High-Resolution Real-Time Troposphere Estimates for Severe Weather Monitoring and Nowcasting

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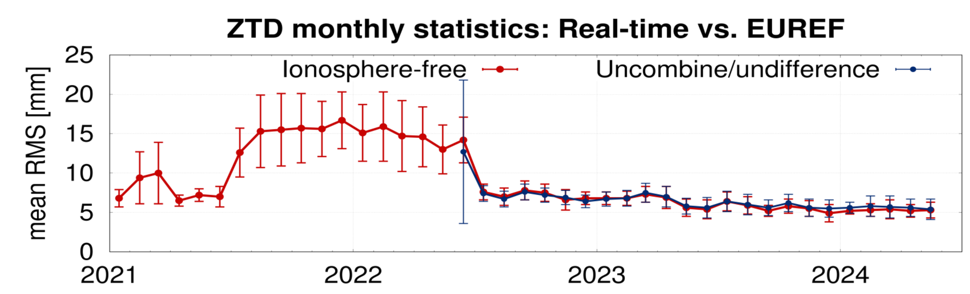
Real-time troposphere solutions at Geodetic Observatory Pecný (GOP)

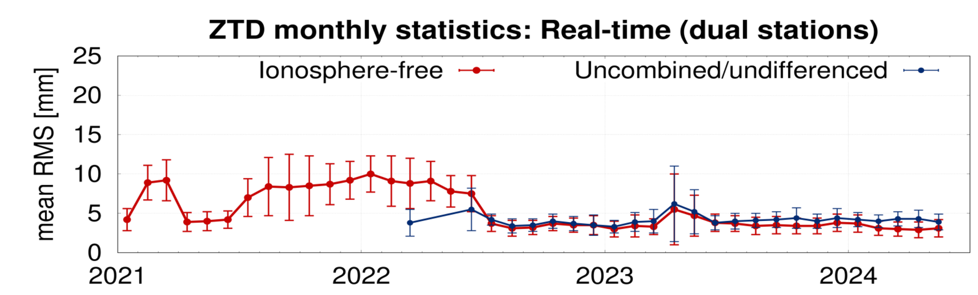
Real-time troposphere monitoring based on a PPP processing method started in 2013 along with the official announcement of the IGS Real-Time Service (RTS) and the initial development of the G-Nut/Tefnut PPP software (www.gnutsoftware.com). Various solutions were performed routinely for selected stations and regions, however, an operational solution for real-time stations from the EUREF permanent network has been provided since 2021 and, for global stations of the REGINA network since 2024. Various precise orbit and clock corrections supporting different GNSS constellations have been tested within past years for which geodetic/low-cost receivers in static/kinematic modes were used. Dual-stations collocated at various European sites have been used to assess all processed solution variants, e.g. in terms of input precise corrections, GNSS constellations, estimated parameters, processing strategies, time resolution and latency, etc.

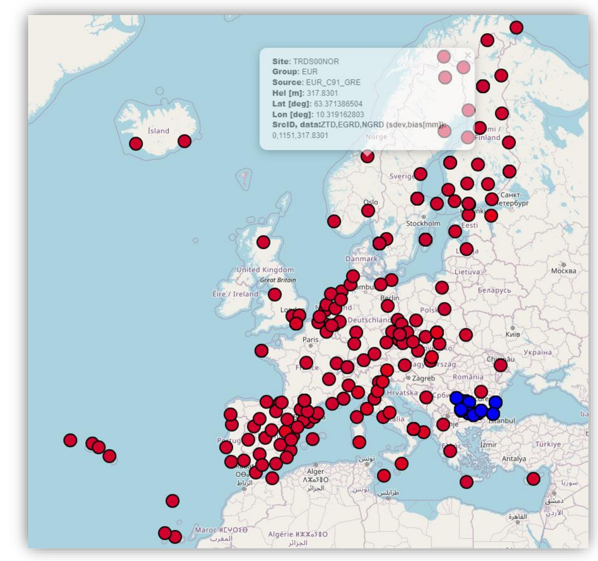
European solution - long-term assessment vs EUREF (Jan 2021 – May 2024)

A long-term assessment of real-time ZTDs estimated using the CNES real-time products were assessed with EUREF combined product. Two operational PPP solutions based on uncombined-undifferenced (UC) and ionosphere-free (IF) observations are validated over period of 3+ years (2021-2024). Unfortunately, during initial months, high RMS values from the comparison are due to incorrectly handled satellite/receiver/site metadata which were fixed in June 2022.

