Wrocław University of Environmental and Life Sciences

Multi-GNSS real-time troposphere delay estimation

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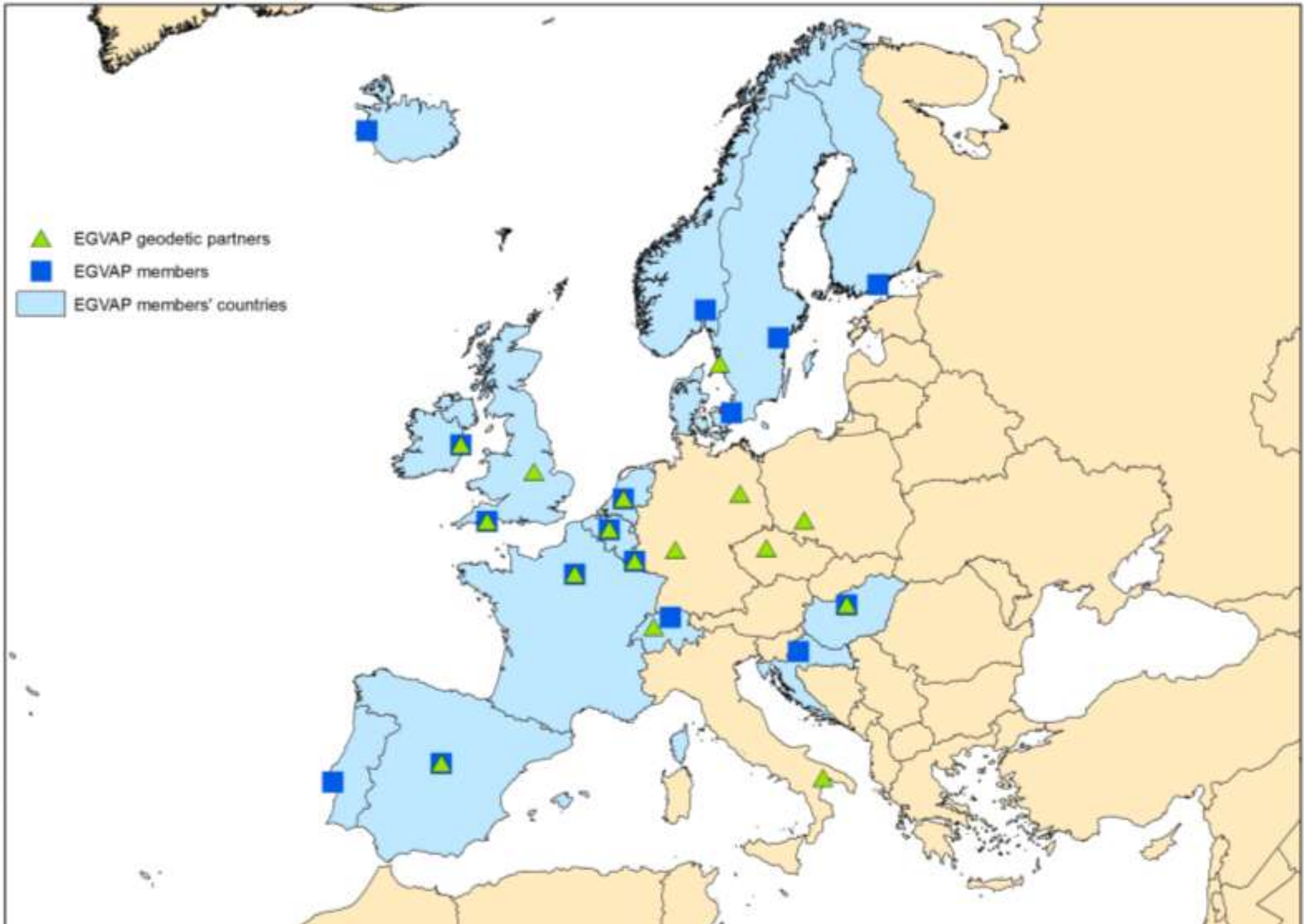
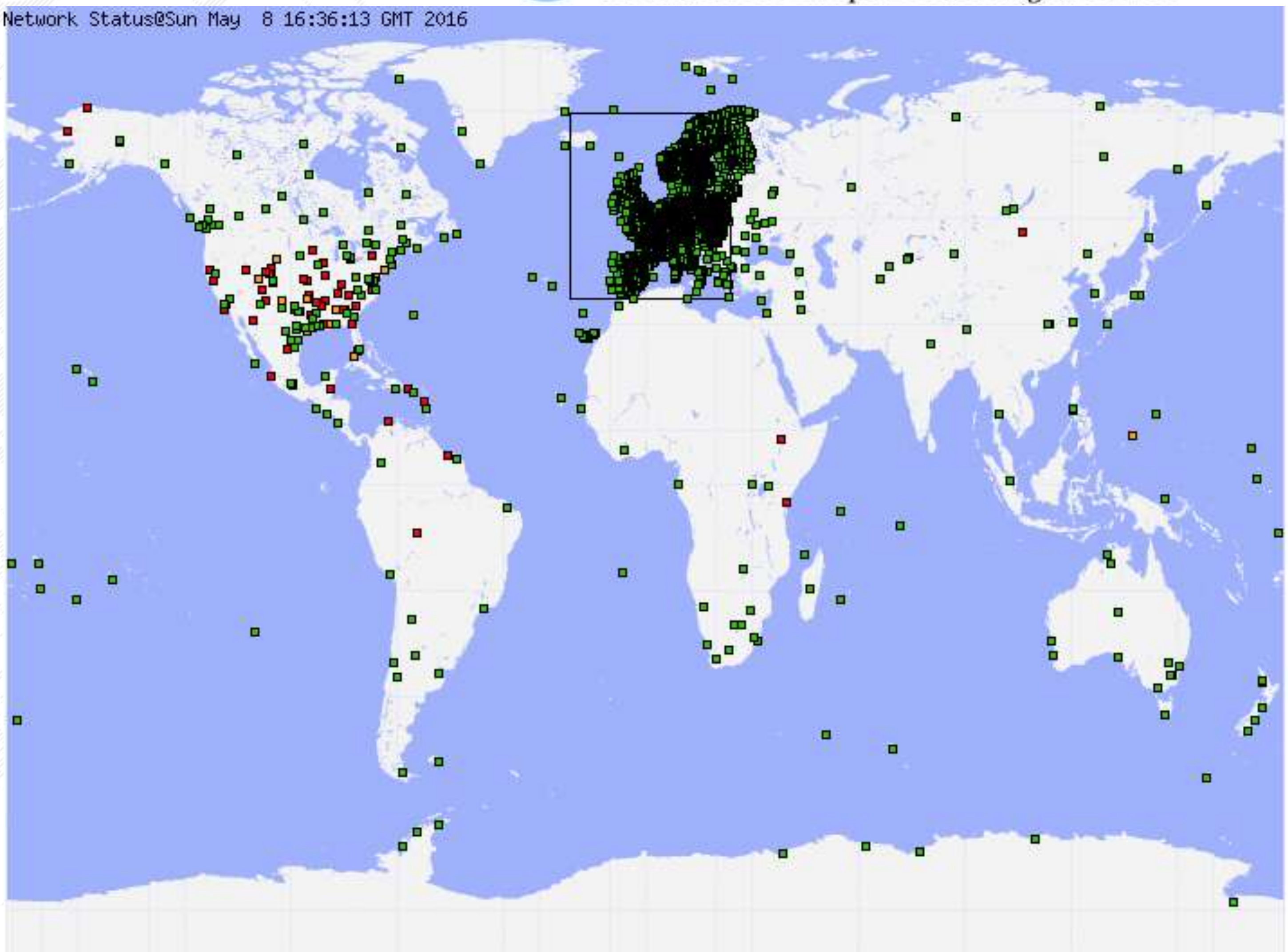
E-GVAP The EUMETNET EIG GNSS water vapour programme (http://egvap.dmi.dk)



