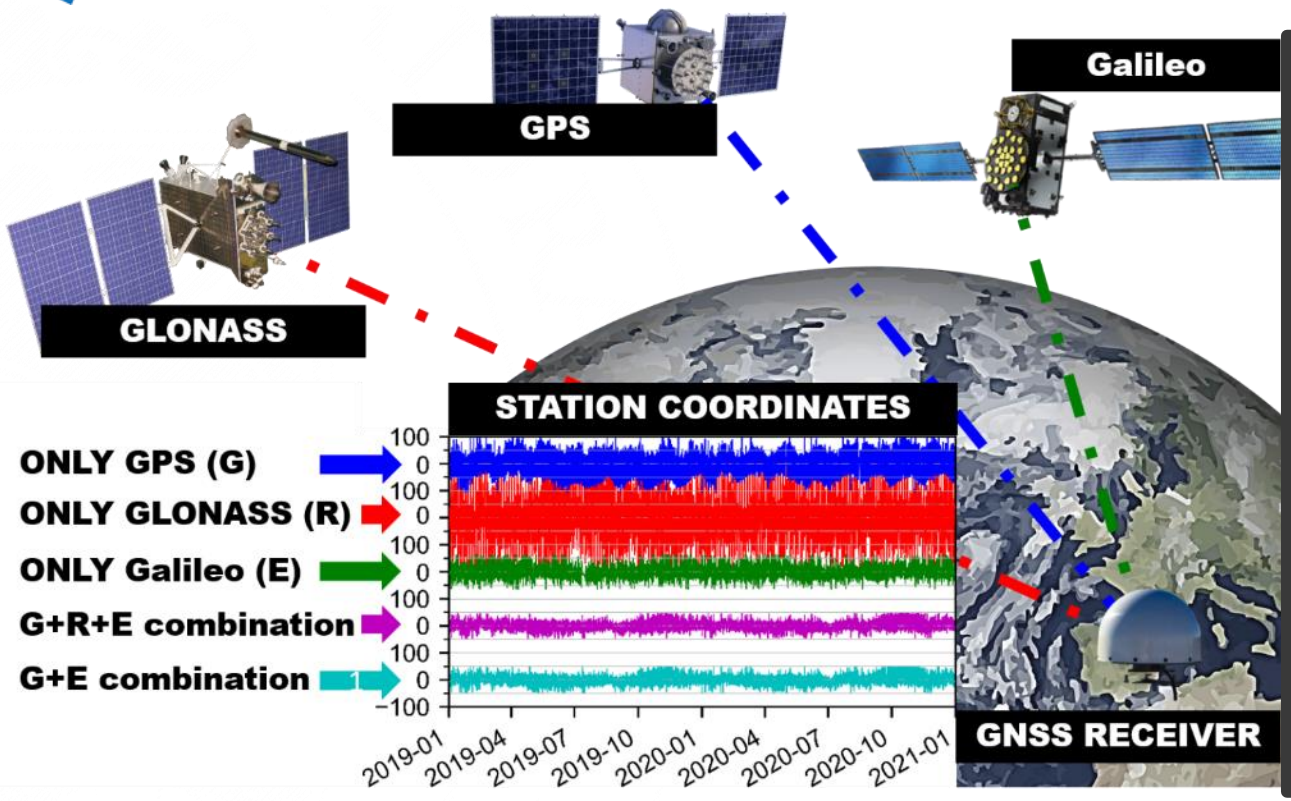
EGU General Assembly 2022

Wrocław University of Environmental and Life Sciences



Inconsistency in Precise Point Positioning products from GPS, GLONASS and Galileo

