Global GNSS processing based on the raw observation approach

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Introduction

The raw observation approach is a GNSS processing approach developed at Graz University of Technology (TUG). The basic principle is to utilize GNSS observations as they are observed by the receiver. The observation equations are set up directly for each observation type and measurements are only corrected for known influences in advance.

Since no linear combinations or differences are involved in the least squares adjustment, unknown influences, e.g. the ionosphere, have to be estimated as additional parameters. This is both a drawback and an advantage. An increased number of estimated parameters reduces the redundancy. At the same time it gives the possibility to directly access and analyze various constituents. The avoidance of combinations and differences also enables a straightfoward incorporation of new observables.

Station displacements

Figure 1 shows estimated station displacements of all processed IGS14 stations for a single day solution. A one year station displacement time series for the IGS station NRIL in Siberia is shown in Figure 2, which compares the TUG solution with the IGS combined solution of the 2nd reprocessing campaign (repro2).

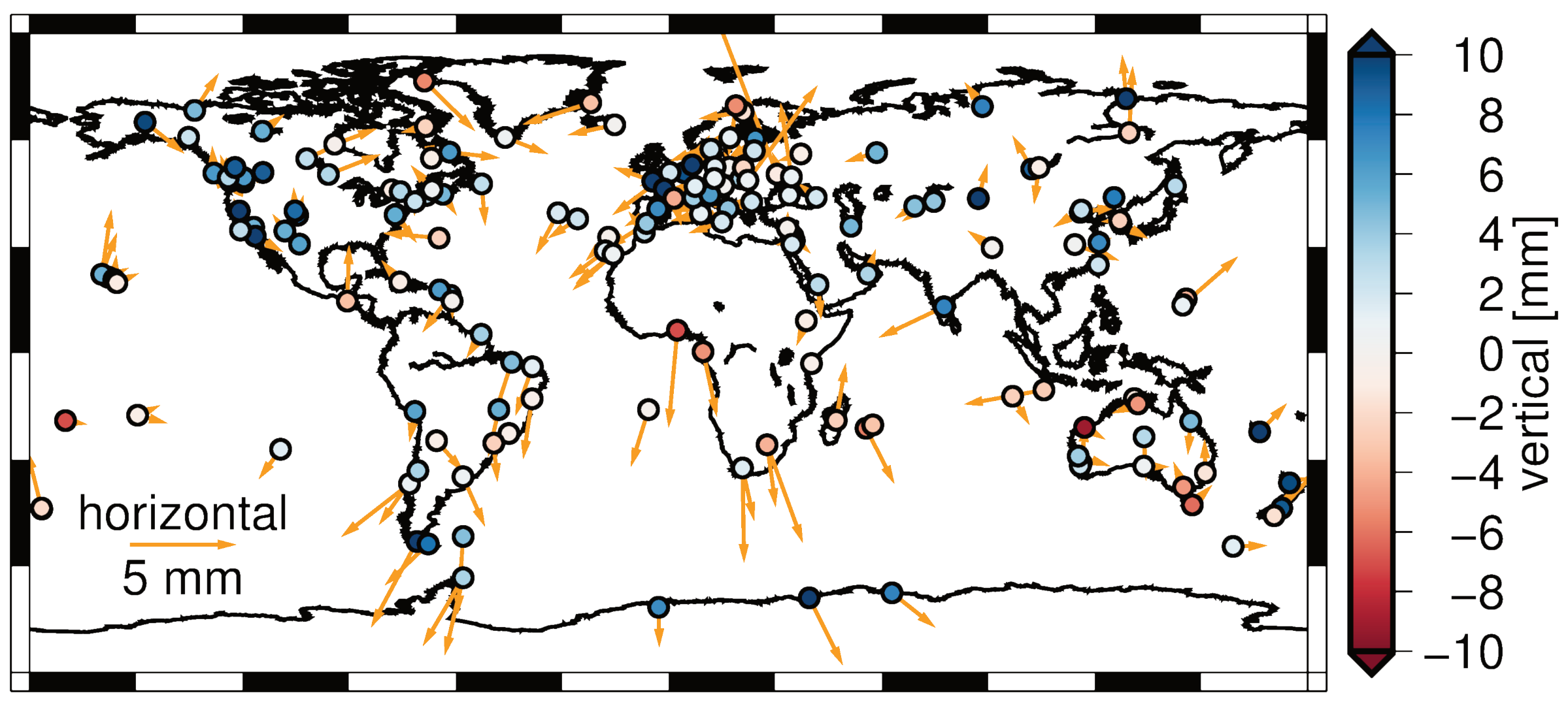


Fig 1: Station displacement difference between TUG solution and IGS repro2 combined solution for all processed IGS14 stations on 2012-01-01.

