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An Evaluation of Real-Time Troposphere Products Based on multi-GNSS Precise Point Positioning

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Overview

- Motivation
- Previous results of real-time (RT) Precise Point Positioning (PPP) zenith total delay (ZTD) estimates
- Evaluation of RT PPP ZTD estimates from PPP-Wizard
- Results
- Conclusions

GNSS Meteorology

- Assimilation of GNSS-derived Zenith Total Delay (ZTD) in Numerical Weather Prediction (NWP) models
  - Has a reported positive impact on weather forecasting
  - Is in practice at various meteorological institutions

- Low-latency ZTD estimates are needed for high update-rate NWP models used for now-casting

- Meteorology user requirements for now-casting (TOUGH, 2004):

Integrated Water Vapour (IWV)		
	Target	**Threshold**
Horizontal Domain	Europe to National	
Repetition Cycle	5 min	1 hour
Integration Time	MIN(5 min, rep cycle)	
Relative Accuracy	1 kg/m^2	5 kg/m^2
Timeliness	5 min	30 min

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≈ 6 mm, 30 mm in ZTD

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Motivation for real-time processing

RT ZTD Processing Systems at UL

- In 2014 we evaluated several RT software packages (BNC, PPP-Wizard, G-nut/Tefnut), see Ahmed et al. (2016)
- Since June 2015 we contributed to the GNSS4SWEC RT Campaign with 2 solutions based on BNC
- In July 2015 we started modifications of PPP-Wizard
- Since September 2015 we predominantly worked with the PPP-Wizard.

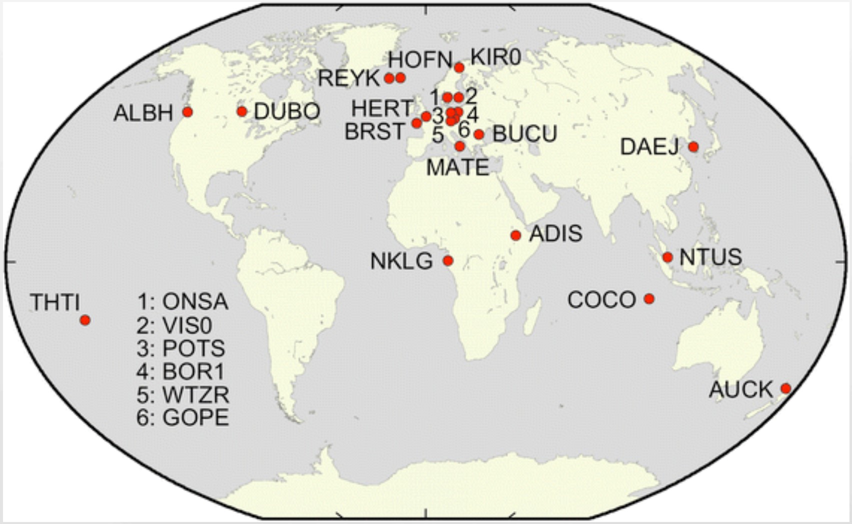

Table 7 Biases in RT-PPP ZTD solutions to IGFT

Solution	Mean [cm]	STD [cm]	RMS [cm]
BN01	3.17	4.61	6.04
BN02	0.46	2.72	2.92
PWFL	6.81	2.42	14.96
GN01	1.16	0.82	1.43
GN02	1.11	0.80	1.38

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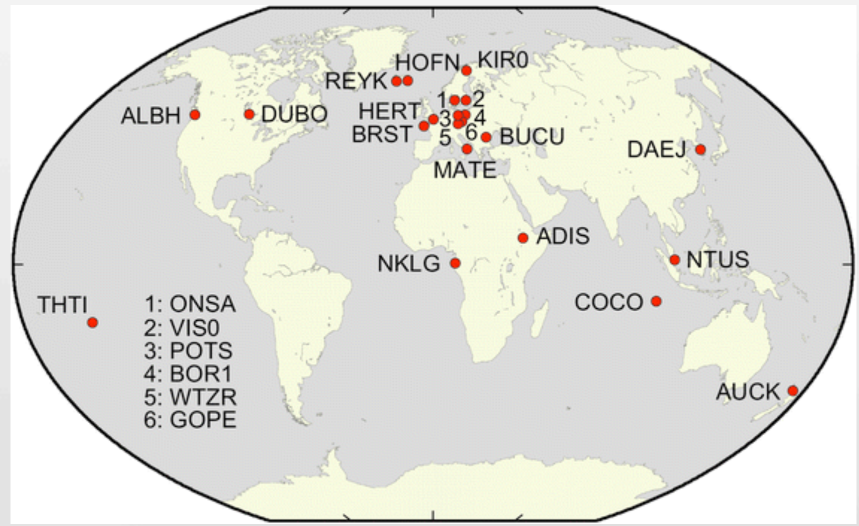
Largely due to
no PCO corrections
In PPP-Wizard



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PPP-Wizard Modifications

PPP-Wizard developed by CNES

- GPS/GLONASS/Galileo observations
- Real-time products from CNES CLK93, including satellite orbit, clock and code/phase biases
- PPP ambiguity resolution (GPS only) [zero-difference ambiguity resolution]