E-GVAP The EUMETNET EIG GNSS water vapour programme (http://egvap.dmi.dk)

EUMETNET
The Network of European Meteorological Services



GNSS troposphere monitoring

PPP estimates: X,Y,Z, dt_{rec}, 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]

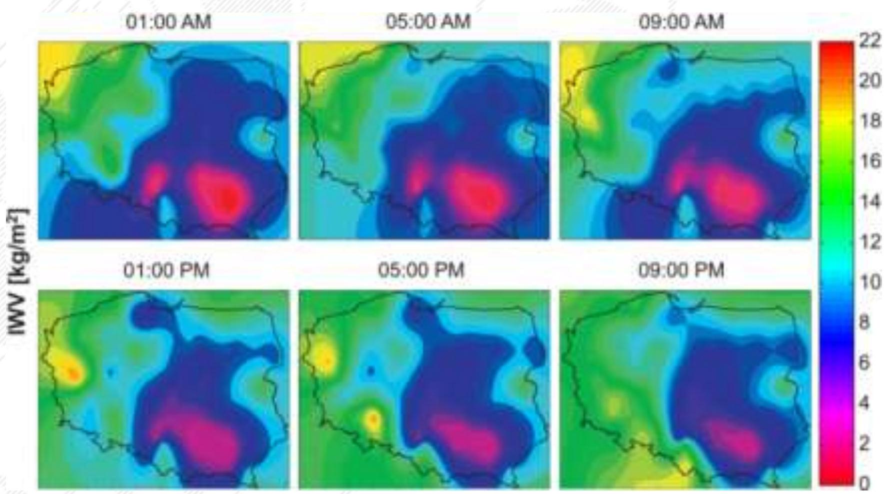
ϕ - point latitude [rad]

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

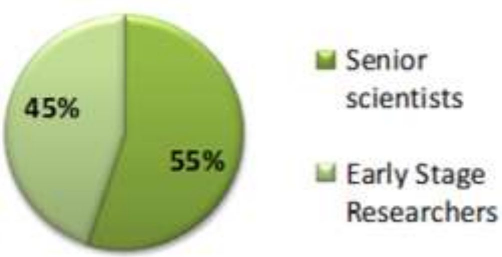
COST Action ES1206 - **GNSS4SWEC - Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate** *(http://gnss4swec.knmi.nl)*

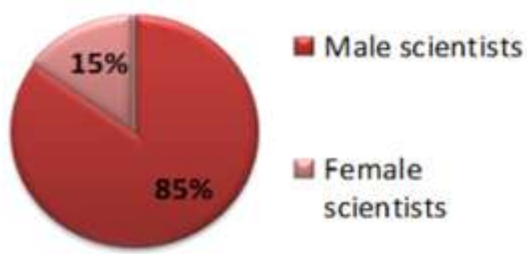
23 COST Countries

55 Participants

25 ESRs (45%)

8 Female Scientists (15%)





COST Action ES1206 - **GNSS4SWEC - Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate** *(http://gnss4swec.knmi.nl)*

Action Chair: Jonathan Jones (esr)
Action co-chair: Guergana Guerova (f)

- WG1 - Advanced GNSS Processing Techniques
  Chair: Jan Dousa
  Co-chair: Galina Dick (f)
- WG2 - GNSS for Severe Weather Monitoring
  Chair: Siebren de Haan (esr)
  Co-chair: Eric Pottiaux (esr)
- WG3 - GNSS for Climate Monitoring
  Chair: Olivier Bock
  Co-chair: Rosa Pacione (f)

The RT PPP service is realized in the frame of WG1

GNSS-WARP

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

- original, self-developed, state-of-the-art PPP software
- purpose: multi-GNSS RT-PPP & PPP-RTK algorithms development
- GNSS: GPS+GLO, GAL & BDS only with MGEX products, RT
- 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: >200 stations every 60 seconds)

Strategy:

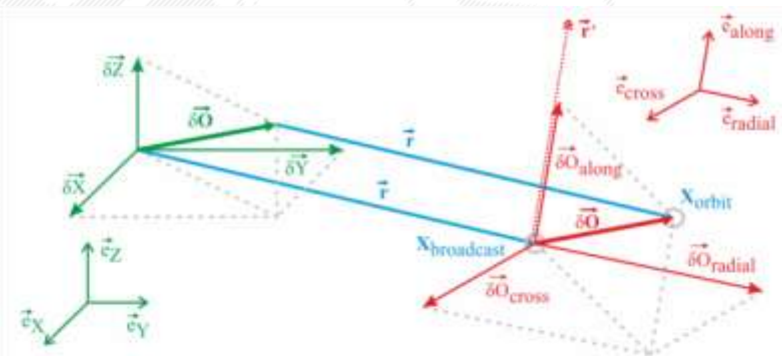
- PPP, static positioning, VMF, IGS03, IERS 2010 models

