University of Stuttgart
Germany

Institute of Navigation

Contribution of Galileo to real-time GNSS meteorology

Tomasz Hadas and Thomas Hobiger
Institute of Navigation, University of Stuttgart, Germany

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 Galileo's 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

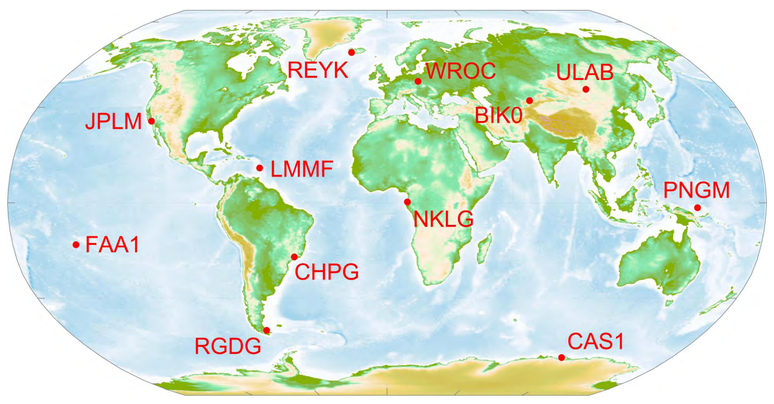

Fig.1: Location of test stations

- 12 IGS stations
- test period: 01.01.2019 – 31.12.2019
- reference solution: IGS Final troposphere

2.2 GNSS data processing

- uncombined & undifferenced (raw) PPP model for pseudorange P_i^s and carreir phase L_i^s observations:

$$P_i^s - \rho_0^s + c\delta t^s - m_h^s Z_h - \Delta_P^s = \boldsymbol{e_r^s \delta X_r} + c\left(\delta t_r + ISB_S^G\right) + Z_w m_w^s + f_1^2/f_i^2\, I^s$$

$$L_i^s - \rho_0^s + c\delta t^s - m_h^s Z_h - \Delta_P^s = \boldsymbol{e_r^s \delta X_r} + c\left(\delta t_r + ISB_S^G\right) + Z_w m_w^s - f_1^2/f_i^2\, I^s + \lambda_i N_i^s$$

- processing strategy

Frequencies	GPS L1/L2 Galileo E1/E5a
Observation σ	σ_0=0.30 m for P_i σ_0=0.01 m for L_i
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 PNR, 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

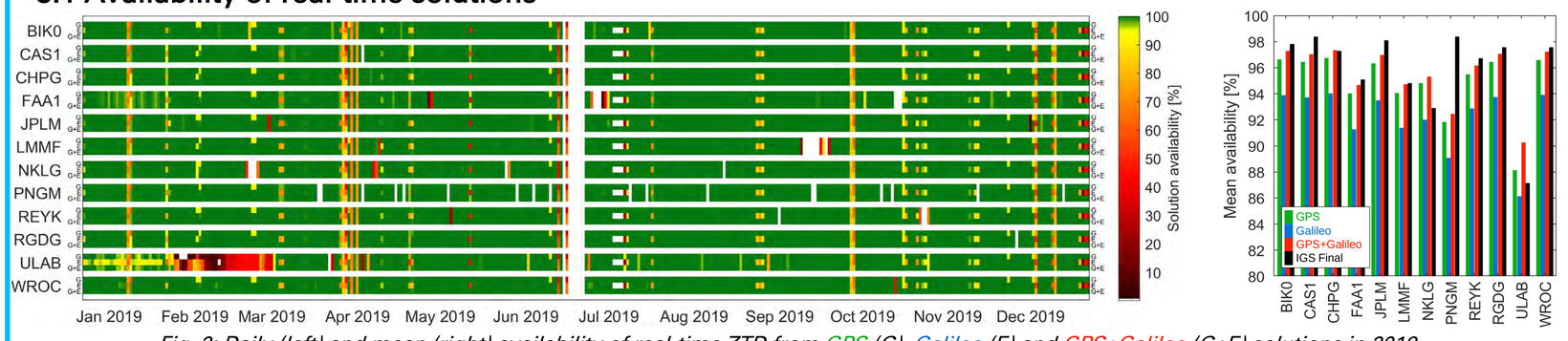

Fig. 2: Daily (left) and mean (right) availability of real-time ZTD from GPS (G), Galileo (E) and GPS+Galileo (G+E) solutions in 2019