Modifications

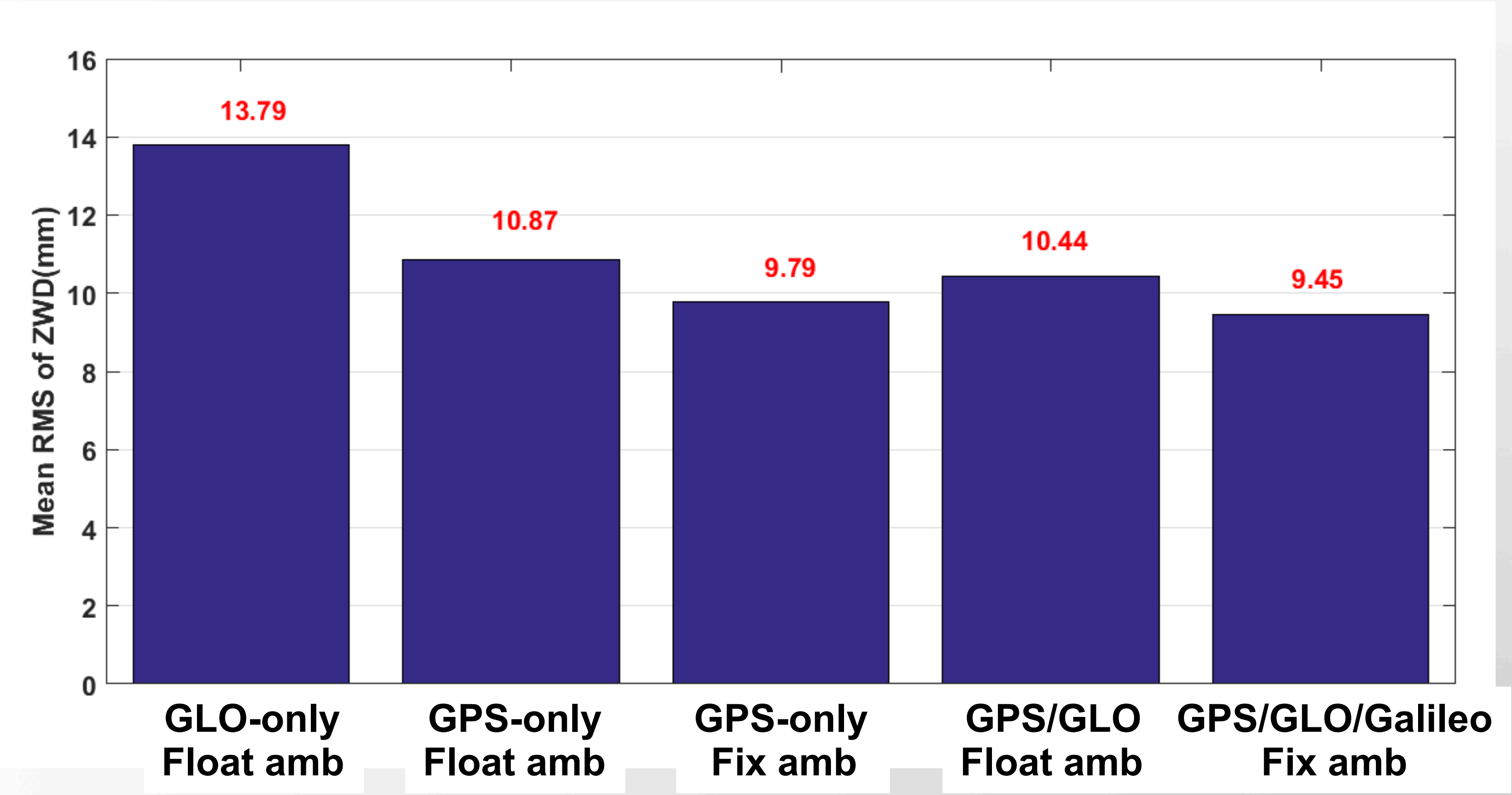
- Apply Antenna Reference Point (ARP) correction from igs08.atx
- Apply receiver PCO + PCV correction from igs08.atx
- Solid earth tide + ocean tide loading correction (FES2004)
- ZTD (GPT and Saastamoinen) + ZWD (modeled as random walk process)
- Troposphere Mapping Function (GMF)
- Elevation dependent weighting strategy (Q = 1/cos(zen)**2)

September 2015 Analysis

(Ding et al., 2015)

- Real-time stream of multi-GNSS observations from IGS/MGEX
- Real-time products from CNES CLK93, including satellite orbit, clock and code/ phase biases
- Elevation cut-off: 7 degrees; processing interval
- A continuous analysis of three weeks (16/08/2015-05/09/2015) is conducted
- Applied CODE tropospheric products as reference for accuracy evaluation
- The first 1 hour of each initialization process was ignored in the accuracy evaluation

September 2015 Results: Mean RMS of ZWD Differences



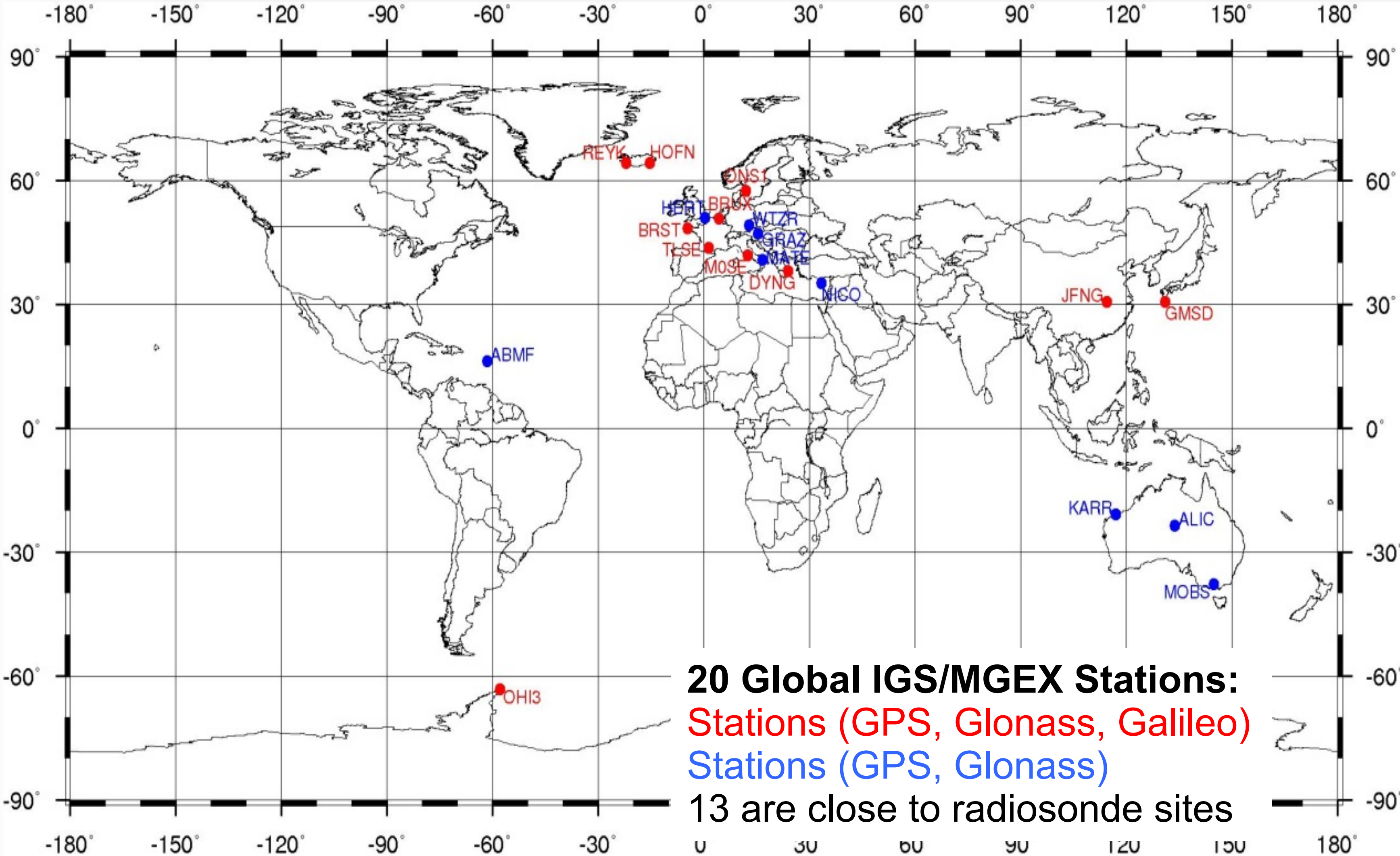
(Ding et al., 2015)

