Towards Real-time GNSS Troposphere Delay Monitoring Service for Poland

Tomasz Hadas, Kaplon Jan, Bosy Jaroslaw

Institute of Geodesy and Geoinformatics
Wroclaw University of Environmental and Life Sciences

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Presentation plan

1. Introduction:

- Real-time PPP
- GNSS for NWP

2. Near-real time ZTD service

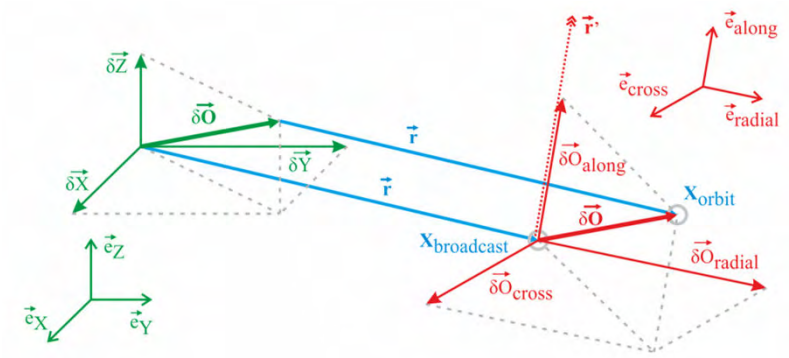
- Processing strategy
- Quality of results

3. Development of real-time ZTD service

- GNSS-WARP software
- Benchmark campaigns
- Current status

IGS RTS - IGS Real Time Service

- real-time orbit and clock correction (SSR RTCM) + broadcast messages (RCTM)



$$\delta \boldsymbol{O} = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix} + \begin{bmatrix} \delta \dot{O}_{radial} \\ \delta \dot{O}_{along} \\ \delta \dot{O}_{cross} \end{bmatrix} (t - t_0)$$

$$e_{along} = \frac{\dot{r}}{|\dot{r}|} \quad e_{cross} = \frac{r \times \dot{r}}{|r \times \dot{r}|} \quad e_{radial} = e_{along} \times e_{cross}$$

$$\delta \boldsymbol{X} = [e_{radial} \quad e_{along} \quad e_{cross}]\delta \boldsymbol{O}$$

$$\boldsymbol{X} = \boldsymbol{X}_{broadcast} - \delta \boldsymbol{X}$$

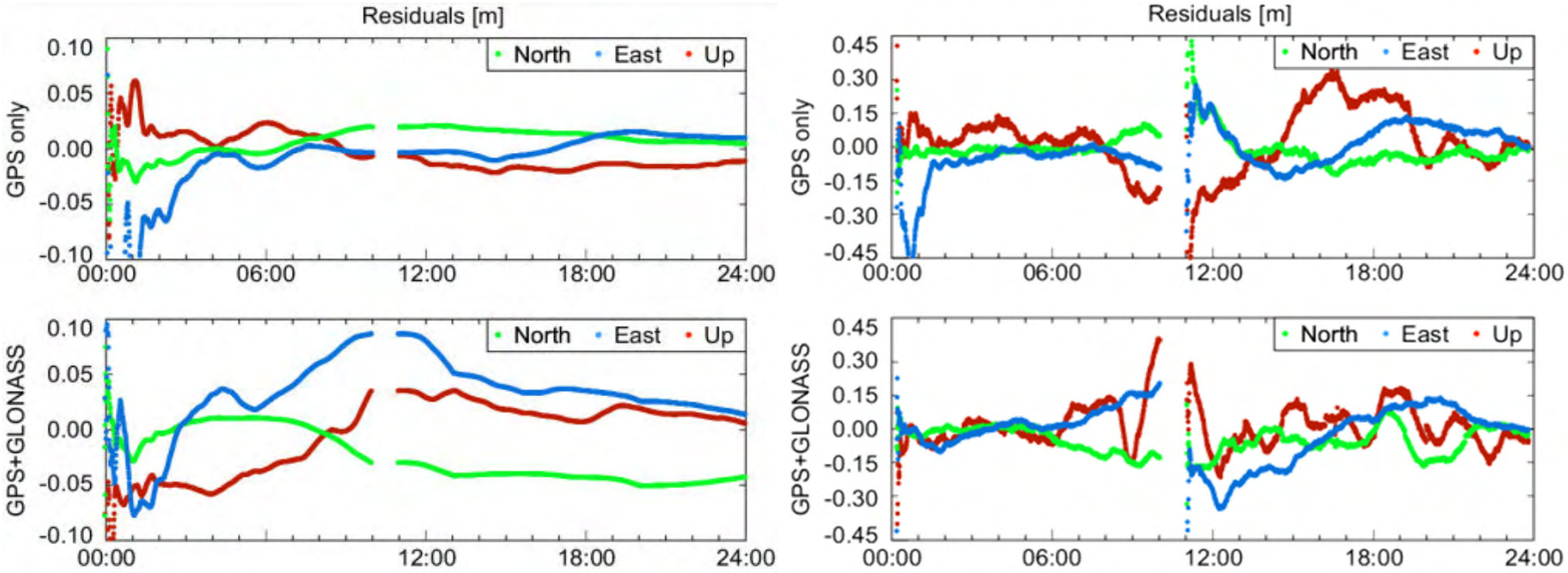
$$\delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2$$

$$t^{sat} = t^{sat}_{broadcast} - \frac{\delta C}{c}$$

- official products for GPS: 5cm for orbits, 0.3ns (8.5cm) for clocks
- unofficial for GLONASS: 13cm for orbits, 0.8ns (24.5cm) for clocks
- availability >90%, latency ~30 sec.

Hadaś T., Bosy J.: ***IGS RTS precise orbits and clocks verification and quality degradation over time,*** GPS Solutions, Vol. 19, 2015, pp. 93-105

Real-time PPP in static / kinematic mode



Time series of residuals for GPS only with IGS01 stream (top) and GPS+GLONASS with IGS03 stream (bottom) real-time positioning in static (left) and kinematic (right) mode for station WROC, DOY 114, 2014

	GPS only		GPS+GLO	
	Mean	Std.Dev.	Mean	Std.Dev.
North	0.005	0.002	**0.025**	**0.013**
East	0.007	0.006	**0.012**	**0.018**
Up	0.001	0.006	**-0.033**	**0.011**

	GPS only		GPS+GLO	
	Mean	Std.Dev.	Mean	Std.Dev.
North	0.007	0.03	0.015	0.035
East	0.004	0.027	0.004	0.032
Up	0.057	0.12	**-0.031**	**0.092**

GNSS troposphere monitoring

PPP estimates: X,Y,Z, dtrec, troposphere zenith delays (**ZTD**) and gradients

Integrated Water Vapour (IWV):

$$ZHD = [0.0022768 m/mbar] \cdot \frac{P_0}{f(\phi, h)}$$

$$f(\phi, h) = 1 - 0.00266\cos(2\phi) - 0.00000028h \approx 1$$

$$ZWD = ZTD - ZHD$$

$$IWV = \frac{ZWD}{10^{-6}(k_2' + k_3/T_m)R_v}$$

P_0 - surface air pressure [mbar]

h - point height [m]

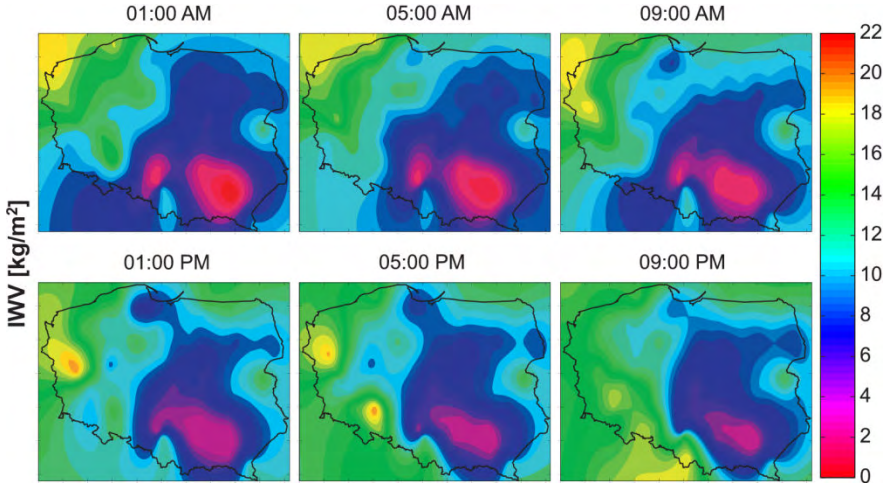
ϕ - point latitude [rad]

k_2', k_3 - empirical coefficients

T_m - $70.7 + 0.72T_0$

T_0 - surface air temperature

R_v - 461.525 [J/(kg·K)]



