Impact of Non-gravitational Force Model Deficiencies for Genesis Orbit and Geodetic Parameter Estimation Based on GNSS

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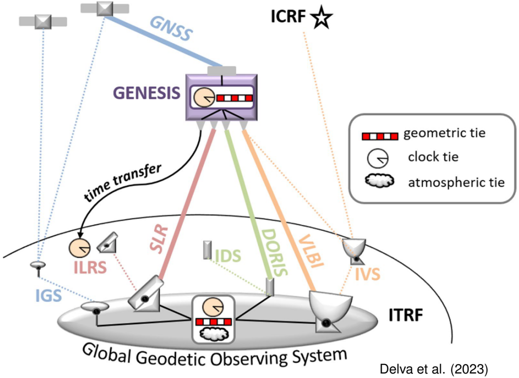
Genesis mission (to be launched in 2028)

- 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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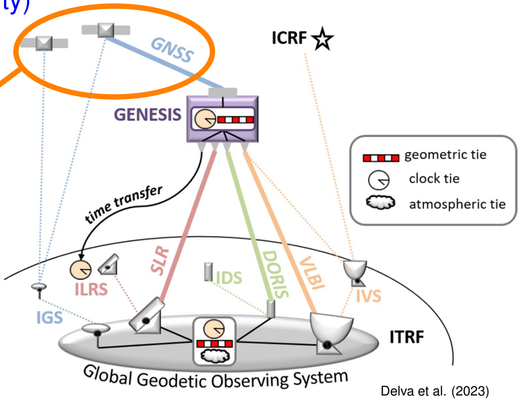
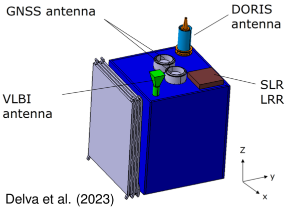
This presentation

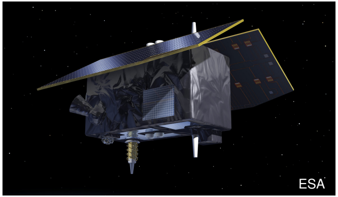


Delva et al. (2023)

Genesis satellite and orbit



Original design (Genesis white paper)

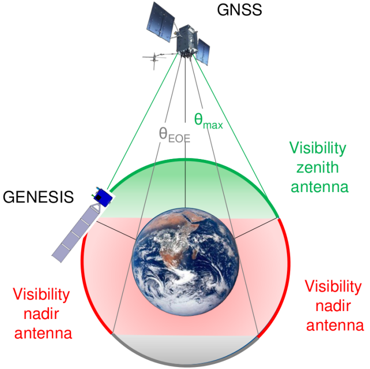


Current design (similar to Sentinel-6)

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

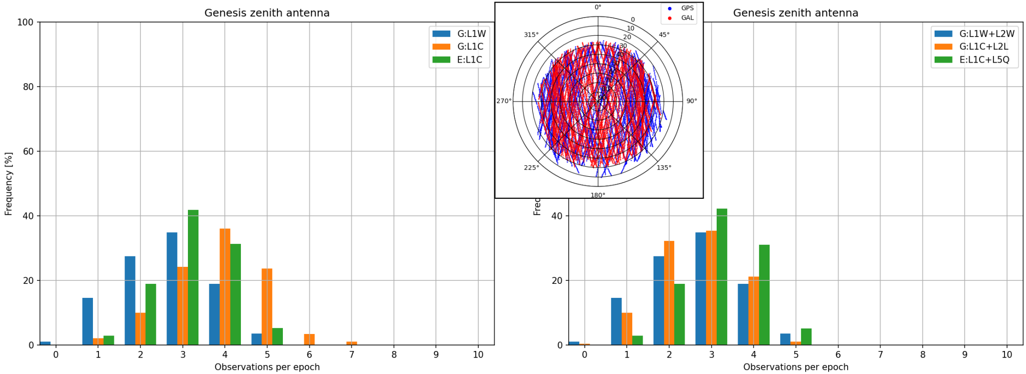
→ rather unfavorable GNSS tracking conditions