3.2 Time series of real-time ZTD

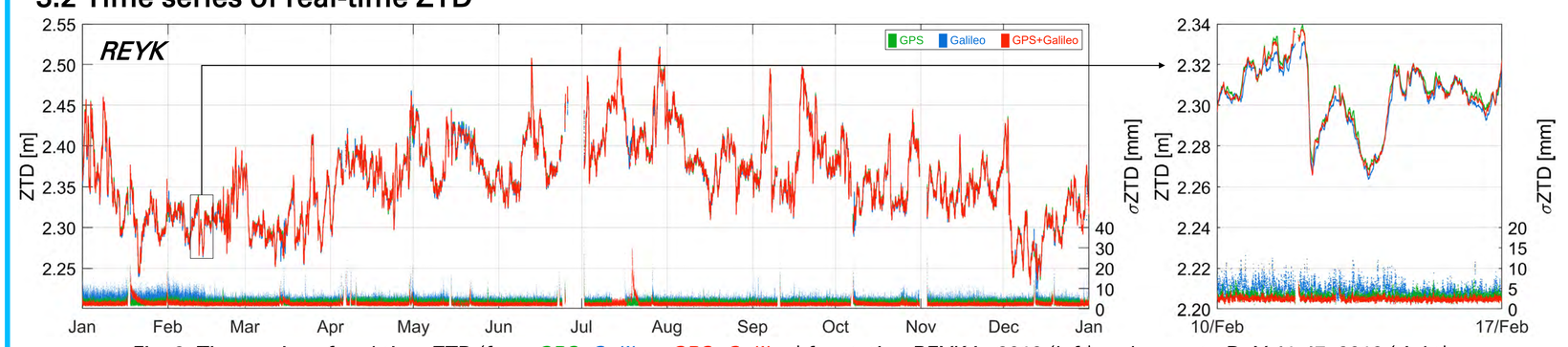

Fig. 3: Time series of real-time ZTD (from GPS, Galileo, GPS+Galileo) for station REYK in 2019 (left) and zoom to DoY 41-47, 2019 (right)

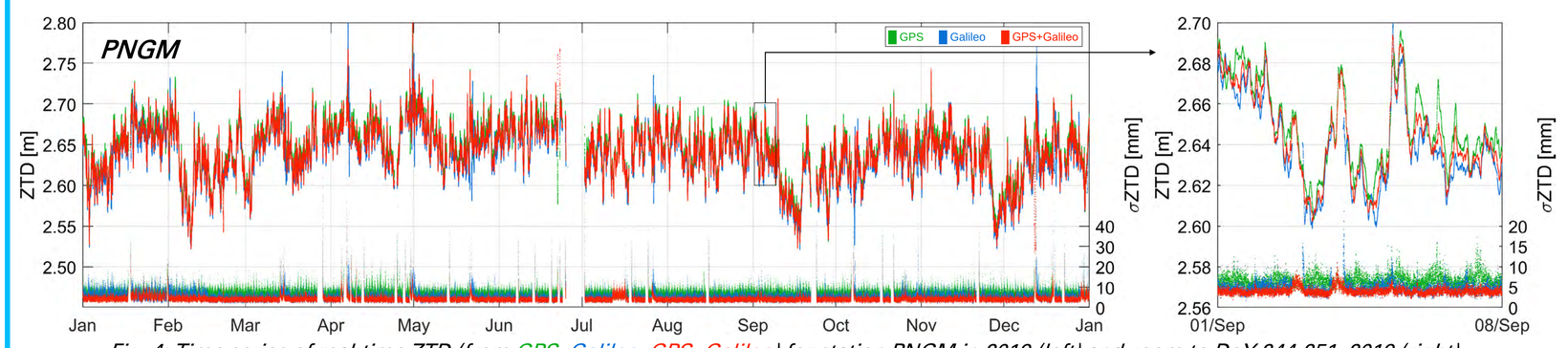

Fig. 4: Time series of real-time ZTD (from GPS, Galileo, GPS+Galileo) for station PNGM in 2019 (left) and zoom to DoY 244-251, 2019 (right)