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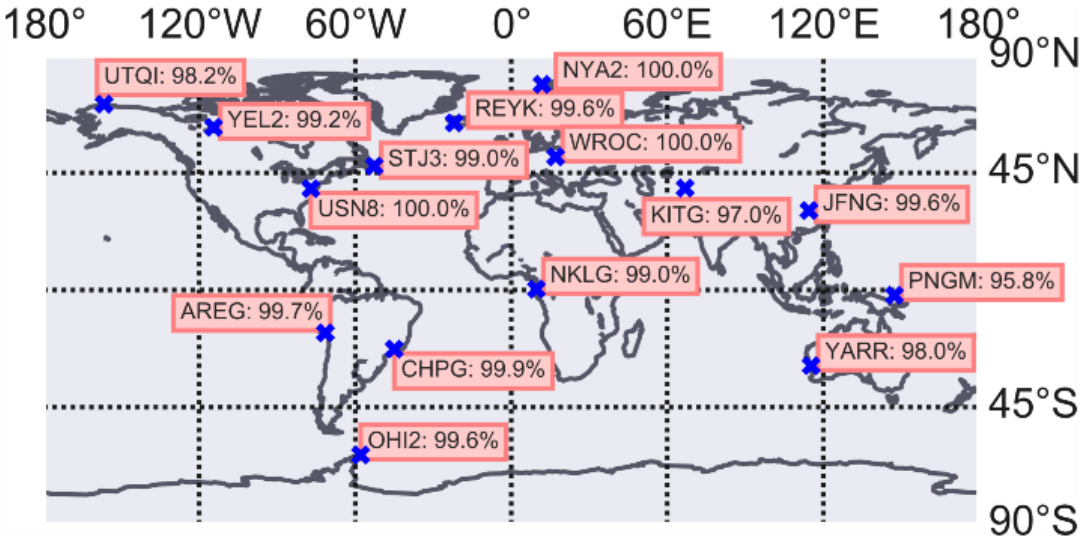
PPP Solutions - Overview

Software	GNSS-WARP (Hadas, 2015)
Observables	Undiferenced uncombined model with pseudorange and carrier-phase
Sampling rate and test period	60 s → 01/2019 | 12/2020 (2 years)
Satellite orbits and clocks	fixed from TUG R3 mutli-GNSS (Strasser et al. 2019)
All details: Zajdel, R., Kazmierski, K., & Sośnica, K. (2022). Orbital artifacts in multi-GNSS precise point positioning time series. JGR: Solid Earth, 127, https://doi.org/10.1029/2021JB022994	