→ zenith- and nadir-pointing GNSS antennas



Montenbruck et al. (2023)

Genesis GNSS tracking (zenith antenna)

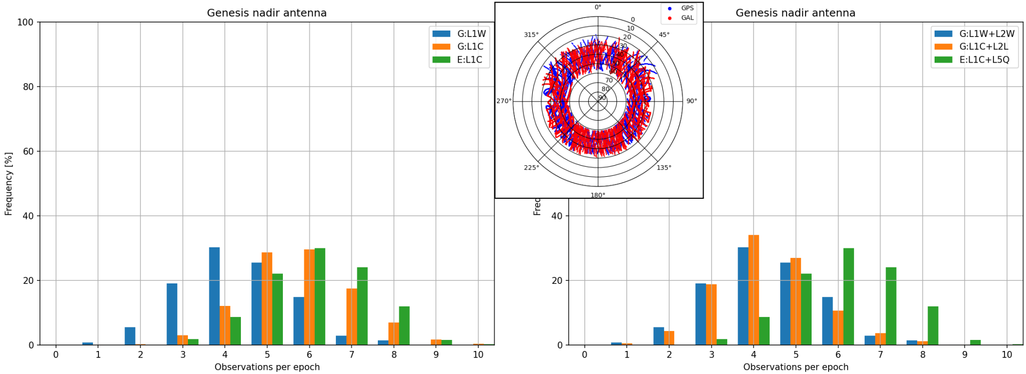


GPS	L1W:	2.7	±	1.1
GPS	L1C:	3.8	±	1.1
GAL	L1C:	3.2	±	0.9

GPS	L1W+L2W:	2.7	±	1.1
GPS	L1C+L2L:	2.7	±	1.0
GAL	L1C+L5Q:	3.2	±	0.9

Only 3-4 satellites tracked on average per epoch (worse for higher altitudes!)

Genesis GNSS tracking (nadir antenna)



GPS	L1W:	4.4	±	1.3
GPS	L1C:	5.7	±	1.3
GAL	L1C:	6.1	±	1.3

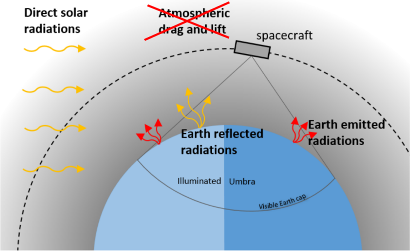
GPS	L1W+L2W:	4.4	±	1.3
GPS	L1C+L2L:	4.3	±	1.2
GAL	L1C+L5Q:	6.1	±	1.3

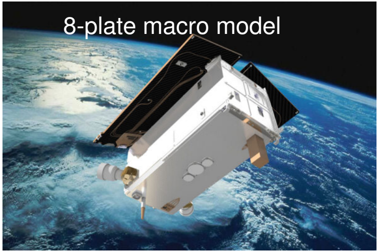
4-6 satellites tracked on average per epoch (worse for higher altitudes!)

Non-gravitational force modeling

For Genesis, a dynamic orbit modeling is desired, as empirical orbit parameters might correlate significantly with specific geodetic parameters (to be verified)