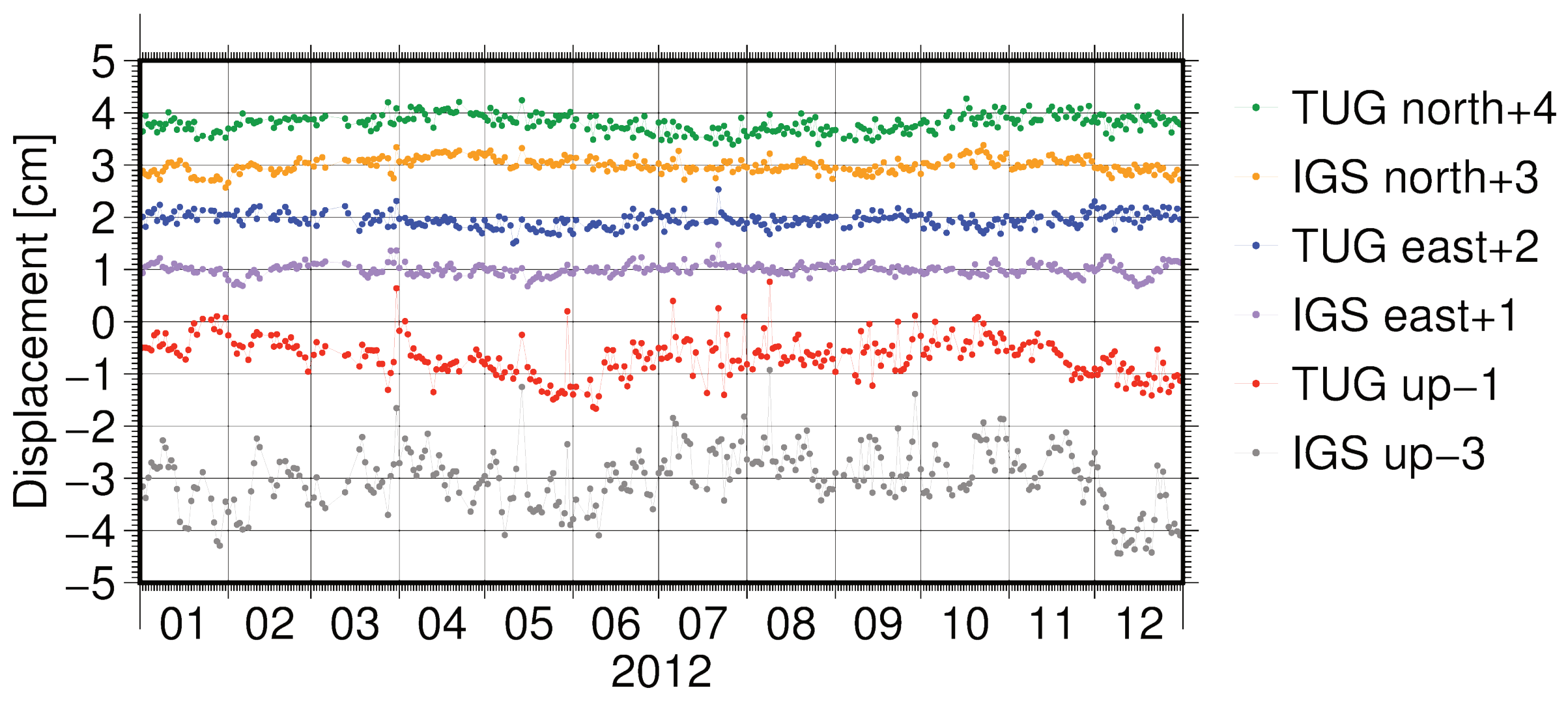