	Daily solution	**Sub-daily solution**
Station coordinates	1 set every 24 h	Every minute as a random walk process (σ=60 $\frac{mm}{h}$)
Troposphere	Every minute as a random walk process (σ=4 $\frac{mm}{h}$)	
Receiver clock	Every minute as a white noise	
Available solutions	>96%	>90%



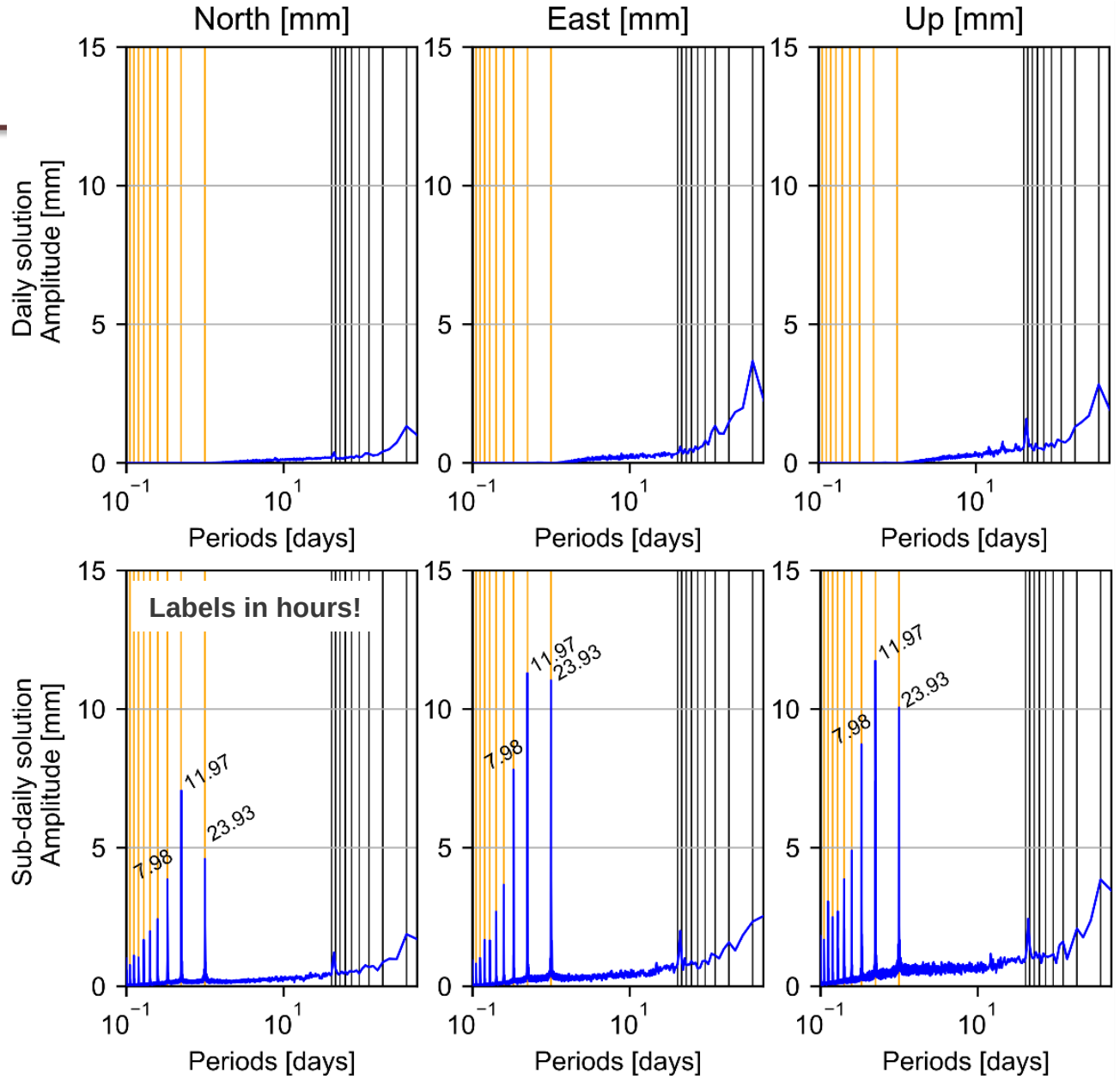
- **15 stations selected for tests**
- **IGS Repro3 products** (TUG contribution, Strasser et al. 2021)
- All the background models consistent with TUG products; e.g., FES2014, HF EOP (Desai Sibois, 2016) etc.
- Float ambiguities
- System-specific solutions