Spring 2016 Analysis

(Ding et al., 2016)

- Real-time stream of multi-GNSS observations from IGS/MGEX
- Real-time products from CNES CLK93, including satellite orbit, clock and code/phase biases (GPS, Glonass and Galileo)
- Elevation cut-off: 7 degrees; processing interval 5 s
- A continuous analysis of 1 Month (14/02/2016-14/03/2016) is conducted
- Relative evaluation with CODE and USNO final tropospheric products
- External evaluation with integrated ZTD from radiosonde profiles

Real-Time Campaign 2016



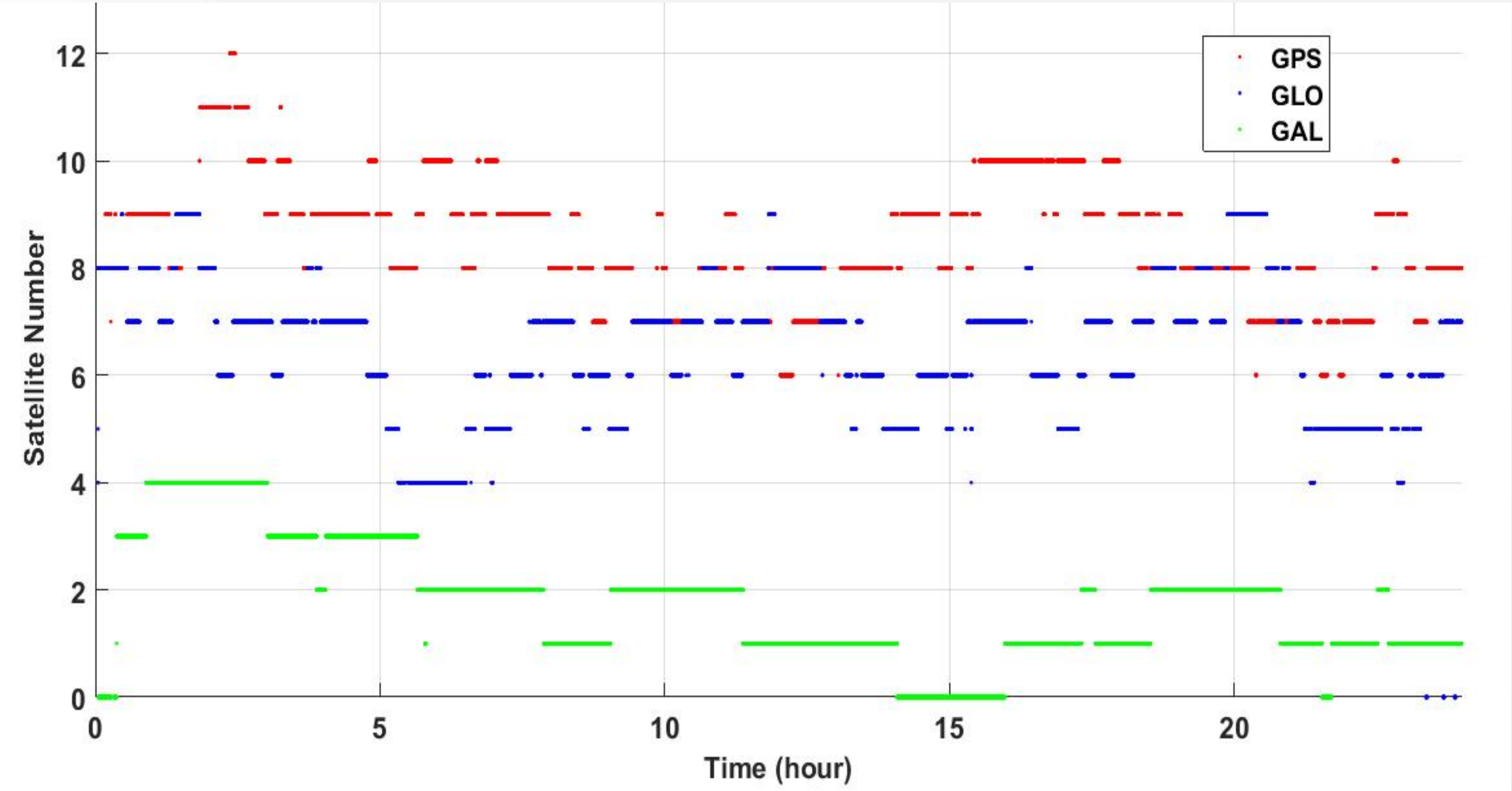
20 Global IGS/MGEX Stations:

Stations (GPS, Glonass, Galileo)

Stations (GPS, Glonass)

13 are close to radiosonde sites

RT Satellite Tracking at BRST (Example for DOY 45, 2016)