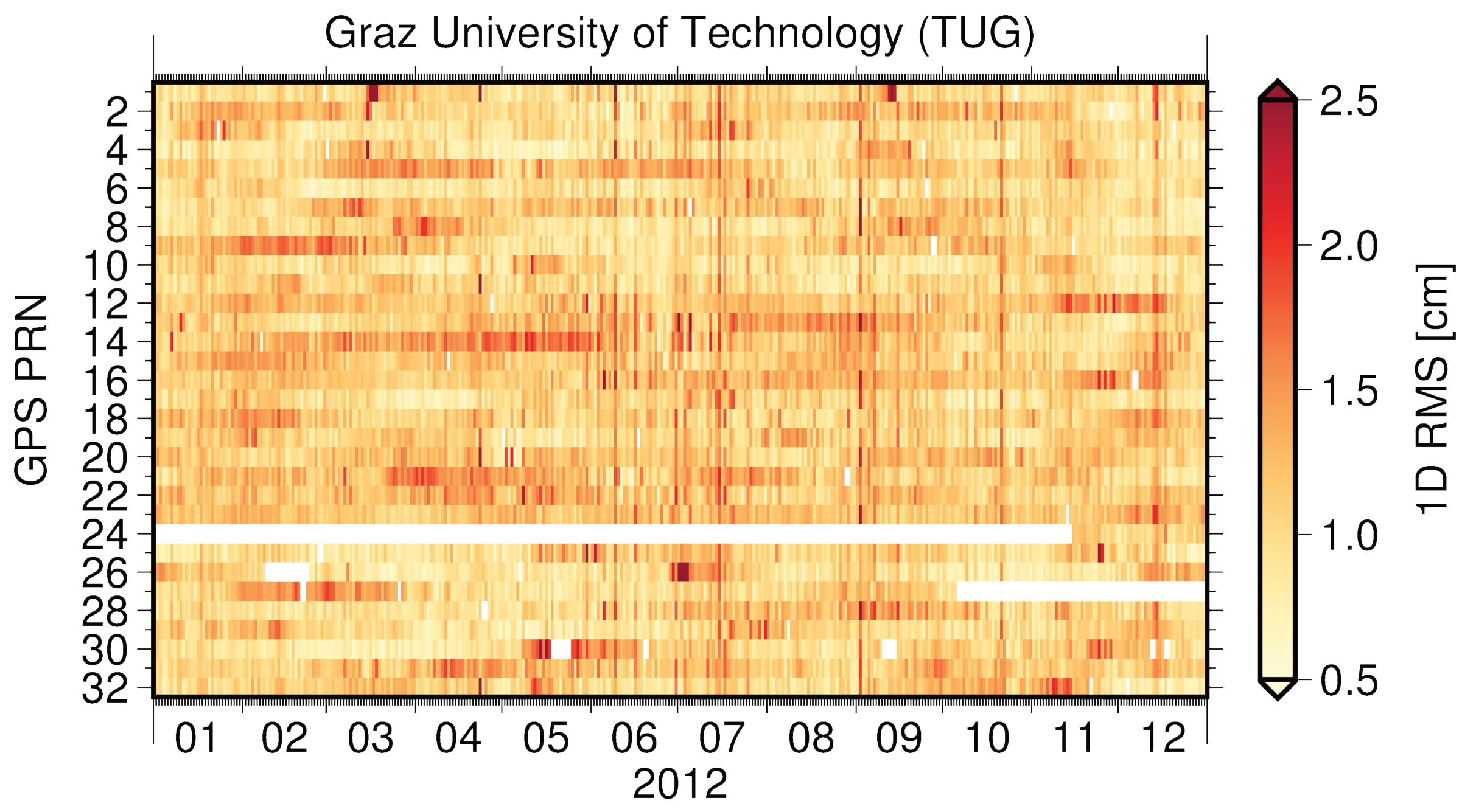