Example of the Integrated Water Vapour (IWV) 2D distribution over the area of Poland calculated for November 7, 2012, shown as a time series with 4 hours interval

NWP requirements

Running projects / actions:

- EIG EUMETNET, GNSS Water Vapour Programme (E-GVAP-II)
- Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)

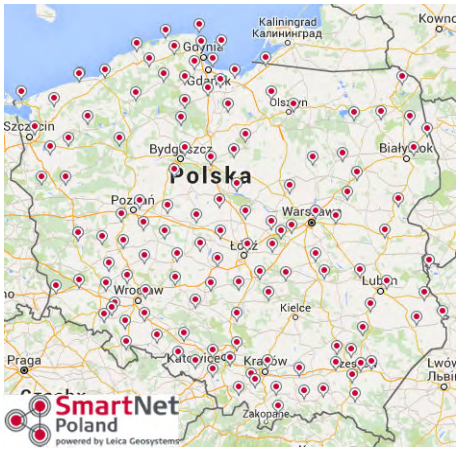
Hourly ZTD	Treshold	Target	Optimal
Accuracy	15 mm	10 mm	5 mm
Timeliness	2 h	1.5 h	1 h
Spatial coverage	Europe	Europe + N. America	Global
Horizontal Sampling	200 km	100 km	30 km

Sub-hourly ZTD	Treshold	Target	Optimal
Accuracy	15 mm	10 mm	5 mm
Timeliness	1 h	30 min	15 min
Spatial coverage	Europe	Europe to National	Regional to National
Horizontal Sampling	100 km	50 km	20 km

Commercial RTK networks in Poland

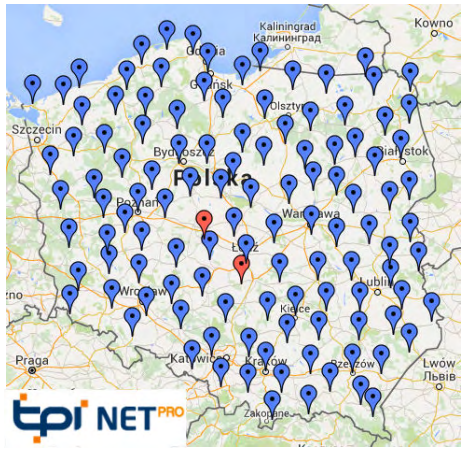
ASG-EUPOS:

102 in Poland + 23 foreign:
- 125 GPS / 73 GLO / 39 GAL
- permanent service since 2009
- GPS RTN (+GLO at some areas)



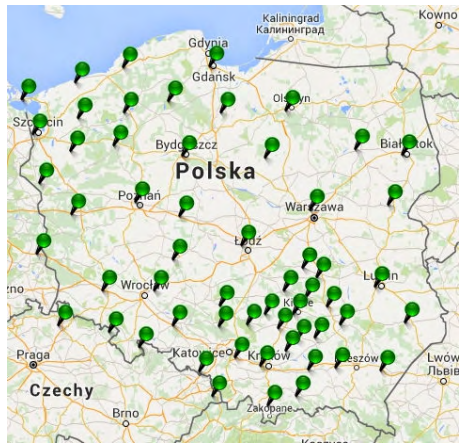
Leica SmartNet:

now: 135 stationsin Poland
- GPS, GLO, GAL, BDS, QZSS
- operational + developments
- GNSS RTN



TPI Net PRO:

136 in Poland
- GPS, GLO, GAL
- operational
- GNSS RTN



Trimble VRS Net:

now: 56 in Poland
- GPS, GLO, GAL, 1 BDS
- under development?
- GNSS RTN

4 commercial RTK/RTN networks (2 still under developments) with > 370 stations

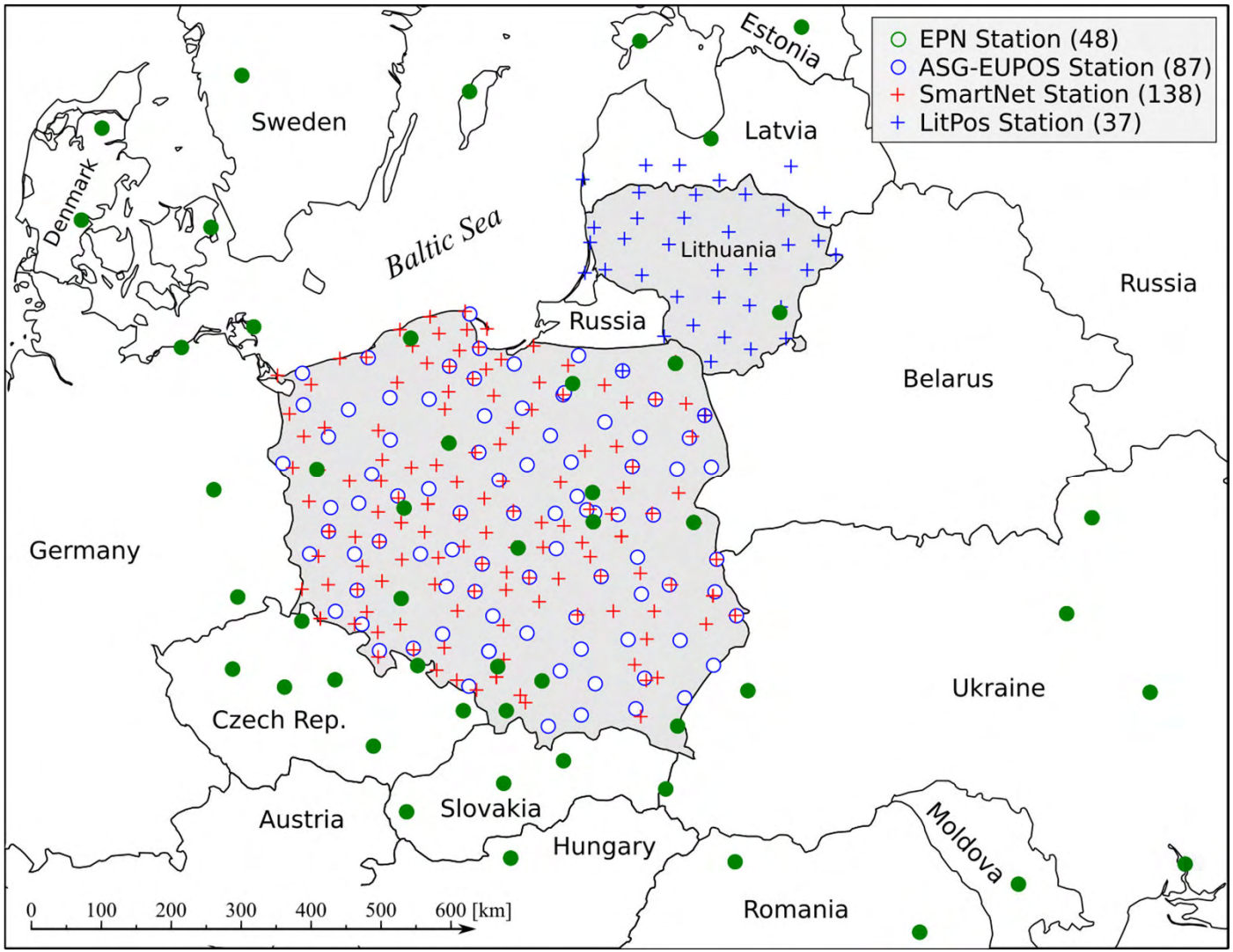
WUELS cooperates with ASG-EUPOS and Leica SmartNet:
- hourly RINEX files from both network, including foreign stations
- 1Hz data streams from ~100 Leica SmartNet stations
- hopefully soon 1Hz data streams from ASG-EUPOS and +30 from Leica SmartNet

NRT DD processing details

Parameter	Value
Processing type	Post-processing (Double-differenced) with IGU orbits and clocks
Satellite system considered	GPS only
Observation window	6 hours
Observation cut-off angle	5^{o}
Baseline forming strategy	OBS-MAX
Ambiguity resolution strategy	Baseline length dependent: a) < 20km: SIGMA on L1 and L2, b) 20km to 180km: SIGMA L5/L3 (wide-lane/narrow-lane), c) > 180km: QIF (quasi iono-free)
Ionosphere handling	Baseline length dependent: a) < 20km: Global model (CODE) for L1L2; b) 20km to 180km: Global model (CODE) for L5 and HOI L3; c) 180km to 1000km: Global model (CODE) + stochastic ionosphere parameters estimation (QIF)
Troposphere handling	**Phase observables screening stage:** a) A priori model DRY GMF, b) Site specific parameters WET GMF (ZTD spacing: 2h; no constraining), **Final solution stage:** a) A priori model: DRY GMF, b) Site specific parameters: WET GMF (ZTD spacing: 30min; no constraining; gradient model: CHENHER *Chen and Herring (1997)*, gradient spacing: 6h) **Product output:** Relative constraining over 1 hour (3mm for ZTD and 0.5 mm for gradients).
Method of referencing epoch solutions	Minimum constraining on all reference station positions.