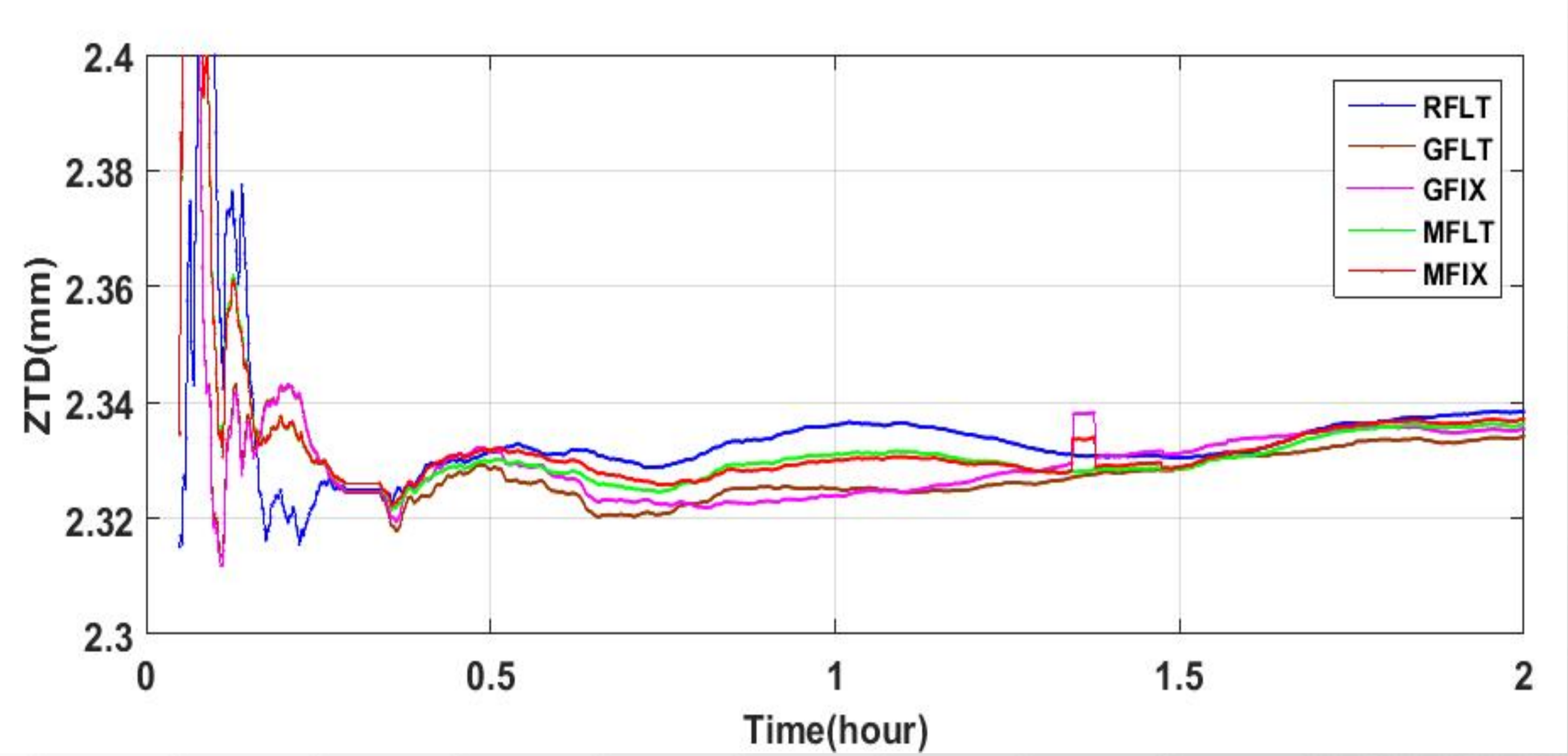
At least 6 GPS and 4 GLONASS satellites were tracked and on average 9 and 7, respectively. For Galileo a maximum of 4 satellites were observed.

RT-PPP ZTD Solutions

- GPS-only, Glonass-only and GPS+Glonass +Galileo solutions
- Float and fixed ambiguity solutions

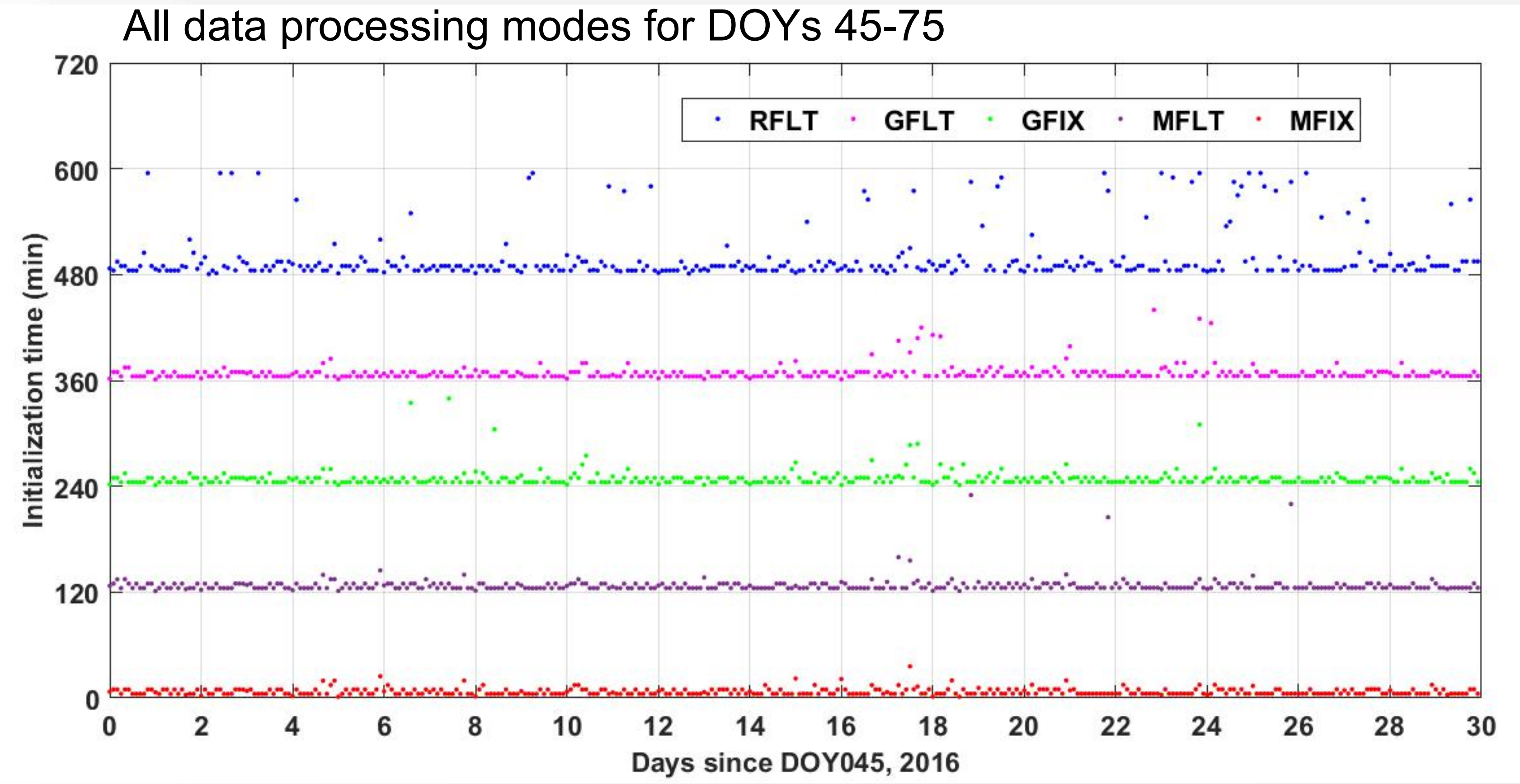
Modes	Details
RFLT	Float PPP solution based on GLONASS-only observations
GFLT	Float PPP solution based on GPS-only observations
GFIX	Fixed PPP solution based on GPS-only observations
MFLT	Float PPP solution based on GPS/GLONASS observations
MFIX	Fixed PPP solution based on GPS/GLONASS/Galileo observations