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

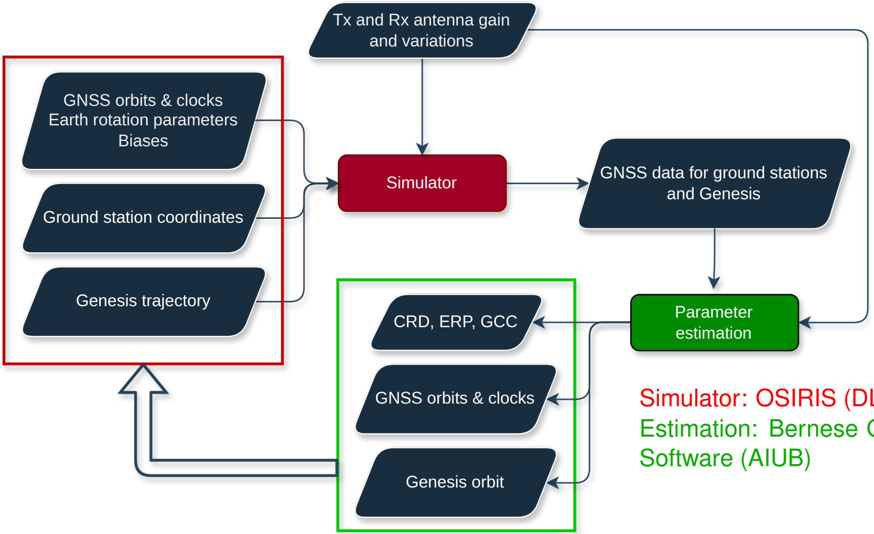




Question

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

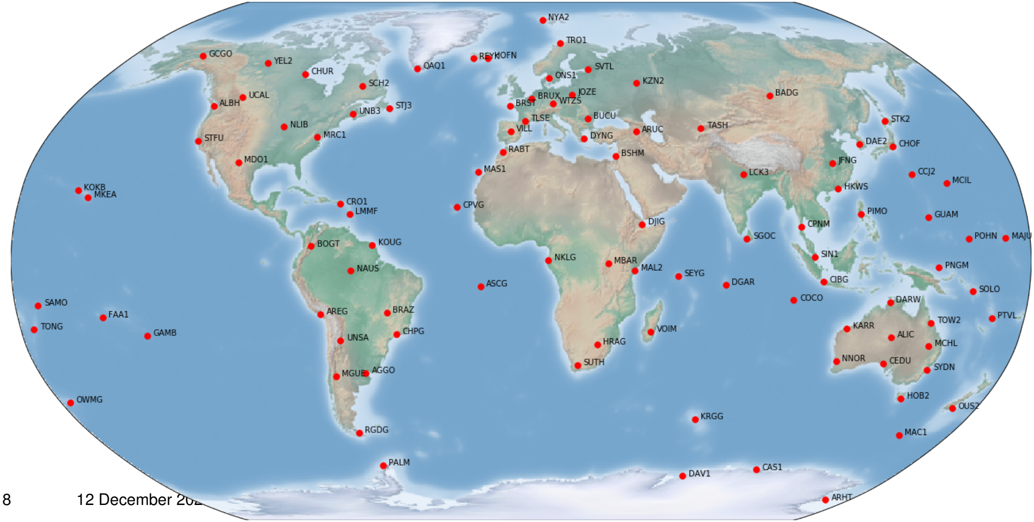
Methods



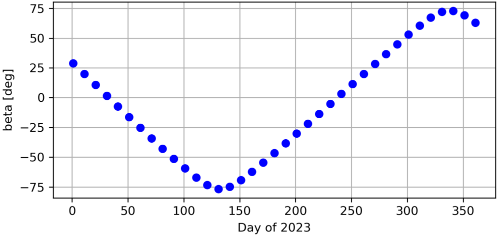
Simulator: OSIRIS (DLR)
Estimation: Bernese GNSS Software (AIUB)

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 Earth pointing attitude
- GNSS products: Center for Orbit Determination in Europe (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