3.3 Comparison against IGS Final ZTD

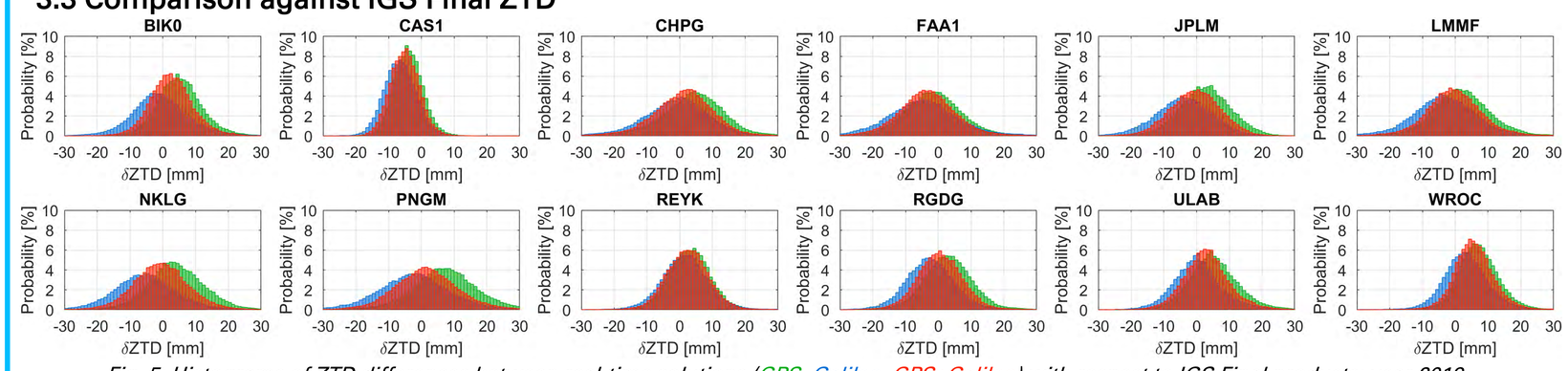

Fig. 5: Histograms of ZTD differences between real-time solutions (GPS, Galileo, GPS+Galileo) with respect to IGS Final products; year 2019

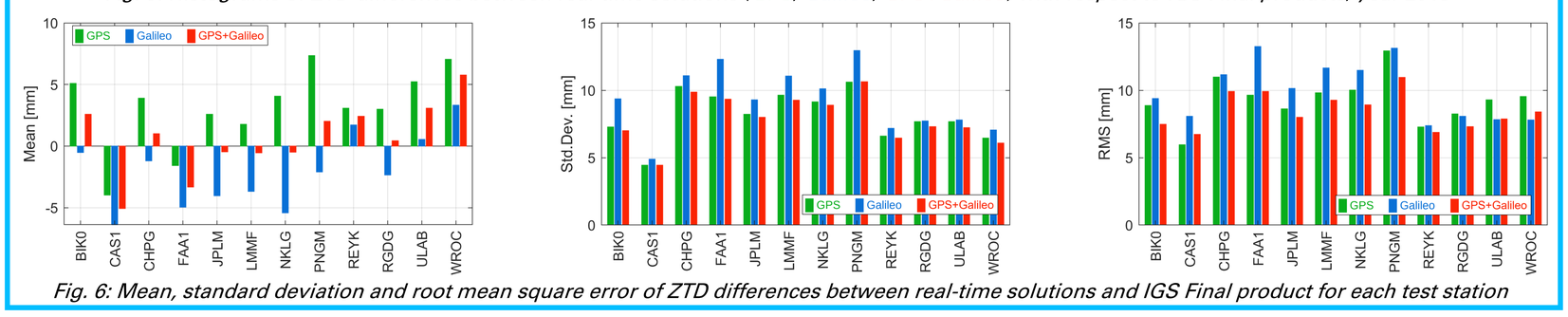

Fig. 6: Mean, standard deviation and root mean square error of ZTD differences between real-time solutions and IGS Final product for each test station

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 conection 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 (*σZTD*):

- *σZTD* 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 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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 835997 (Real-Time GNSS for European Troposphere Delay Model, ReS4ToM)

University of Stuttgart
Germany

Contact information
Tomasz Hadas: tomasz.hadas@nav.uni-stuttgart.de
Homepage: www.nav.uni-stuttgart.de