GNSS4SWEC real-time demonstration campaign: development and assessment of future tropospheric products

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IAG Commission 4 Symposium, Sept 5-7, 2016, Wroclaw, Poland

IAG SG 4.3.7 – Real-time GNSS tropospheric products

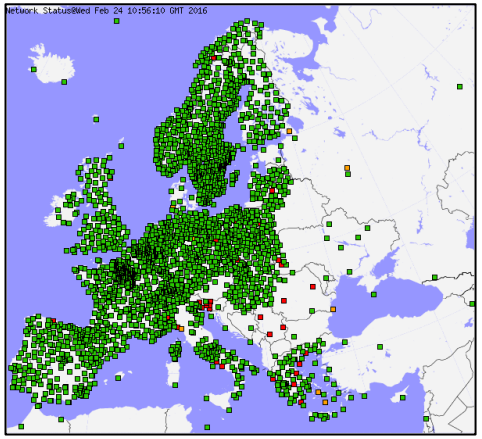
Chair/vice-chair: Jan Douša (GOP, Czech R) / Eric Pottiaux (ROB, Belgium)

Members: Kefei Zhang, Xiaoming Wang (*RMIT SPACE, Australia*), Fabian Hinterberger (*TUW, Austria*), Thalia Nikolaidou (*UNB, Canada*), Junping Chen (*SHAO, China*), Min Li (*Wuhan University, China*), Pavel Václavovic (*GOP, Czech* R), Henrik Vedel (*DMI, Denmark*), Galina Dick, Xingxing Li (*GFZ, Germany*), Rosa Pacione (*ASI/e-GEOS S.p.A., Italy*), Yoshinory Shoji (*MRI, Japan*), Felix Norman Teferle (*Uni Luxembourgh*), Siebren de Haan (*KNMI, Netherland*), Tomasz Hadaś (*WUELS, Poland*), Jonathan Jones (*Met Office UK*), John Braun (*UCAR, USA*)

Objectives:

- Develop optimal strategies for real-time/ultra-fast tropospheric products suitable for numerical or non-numerical weather nowcasting applications or severe weather event monitoring.
- Stimulate development of application software for supporting routine production.
- Demonstrate real-time/ultra-fast production, assess applied methods, software and precise orbit and clock products.
- Evaluate tropospheric parameters, their potential for applications in meteorology.
- Setup a link to potential users, review format and requirements.

→ prepare testing/semi-operational contributions to the EUMETNET EIG GNSS Water Vapour Programme – E-GVAP http://egvap.dmi.dk



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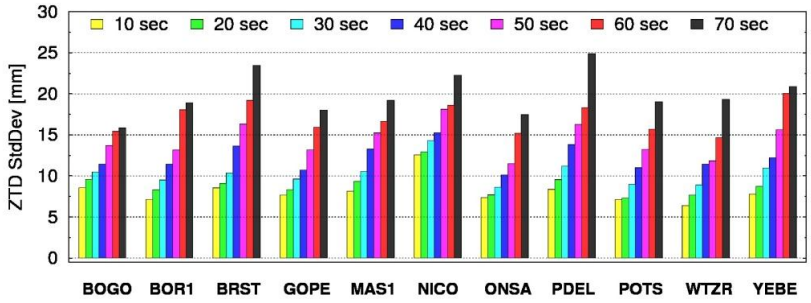
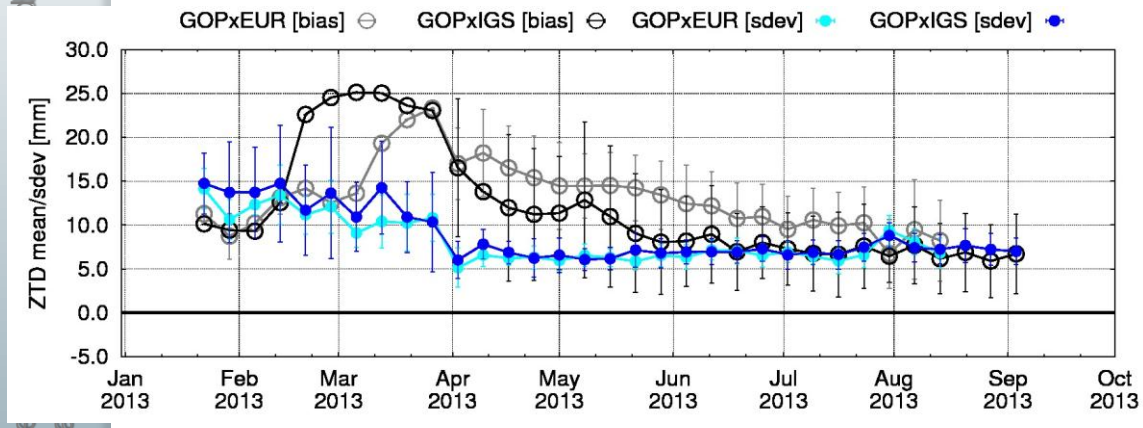
Initial real-time ZTD assessment

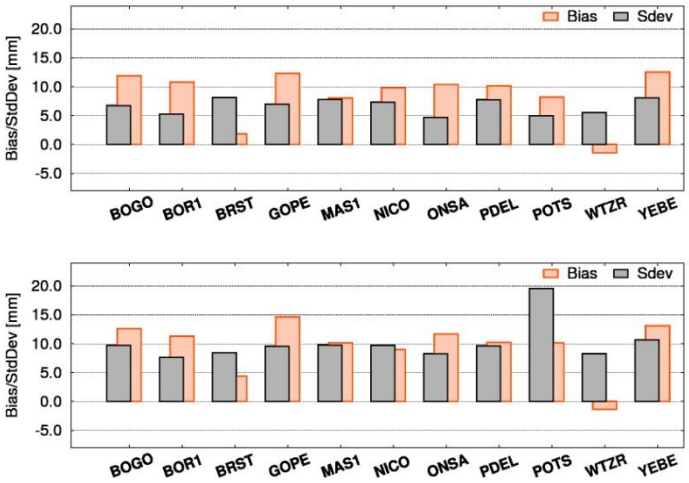
GOP: half-a-year RT processing demonstration