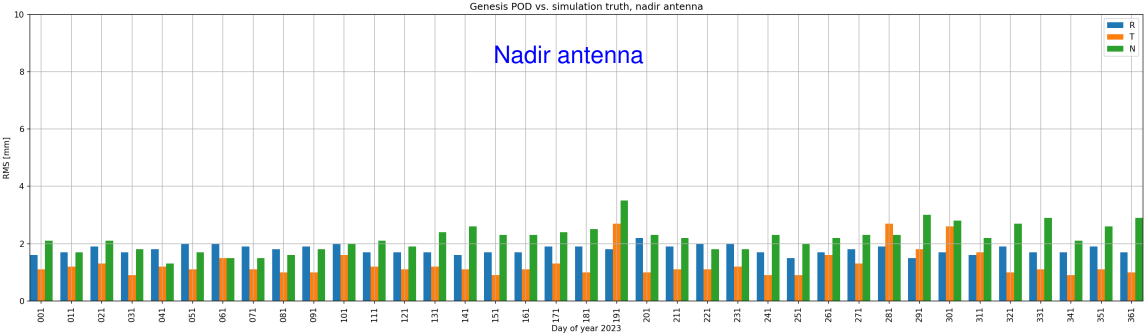
Estimation

- 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., 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)

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

“Zero” test: Genesis orbit

Genesis POD using CODE final GNSS products and the correct macro model, 30 s sampling. Differences to “true” Genesis orbit:



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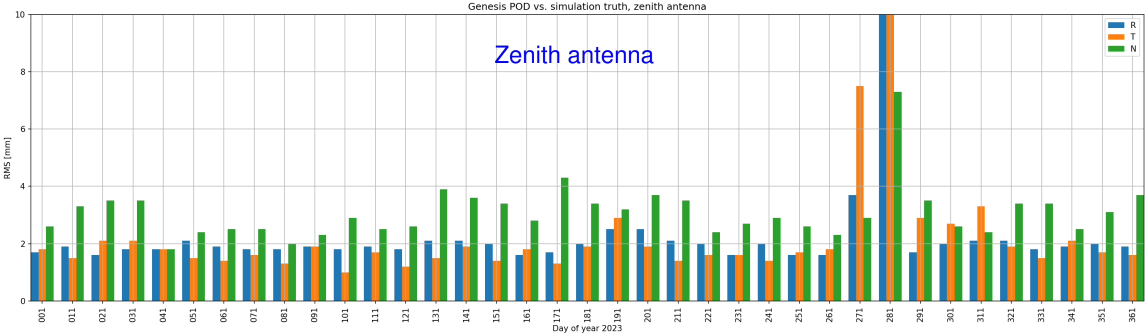
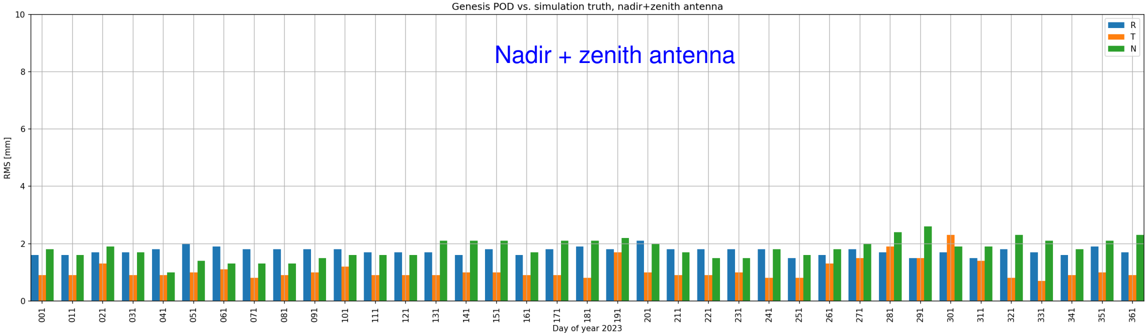


