The influence of non-gravitational force modeling on Genesis and GNSS orbit and geodetic parameter estimations using two different macro models

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

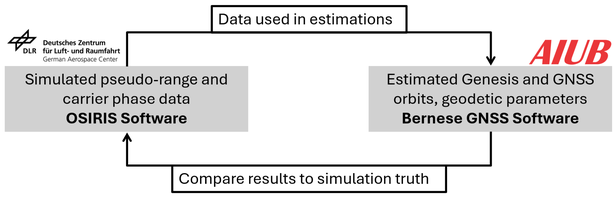
[1] University of Bern, Astronomical Institute, Bern, Switzerland
[2] German Space Operations Center, Deutsches Zentrum für Luft- und Raumfahrt, Weßling, Germany

Introduction

ESA's Genesis mission will

- contribute to achieve the **accuracy and stability goals** stated by the Global Geodetic Observing System (GGOS) for the **Terrestrial Reference Frame (TRF)**
- act as the first ever space-tie between all four space-geodetic techniques
- be equipped with a nadir- and a zenith-pointing GNSS receiver antenna (due to challenging tracking geometry at ~6000 km altitude)

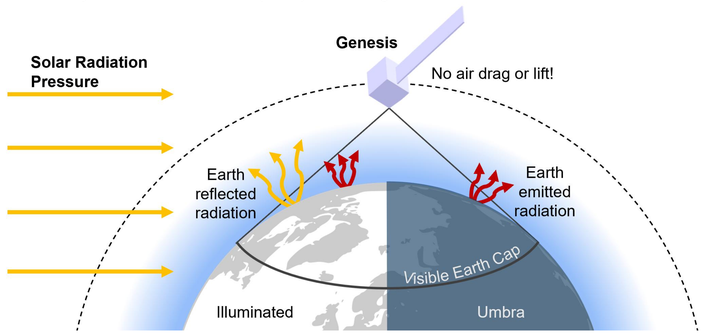
We investigate the **importance of dynamic orbit modeling** for the Genesis mission, focusing on the spacecraft's geometry and its optical properties for two satellite designs. We perform a **closed-loop simulation using two simulated GNSS pseudo-range and carrier phase data sets for Genesis** and 100 IGS ground stations over 37 days in 2023 to assess the impact of possible mismodelings of non-gravitational forces.



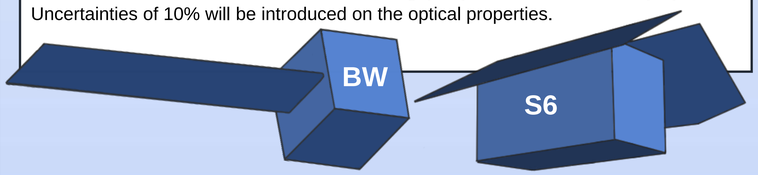
Non-Gravitational Force Modeling

The modeled non-gravitational forces are

- Solar Radiation Pressure (SRP)
- Planetary Radiation Pressure (PRP), including reflected and emitted radiation



Different Genesis designs → different **spacecraft geometry and optical properties,** described by the **macro model (MAC).** Each MAC is related to a separate simulation data set. Here, we will focus on the **box-wing (BW)** and **Sentinel-6-like (S6)** model. Uncertainties of 10% will be introduced on the optical properties.



Absorbing Mismodeled Forces

To absorb possible mismodeling, **Piecewise Constant Accelerations (PCAs)** are estimated over 6 min intervals. Their magnitude is constrained using the a priori standard deviation σ_{abs}.

- **Constraining:**
  - **Relaxed:** orbit is more data-driven
  - **Strict:** orbit is more dynamic and model-driven

	σ_{abs}
Relaxed	5.0 nm/s^2
Strict	0.1 nm/s^2

Genesis-Only Orbit Determination

Here, the Genesis orbits estimated during the **Genesis-only processing** are compared to the simulation truth. The true geodetic parameters and GNSS orbits and clocks are used.

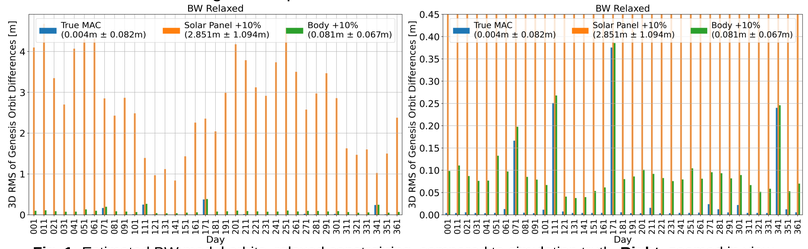


Fig. 1: Estimated BW model orbits, relaxed constraining, compared to simulation truth. **Right:** zoomed in view.