Douša J, Václavovic P (2014) Real-time zenith tropospheric delays in support of numerical weather prediction applications. Adv Space Res, 53(9):1347-

- ZTD from static processing
- ZTD from pseudo-kinematic processing
- Impact of IGS RTS precise corrections delays
- Impact various RT precise corrections







GOP + Uni Luxembourgh: 2-month RT campaign (Global + Europe)

Ahmed F, Václavovic P, Teferle FN, Douša J, Bingley R, Laurichesse D (2016), Comparative analysis of real-time precise point poisitioning zenith total delay estimates, GPS Solut, Vol 20(2):187-199

- Different software (BNC, PPP-wizard, G-Nut/Tefnut)
- Impact of phase ambiguity resolution (PPP-wizard

COST Action ES1206 - GNSS4SWEC

Advance GNSS tropospheric products for severe weather event monitoring and climate
(May 2013 – May 2017)

WG1 Advanced GNSS processing techniques

Chair: **Dr Jan Dousa,** GOP (jan.dousa@pecny.cz)
Co-chair: **Dr Galina Dick,** GFZ (galina.dick@gfz-potsdam.de)

WG2 GNSS for severe weather monitoring

Chair: **Dr Siebren de Haan**, KNMI (siebren.de.haan@knmi.nl
Co-chair: **Dr Eric Pottiaux**, ROB (eric.pottiaux@oma.be)

WG3 GNSS for climate monitoring

Chair: **Dr Olivier Bock**, IGN (olivier.bock@ign.fr)
Co-chair: **Dr Rosa Pacione**, ASI (rosa.pacione@e-geos.it)

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GNSS4SWEC - WG1: Main goals

- **Coordinating of development advanced tropospheric products in** support of weather forecasting (**ultra-fast products, asymmetry** monitoring, tomography, multi-constellation processing)
- **Exploiting numerical weather data in precise GNSS positioning** (tropospheric models for real-time positioning, tropospheric gradients, mapping functions, a priori ZHD modeling, parameter conversions)
- **GNSS data reprocessing and assessment of involved models** (to provide consistent tropospheric products for climatology)
- **Stimulating transfer of knowledge**, tools and data exchange in support of new analysis centres and new networks setup

Real-time demonstration campaign

- The RT Demonstration campaign (RT-Demo): organized by WG1/GNSS4SWEC, designed in 2014, officially started in April 1, 2015

- Contributing Analysis Centres (ACs) are requested to generate
  - Tropospheric products (zenith total delays and, optionally, linear horizontal gradients)
  - In real-time or sub-hourly processing,
  - With a 5-minute temporal resolution for all parameters
  - Using set of predefined 32 GNSS stations (European and global sites)

- Strategy is generally free (PPP and state-of-the-art knowledge). More details can be found at http://www.pecny.cz/COST/RT-TROPO/about.php

- Tropospheric products, including relevant meta-data, are converted into the COST-716 format (E-GVAP style) and uploaded on hourly basis to an FTP server at Geodetic Observatory Pecný (GOP)