Galileo-only (E) | **GPS-only (G)** | **GLONASS-only (R)** | **Multi-GNSS (GRE)** | **Multi-GNSS (GE)**

GPS series

Stacked periodogram of FFT series from all 15 stations

- GPS sub-daily series contain loads of spurious signals with periods at the harmonics of a sidereal day.
- The amplitudes of these signals reach about 1 cm.
- GPS series were treated as references for the next analyses.



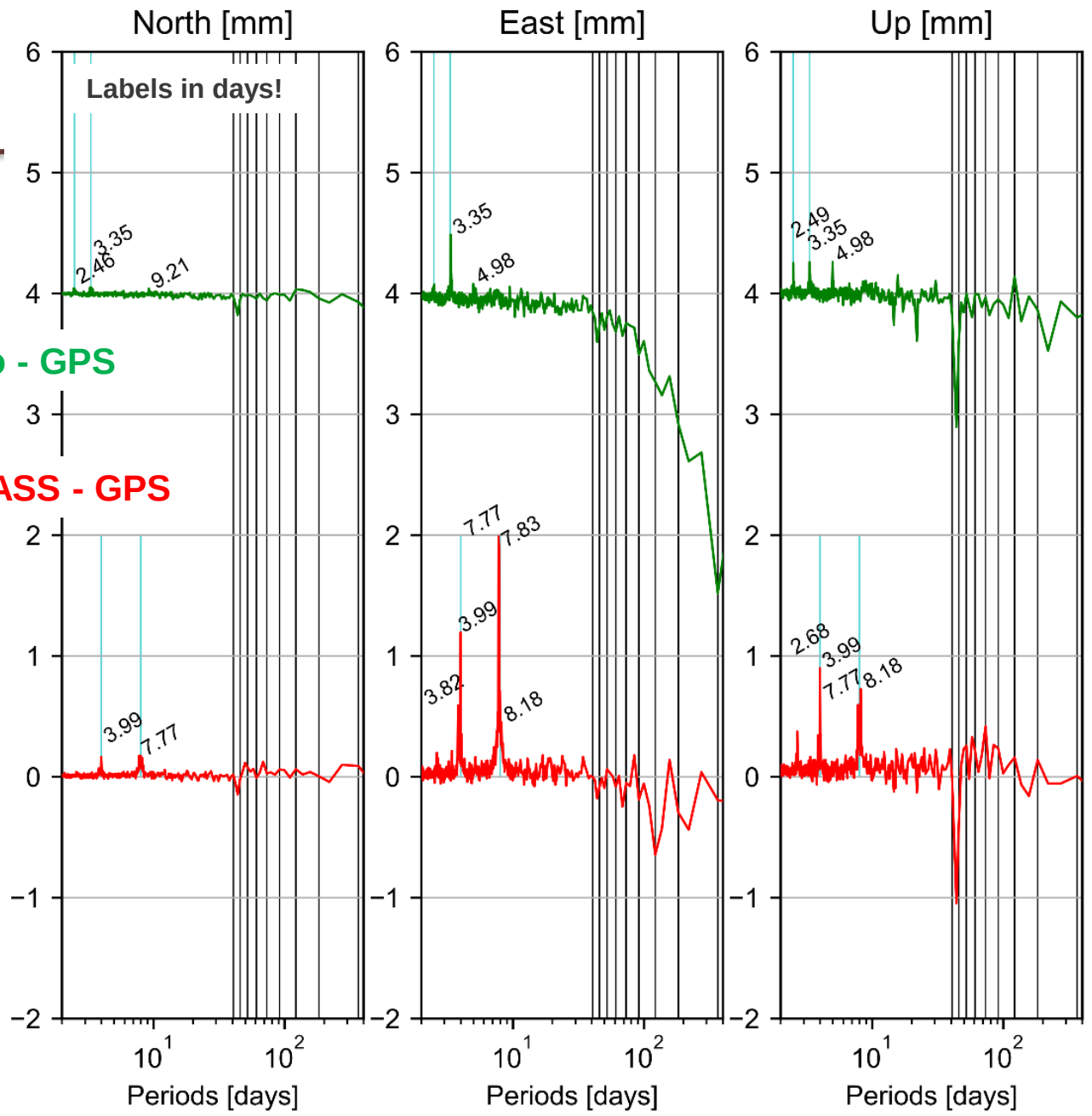
System-specific signals in daily PPP solutions (periods: 2-400 days)