RT ZTD for BRST (Example, DOY 45, 2016)



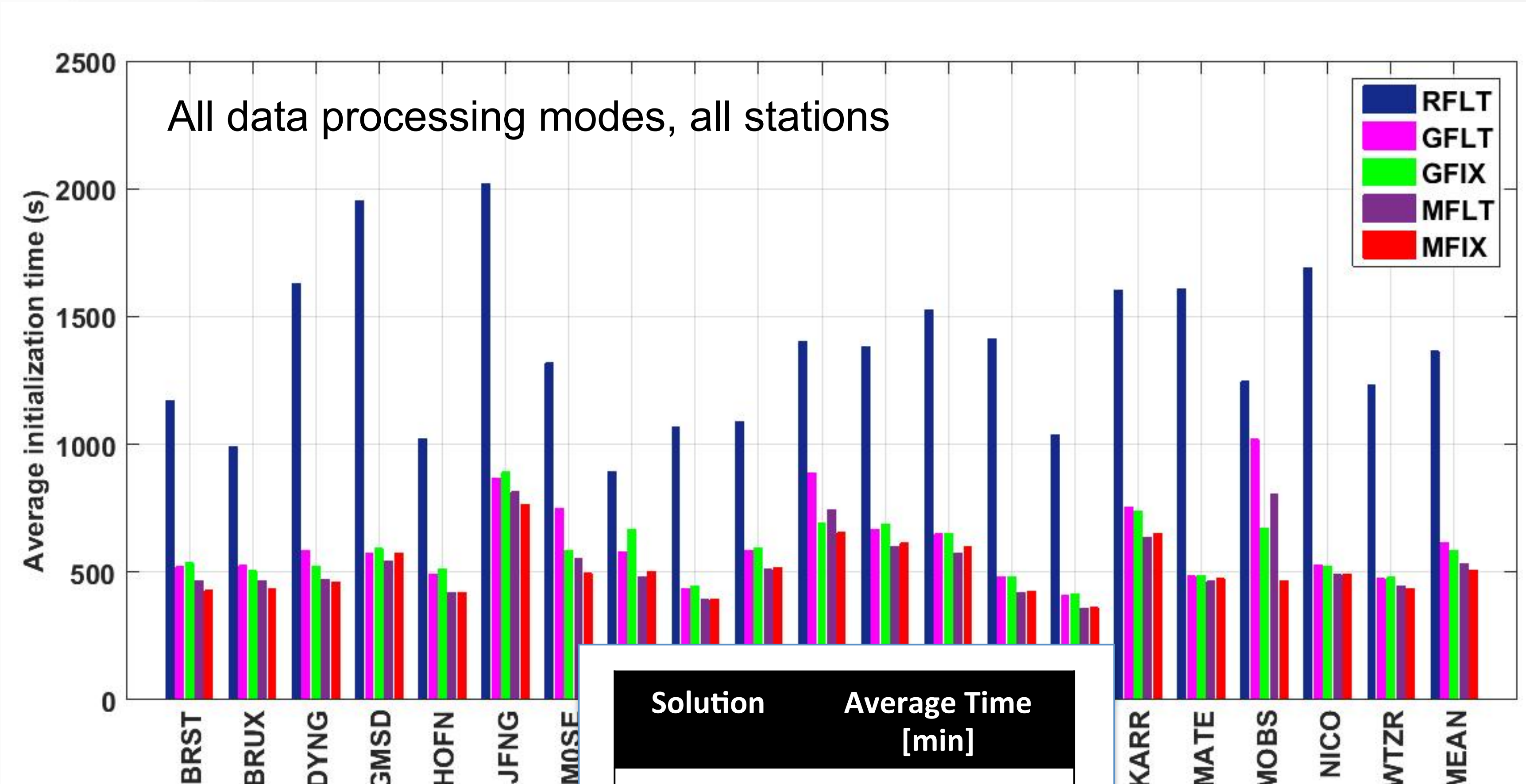
All data processing modes during the two hours of DOY 45, 2016