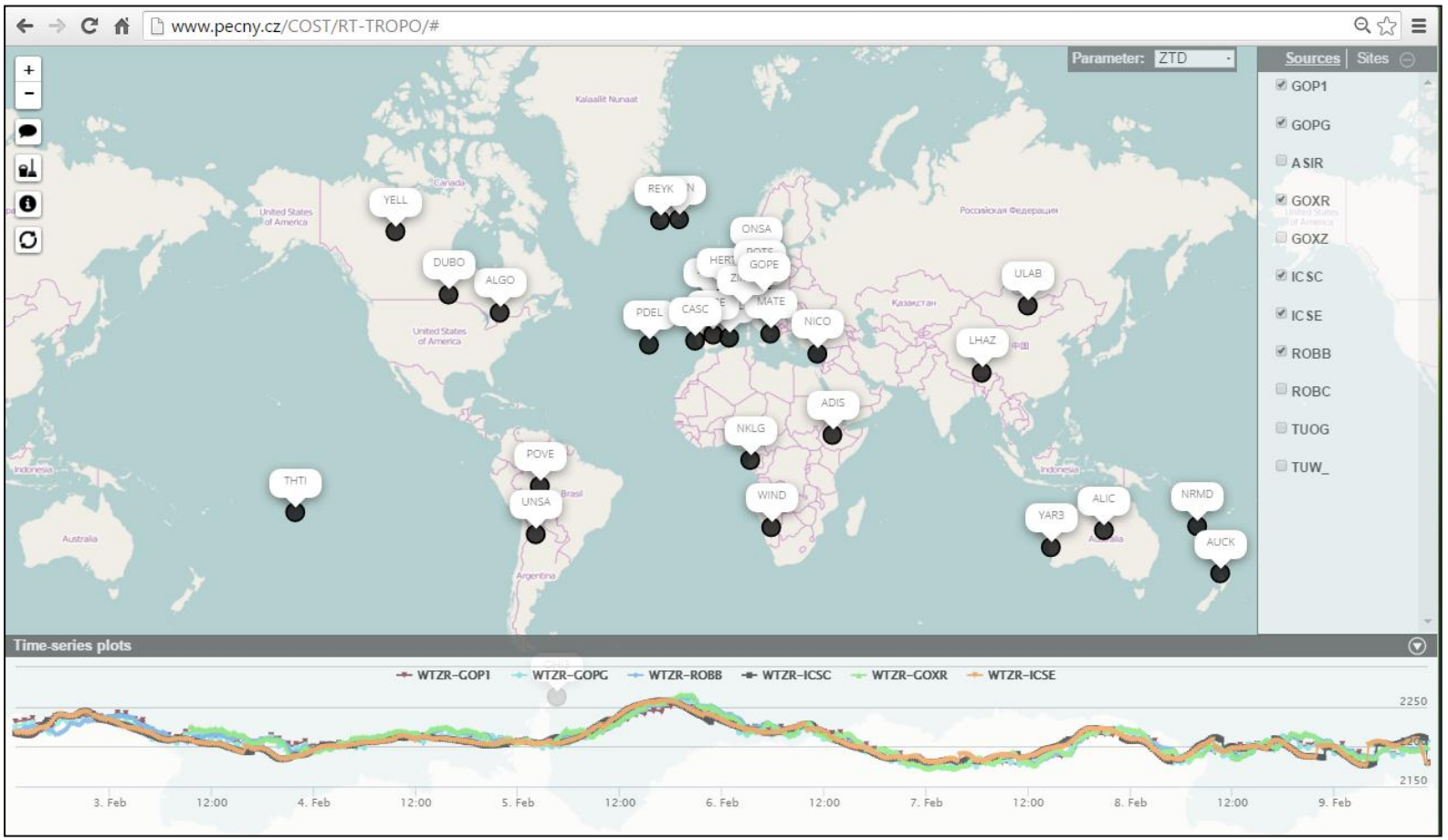
RT-Demo contributions

7+1 Analysis centers / 6+1 software / 17 solutions (Status: Sept 4, 2016)

Analysis center	Software	Start	Processing	Solutions
GOP, Geodetic Observatory Pecny, RIGTC	G-Nut/Tefnut	April 2015	Real-time PPP	GOXR – IGS03(GPS) GOXQ – IGS03(GPS+GLO) GOXK – CNS91(GPS) GOXL – CNS91(GPS+GLO)
TUW, Vienna University of Technology	TUW software	April 2015	Real-time PPP	TUW0 – IGS03(GPS)
ROB, Royal Observatory of Belgium	G-Nut/Tefnut	April 2015	Real-time PPP	ROBA – IGS02(GPS) ROBB – IGS03(GPS) ROBC – IGS03(GPS+GLO) ROBD – CNS91(GPS+GLO)
ASI, E-GEOS and Italian Space Agency	GIPSY	May 2015	Hourly PPP	ASIR – IGS03 (converted into SP3/RINEXC)
ULX, University of Luxembourgh	BNC/PPP-wizard	July 2015	Real-time PPP	ULXG – IGS03(GPS) ULXR –IGS03(GPS+GLO)
GOP & ICS, Institute of Computer Science, AS CR	G-Nut/Shu	July 2015	NWP model → WRF forecast	ICSE – D01 (EU:9km) ICSC – D02 (CZ:3km)
TUO, Technical University of Ostrava	RTKlib 2.4.2	November 2015	Real-time PPP	TUOG – IGS03(GPS)
BKG, Federal Agency for Cartography and Geodesy	BNC	March, 2016	Real-time PPP	BKGR – IGS03(GPS) BKGG – IGS03(GPS+GLO)

Web monitoring

- Tropospheric parameters estimated by individual analysis centers are initially visualized at the http://www.pecny.cz/COST/RT-TROPO providing time-series for past two months with a possible selection and combination of individual products.
- Monitoring includes ZTD and horizontal tropospheric gradients.



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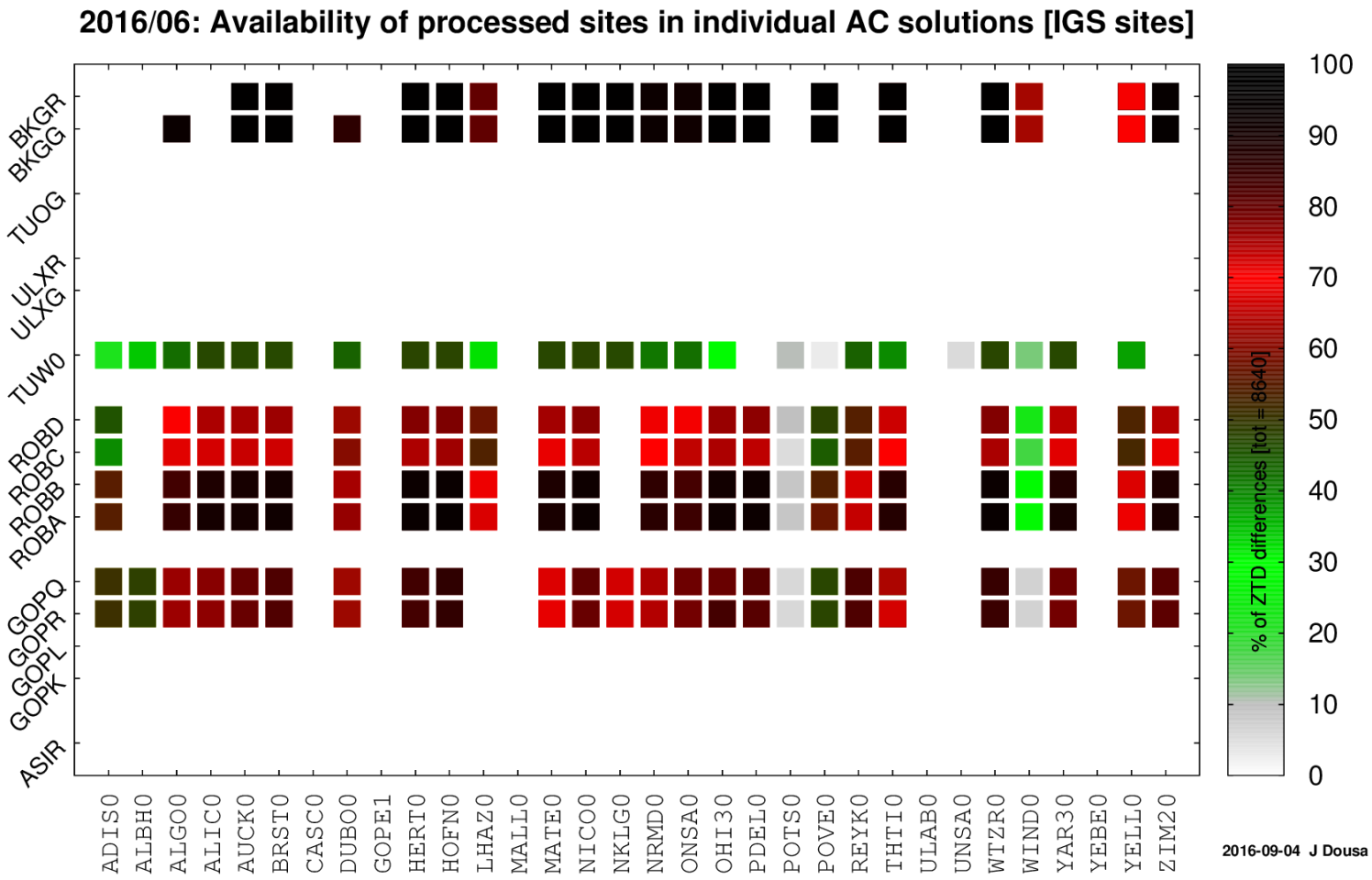
Results analysis - availability