GNSS NRT ZTD network

Total: 310 stations
Mean dist.: 40 km



„VICNET" network

Total: 156 stations
Mean dist.: ~70 km

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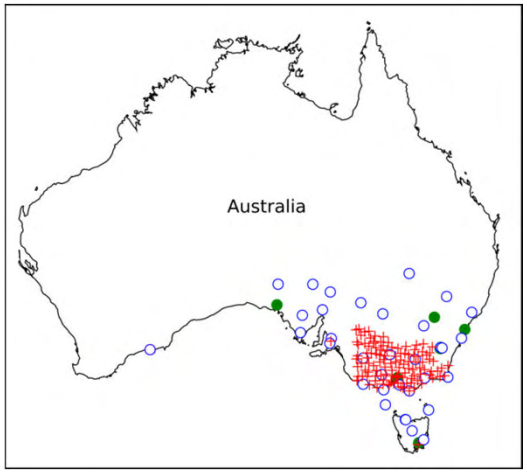
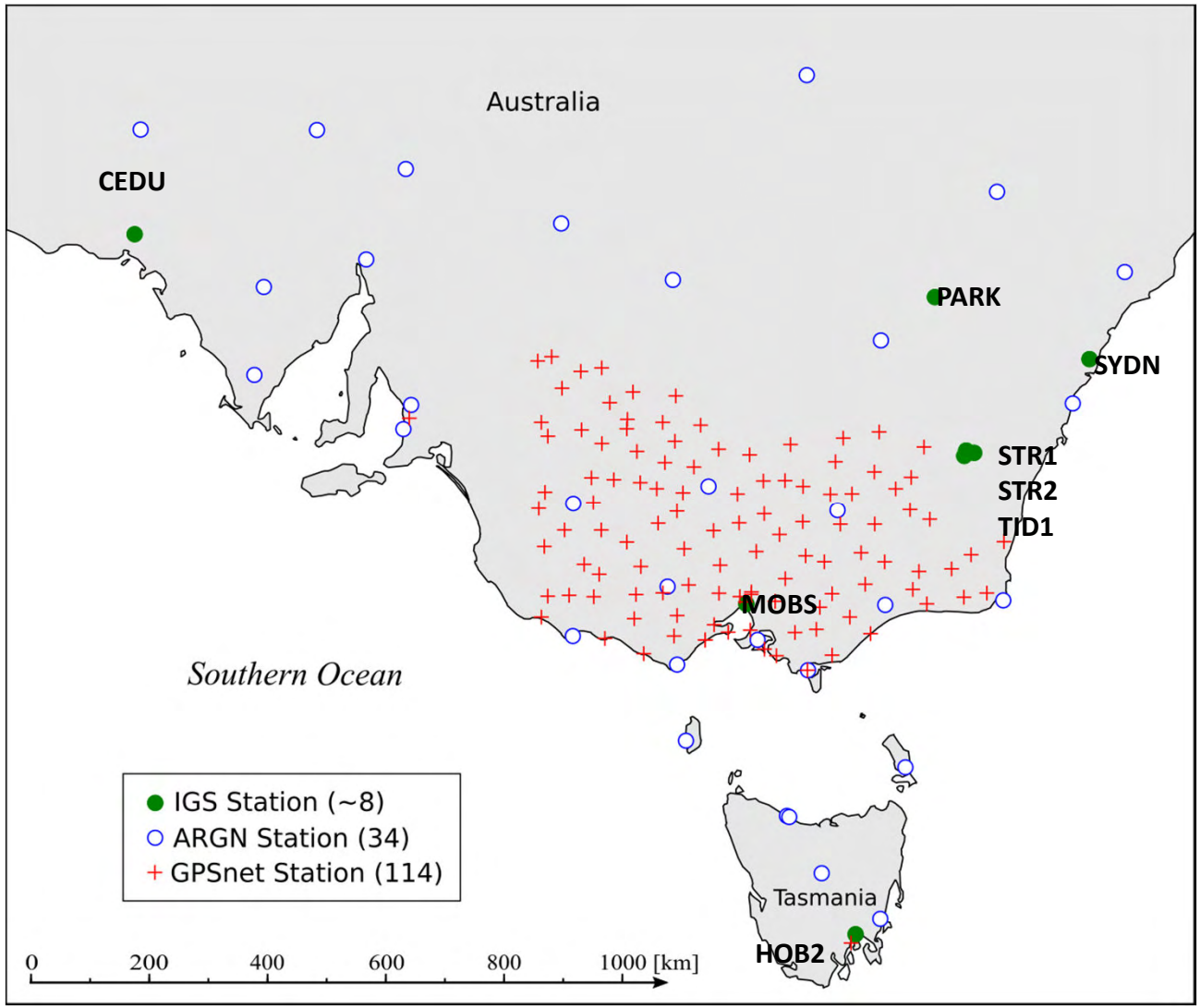
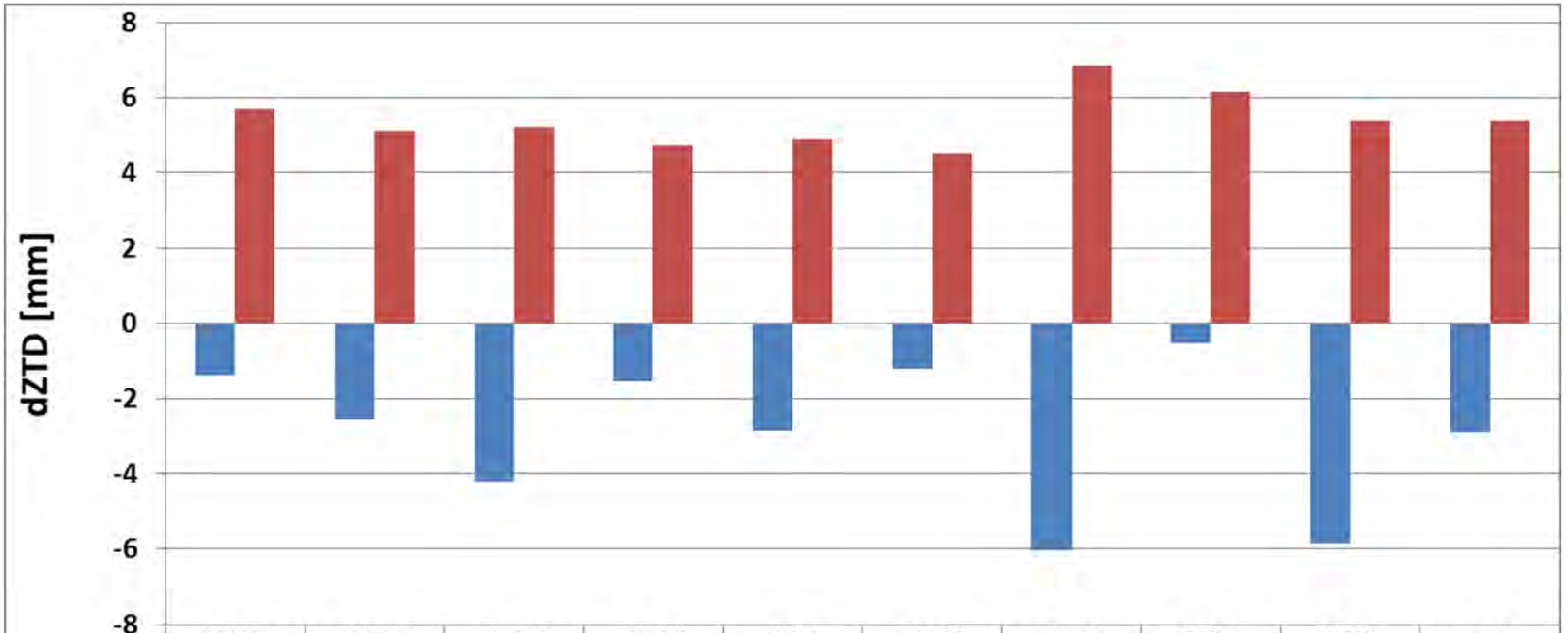