Stacked periodogram of FFT differences w.r.t. GPS-only solution

- Stacked periodogram from all 15 independent stations
- Series shifted along y-axis
  Signals above „0” – **Insertion of system-specific artifacts**
  Signals below „0” – **Reduction of GPS artifacts**
- **Resonances** between Earth rotation and satellite revolution period (orbital periods)

  When f_E and f_S are the frequencies of Earth rotation and satellite revolution, respectively, then we have:

$$\left| \frac{1}{n * f_S + m * f_E} \right|$$



System-specific signals in sub-daily PPP solutions (periods: 0.1-60 days)

Stacked periodogram of FFT differences w.r.t. GPS-only solution

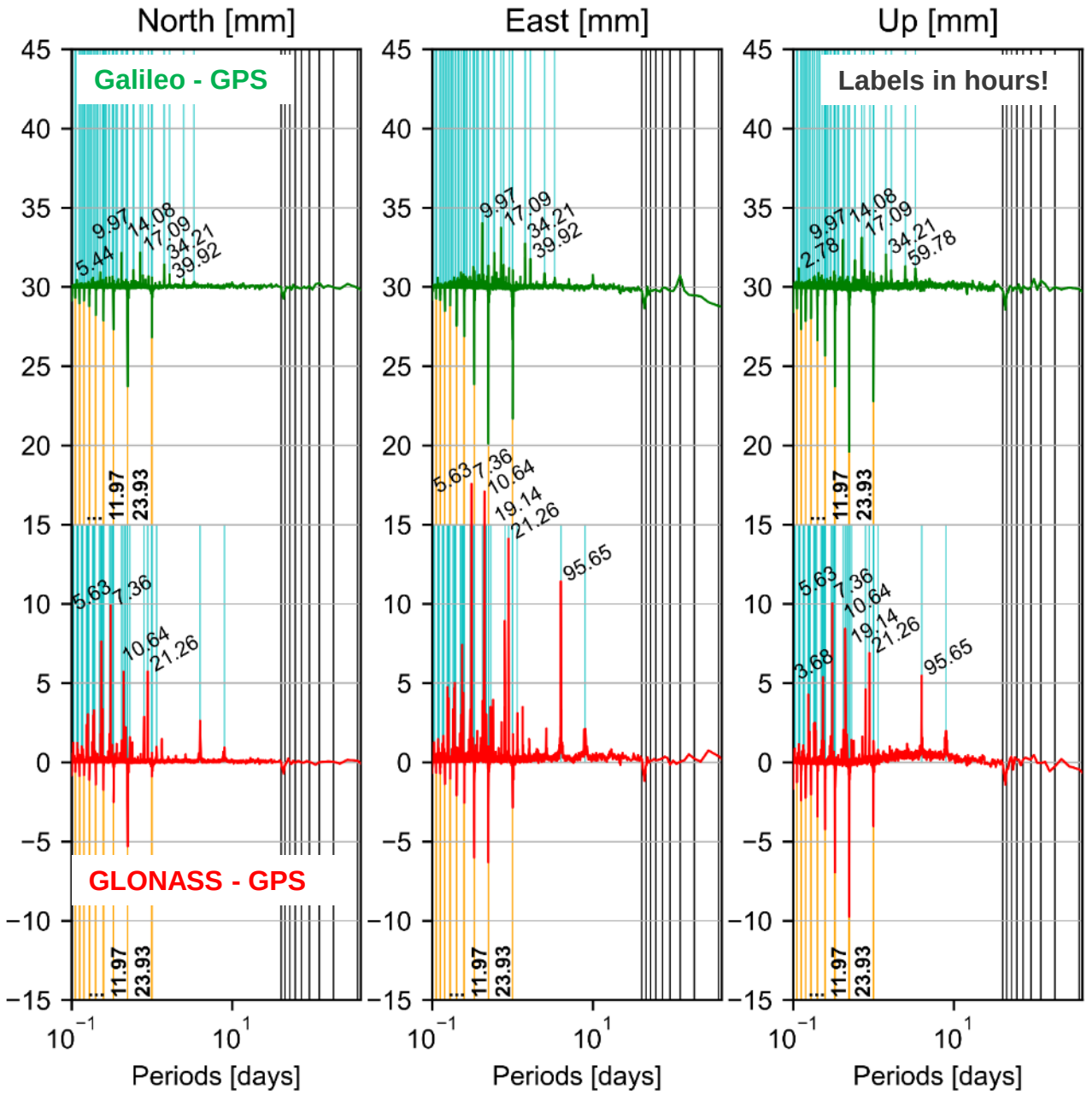
- Stacked periodogram from all 15 independent stations
- Series shifted along y-axis
  Signals above „0” – **Insertion of system-specific artifacts**
  Signals below „0” – **Reduction of GPS artifacts**
- **Resonances** between Earth rotation and satellite revolution period (orbital periods)

  When f_E and f_S are the frequencies of Earth rotation and satellite revolution, respectively, then we have:

$$\left|\frac{1}{n * f_S + m * f_E}\right|$$

- Same signals visible in the series of high-frequency variations in Earth rotation delivered from GNSS

Zajdel, R., Sośnica, K., Bury, G. et al. Sub-daily polar motion from GPS, GLONASS, and Galileo. J Geod 95, 3 (2021). https://doi.org/10.1007/s00190-020-01453-w



What to choose ? *GPS ? Galileo ? GPS+GLONASS+Galileo ? GPS + Galileo ?*

Interquartile Range of Station Coordinate Residuals Decomposed Into North, East, and Up Components