- Monthly product availability - based on long-term evaluation results
- Identification of problems related to AC solution availability, data availability precise product availability etc.



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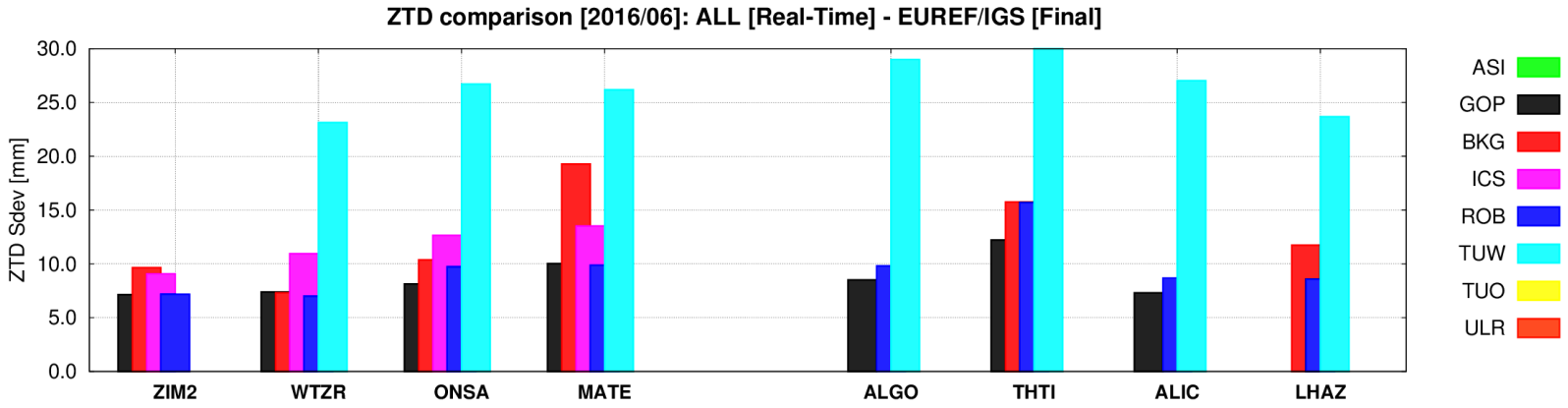
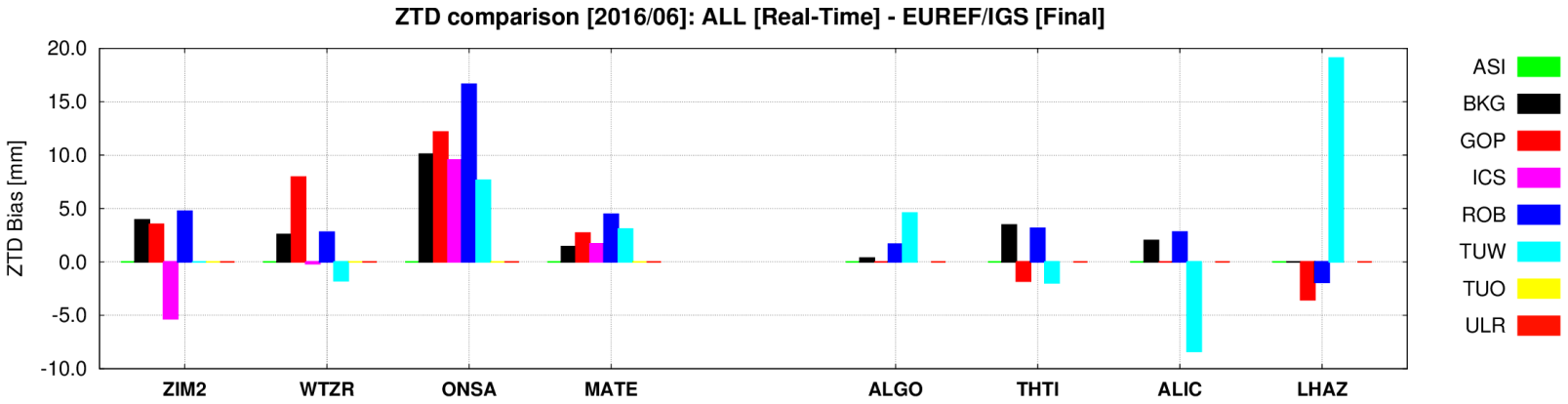
Results analysis – accuracy