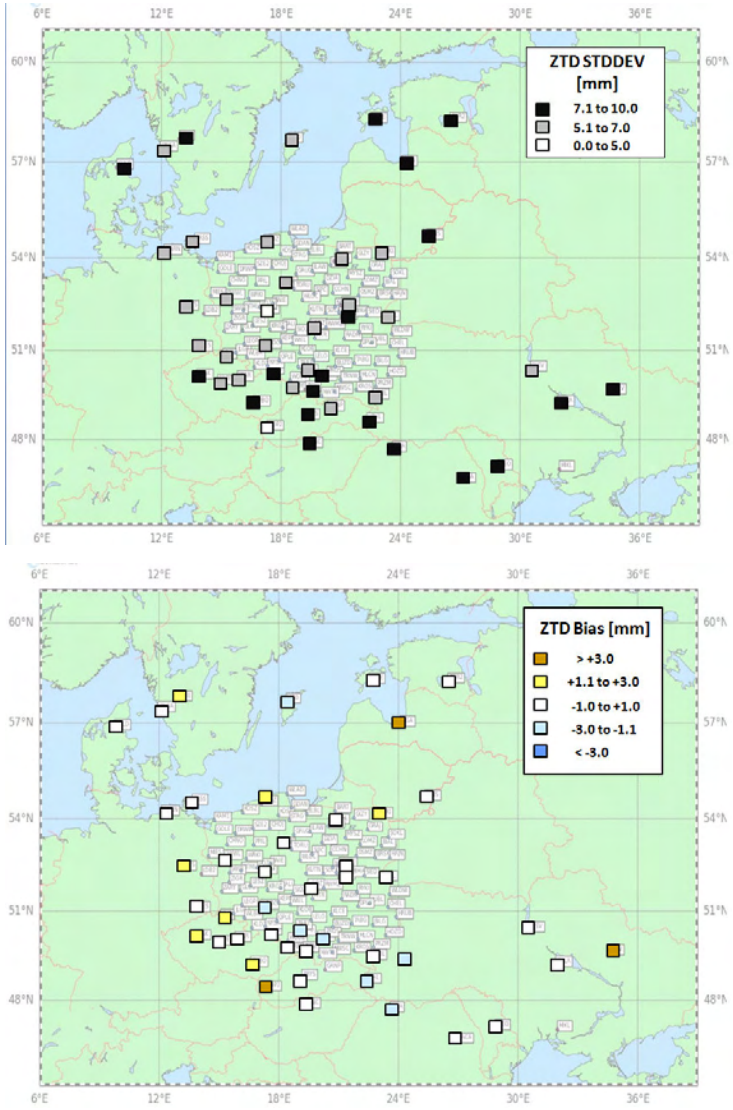
Quality assessment of „WUEL" NRT service (1)

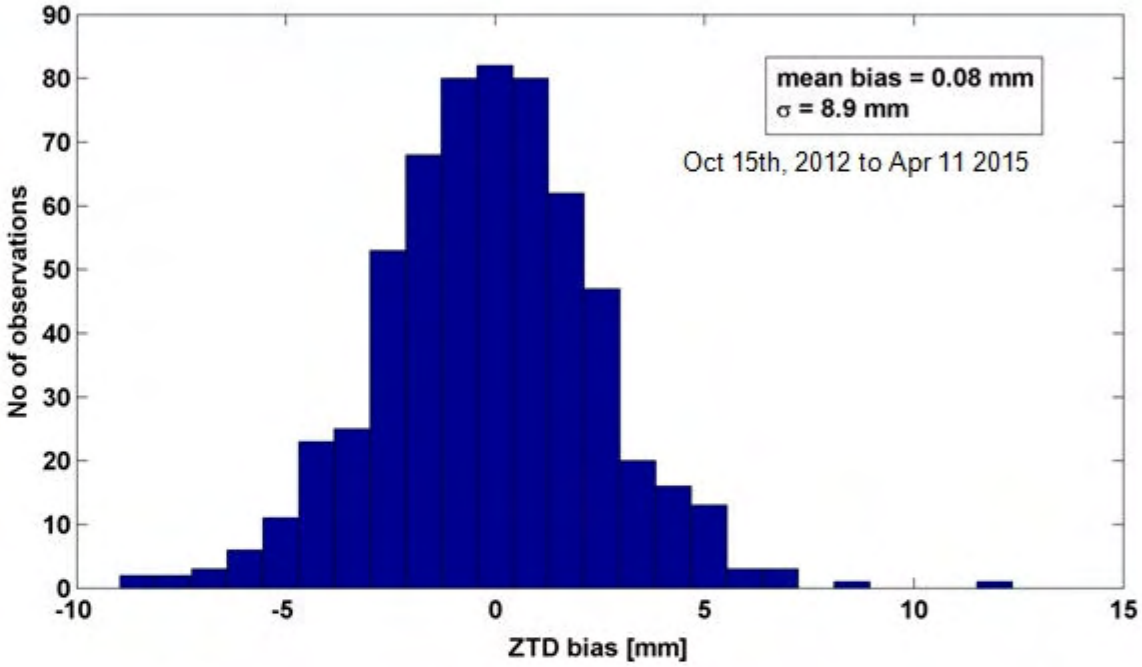


	BOGO	GANP	GLSV	GOPE	JOZ2	LAMA	ONSA	PENC	POTS	mean
bias	-1.39	-2.59	-4.21	-1.55	-2.86	-1.21	-6.03	-0.52	-5.84	-2.91
stdev	5.69	5.11	5.22	4.73	4.89	4.50	6.85	6.14	5.36	5.39

Comparison of ZTD estimates with CODE Rapid ZTDs on common IGS stations for the last three weeks of September 2015

Quality assessment of „WUEL" NRT service (2)





Histogram of mean daily ZTD residuals calculated w.r.t. final EPN ZTD

GNSS-WARP software (1)

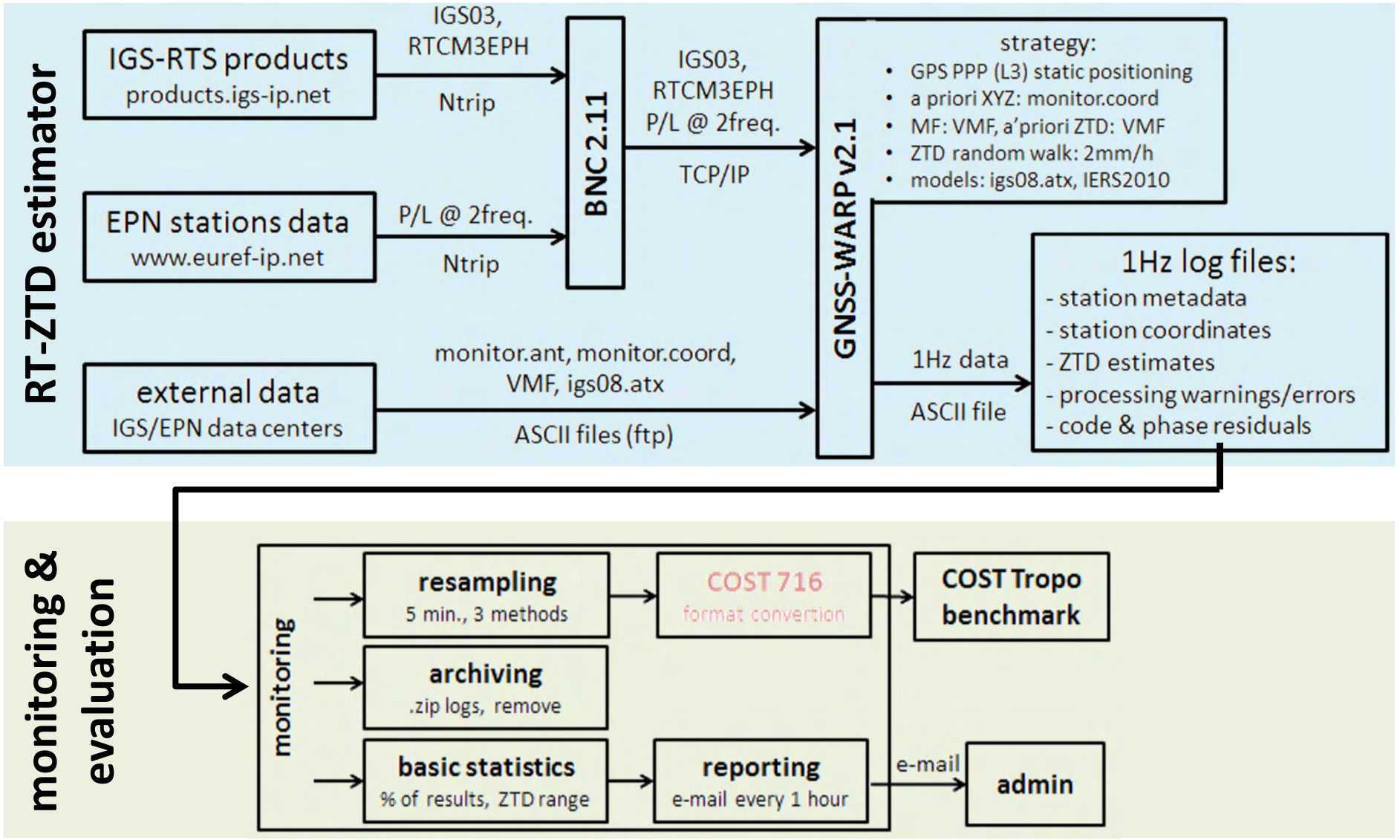
GNSS-WARP
Wroclaw **A**lgorithms for **R**eal-time **P**ositioning

