

Contribution of Galileo to real-time GNSS meteorology

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1. Motivation

Real-time GNSS meteorology, i.e. estimation of Zenith Troposphere Delay (ZTD), is of particular interest for weather nowcasting. The achievable ZTD accuracy lies between 5 and 20 mm. So far limited improvements of multi-GNSS solutions with respect to GPS-only solutions were reported, because of the lower accuracy of real-time products for other GNSS and due to the smaller number of available Galileo and BeiDou satellites. However, the recent development of a new space segment already allows for worldwide Galileo-only positioning, while the availability and accuracy of real-time products for Galileo are also comparable to GPS products.

2. Methodology

2.1 Data and products

Fig. 1: Location of test stations

- ~ 12 IGS stations
- ~ testperiod: 01.01.2019 - 31.12.2019
- ~ referencesolution: IGS Final troposphere

2.2 GNSS data processing

- ~ uncombined & undifferenced (raw) PPP model for pseudorange P_f^s and carrier phase L_f^s observations:

$$\left(\begin{matrix} \delta ZTD \\ \delta ZTD \end{matrix} \right)$$

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- ~ processing strategy

Frequencies	GPS L1/L2 Galileo E1/E5a
Observation	$\sigma = 0.30\text{m}$ for $\sigma = 0.01\text{m}$ for
Elevation weighting	$1/\sin(e)$
Elevation cut-off angle	3°
Sampling rate	60 s
Troposphere delay	VMF1-FC wet delay estimated as random walk process no gradients
Satellite orbits and clocks	real-time CNES stream (mountpoint CLK93)
Code and phase biases	observation specific (from CLK93)
Solution type	static with float ambiguities
Correction models	phase wind-up, relativistic delays, solid earth tides
Receiver PCO and PCV	igs14.atx; E1/E5a from L1/L2

2.3 Solutions

- GPS only (31 PRN, avg. observed: 10)
- Galileo only (22 PRN, avg. observed: 7)
- GPS+Galileo (53 PRN, avg. observed: 17)

3. Results

3.1 Availability of real-time solutions

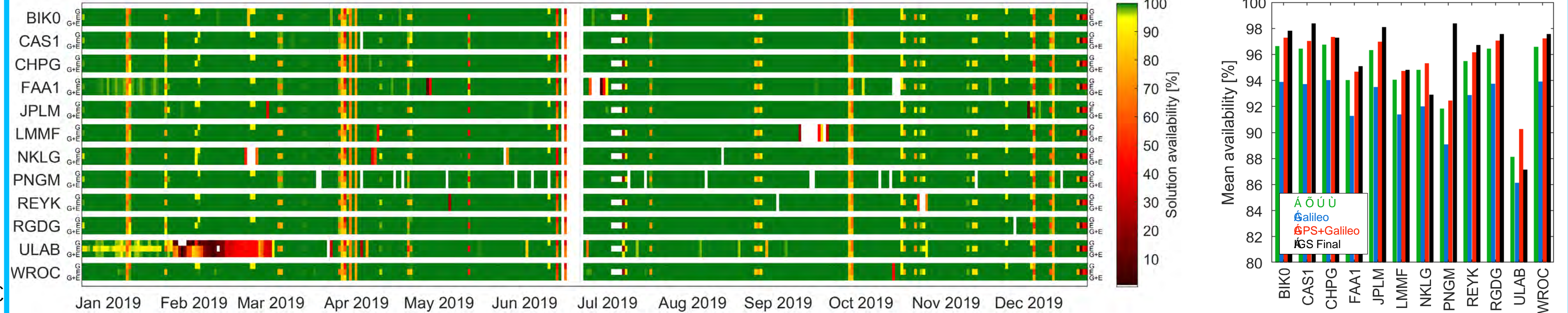


Fig. 2: Daily (left) and mean (right) availability of real-time ZTD from GPS (G), Galileo (E) and GPS+Galileo (G+E) solutions in 2019