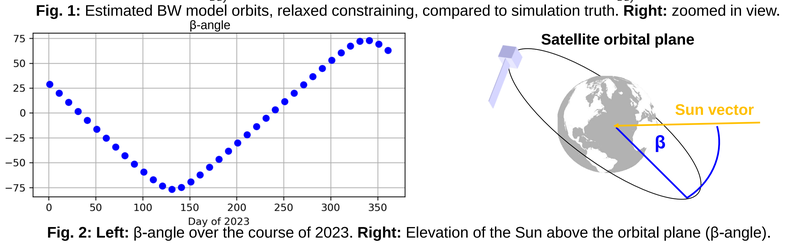


Fig. 2: Left: β-angle over the course of 2023. **Right:** Elevation of the Sun above the orbital plane (β-angle).

Errors due to mismodeling of the solar panel forces (Fig. 1, right) are most pronounced at low β-angles (Fig. 2).

Fig. 3: Left: BW model orbits, strict constraining. **Right:** S6 model orbits, strict constraining.

Comparing the left sides of Fig.1 and Fig. 3, **stricter constraining reduces RMS on "problem days"** but makes modeling uncertainties more prominent. For the **BW** model, **solar panel** uncertainties play a larger role, while for the **S6** model, optical property errors in the **body** plates have more influence. This could be related to the largest surface of the respective model.

GNSS Orbit Estimations

In a **global combined processing**, the Genesis and GNSS orbits and clocks are estimated together with the geodetic parameters. Comparing the estimated **GNSS orbits to the simulation truth**, similar effects as in the Genesis-only solutions can be seen.

Fig. 4: Left: GNSS orbit comparisons to simulation truth. **Right:** Single Galileo orbit difference RMS for DOY 311.

Genesis can improve the GNSS orbit estimations. However, **mismodelings** in the Genesis orbit determination **cause GNSS orbits to deteriorate** as well when strict constraining is applied. The **β-angle dependent behavior** is visible again. If the ground station-only solution already has a larger RMS, the addition of Genesis enlarges it further. The reason for the higher RMS on DOY 311 seems to be related to one specific GNSS satellite (see Fig. 4 on the right).

Geodetic Parameters

In the **global combined procedure**, geodetic parameters are estimated as well. The **geocenter *z*-coordinate** is used here as a benchmark to gauge the possible improvement due to Genesis.

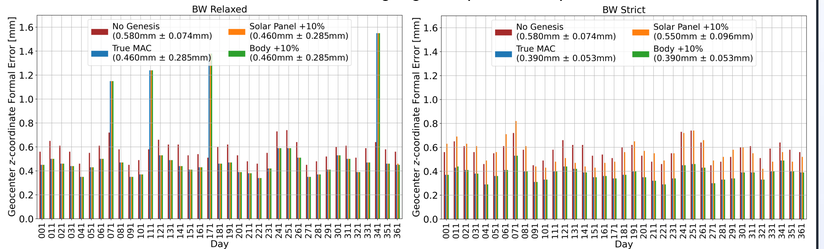


Fig. 5: Formal errors of estimated geocenter *z*-coordinate using the BW model data. **Left:** Relaxed **Right:** Strict

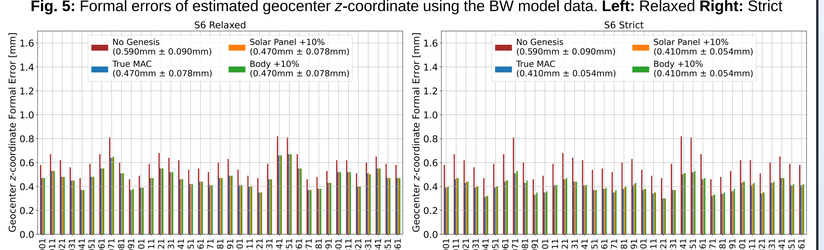


Fig. 6: Formal errors of estimated geocenter z-coordinate using the S6 model data. **Left:** Relaxed **Right:** Strict

There is a **definite improvement**, but the **problem days** seen in Fig. 1 **propagate into the geodetic parameter estimation**. Stricter constraining again reduces the resulting large RMS but enhances MAC errors. **S6 model estimations are seemingly less influenced** by such uncertainties, but this could be due to **differences in the two data sets** and the attitude handling.

Conclusions and Outlook

- The **addition of Genesis generally improves** both the GNSS orbit as well as the geodetic parameter **estimations.**
- **Constraining of PCAs needs to be carefully chosen**, since strict constraining reduces the effects of "problem days", but increases influence of MAC uncertainties.
  - Are PCAs sufficient for Genesis? Should alternatives, e.g., scaling factors be used instead?
- **Optical properties** of the spacecraft **need to be accurately known** to avoid deteriorating the global combined estimations.
- **Both designs show improvements**, however current results suggest that the S6 model results in smaller RMS values for the global combined estimations.
- When introducing MAC uncertainties, the largest surface seems to be of most importance.
- The **reasons for the "problem days" should be determined**, as they propagate into the global combined solution.
  - Additional tests suggest that outliers on individual days are related to ambiguity resolution problems, which are possibly triggered by small model differences between measurement simulation and processing, which needs further analysis.

Acknowledgements

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Contact address

Alexandra Miller
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
alexandra.miller@students.unibe.ch

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