- original, self-developed, state-of-the-art PPP software
- purpose: RT-PPP & PPP-RTK algorithms development
- implemented in Matlab (2015a) + Instrument Control Toolbox
- BNC used as RTCM decoder of IGS RTS streams

RT-ZTD optimization (GNSS-WARP v2.1m):
- redeveloped and optimized for multi-station, continuous processing
- performance: >10stations / 1 second @1CPU
  (currently: 147 stations every 60 seconds)

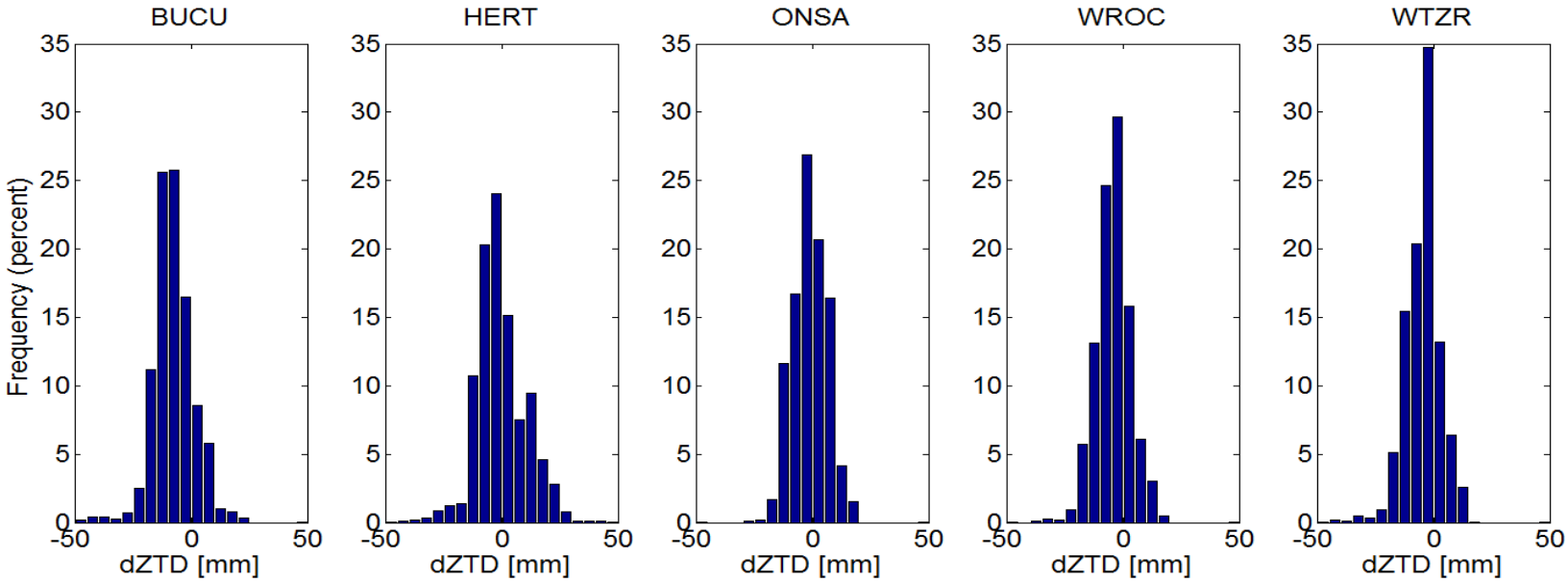
Strategy:
- GPS PPP, static positioning, VMF, IGS03, IERS 2010 models

GNSS-WARP software (2)



Benchmark 1 – simulated real time

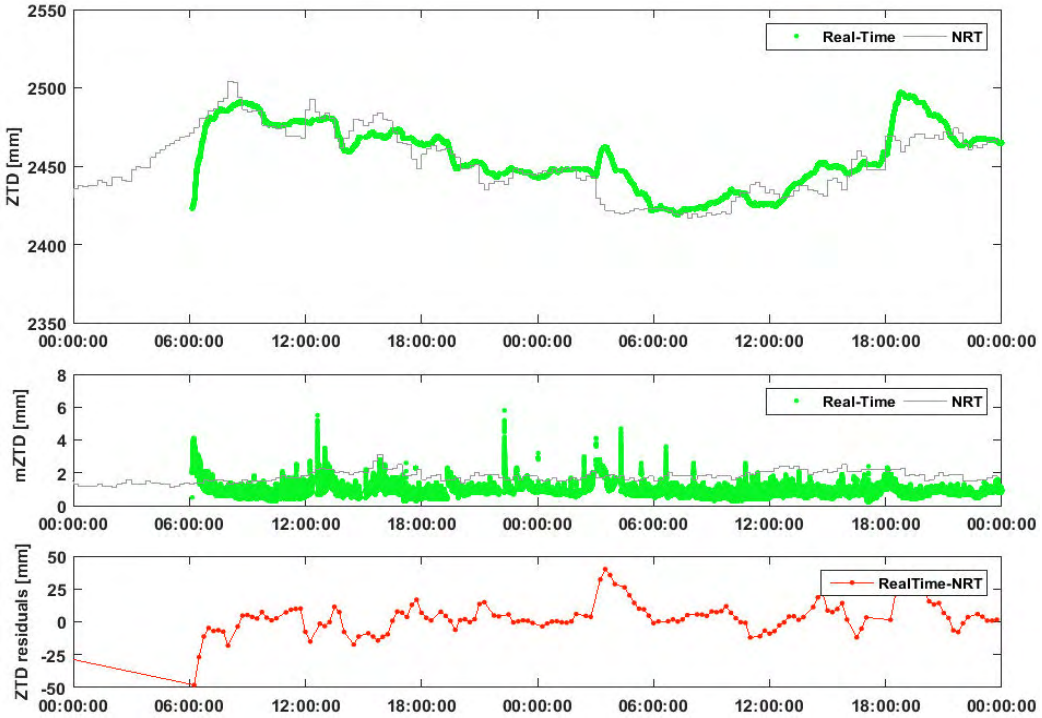
- RTS IGS03 stored (BNC) in **SP3** and **CLK** files, **RINEX** files for **10 stations**, **one week**
- station by station **postprocessing** (0.1Hz) with GNSS-WARP v2
- comparison with **final-ZTD** estimates from EPN (**1 hour sampling**)
- purpose: optimize methodology, evaluate possible quality



An optimal solutions among all stations were obtained for 2mm/h to 5mm/hour random walk. The results were slightly biased: -4 mm to +7 mm (note: DD vs PPP solution) and the standard deviations varies from 7 mm to 12 mm.

Benchmark 2 – real-time demonstrator (1)

- RTS **IGS03 stream** and **10 observation streams** decoded with BNC, **one week**
- **multi-station real-time** processing with GNSS-WARP v2.1M
- comparison with **NRT** from MetOffice (ROBH, **15min sampling**)
- purpose: optimize methodology, detect bugs & errors



