)

Impact on geocenter coordinates

Estimated geocenter coordinates (nadir+zenith antenna):



Median ± MAD:

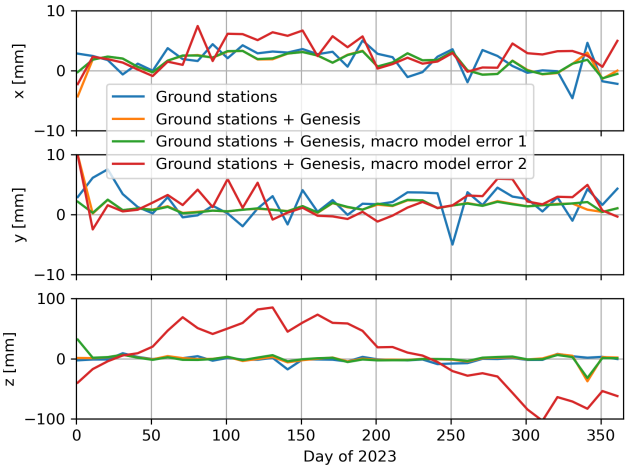
$+2.2 \pm 2.0$ mm
$+1.8 \pm 1.6$ mm
$+1.8 \pm 1.6$ mm
$+2.4 \pm 2.7$ mm

$+2.1 \pm 2.3$ mm
$+1.2 \pm 0.7$ mm
$+1.3 \pm 0.8$ mm
$+1.6 \pm 2.1$ mm

-1.3 ± 3.1 mm
-0.1 ± 2.8 mm
$+0.1 \pm 3.2$ mm
$+9.1 \pm 61.1$ mm

Impact on geocenter coordinates

Estimated geocenter coordinates (nadir+zenith antenna):



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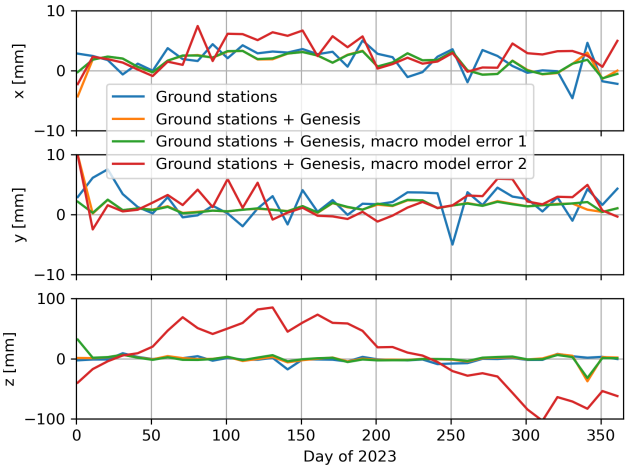
$+1.3 \pm 0.8$ mm
$+1.6 \pm 2.1$ mm

-1.3 ± 3.1 mm
-0.1 ± 2.8 mm
$+0.1 \pm 3.2$ mm
$+9.1 \pm 61.1$ mm

Macro model error 1:
Slight degradation

Impact on geocenter coordinates

Estimated geocenter coordinates (nadir+zenith antenna):



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$+1.2 \pm 0.7$ mm
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$+1.6 \pm 2.1$ mm

-1.3 ± 3.1 mm
-0.1 ± 2.8 mm
$+0.1 \pm 3.2$ mm
$+9.1 \pm 61.1$ mm

Macro model error 2:
Huge degradation

Conclusions

- The GNSS tracking of Genesis is less straightforward than for LEOs (especially zenith antenna).
- Established a simulation framework to study impact of systematic non-gravitational force modeling errors on orbit and global solutions.
- Without the estimation of an SRP scaling factor, an error of 0.1 in solar panel optical properties has a large, β-dependent impact on Genesis and GNSS orbits and geocenter coordinates.
- To fully exploit Genesis for TRF contributions, satellite geometry and optical properties should be known/made available!

Thank you!

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