Figures show all the stations in the region and time series of monthly mean ZTD RMSs and discrepancies (error bars) calculated from all the stations. The accuracy of real-time ZTDs are well bellow 10 mm during the last 2 years which is true for both PPP IF & UC processing strategy. Additionally, we assessed the quality of ZTDs estimated from two receivers at collocated stations achieving a high agreement, in general about 5 mm during the last two years.

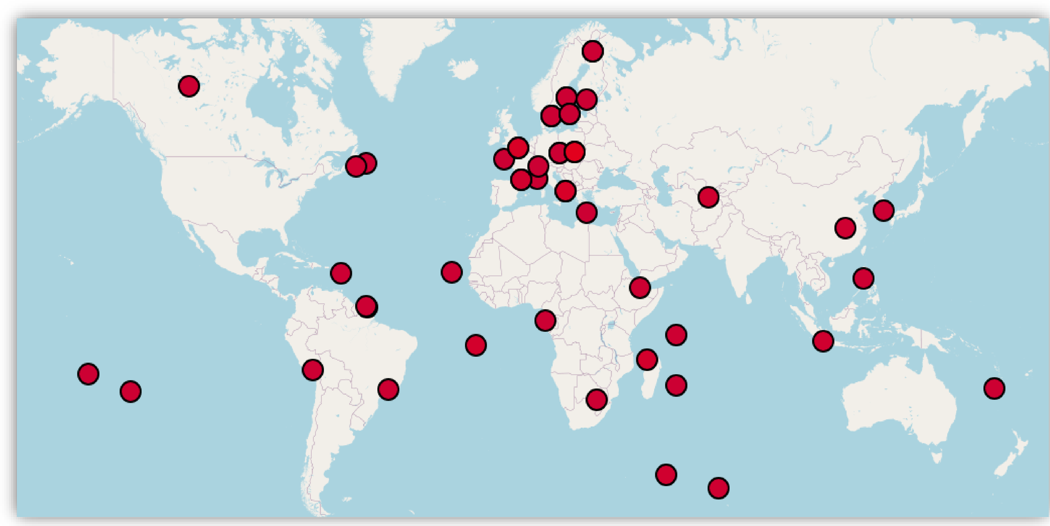




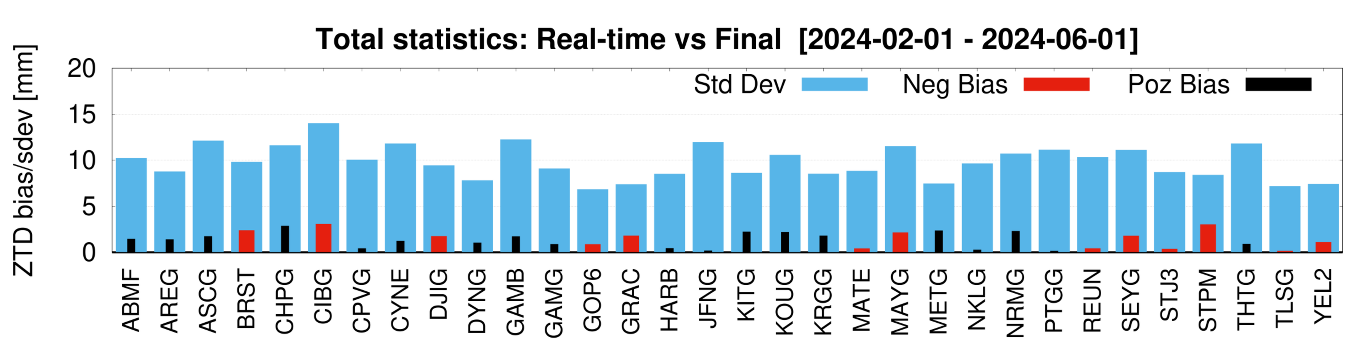


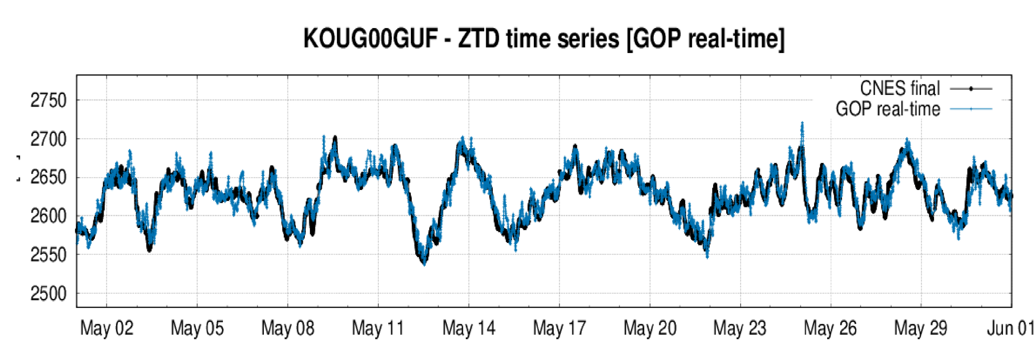
Global solution using Galileo HAS corrections (Feb – May, 2024)

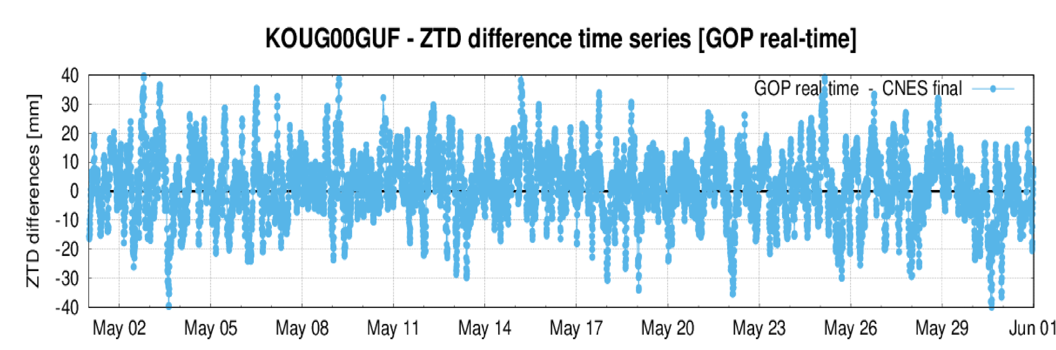
Since February 2024, the corrections of the Galileo High Accuracy Service (HAS) disseminated via the Internet (IDD) has also been exploited for real-time troposphere estimates at stations of the REGINA network operated by CNES & IGN. Resulted ZTDs for selected global stations were assessed on a monthly basis with respect to a GOP final product (PPP with a backward smoothing and using final precise CNES orbit and clocks). Bottom figures (right) show time series of ZTDs and ZTD differences for the station KOUG during May 2024. An overall statistics is summarized in the figure below (left). The station with the highest ZTD RMS are placed in East-Asia, Australia, or Pacific, i.e. in the area not supported by the Galileo HAS (Phase 1).