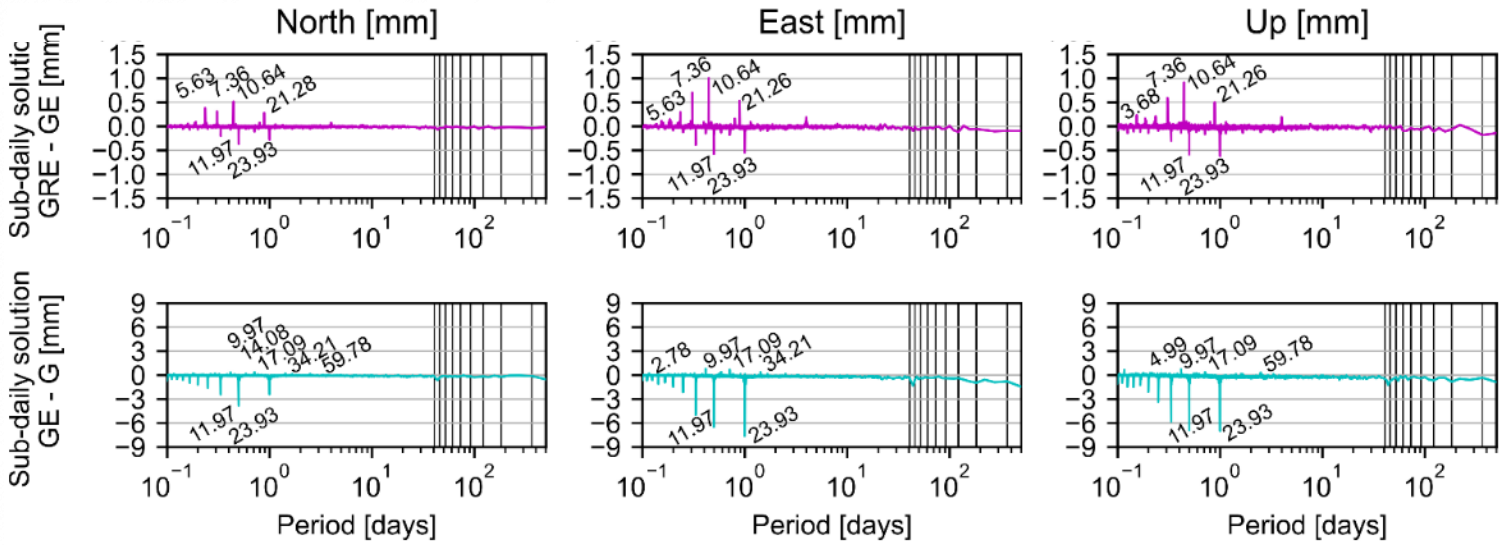
	Daily (mm)			Sub-daily (mm)		
	North	East	Up	North	East	Up
G	2.9	6.2	8.0	22.2	37.2	56.1
R	3.2	8.7	9.8	35.4	65.3	68.1
E	2.6	3.9	7.3	17.3	26.3	43.8
GRE	**2.5**	**3.7**	**6.5**	**11.1**	**16.0**	**31.1**
GE	**2.6**	**3.9**	**6.6**	**11.8**	**17.2**	**32.8**

- Galileo-only better than GPS-only
- multi-GNSS always better than single-system solutions
- Both multi-GNSS solutions are comparable in terms of IQR

Linear drift + offset and the annual and semiannual signals have been removed beforehand from the individual series.