Initialization Times for BRST



Forced re-initialization every two hours

Average Initialization Times



Solution	Average Time [min]
GFLT	10,2
GFIX	9,7
MFLT	8,9
MFIX	8,5

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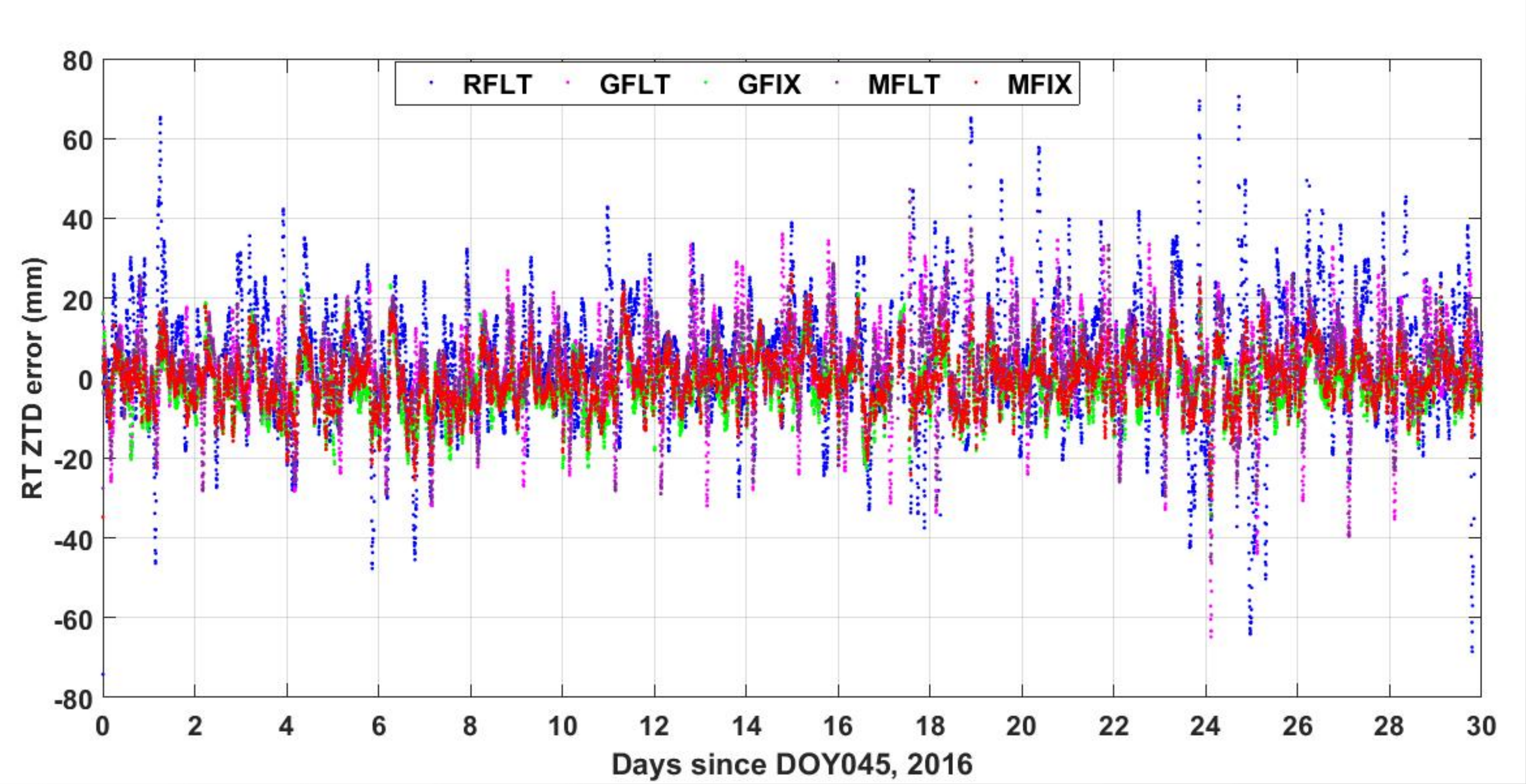
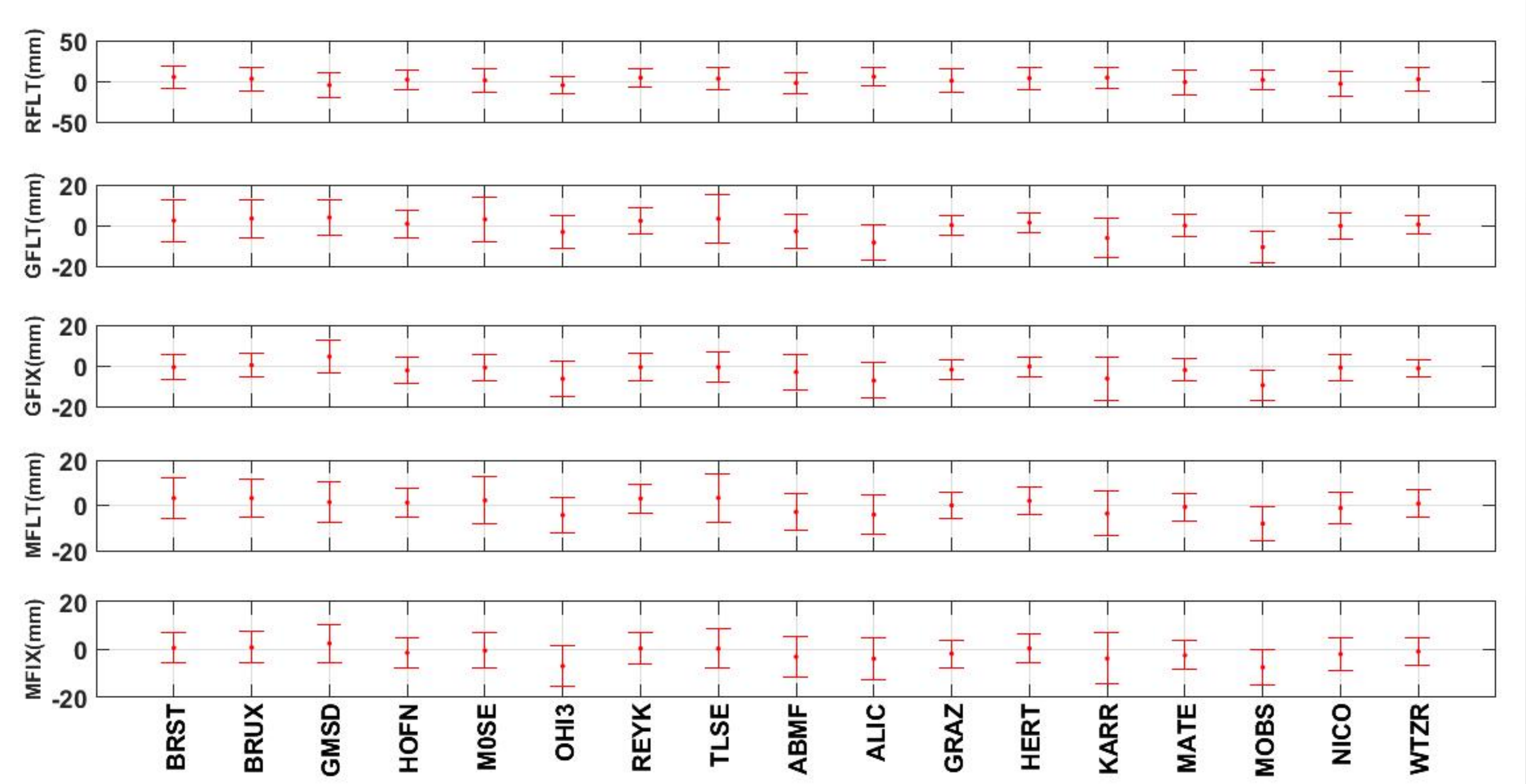
Example RT ZTD Error for BRST

