Initial Orbit Determination Results from the University of Luxembourg using Spire GNSS Tracking Data

Parisa Shafiei[1*], Jean Bemtgen[1], Matthieu Talpe[2], Sajad Tabibi[1]

[1] University of Luxembourg, Faculty of Science, Technology and Medicine (FSTM), Department of Engineering, Esch-sur-Alzette, Luxembourg (* Corresponding author: parisa.shafiei@uni.lu)
[2] Spire Global Luxembourg S.a.r.l., Luxembourg

Introduction

CubeSats are a versatile and cost-effective solution for space applications. Commercial off-the-shelf components have been used to design CubeSat constellations, including for GNSS-RO. The use of GNSS signals is routinely used for orbit determination of LEO CubeSats and has been enabled the detection of the low-degree harmonics of Earth's gravity field, e.g., Baur, O. (2013). This poster presents precise orbit determination for a satellite of the Spire CubeSat constellation.

Method

GNSS kinematic orbit determination for small satellites can be hindered by various issues such as noise, data gaps, and poor geometry. Our research addresses these challenges through two different approaches: GNSS network processing of GPS and Galileo constellations and kinematic orbit determination for Spire CubeSats with a GNSS-RO payload. We adopt the raw observation approach developed by Mayer-Gürr et al. (2021), which uses raw GNSS code and phase observations on all frequencies and solves phase ambiguity to enhance the accuracy of orbit determination (Figure 6).

GNSS Network Processing

The first part of our research involves determining precise orbits, clocks, and signal biases for GPS and Galileo satellites using the strategy proposed by Strasser et al. (2019). To match the Spire dataset provided, we processed GPS and Galileo products for August 2021, using approximately 650 IGS Repro3 stations with a 30s sampling rate. The 3D RMS values derived for GPS and Galileo constellations in August 2021 are shown in Figure 1.

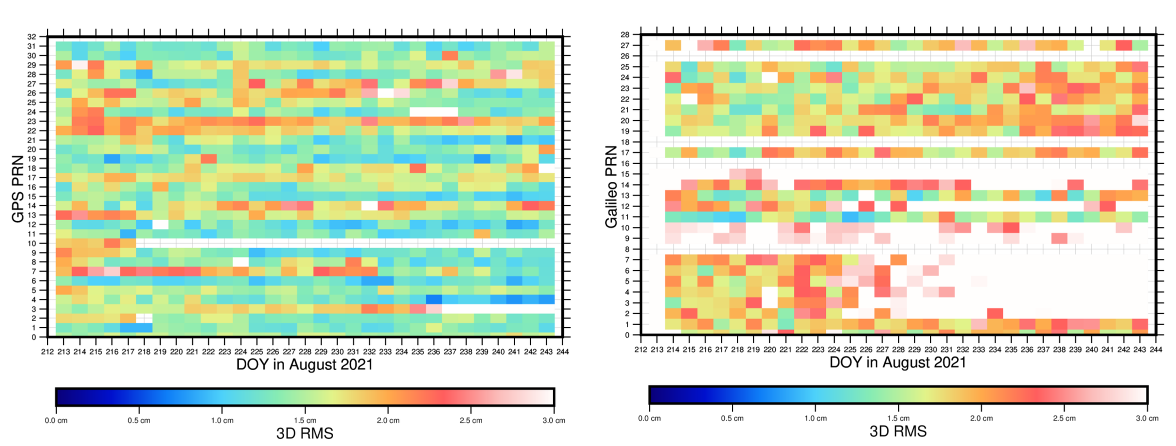

Fig 1. 3D RMS of comparison of in-house processed GNSS orbits and final Repro3 orbits processed at CODE for GPS constellation (**left**) and Galileo (**right**) in August 2021.