3.2 Time series of real-time ZTD

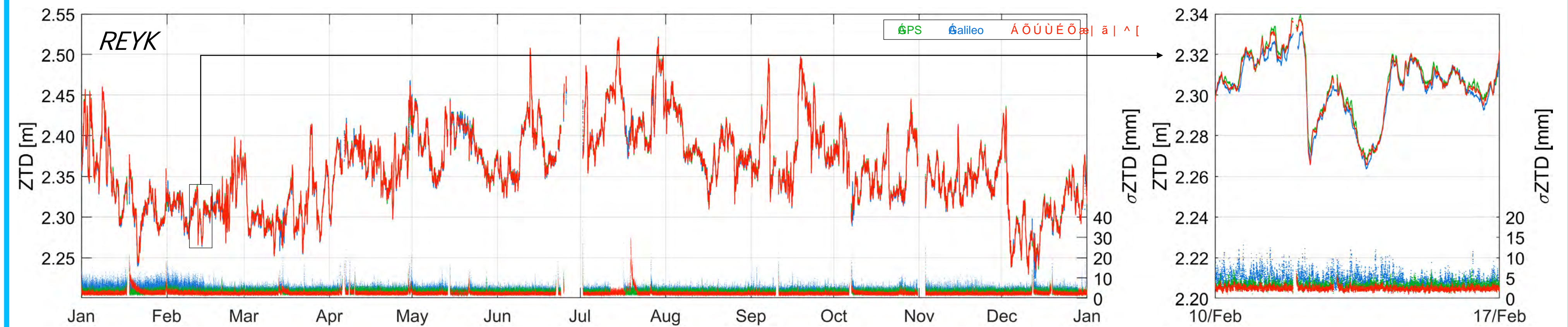


Fig. 3: Time series of real-time ZTD (from GPS, Galileo, GPS+Galileo) for station REYK in 2019 (left) and zoom to day 41-47, 2019 (right)

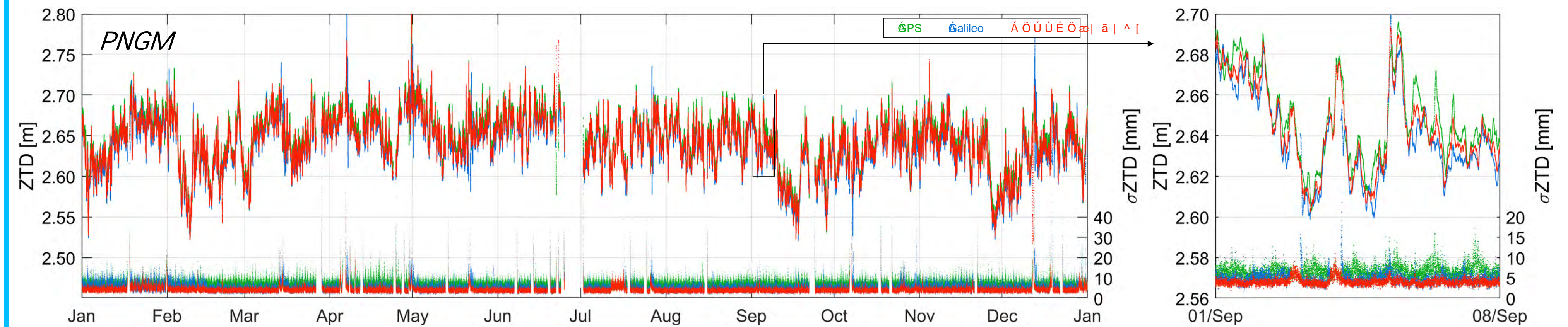


Fig. 4: Time series of real-time ZTD (from GPS, Galileo, GPS+Galileo) for station PNGM in 2019 (left) and zoom to day 244251, 2019 (right)