Site	ZTD bias [mm]	ZTD sdev [mm]	ZTD rms [mm]
AREG	0.1	7.1	7.1
ASCG	5.4	10.1	11.4
CIBG	-9.1	13.5	16.3
GAMG	0.6	11.0	11.0
HARB	2.8	8.1	8.6
KITG	3.8	8.2	9.0
KOUG	2.6	11.4	11.7
MAYG	-4.2	9.1	10.1
NRMG	3.9	11.9	12.6
STJ3	-4.9	7.3	8.8
TLSG	1.0	6.4	6.5
YEL2	-2.6	6.0	6.6
Mean	**-0.3**	**9.3**	**9.8**

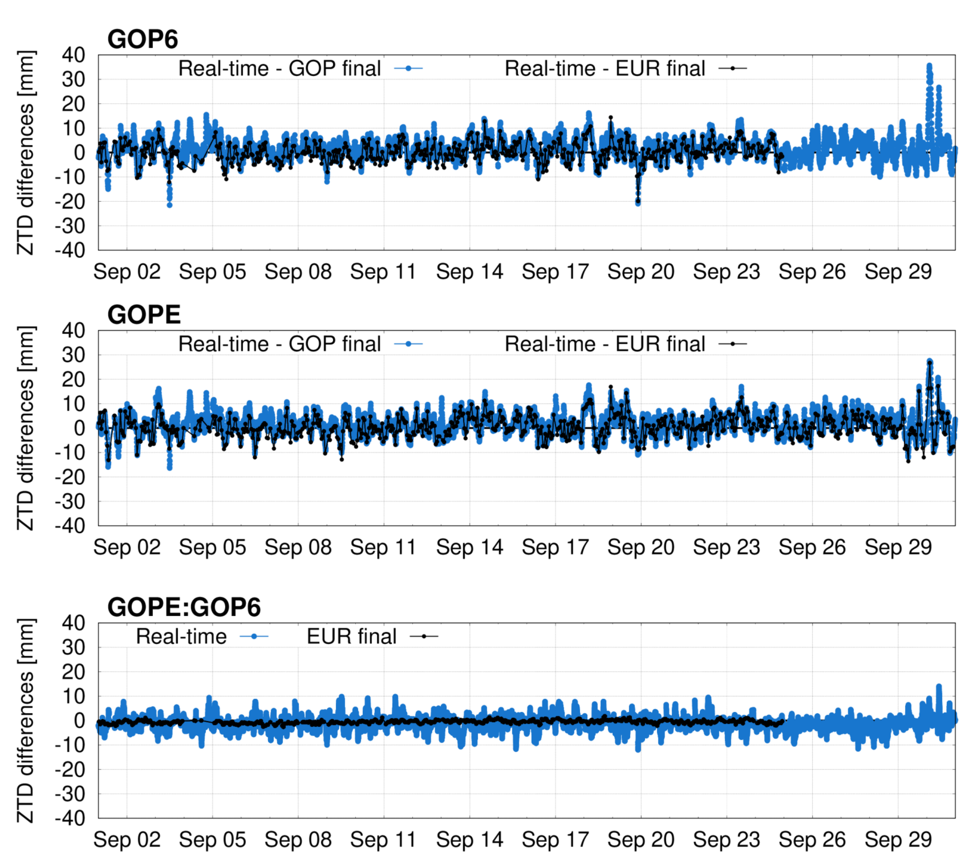


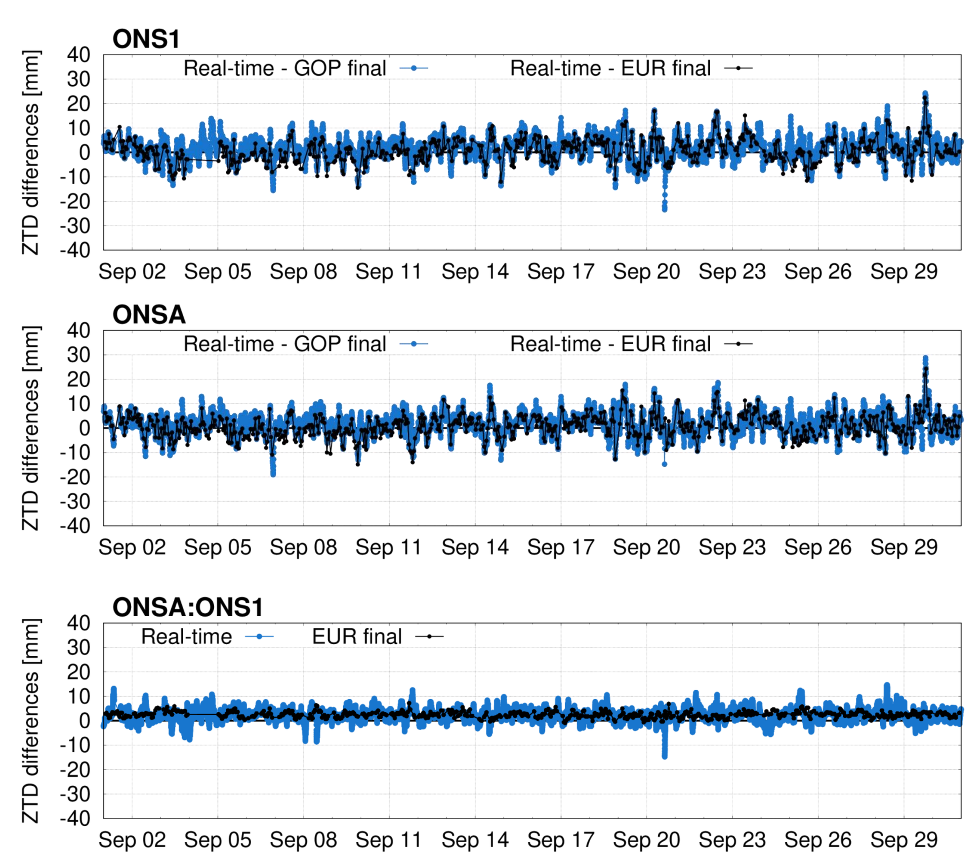


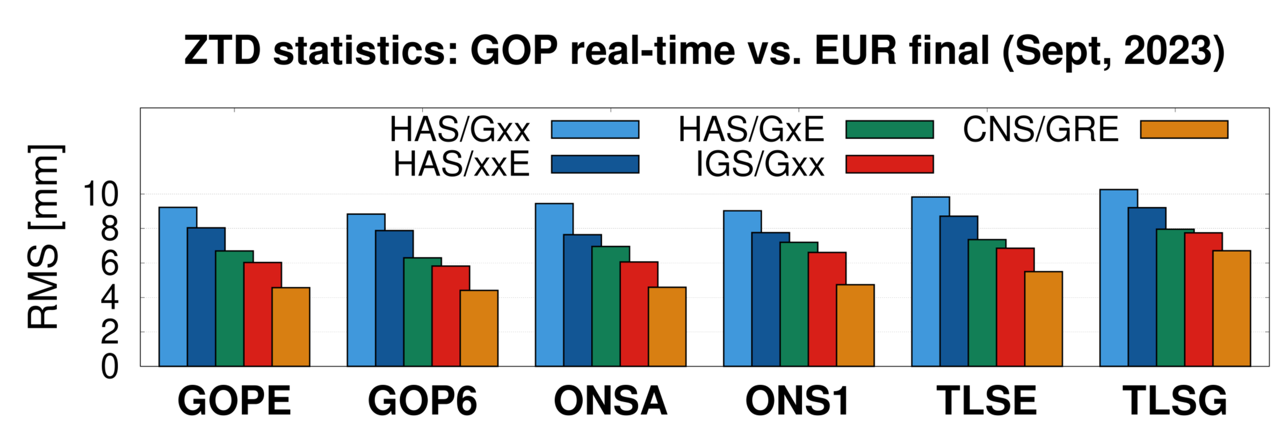


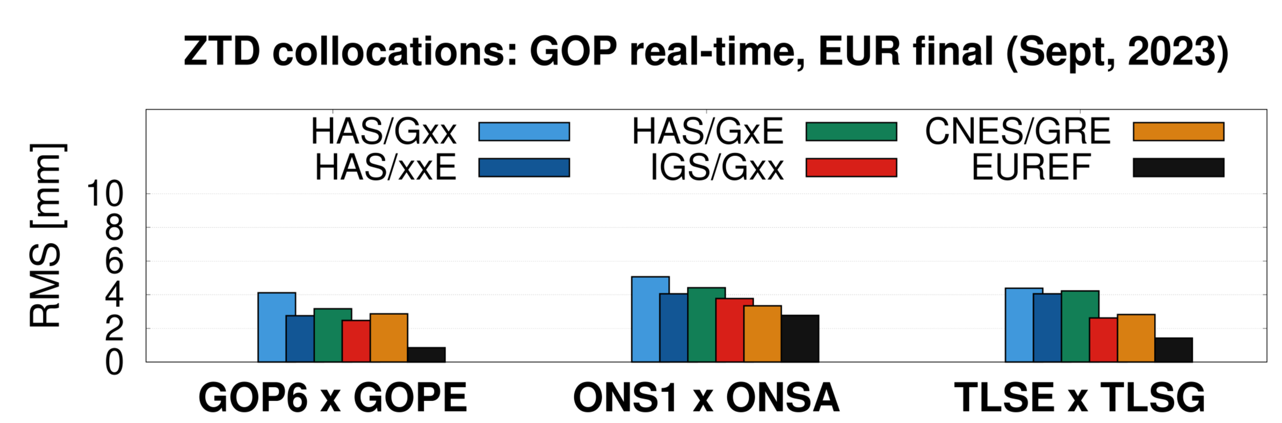
Dual stations – impact of real-time corrections & multi-constellation (Sept, 2023)

Three collocated stations (GOPE/GOP6, ONSA/ONS1, TLSE/TLSG) were used for assessing the impact of solutions based on different real-time corrections (HAS, IGS, CNES) and constellations (G=GPS, E=Galileo, R=GLONASS). Figures below (left) show time series of ZTD differences: 1) for individual stations when compared real-time ZTDs to GOP and EUREF final products, and 2) for dual stations when compared ZTDs estimated in real-time (post-processing) at collocated sites. The figure below (right) shows ZTD statistics for various precise products and constellations using individual sites (real-time vs. final) and collocated ones. The multi-GNSS (GRE) solution based on CNES products outperformed GPS-only solution driven by the IGS product. A lower accuracy of ZTDs based on the HAS is attributed to a sparse global network, while Galileo-only solution providing better results compared to GPS-only one (attributed to worse GPS clocks). Significantly reduced RMSs of ZTD differences at dual stations (and well comparable to EUREF differences) indicate a strong impact of quality of real-time corrections on real-time estimates.