Code and Phase Residuals

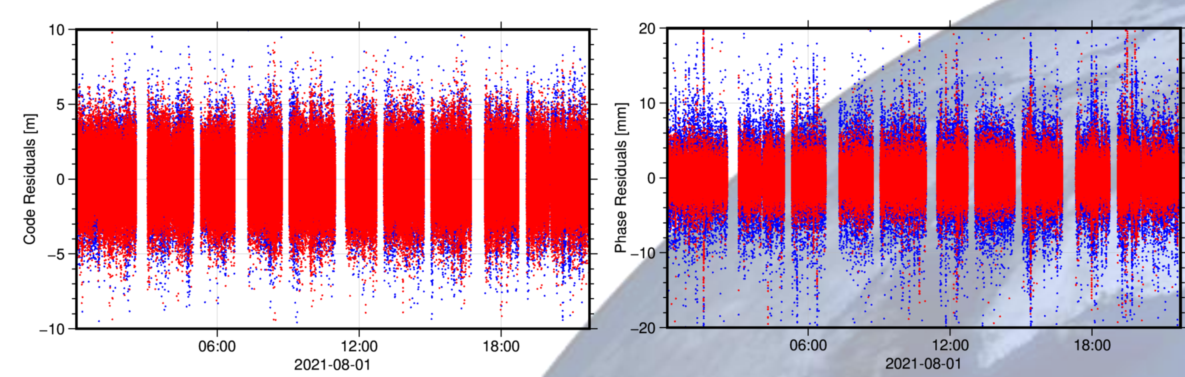

Fig 2. Example of code (**left**) and phase (**right**) residuals for both frequencies (**L1** and **L2**). Due to the regular gaps in the Spire satellite data, the resulting kinematic orbits also contain gaps, as is evident in the derived residuals. Over the course of a day-long comparison, the residuals varied between -5 m to 5 m for code residuals and -10 mm to 10 mm for phase residuals.

Orbit Comparison

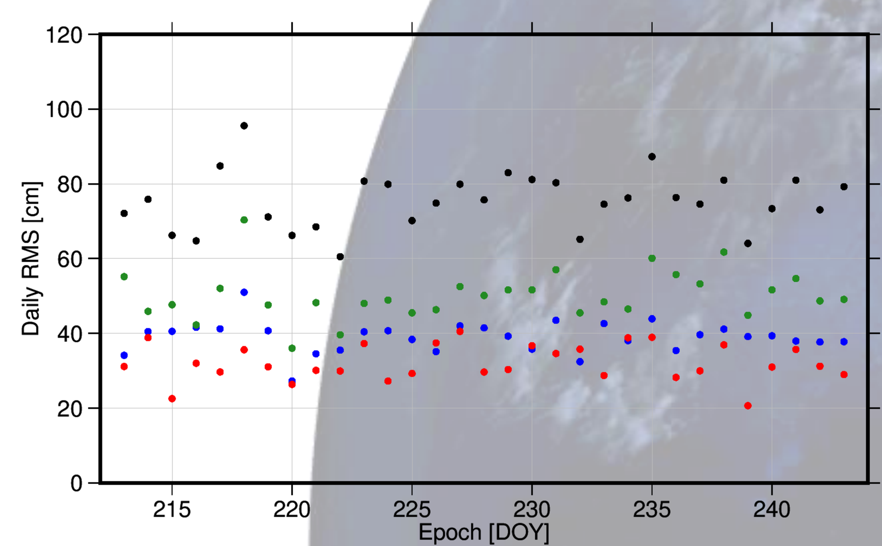

Fig 3. RMS of orbit comparison between the derived kinematic orbits for FM099 (with the processing settings: 1s sampling rate, fixed phase ambiguities, in-house processed GNSS orbit, clock and signal bias products , 0° elevation cut-off angle) and Spire official L1B orbits for August 2021, presented in the **along-track** , **cross-track**, **radial** components and **3D RMS**.

Antenna Center Variations

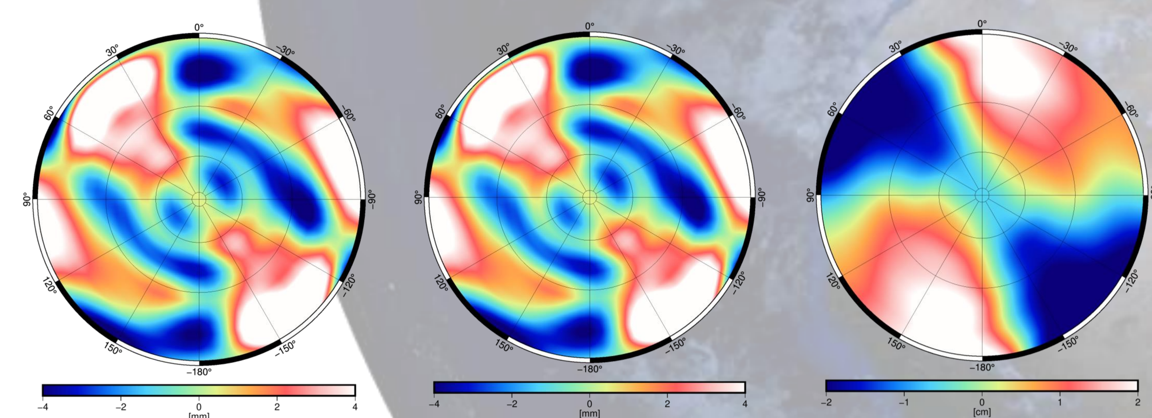

Fig 4. Ground based ACV patterns for Spire for L1/L2 (**left**), P1 (**middle**), and P2 (**right**) observables.