Multi-GNSS

Stacked periodogram of FFT differences



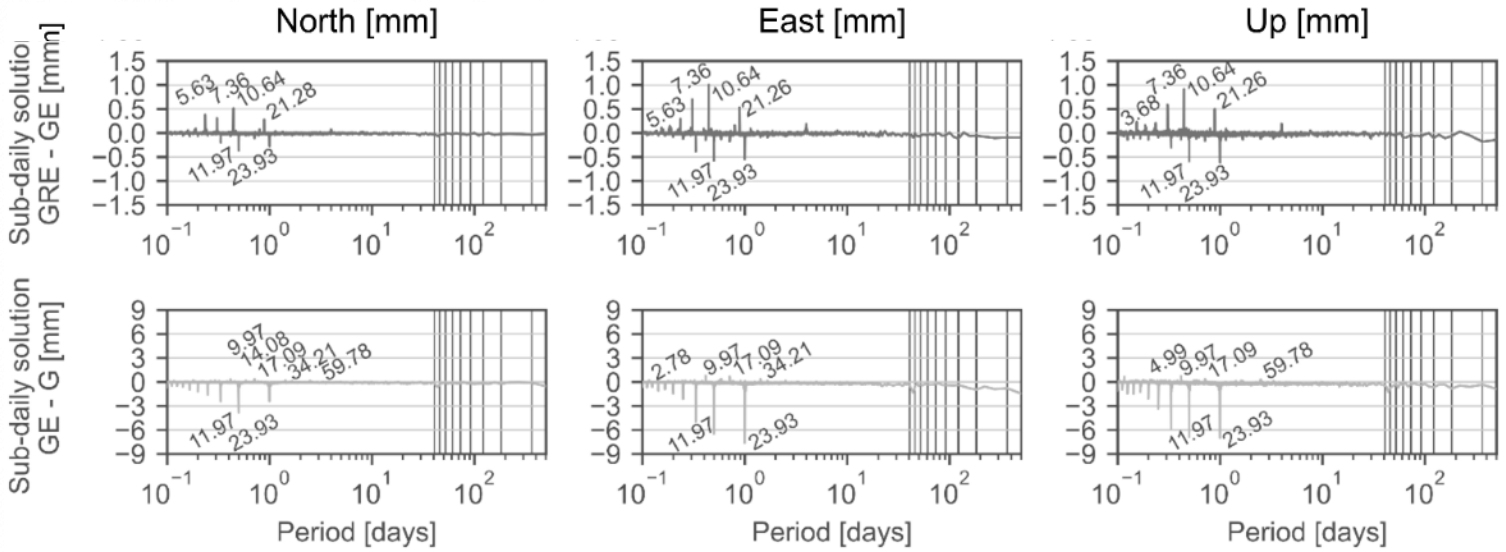
Sub-daily solutions

- **Using GLONASS introduces the GLONASS-related orbital signals (milimeter level in magnitude)**
- **Using Galileo** in the multi-GNSS combination **does not introduce any significant Galileo-related orbital signals**
- Using multi-GNSS reduces the amplitudes of the artificial signals at the harmonics of a sidereal day! **(centimeter level in magnitude)**

Multi-GNSS

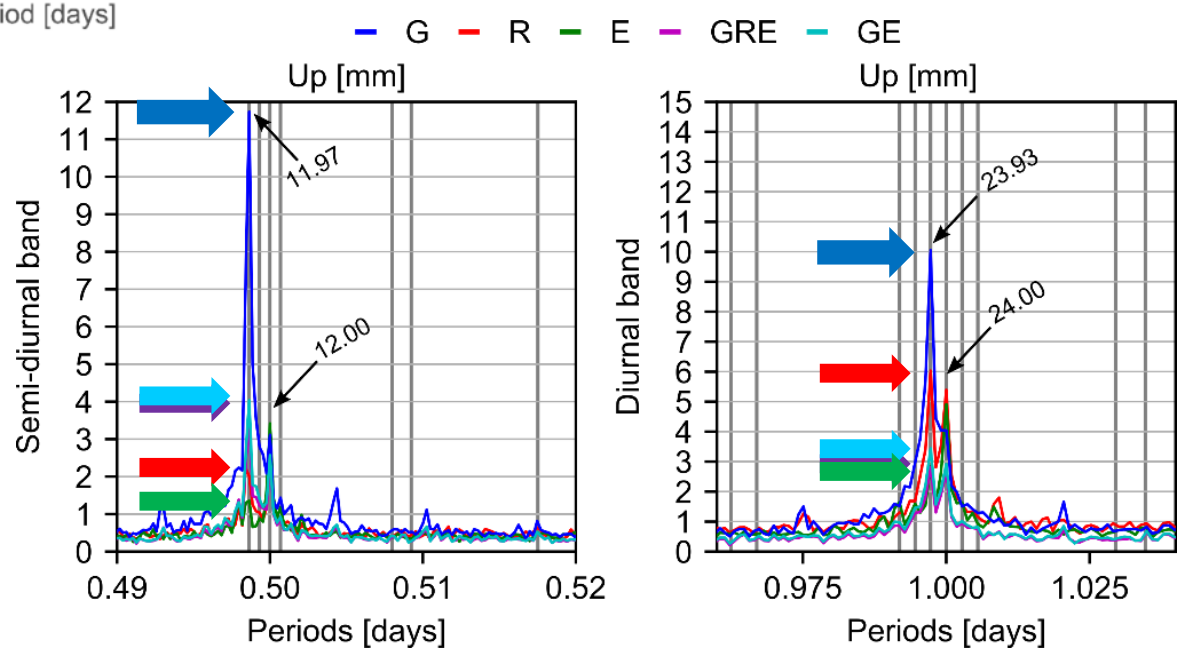
Sub-daily solutions

Stacked periodogram of FFT differences



- GPS sees residual signals reaching 11–12 mm in amplitude at K2 and K1 tidal lines, coinciding with the GPS orbital period and GPS ground repeat period, respectively.

- The residual signal at these frequencies measured by GLONASS is about **twice less**, while Galileo seems to be free from this issue, and residual signals **do not exceed 3 mm at the K2 and K1 tidal lines.**



Conclusions

- System-specific signals are visible for all the GNSS constellations in both standard static 24h and sub-daily PPP products.
- These signals inherently propagate to the multi-GNSS solutions; however, the magnitude of the GLONASS-related signals is much larger than those, which originate from using Galileo.
- The multi-GNSS diversity mitigates most of the system-specific deficiencies and clearly stands above any individual GNSS solutions.
- There is no much benefit from using GLONASS in the multi-GNSS solution.