Fig 2: Estimated station displacement time series of IGS station NRIL in Siberia for 2012. The comparison between TUG solution and IGS repro2 combined solution shows slightly more noise in the TUG solution for the north and east components. The up component is more stable for the TUG solution than for the IGS solution due to the correction for atmospheric loading.

GPS orbit comparison

To evaluate the new approach, several years of GPS satellite orbits have been processed and compared to orbits of the IGS analysis centers. The orbits used for comparison were taken from the 2nd IGS reprocessing campaign (repro2) to achieve a consistent comparison independent of evolving processing methods over time.

Figures 3, 4, and 5 show that the orbits produced at TUG generally fit well to the IGS combined orbits. The deviation is comparable to those of the best-fitting IGS analysis centers for the respective time period. This is notable since the combined orbits are a product of the analysis center orbits, but do not contain the TUG orbits.



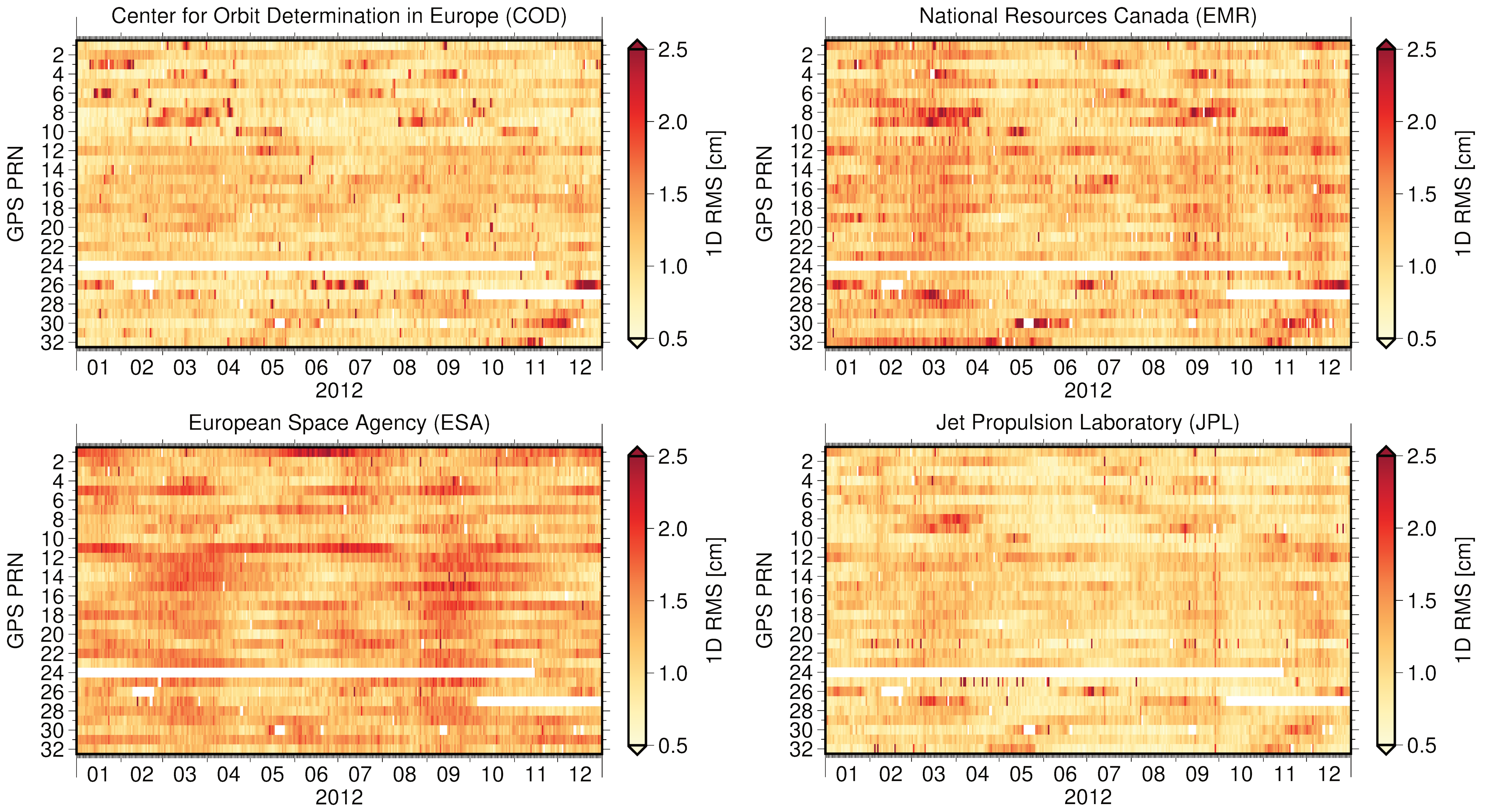


Fig 3: Comparison of **daily RMS values** between TUG orbits and selected IGS analysis center orbits from the 2nd IGS reprocessing campaign (repro2). The RMS values are in reference to IGS repro2 combined orbits. Overall, the quality of the orbits produced at **TUG is comparable to the best-fitting IGS analysis centers**. All solutions show **increased RMS values around eclipse seasons** (esp. for block IIA) and **single outlier satellites** on certain days.

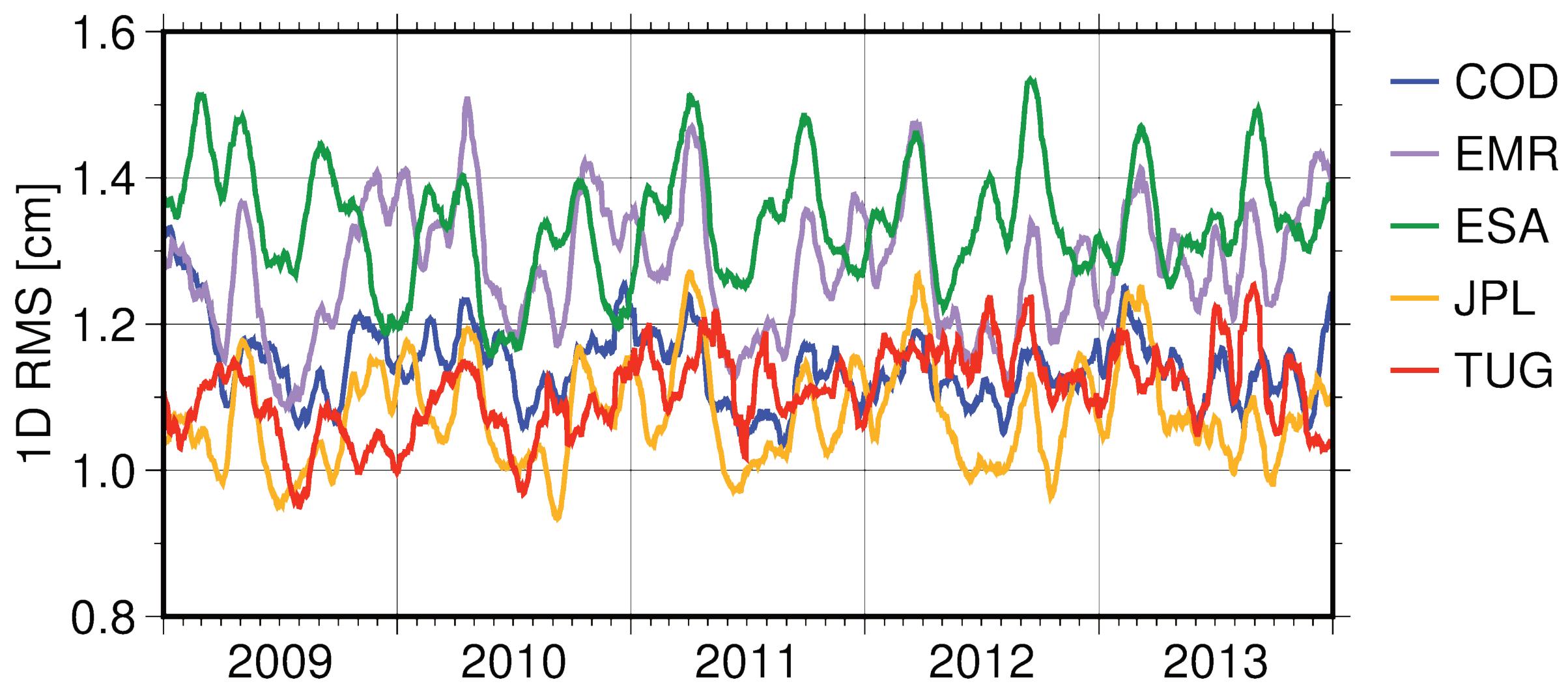


Fig 4: Comparison of **daily overall RMS values** between TUG orbits and selected analysis center repro2 orbits. The RMS values refer to IGS repro2 combined orbits and are 31-day moving average filtered.