wrt final troposphere products from USNO



Mean Biases and SD of RT ZTD wrt USNO



All biases and SDs are <10mm except for those for RFLT.

Accuracy Statistics of RT ZTD wrt CODE and USNO Final Products

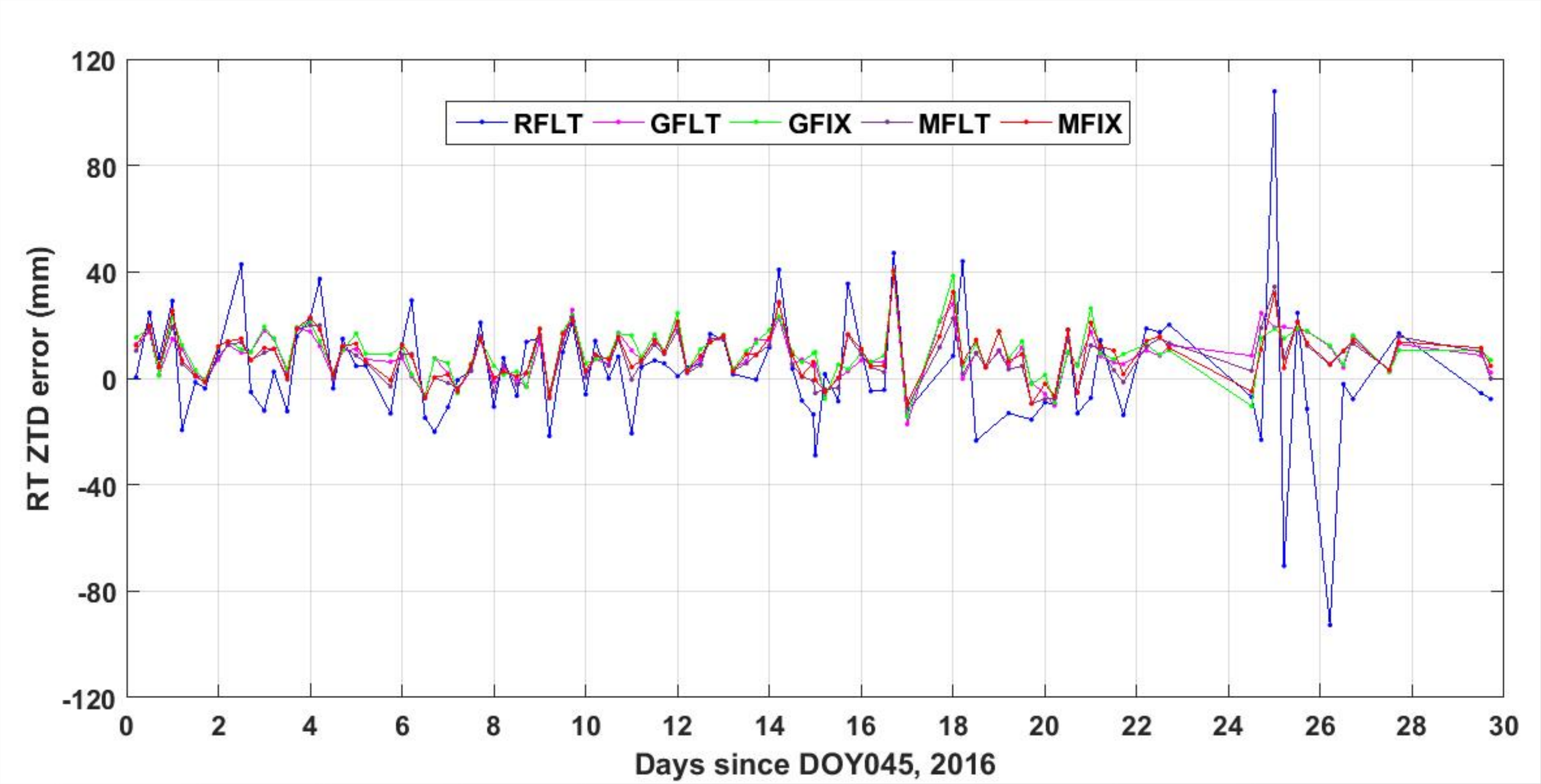
	CODE			USNO		
	Mean(mm)	STD(mm)	RMS(mm)	Mean(mm)	STD(mm)	RMS(mm)
RFLT	0.82	11.26	11.61	0.61	13.67	13.98
GFLT	-0.83	6.32	7.05	-0.59	8.27	8.95
GFIX	-2.09	5.65	6.37	-2.03	7.45	8.17
MFLT	-0.47	6.41	6.87	-0.41	8.27	8.69
MFIX	-1.48	5.96	6.42	-1.52	7.69	8.14

- Statistics for both benchmark products are similar, with CODE slightly better
- RMS of Glonass-only solution is the worst and of M-GNSS with ambiguities fixed is best.