- Statistics w.r.t. EUREF and IGS final products (selected stations) since the beginning of RT-Demo **(2015/Mar – 2016/Jun)**
- Several analysis centers achieved stable and robust solution over the time and all stations





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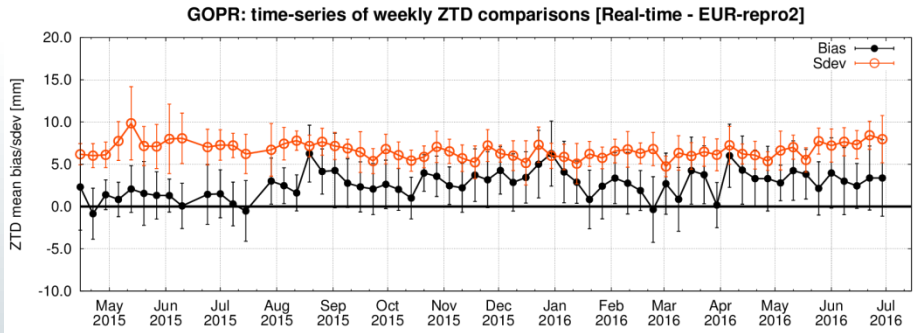
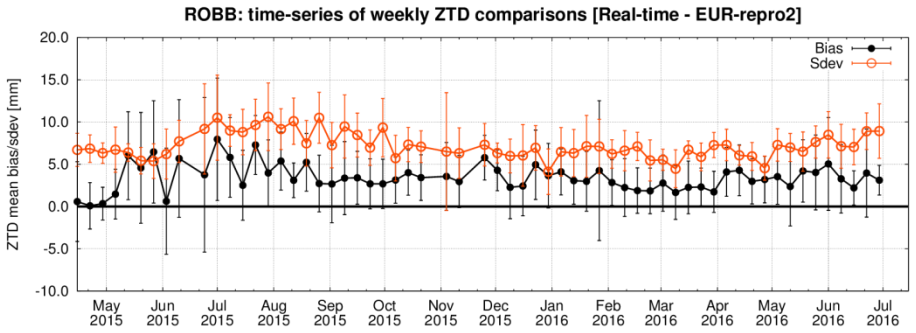
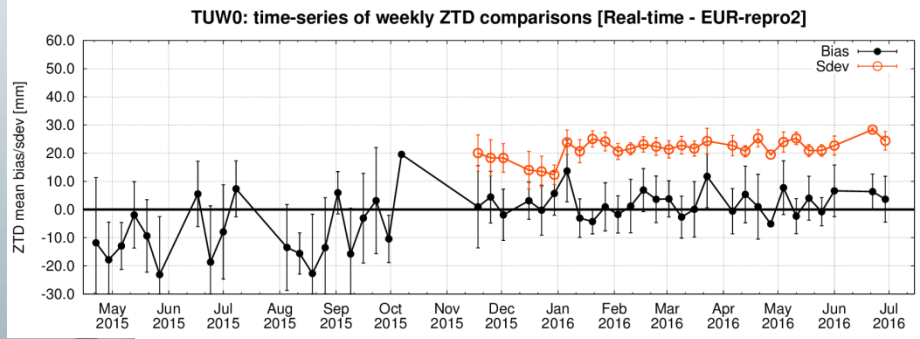
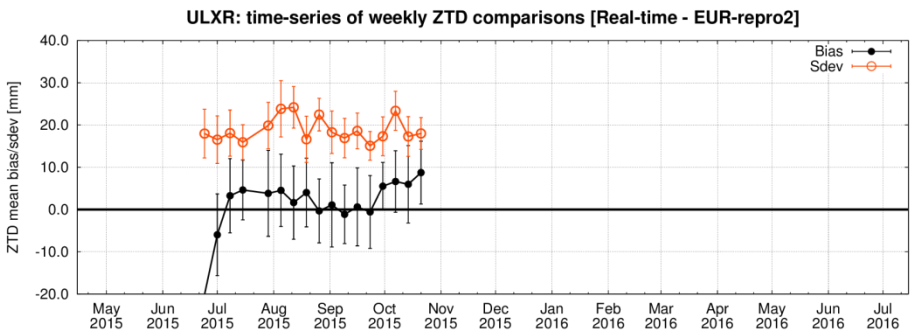
Results analysis – stability

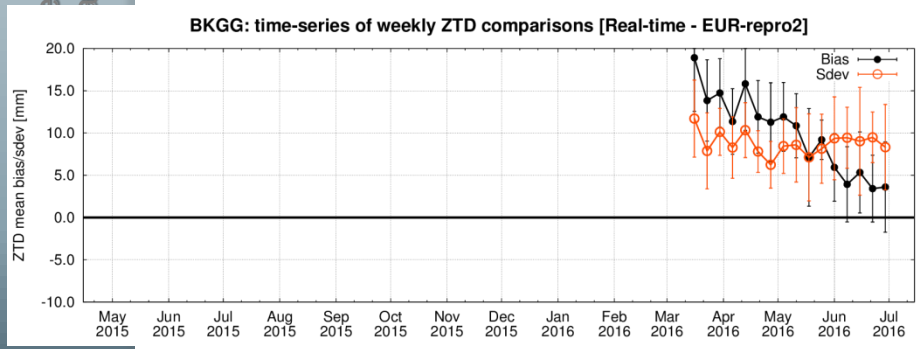
- Results from the two stable solutions since the beginning of RT-Demo -
  → *figures in first row GOP + ROB - both using G-Nut/Tefnut software*