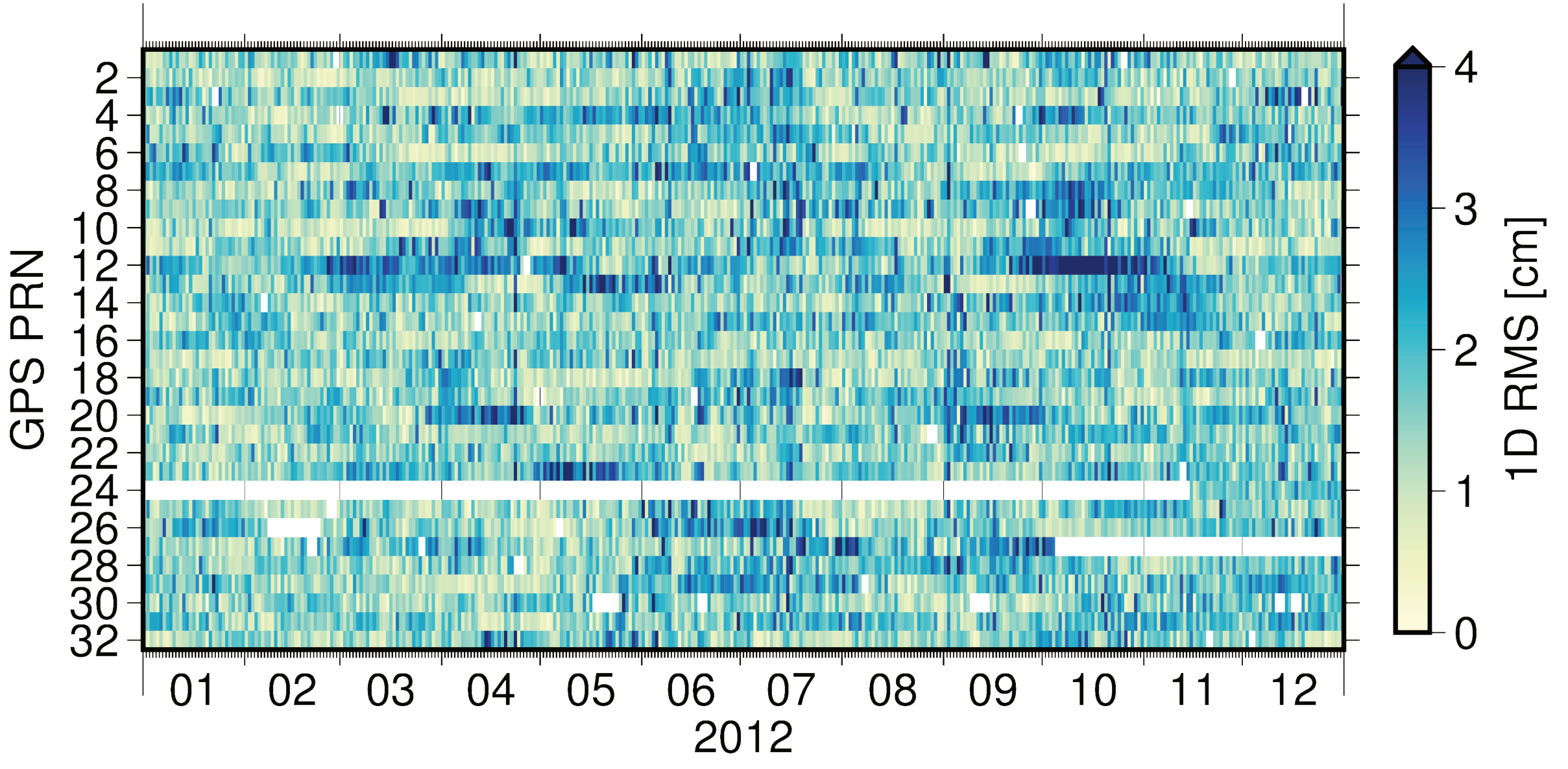


Fig 5: Orbit overlap RMS values of TUG orbits at midnight. Total overlap RMS for 2012 is 1.8 cm. Block IIA shows increased RMS during eclipse season, while for some IIR/IIR-M satellites the opposite is the case.