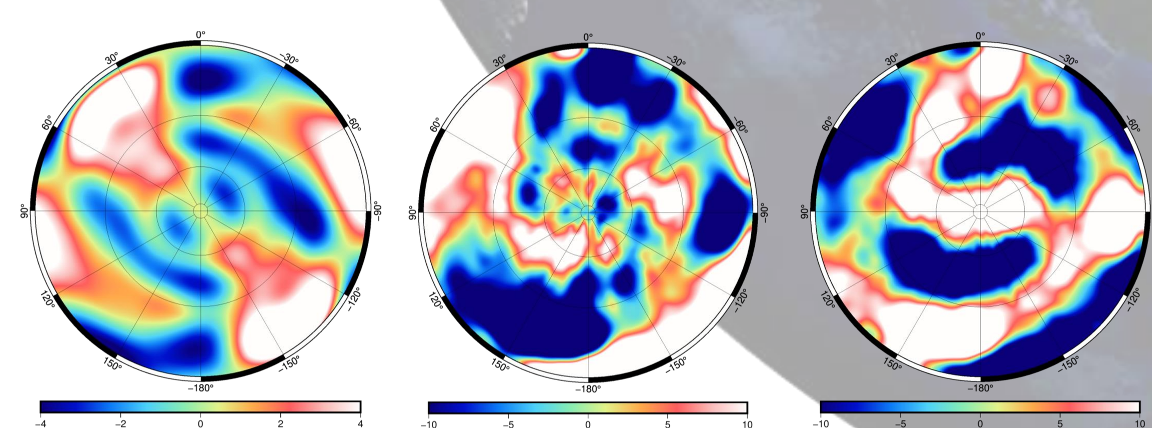

Fig 5. ACVs for Spire FM099 satellite by analyzing one month of data for phase L1/L2 (**left**), code P1 and P2 observations (**middle** and **right**). The estimated patterns show a significant difference from the ground calibrations for the code observations (both P1 and P2). The variation for phase measurements and code measurements are in the range of ±4 mm and ±10 cm, respectively.