Open questions

- To what extent the unmodelled sub-daily harmonic signals propagate into 24h time series?

- How to model the orbital signals in the GNSS-based analyses?

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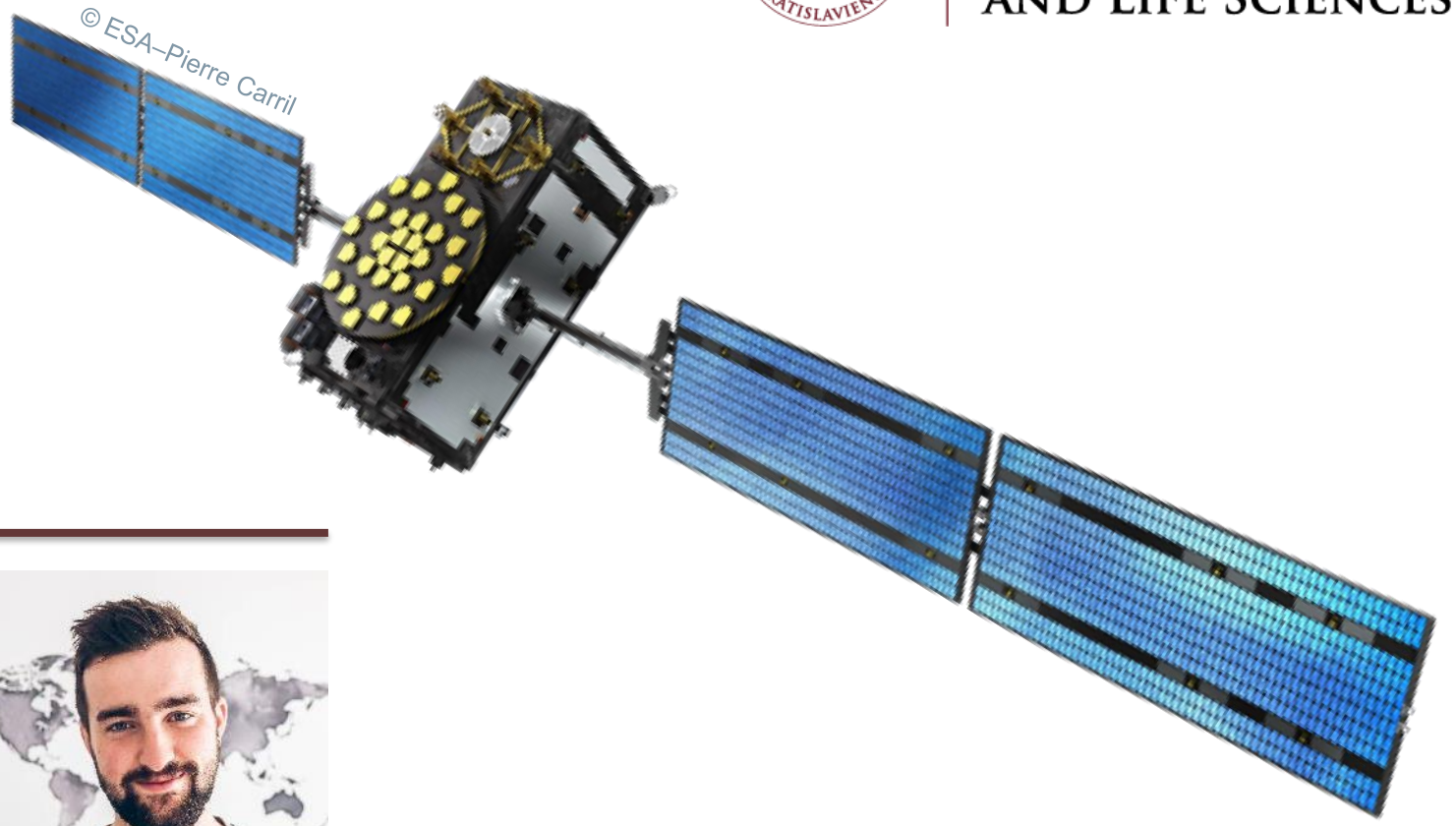

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Zajdel, R., Kazmierski, K., & Sośnica, K. (2022). Orbital artifacts in multi-GNSS precise point positioning time series. JGR: Solid Earth, 127, https://doi.org/10.1029/2021JB022994