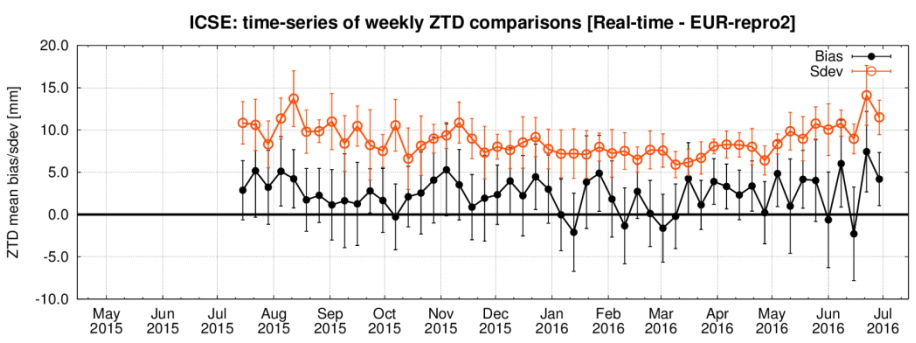












GNSS Benchmark campaign

May-June 2013 - floods of Danube, Moldau,Elbe rivers

Data set

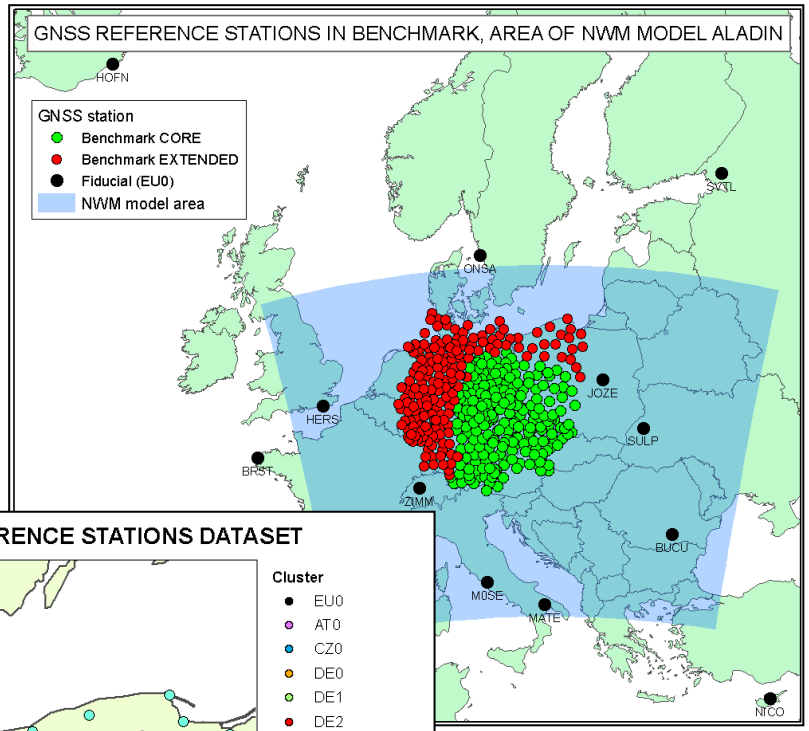
GNSS: ~500 stations (AT, CZ, DE, PL)
SYNOP: ~200 stations (AT, CZ, DE, PL)
NWM: regional (Aladin-CZ),
global (ERA-Interim, NCEP GFS)
RAOBS: E-GVAP + two high-resolution (CZ)
WVR: Potsdam, Lindenberg (DE)
RADAR images: Brdy, Skalka (CZ)

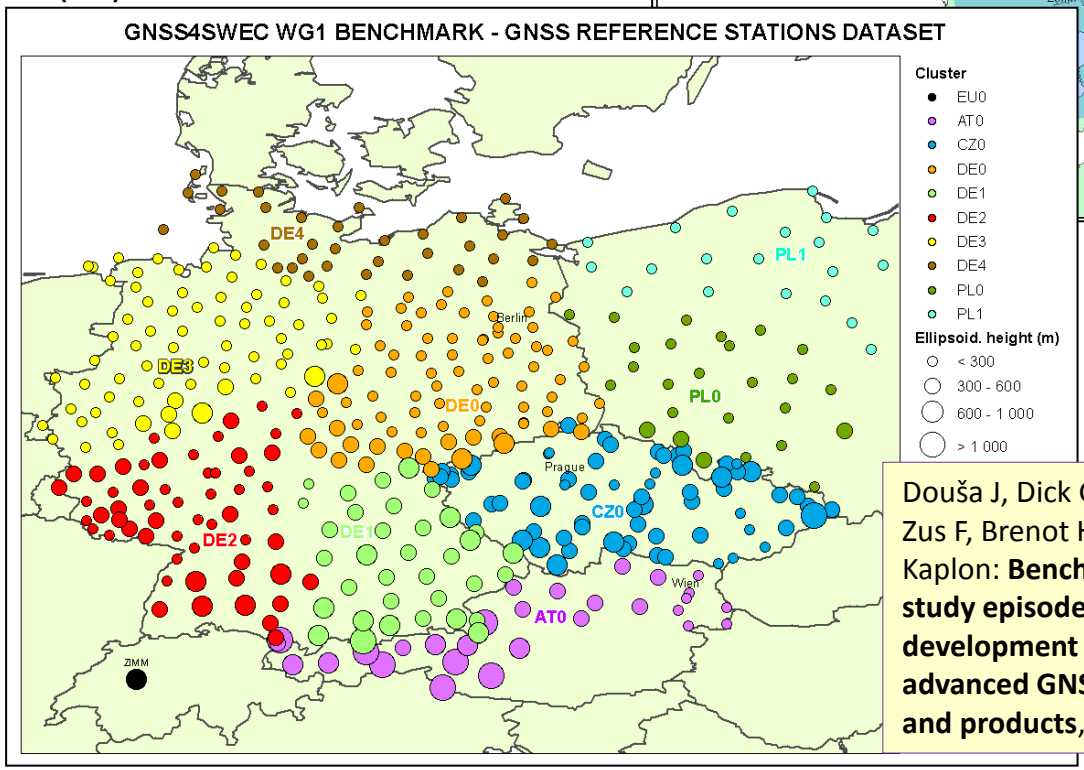
Reference products

GNSS: Bernese (GOP)
EPOS (GFZ)
NWM: G-Nut/Shu (GOP)
DNS (GFZ)