Workflow

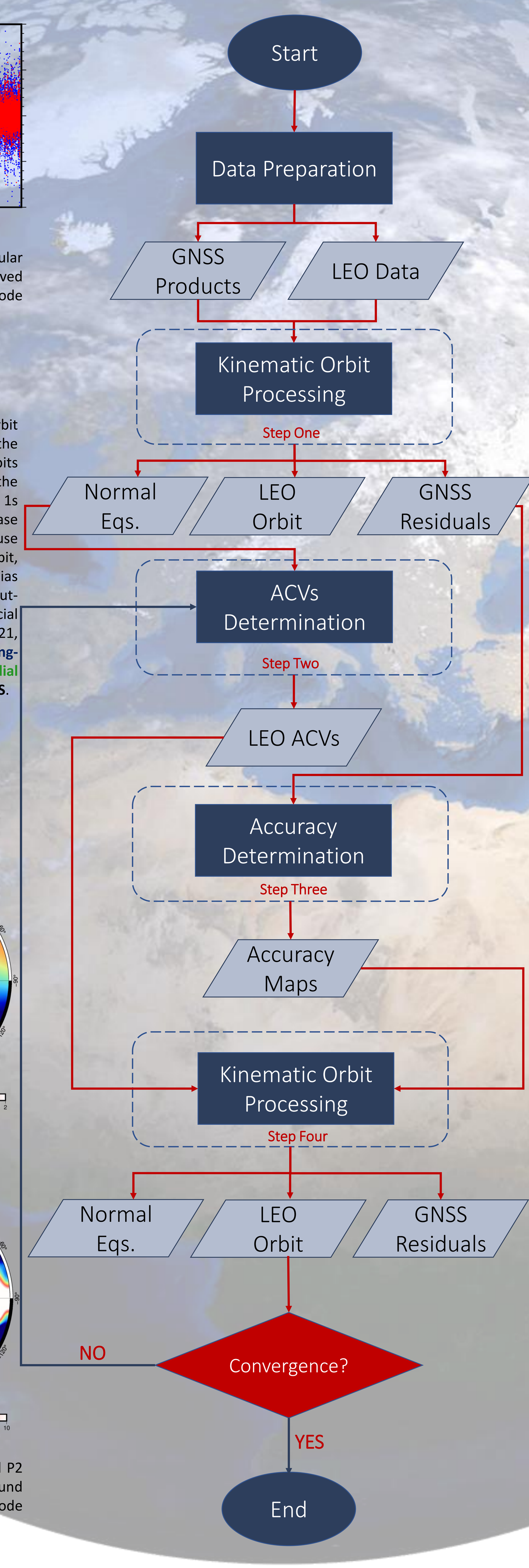

Fig 6. Process flow for LEO kinematic orbit processing.

Accuracy Maps

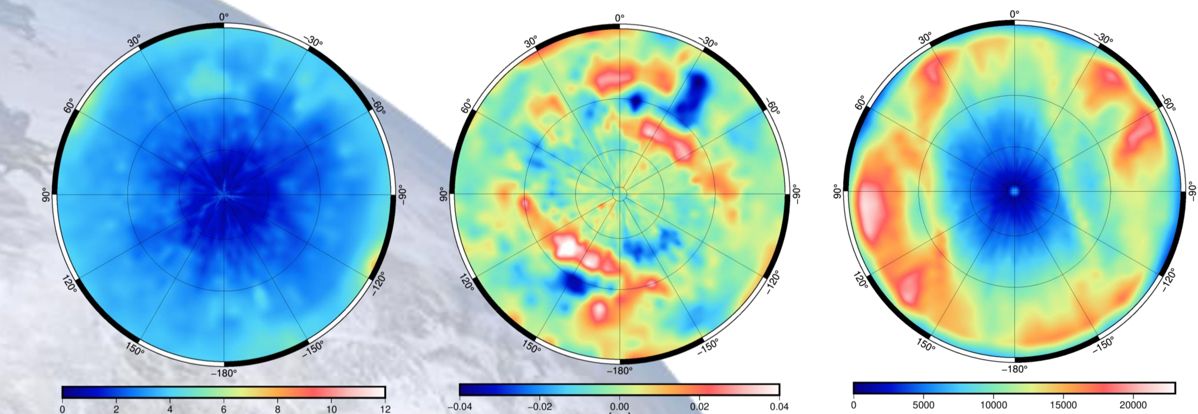

Fig 7. Accuracy (**left**), antenna mean (**middle**), and redundancy (**right**). A nearly zero mean indicates that appropriate antenna center variations (ACVs) patterns were used during processing.

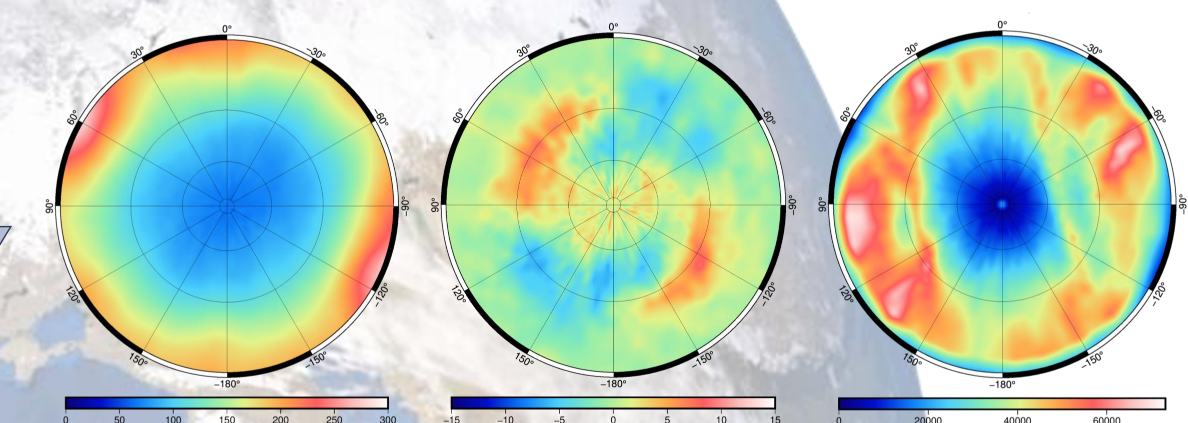

Fig 8. Introduced azimuth and elevation dependent weighting scheme used in processing for P1 observables, including accuracy (**left**), antenna mean (**middle**), and redundancy (**right**) in which, the accumulated antenna redundancy of the computed pattern grid is shown.