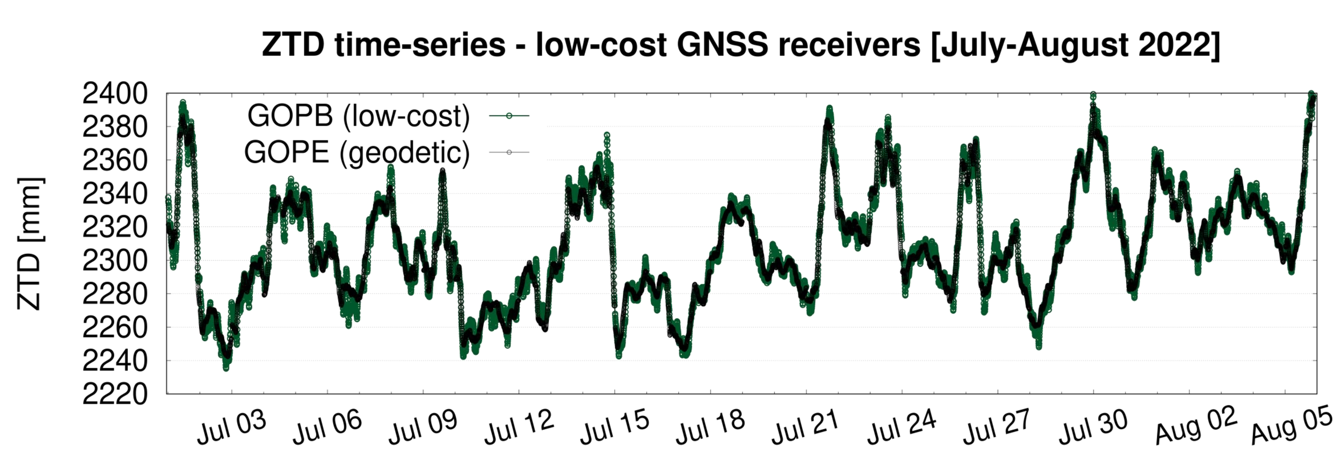


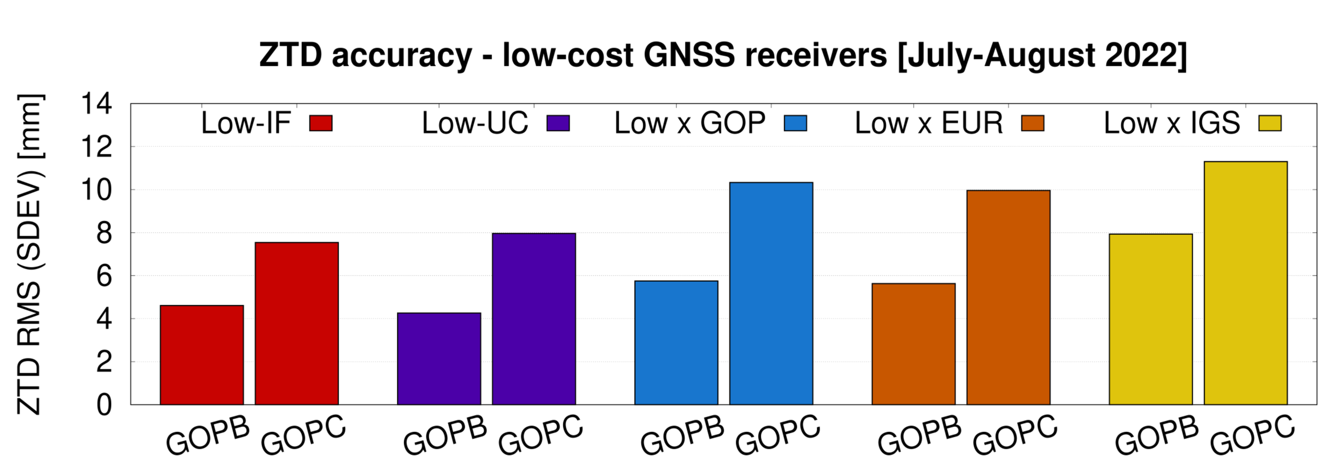




Low-cost receiver solution (July-Aug 2022)

During summer 2022, we operated a real-time solution for two low-cost GNSS receivers (Septentrio and U-Blox) placed at a short baseline aside of GOP geodetic-grade IGS/EUREF reference stations. The two dual/multi-frequency receivers were attached to a multi-band Ardusimple Survey antenna (GOPB) and to the lowest prize dual-band Ardusimple ANN-MB antenna (GOPC). A comparison of both with respect to ZTDs estimated from the GOPE & GOP6 reference stations equipped with geodetic-grade receivers and antennas indicates a very good performance of the former, while much worse for the latter. The impact of the quality of antenna is more significant compared to the used receiver manufacture.





Conclusion

- The accuracy of the PPP-based real-time ZTD estimates is already achieved a sub-cm level which is comparable with a traditional near real-time double-difference solutions routinely generated within the E-GVAP –EUMETNET GNSS Water Vapour Programme.
- Comparison at collocated stations indicates a strong impact of real-time precise corrections on the quality of ZTD (and even more gradients) estimates.
- Galileo High Accuracy Service (HAS) demonstrated a high-quality solution, although slightly worse compared to the IGS combined or CNES individual real-time products.
- A very good products from a low-cost receivers can be obtained in real time ZTD estimates if a dual/multi-band antenna is reasonably selected which is more important compared to the receiver equipment.

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