3.3 Comparison against IGS Final ZTD

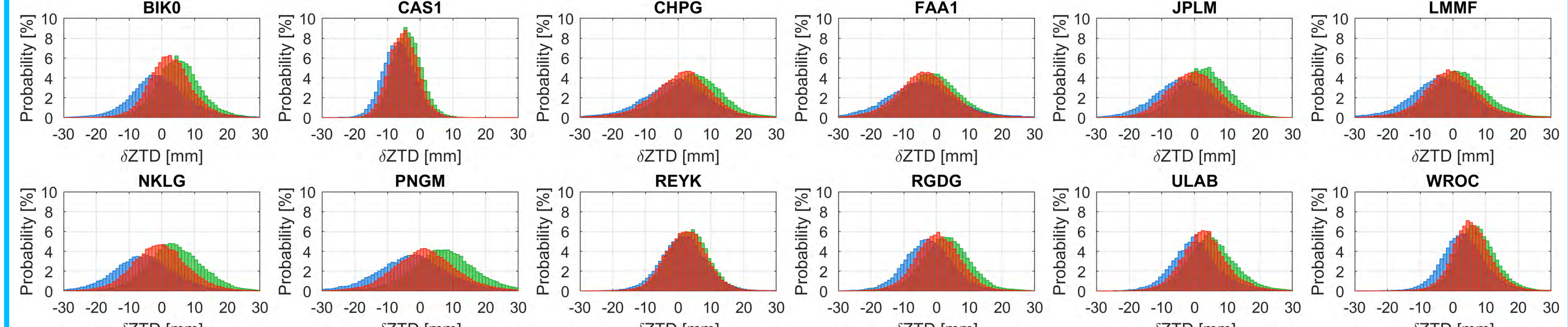


Fig. 5: Histograms of ZTD differences between real-time solutions (GPS, Galileo, GPS+Galileo) with respect to IGS Final products: year 2019

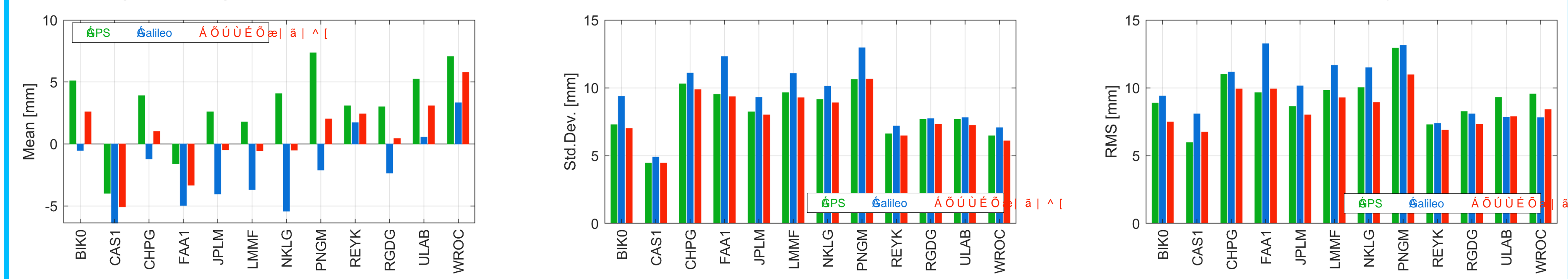


Fig. 6: Mean, standard deviation and root mean square error of ZTD differences between real-time solutions and IGS Final product for each test station

4. Conclusions

Availability of real-time ZTD solutions:

- ~ similar to IGS Final ZTD (~95%, except ULAB due to missing observations);
- ~ could be even higher by >2% if no failure of Internet connection at user side (end of June, 2019);
- ~ Galileo-only solution suffers from system outage (July 11-18, 2019 i.e. ~2% time of the year);
- ~ 1% (3.5 days!) gain in availability with GPS+Galileo solution compared to GPS-only (e.g. >45% more solutions on April 6, 2019 for all stations, 82% more solutions for ULAB on February 10, 2019).

Uncertainty of estimated ZTD (δZTD):

- ~ ZTD from Galileo-only solution is significantly smaller since mid-February 2019 (4 satellites announced);
- ~ reduced by a factor of two to three for GPS+Galileo solution compared to GPS-only solution.

Agreement between ZTD products

- ~ all real-time solutions are consistent to each other ($R^2 > 0.99$); GPS minus Galileo: $RMSE_{ZTD} = 9.0\text{ mm}$;
- ~ Galileo underestimates real-time ZTD with respect to real-time ZTD from GPS (missing PCO, PCV?);
- ~ std. dev. of real-time ZTD vs. IGS Final ZTD: 7.9 mm, 8.9 mm, 7.7 mm for GPS, Galileo, GPS+Galileo;
- ~ GPS+Galileo improves precision of real-time ZTD by 3% on average (up to 6% for station ULAB).

5. Acknowledgements

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