Models and methods

Measurement models

Preprocessing:
- Test all available IGS14 stations (cycle slips, outliers)

Observables:
- Undifferenced raw carrier phases and pseudoranges
- Elevation cutoff: 5°, minimum track elevation: 15°
- Sampling rate: 30 seconds
- Weighting: 1/cos(z) with $\sigma_{phase} = 1$ mm, $\sigma_{range} = 22$ cm

A priori corrections:
- Code biases: CODE monthly mean DCBs
- Antenna center: Variations and offsets from igs14.atx
- Troposphere: VMF1 mapping functions and z-delays
- Ionosphere: Higher order corrections and bending
- Solid Earth tides: IERS 2010
- Ocean tides: FES 2014b
- Pole and ocean pole tides: IERS 2010
- Atmospheric tides: S1, S2 (van Dam and Ray, 2010)[1]
- Atmospheric and ocean dealiasing: AOD1B RL06

Orbit models

Gravitational forces:
- Gravity field: GOCO05s (static, trend, annual)
- Astronomical tides: JPL DE421
- Solid Earth tides: IERS 2010
- Ocean tides: FES 2014b
- Pole and ocean pole tides: IERS 2010
- Atmospheric tides: S1, S2 (van Dam and Ray, 2010)[1]
- Atmospheric and ocean dealiasing: AOD1B RL06
- Relativistic effects: IERS 2010

Nongravitational forces:
- Solar radiation pressure: Box-wing model
- Earth radiation pressure: Box-wing model
- Antenna thrust: IGS model values

Attitude and shadow crossings:
- Attitude model: Kouba (2009)[2] including updates
- Earth and Moon shadow model: Umbra and penumbra

Estimated parameters

Orbits, station positions, and clocks:
- Orbits: initial state, station positions: constant per day
- SRP: ECOM (D0, Y0, B0, B1C, B1S, D2C, D2S)
- Pseudo-stochastic pulse at 12:00 ($\sigma = 0.1$ µm/s)
- 30 second transmitter and receiver clocks

Troposphere:
- Zenith wet delay: Linear every 1 hours
- Gradients: Linear north and east per day

Ionosphere:
- Slant TEC per observation group and epoch

Code and phase biases:
- Differential P1-P2 and P1-C1 code biases
- Transmitter and receiver phase biases

Ambiguities:
- Custom "double-difference" method utilizing phase biases to access integer ambiguites
- Integer ambiguity resolution using LAMBDA method

References and acknowledgments

[1] van Dam, T., and R. Ray (2010), S1 and S2 Atmospheric tide loading effects for geodetic applications. Data set/Model available online at URL: http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html.
[2] Kouba, J. (2009), A simplified yaw-attitude model for eclipsing GPS satellites. GPS Solut 13, 1–12. doi:10.1007/s10291-008-0092-1.

GNSS data were obtained from the IGS Global Data Centers hosted at the Crustal Dynamics Data Information System (CDDIS) at NASA Jet Propulsion Laboratory, Pasadena, CA and at the Institut Géographique National, Paris, France.

Research on this topic was conducted within the scope of the project CAKAO. This project has received funding from the Austrian Research Promotion Agency (FFG) within the Austrian Space Applications Programme (ASAP).

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Conclusion

GNSS products generated at TUG using the raw observation approach comprise precise GNSS satellite orbits and clocks, station positions and clocks, and code and phase biases. Comparisons with products generated at the IGS analysis centers show that the TUG products are on a similar level of quality. This confirms that the raw observation approach is applicable to global GNSS processing. Extended and longer-term evaluation is still required to reinforce this conclusion.