*Station **WROC***

13-14.06.2015

availability: 86%

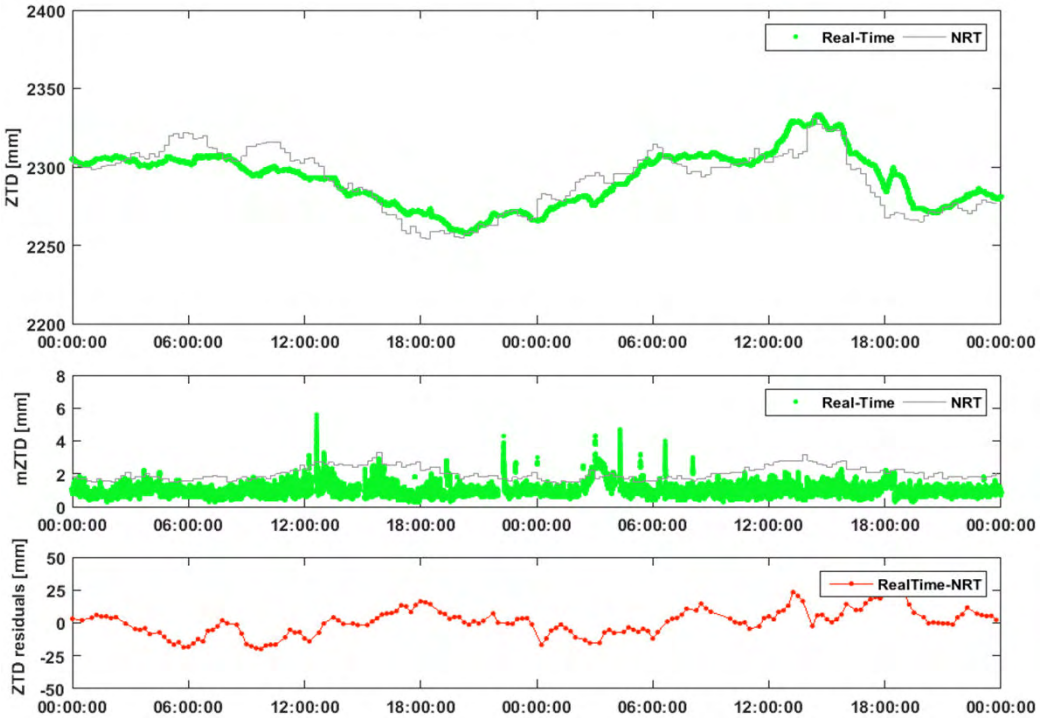
mean formal error: 1.1mm

mean bias: +1.5mm

StdDev of residuals: 15.7mm

Benchmark 2 – real-time demonstrator (1)

- RTS **IGS03 stream** and **10 observation streams** decoded with BNC, **one week**
- **multi-station real-time** processing with GNSS-WARP v2.1M
- comparison with **NRT** from MetOffice (ROBH, **15min sampling**)
- purpose: optimize methodology, detect bugs & errors



*Station **WTZR***

13-14.06.2015

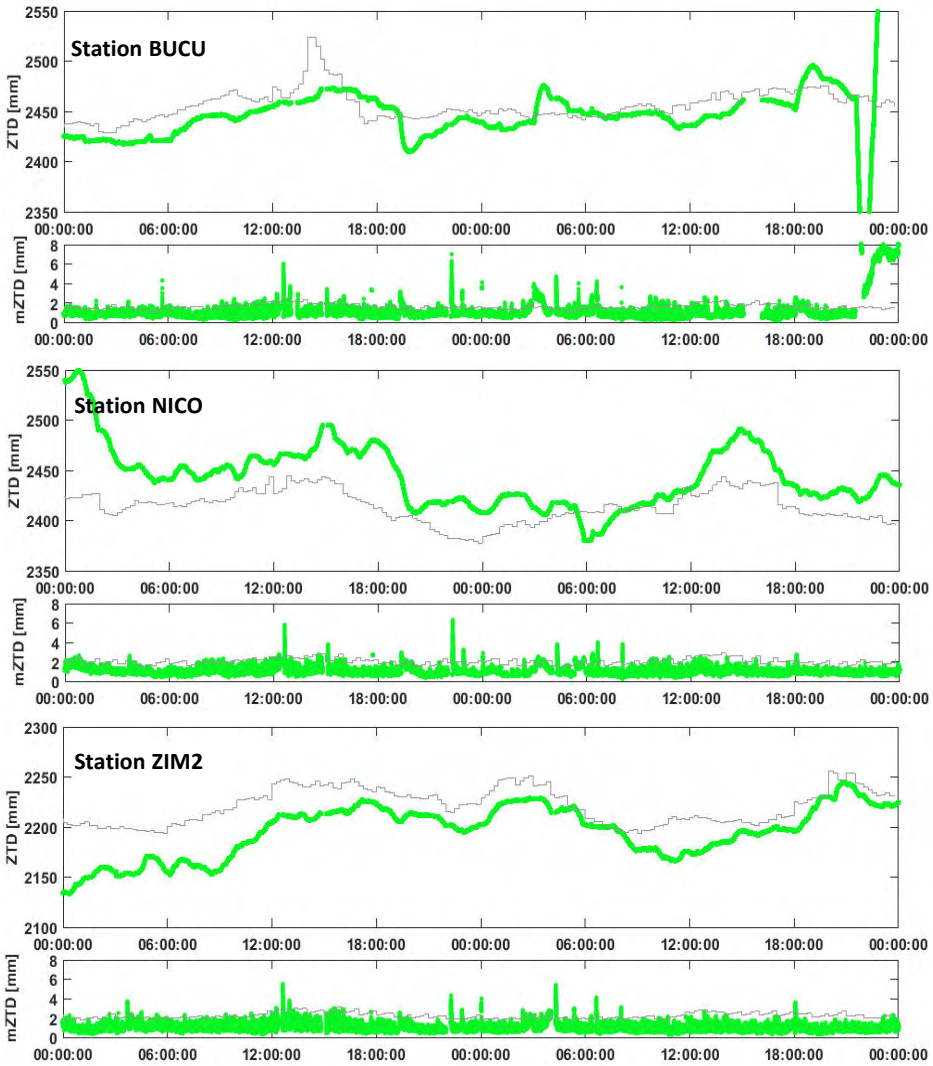
availability: 97%

mean formal error: 1.1mm

mean bias: -1.0mm

StdDev of residuals: 15.5mm

Benchmark 2 – real-time demonstrator (2)



Bugs & errors

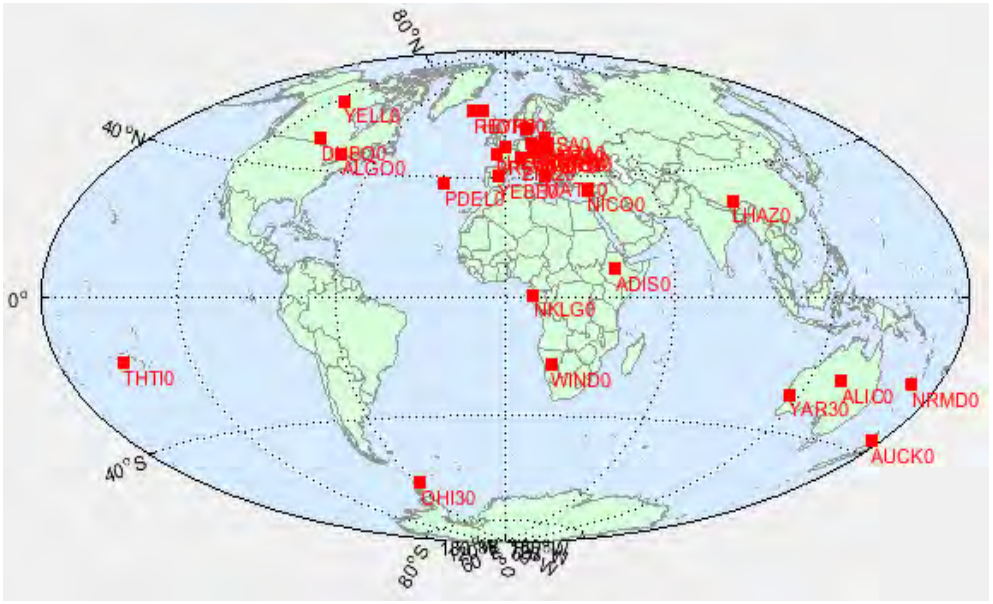
1) Real-time service problems:

- IGS03/RTCMEPH stream failure (e.g. mismatching IOD's)
- stream recovery failure in BNC (solved: use Ntrip 1, not Ntrip 2)
- long gaps in streams availability (re-initialization of the solution)

2) Processing errors:

- some rapid ZTD changes not present in RT estimation
- unexpected ZTD peaks in RT
- systematic biases between RT and NRT (DD vs. PPP)

Towards COST Tropo benchmark (1) – general performance



Real-time ZTD:

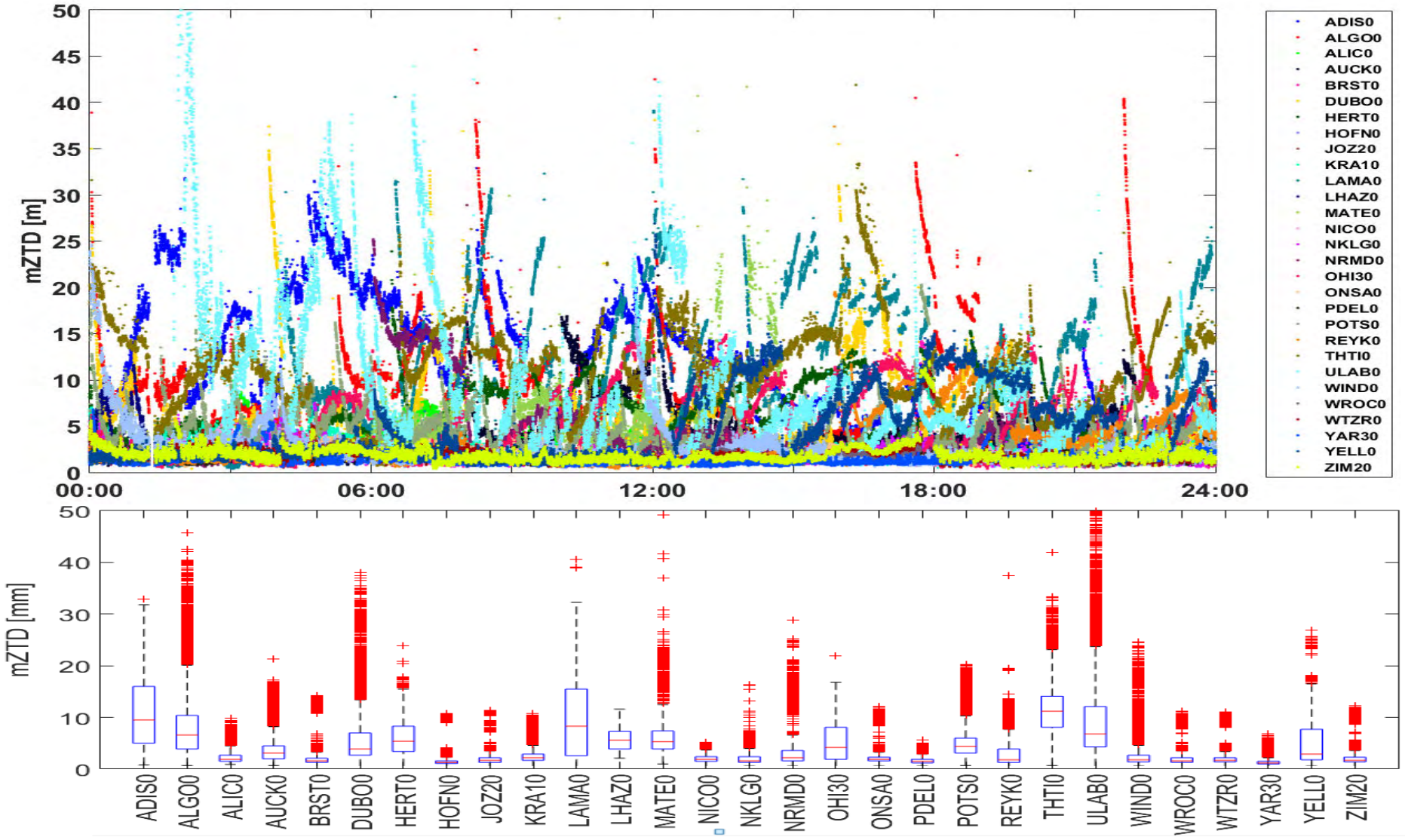
33 stations @ 5 sec. sampling:

- COST RT TROPO benchmark stations (some have problems!)
- Polish EPN stations

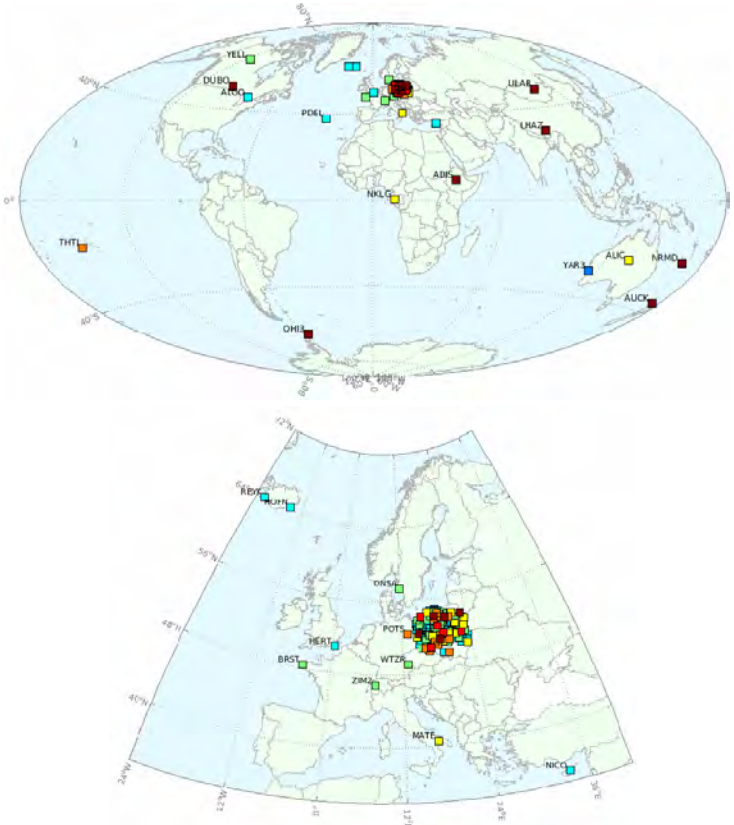
Week 1863 performance:

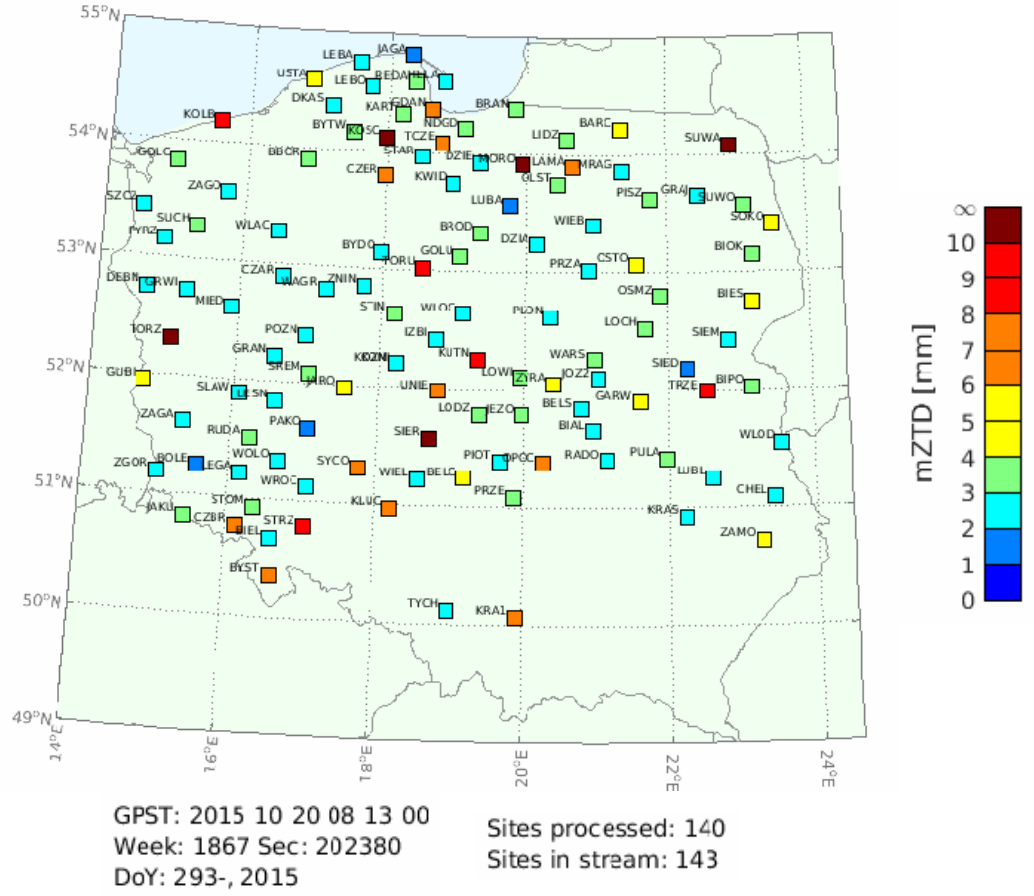
- 68% mZTD is below 0.0036 m
- **95% mZTD is below 0.0148 m**
- 99% mZTD is below 0.0241 m
- data availability: 88.6%