IGS Real-Time Service

IGS INTERNATIONAL GNSS SERVICE

IGS RTS - IGS Real **T**ime **S**ervice

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



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

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

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

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

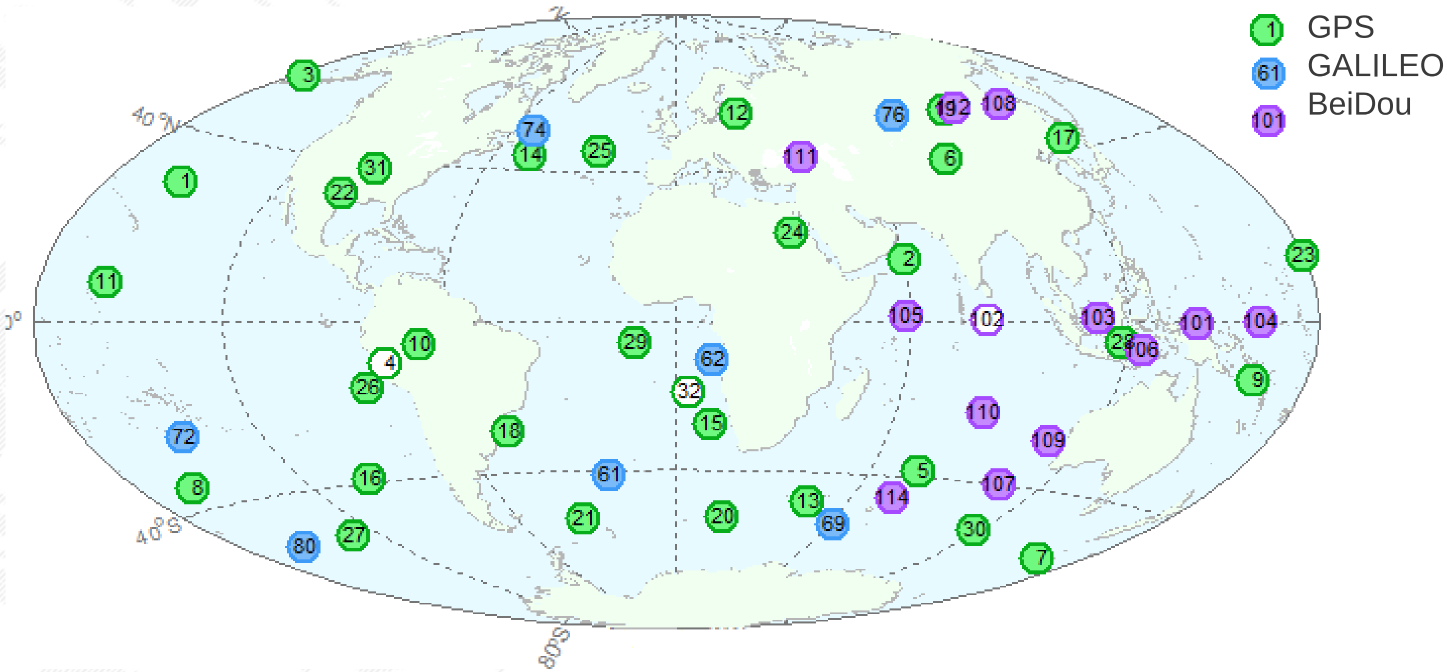
$$\delta C = C_0 + C_1(t-t_0) + C_2(t-t_0)^2$$

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

- 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.