Satellite Info

- FM099 , Johan Loran
- Satellite bus version: LEMUR 2-3.4
- Antenna type: LEMUR 3.1.0
- Orbit: SSO (09:30 LTAN)
- Altitude: 505 km
- Maximum attitude: 82.60°
- 1 Hz dual frequency
- GPS data from POD antenna
- L1A satellite orbits (a priori)
- LeoAtt Attitude quaternions
- Simulated quaternions
- L1B official orbits

Attitude Information

The Spire leoAtt files contain the attitude of the satellites (i.e., as quaternions representing the rotation from satellite body frame to the local orbit frame). These quaternions should be used along with processing the simulated star camera measurements. It is crucial to apply them correctly to obtain reasonable estimates of the kinematic orbits and ACVs, considering that the satellite undergoes multiple yaw flips in a single day.

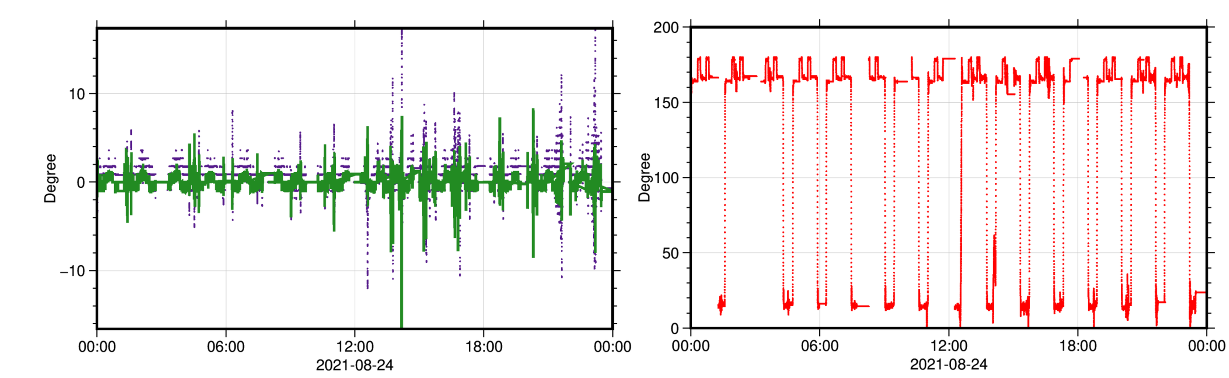

Fig 9. Example for Spire satellite attitude (**roll**, **pitch**, and **yaw** angle) in one day.

Summary and Future Work

We developed an initial architecture for processing kinematic orbits of the Spire GNSS-RO CubeSats and discussed the validations and limitations of the method. Our analysis demonstrated good agreement between the UL and CODE GNSS orbit products. Kinematic orbits were derived for FM099 using the raw observation approach and compared to L1B products. Despite the lower quality and continuity of Spire CubSats GPS data, the results of the initial kinematic orbits are promising. Future work will involve processing other Spire FMs, comparing kinematic with reduced-dynamic orbits, and applying processed kinematic orbits for scientific applications such as Earth's gravity field measurements.

Acknowledgments:

The research is funded by FNR (CSGR, App ID: 15740886).

LUXEMBOURG SPACE AGENCY
Fonds National de la Recherche Luxembourg
GROOPS

Baur, O. (2013), Greenland mass variation from time-variable gravity in the absence of GRACE, Geophys. Res. Lett., 40, 4289– 4293, doi:10.1002/grl.50881.

Strasser, S., Mayer-Gürr, T. & Zehentner, N. Processing of GNSS constellations and ground station networks using the raw observation approach. *J Geod* 93, 1045–1057 (2019). https://doi.org/10.1007/s00190-018-1223-2

Mayer-Guerr, T., Behzadpour, S., Eicker, A., Ellmer, M., Koch, B., Krauss, S., Pock, C., Rieser, D., Strasser, S., Suesser-Rechberger, B., Zehentner, N., Kvas, A. (2021). GROOPS: A software toolkit for gravity field recovery and GNSS processing. Computers & Geosciences, 104864. https://doi.org/10.1016/j.cageo.2021.104864

EGU General Assembly 2023

How to cite:
Shafiei, P., Bemtgen, J., Talpe, M., and Tabibi, S.: Initial Orbit Determination Results from the University of Luxembourg using Spire GNSS Tracking Data, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-15932, https://doi.org/10.5194/egusphere-egu23-15932, 2023.

Sharing is encouraged