Radiosonde (RS) Observations

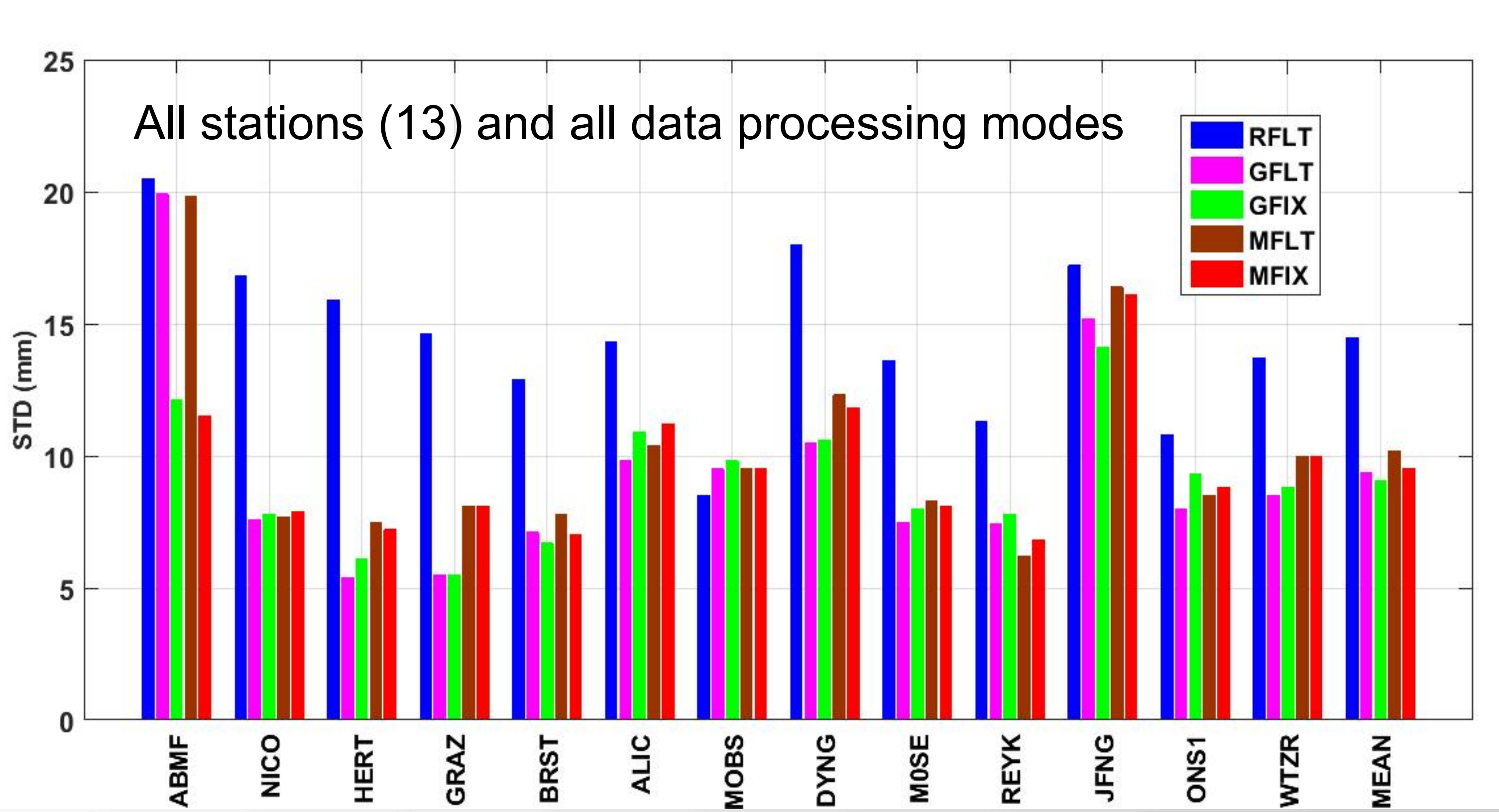
- At 13 Stations it was possible to compare to RS observations
- These were obtained from the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) RS database (http://esrl.noaa.gov/raobs/)
- Integrated ZTDs from RS profiles were calculated using the method in Haase et al. [2003] with outlier detection applied (Dousa and Bennitt, 2013)

RT ZTD Differences wrt ZTD from RS observations at WTZR



All differences are generally within ±4 cm. RFLT is worst while the STD of the others is about 9 mm.

STD of RT ZTD Errors wrt RS Observations



Conclusions

- We have briefly presented the RT PPP ZTD processing systems at UL
  - Contributions to GNSS4SWEC RT demonstration campaign
  - New RT system based on a modified PPP-Wizard
- For the RT system using PPP-Wizard we find for a 1-Month comparison:
  - **Convergence**, the results reveal that an average initialization time of 22 min and 10 min respectively based on GLONASS-only and GPS-only observations is required. The initialization process can be accelerated by both RT PPP ambiguity resolution and utilizing GNSS observations, whereby the latter (observing geometry) is more effective (8,4 min).
  - **Accuracy**, the results reveal that all processing systems can fulfill the user requirements for now-casting, however,
  - the accuracy is improved more effectively through ambiguity resolution rather than using multiple GNSS. This might be due to the lower quality of the Glonass products and the weighting strategy.
  - The best accuracy is achieved for the MFIX solution with an RMS of approx. 8 mm.

Thank you for your attention and for your collaboration!

References

Ahmed F, Václavovic P, Teferle FN, Douša J, Bingley RM and Laurichesse D (2016). Comparative analysis of real-time precise point positioning zenith total delay estimates. GPS Solution, 20(2), 187-199.

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Contributions to GNSS4SWEC WG1 RT Campaign

- University of Luxembourg (UL) provided two RT-PPP solutions
  - Solution based on GPS observations only
  - Solution based on GPS+GLONASS observations
- Processing software: BKG Ntrip Client (BNC) v2.11

Real-Time Solution:	ULXG	ULXR
Processing Strategy	PPP	PPP
Observations Used	GPS Only	GPS+GLONASS
Processing Engine	BNC 2.11	BNC 2.11
Input Raw Data	Real-time streams (RTCM3)	Real-time streams (RTCM3)
Input Clock Stream	IGS03 (IGS)	IGS03 (IGS)
Input Ephemeris Stream	RTCM3EPH (IGS)	RTCM3EPH (IGS)
Ambiguity Resolution	No	No

- Discontinued due to poor performance and development of new system based on a modified PPP-Wizard

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