Zenith antenna-based POD more challenging

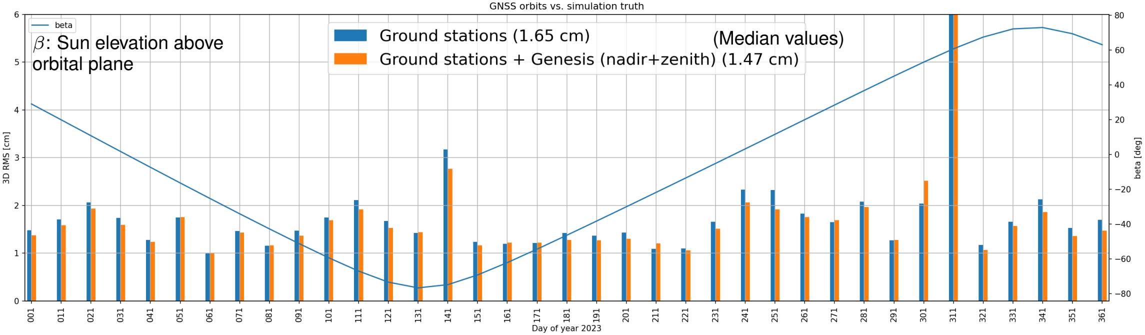
“Zero” test: Genesis orbit

Genesis POD using CODE final GNSS products and the correct macro model, 30 s sampling. Differences to “true” Genesis orbit:



Full parameter estimation: GNSS orbits

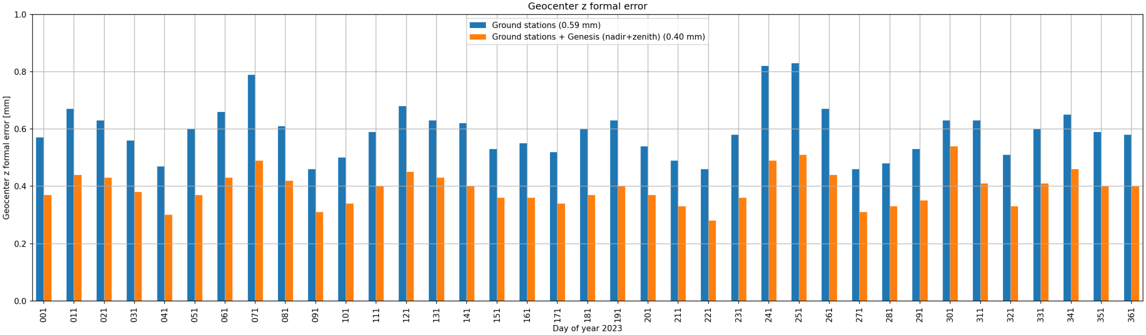
Estimating orbit and geodetic parameters using ground stations and Genesis data and correct macro model. Differences of estimated GNSS orbits compared to "true" orbits:



- 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

Change visual and IR optical properties of solar panels by 0.1:

For simulation

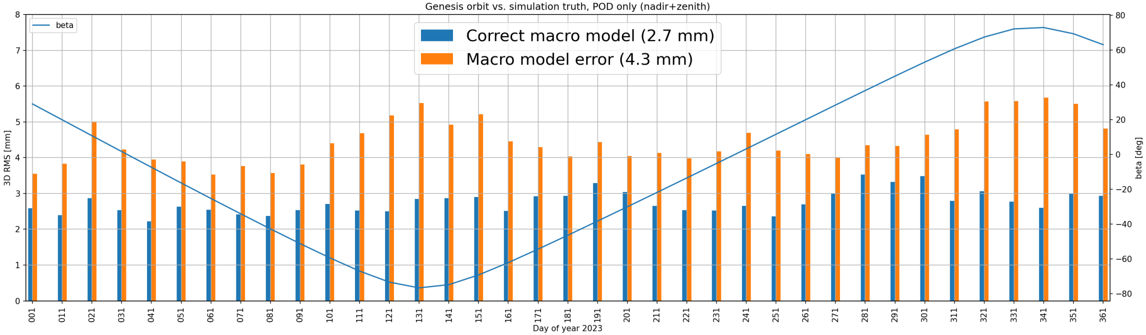
Nr	A [m^2]	n1	n2	n3	IRKspec	IRKdif	VIKspec	VIKdif	Comment
1	0.90	1.0	0.0	0.0	0.200	0.040	0.490	0.040	BODY+X (front)
2	0.90	-1.0	0.0	0.0	0.180	0.040	0.450	0.120	BODY-X (rear)
3	3.90	0.0	0.0	1.0	0.110	0.120	0.350	0.080	BODY+Z (bottom)
4	0.50	0.0	0.0	-1.0	0.220	0.010	0.620	0.030	BODY-Z (top)
5	2.20	0.0	0.61566	-0.78801	0.000	0.200	0.000	0.140	SP_+Y-Z (starboard s.p.)
6	2.20	0.0	-0.61566	-0.78801	0.000	0.200	0.000	0.140	SP_-Y-Z (portside s.p.)
7	0.30	0.0	1.0	0.0	0.130	0.120	0.430	0.140	BODY+Y (starboard)
8	0.30	0.0	-1.0	0.0	0.130	0.120	0.430	0.140	BODY-Y (portside)