Utilization

Gradient estimates
Real-time method
ZTD2IWV conversion
Tomography
NWM assessment
PPP tropo-corrections





Douša J, Dick G, Kačmařík M, Brožková R, Zus F, Brenot H, Stoycheva A, Möller G, Kaplon: **Benchmark campaign and case study episode in Central Europe for development and assessment of advanced GNSS tropospheric models and products**, *Atmosph Meas Tech, 2016*

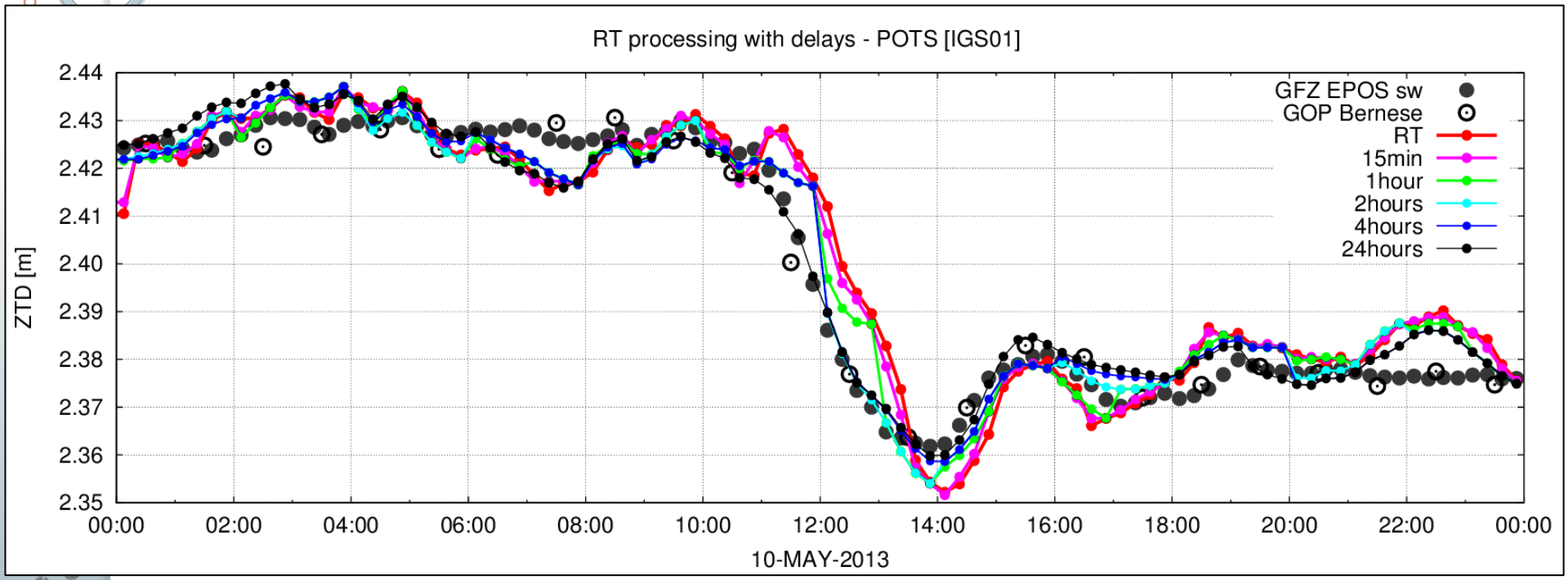
Impact of RT products in Benchmark

- GOP G-Nut/Tefnut 's PPP using IGS Final and IGS real-time orbits + clocks

ZTD (PPP, different inputs)	GNSS reference product (various)	Pairs #	Bias [mm]	Sdev [mm]	RMS [mm]
IGS final SP3	GOP final (Bernese/DD)	1319	+0.9	5.1	5.2
IGS01 RT simulated	**GOP final (Bernese/DD)**	**1158**	**+2.4**	**5.8**	**6.4**
IGS final SP3	GFZ final (EPOS/PPP)	1319	+0.4	4.1	4.2
IGS01 RT simulated	**GFZ final (EPOS/PPP)**	**1158**	**+2.8**	**4.9**	**5.7**
IGS final SP3	ERA-Interim (DNS)	219	- 0.4	9.1	9.3
IGS01 RT simulated	**ERA-Interim (DNS)**	**154**	**+2.1**	**9.0**	**9.4**
IGS final SP3	Aladin-CZ (G-Nut/Shu)	1317	+0.7	7.6	7.8
IGS01 RT simulated	**Aladin-CZ (G-Nut/Shu)**	**1158**	**+2.8**	**8.0**	**8.8**

GNSS PPP	GNSS reference		North gradient			East gradient		
inputs	product	Pairs #	Bias [mm]	Sdev [mm]	RMS [mm]	Bias [mm]	Sdev [mm]	RMS [mm]
PP – IGS final	GOP (Bernese)	1318	+0.09	0.35	0.38	+0.03	0.36	0.37
RT – IGS01	**GOP (Bernese)**	**1158**	**- 0.03**	**0.45**	**0.46**	**+0.26**	**0.44**	**0.52**
PP – IGS final	ERA-Interim	219	+0.09	0.34	0.36	+0.01	0.37	0.38
RT – IGS01	**ERA-Interim**	**154**	**- 0.05**	**0.42**	**0.43**	**+0.19**	**0.42**	**0.47**