Towards COST Tropo benchmark (2) – ZTD formal errors at stations



Towards RT-ZTD monitoring service in Poland (1) – GNSS network

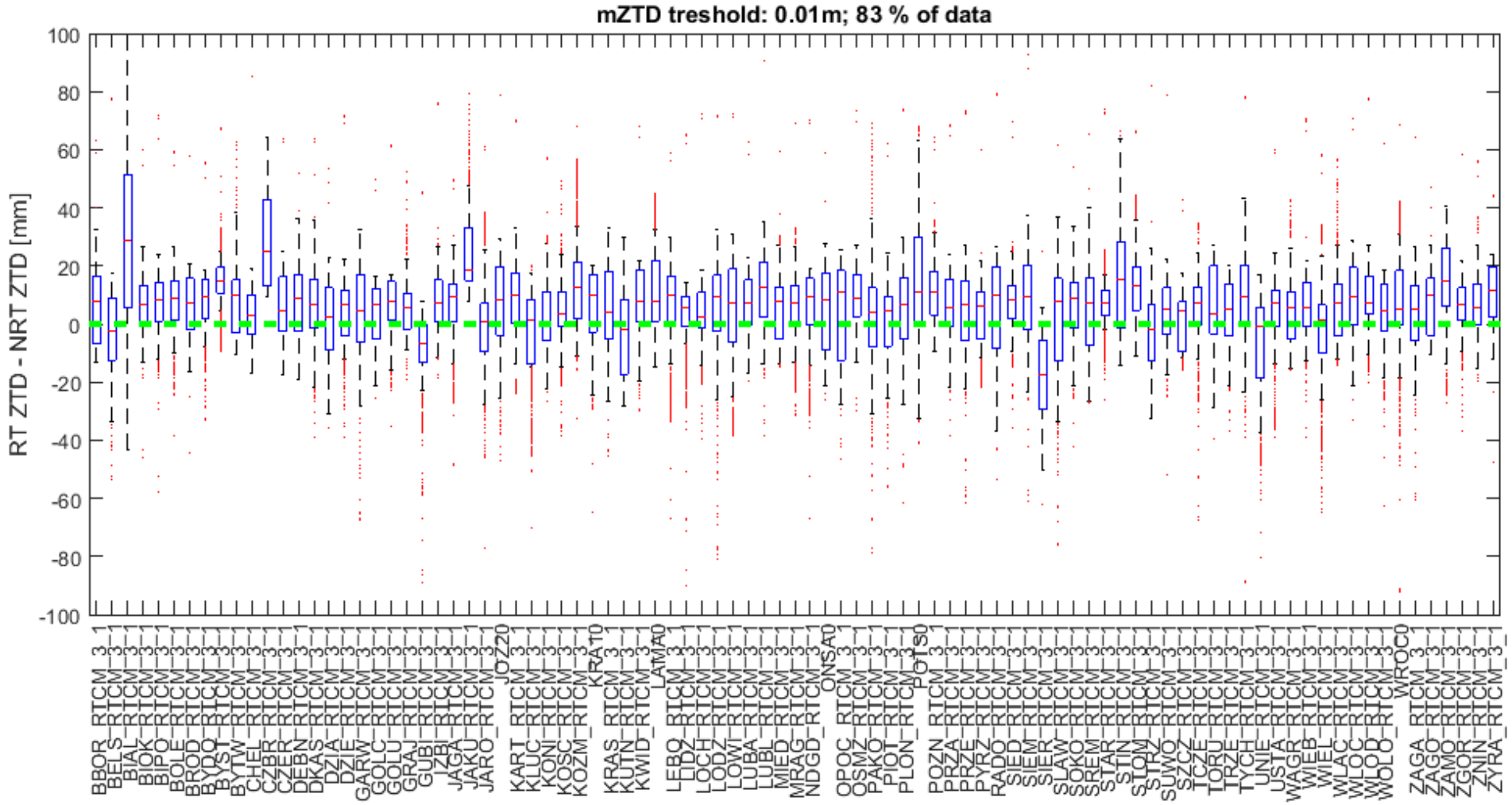




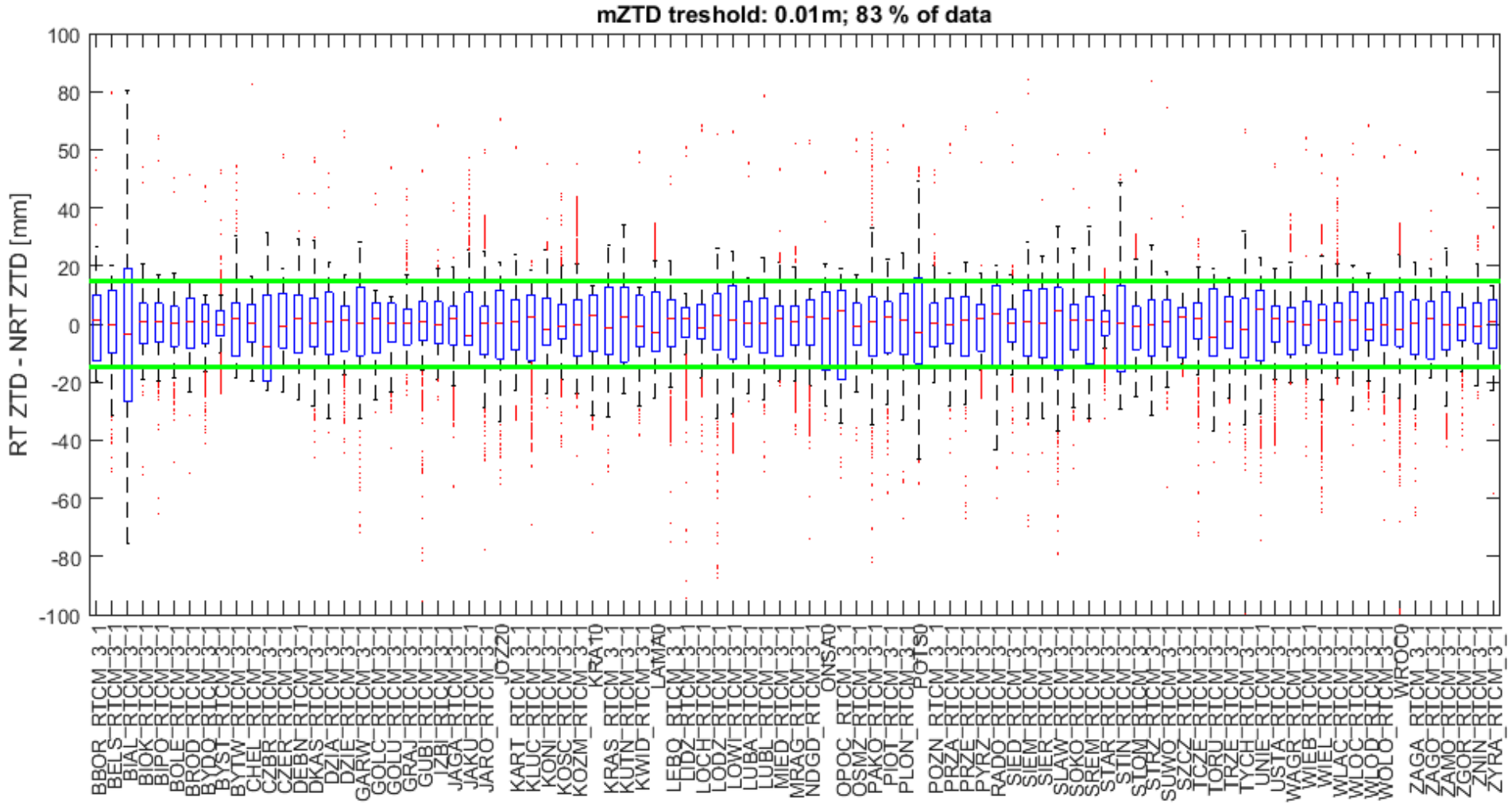
Recent problems:

- bad / missing antenna type (monitor.ant) – station is incorrect / not processed
- BNC 2.11 failure / errors - no data until restarted
- no access to ASG-EPOS streams (all stations) and SmartNet streams (south east)

Towards RT-ZTD monitoring service in Poland (2) – comparison with NRT ZTD



Towards RT-ZTD monitoring service in Poland (2) – comparison with NRT ZTD



Summary

NRT ZTD service (fully operational)

- XXX EPN + XXX ASG-EUPOS + XXX Leica SmartNet

Hourly ZTD	Treshold	Target	Optimal
Accuracy	15 mm	**10 mm**	5 mm
Timeliness	2 h	**1.5 h**	1 h
Spatial coverage	**Europe**	Europe + N. America	Global
Horizontal Sampling	200 km	100 km	**30 km**

RT ZTD service (under development, improvements required)

- 14 IGS + 19 EPN + 110 Leica SmartNet

Sub-hourly ZTD	Treshold	Target	Optimal
Accuracy	**15 mm**	10 mm	5 mm
Timeliness	1 h	30 min	**15 min**
Spatial coverage	Europe	Europe to **National**	Regional to **National**
Horizontal Sampling	100 km	**50 km**	20 km

Thank You!

tomasz.hadas@up.wroc.pl

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