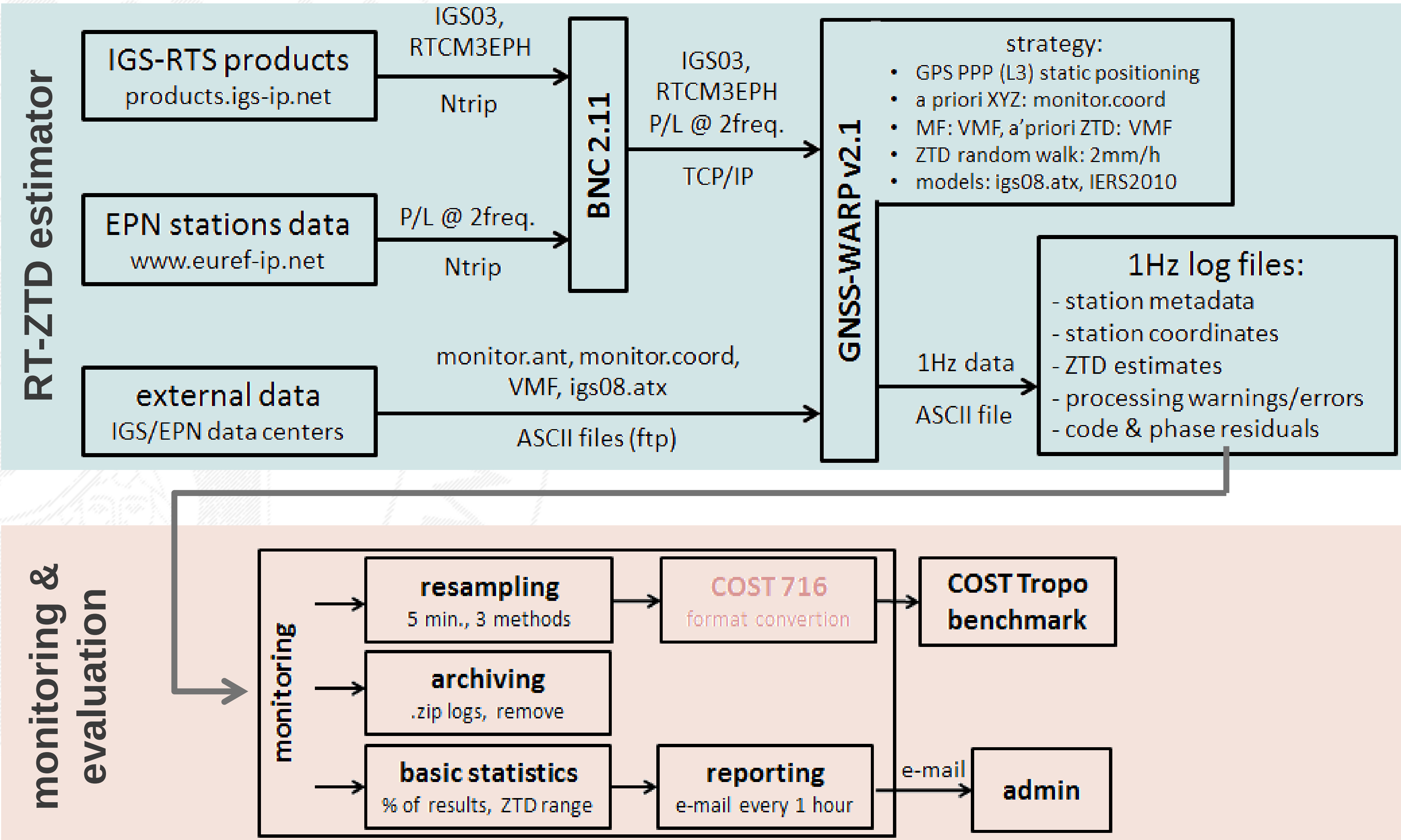
Hadaś T., Bosy J.: ***IGS RTS precise orbits and clocks verification and quality degradation over time***, GPS Solutions, Vol. 19, 2015, pp. 93-105