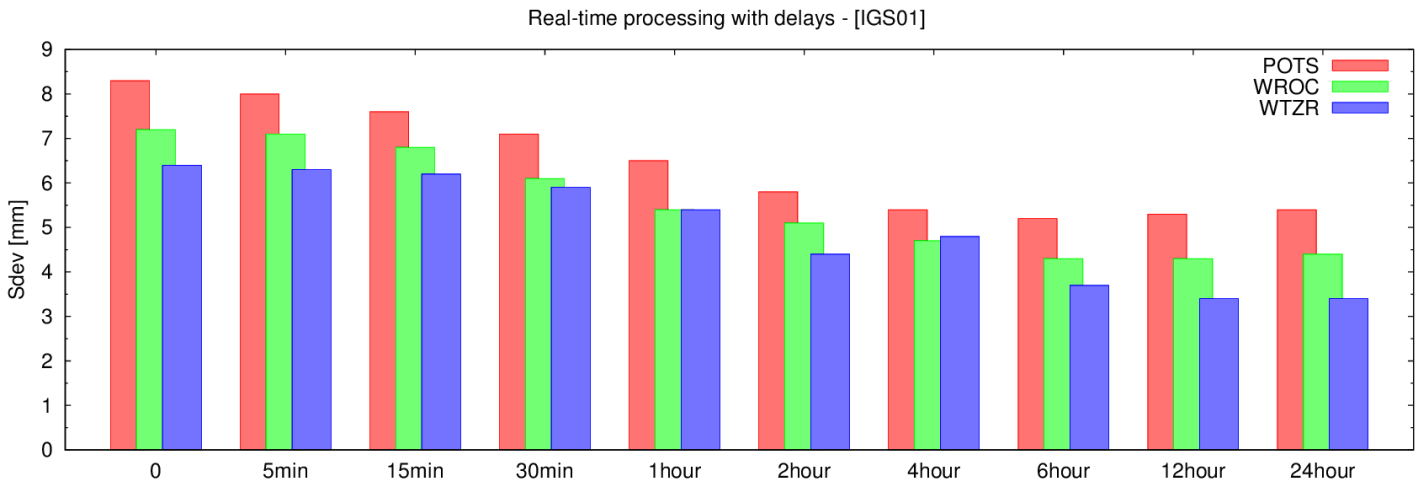
Testing optimal strategy (Benchmark)

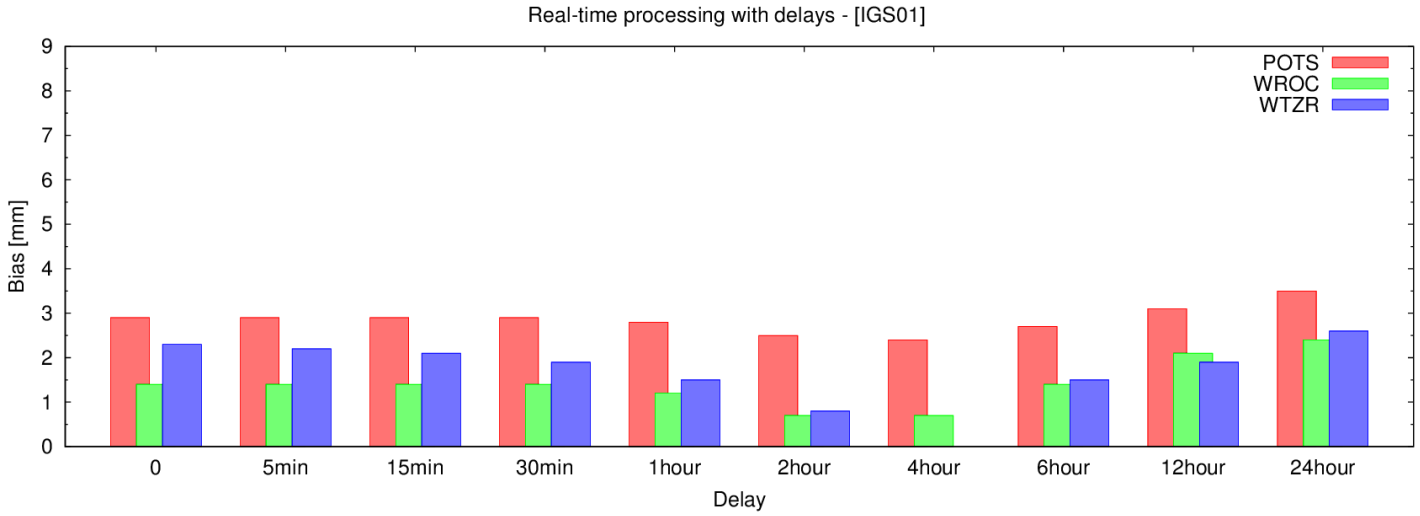


- Final ZTDs: GOP's Bernese (1h, network solution) and GFZ's (15min, PPP)
- Simulated RT ZTDs (IGS01): GOP's G-Nut/Tefnut software (5 min, PPP)
- Kalman+smoother – different smoothing update: 15min, 1h, 2h, 4h, 24h

Kalman + smoother (Benchmark study)

G-Nut/Tefnut – study of impact of smoothing on simulated NRT product





Summary

- Real-time ZTDs studied since 2013 …
- Real-time ZTDs based on IGS RTS developed within in GNSS4SWEC WG1 real-time demonstration campaign (currently 7+1 contributions)
- Web monitoring at http://www.pecny.cz/COST/RT-TROPO
- Two contributions demonstrated stable solutions over last year, the others still in development phase and evolving
- Stable solutions: Sdev 5-9 mm, Bias < ±7mm (a site-specific)
- Several contributions still awaiting
- A control period for the evaluation (~month) is foreseen
- Simulated RT ZTDs using IGS RTS and final product showed a degradation of about 1mm/2mm in ZTD precision/accuracy
- Smoothing is not able to remove biases within a short period
- Work to be done before operational contribution to E-GVAP !

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Thank you for your attention

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