For reconstruction

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	0.490	0.040	BODY+X (front)
2	0.90	-1.0	0.0	0.0	0.180	0.040	0.450	0.120	BODY-X (rear)
3	3.90	0.0	0.0	1.0	0.110	0.120	0.350	0.080	BODY+Z (bottom)
4	0.50	0.0	0.0	-1.0	0.220	0.010	0.620	0.030	BODY-Z (top)
5	2.20	0.0	0.61566	-0.78801	0.100	0.300	0.100	0.240	SP_+Y-Z (starboard s.p.)
6	2.20	0.0	-0.61566	-0.78801	0.100	0.300	0.100	0.240	SP_-Y-Z (portside s.p.)
7	0.30	0.0	1.0	0.0	0.130	0.120	0.430	0.140	BODY+Y (starboard)
8	0.30	0.0	-1.0	0.0	0.130	0.120	0.430	0.140	BODY-Y (portside)

Impact on Genesis orbit

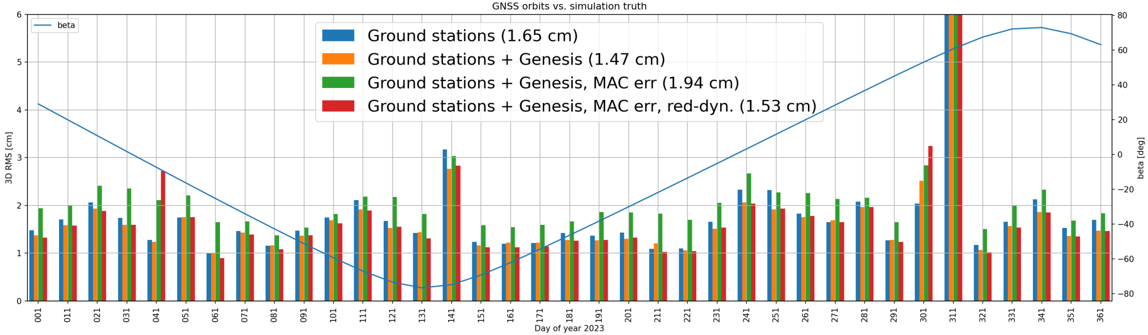
Genesis orbit differences from a dynamic POD-only solution:



β-dependent degradation of Genesis orbit

Impact on GNSS orbits

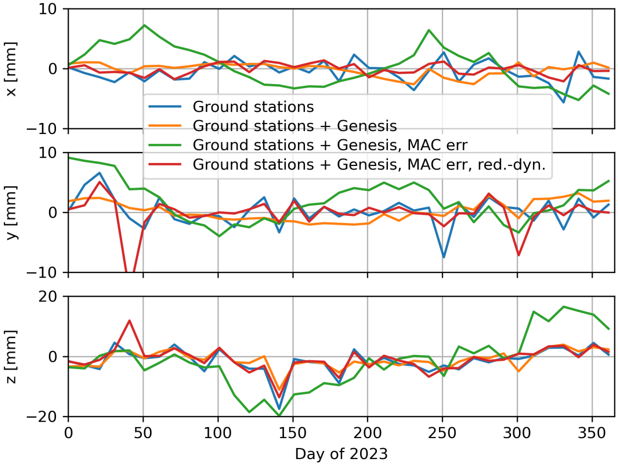
Differences of estimated GNSS orbits compared to “true” orbits:



- Macro model error leads to visible degradation of GNSS orbits
- Relaxing constraints for Genesis piece-wise constant accelerations (red.-dyn. solution) allows to compensate to a large extent for the macro model error

Impact on geocenter coordinates

Estimated geocenter coordinates:



Median ± MAD:

-0.6 ± 1.1 mm
$+0.1 \pm 0.6$ mm
$+0.0 \pm 2.9$ mm
-0.1 ± 0.7 mm

$+0.4 \pm 1.4$ mm
-0.3 ± 1.2 mm
$+1.5 \pm 2.5$ mm
$+0.0 \pm 0.9$ mm

-0.9 ± 1.9 mm
-1.5 ± 1.6 mm
-0.8 ± 3.9 mm
-1.2 ± 1.8 mm

Impact on geocenter coordinates

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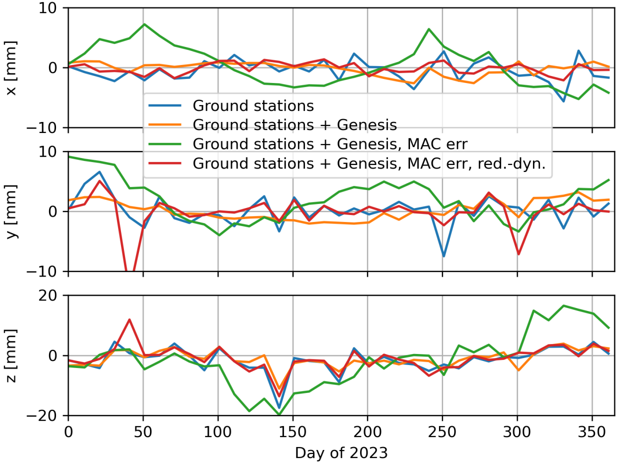

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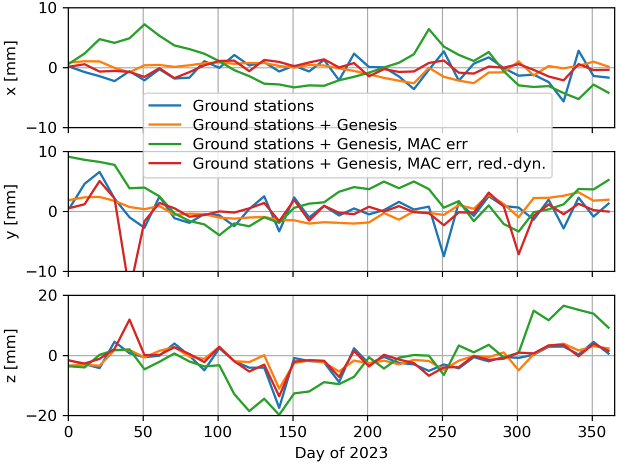
Macro model error leads to degradation

Impact on geocenter coordinates

Estimated geocenter coordinates:



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-1.2 ± 1.8 mm

Reduced-dynamic Genesis orbit helps

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 (and other) errors on orbit and global solutions.
- In case of a dynamic Genesis orbit modelling, an error of 0.1 in Genesis solar panel optical properties has a visible impact on Genesis and GNSS orbits and geocenter coordinates.
- Relaxing constraints of Genesis piecewise-constant accelerations (more reduced-dynamic orbit) mitigates influence of macro model error without a large degradation of orbits and geocenter
- Further geodetic parameters and macro model errors to be studied...

Thank you!

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