GNSS-WARP status



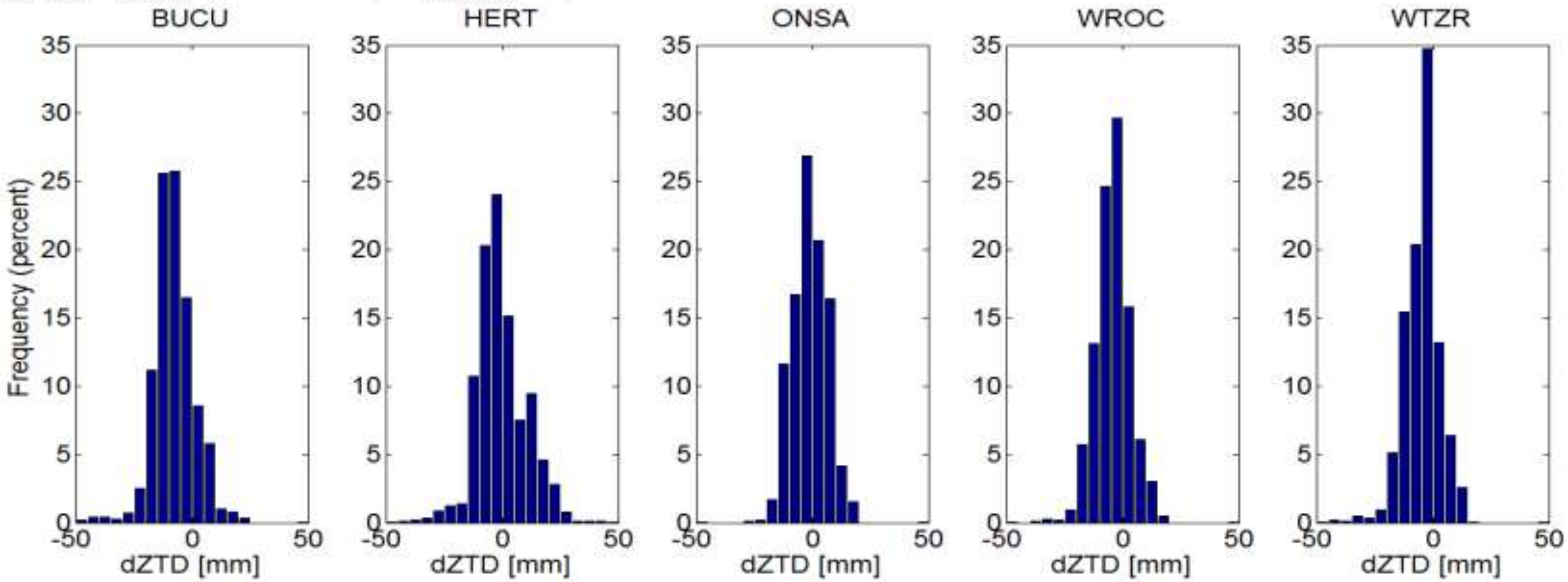
	GPS	GLONASS	Galileo	BeiDou
SP3+CLK	operational	operational	operational	test phase
broadcast	operational	operational	operational	tracked
real-time	operational	IOD problems	test phase	not available

GNSS-WARP software – real-time troposphere service



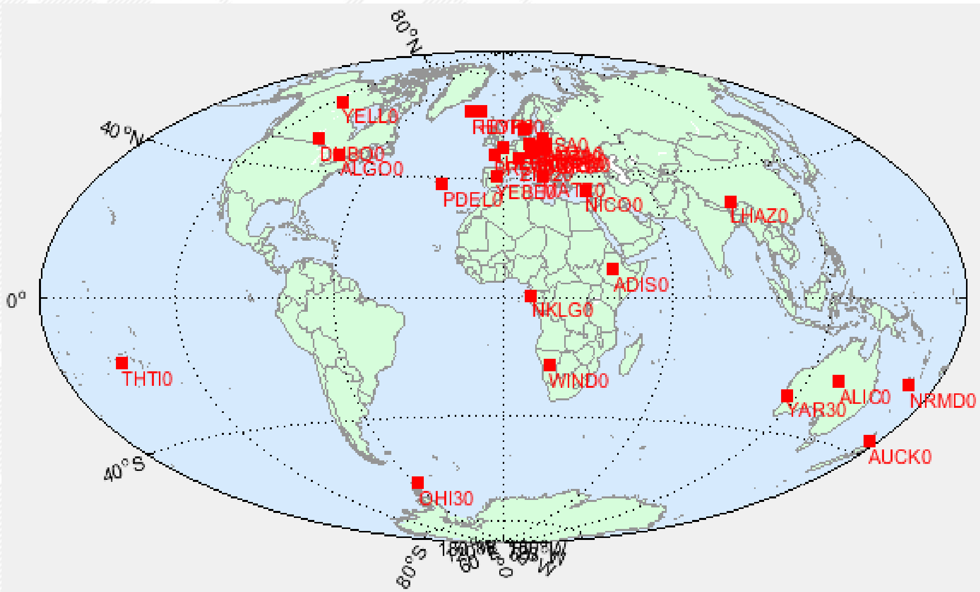
RT ZTD benchmark 1 – simulated real-time

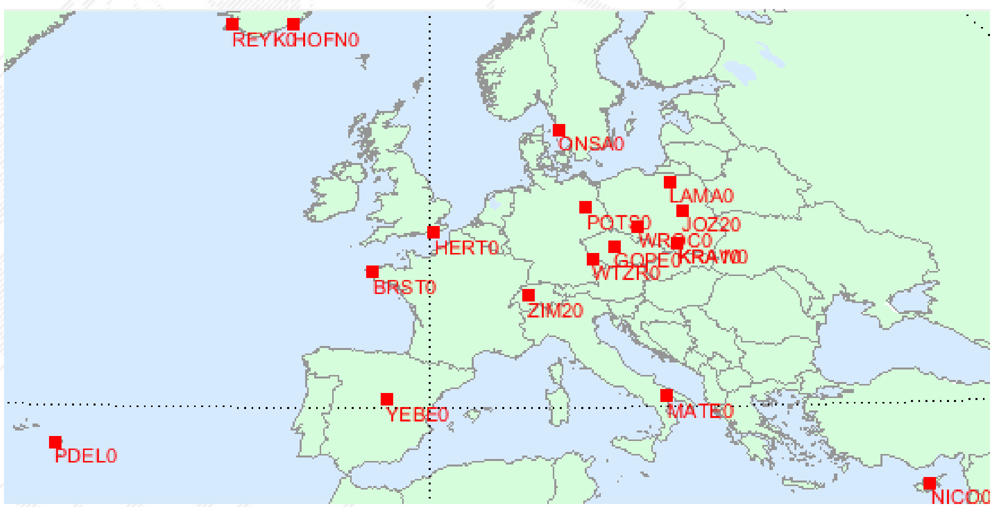
- RTS IGS03 stored (BNC) in **SP3** and **CLK** files, **RINEX** files for **10 stations**, **one week**
- station by station **postprocessing** (0.1Hz) with GNSS-WARP v2
- comparison with **final-ZTD** estimates from EPN (**1 hour sampling**)
- purpose: optimize methodology, evaluate possible quality



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.

RT ZTD benchmark 2 - real-time demonstrator (1)





Real-time ZTD:

33 stations @ 5 sec. sampling:

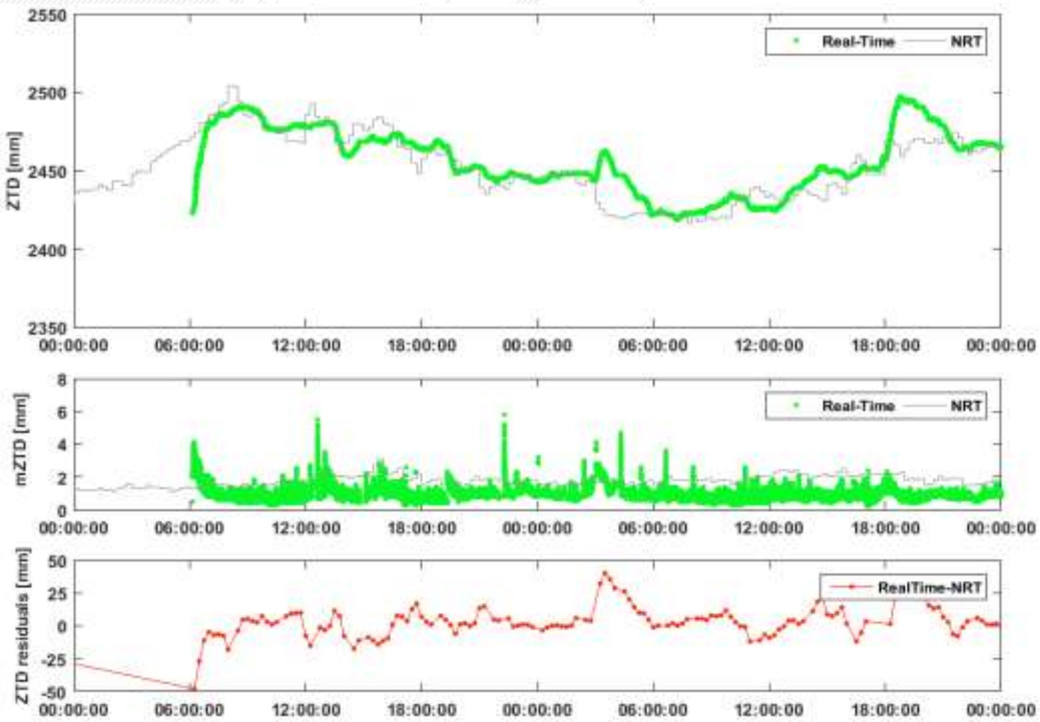
- COST RT TROPO benchmark stations (some have problems!)
- Polish EPN stations

Week 1863 performance (σ - formal error):

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

RT ZTD benchmark 2 - real-time demonstrator (2)

- 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

RT ZTD benchmark 2 - real-time demonstrator (2)

- RTS **IGS03 stream** and **10 observation streams** decoded with BNC, **one week**
- **multi-station real-time** processing with GNSS-WARP v2.1M
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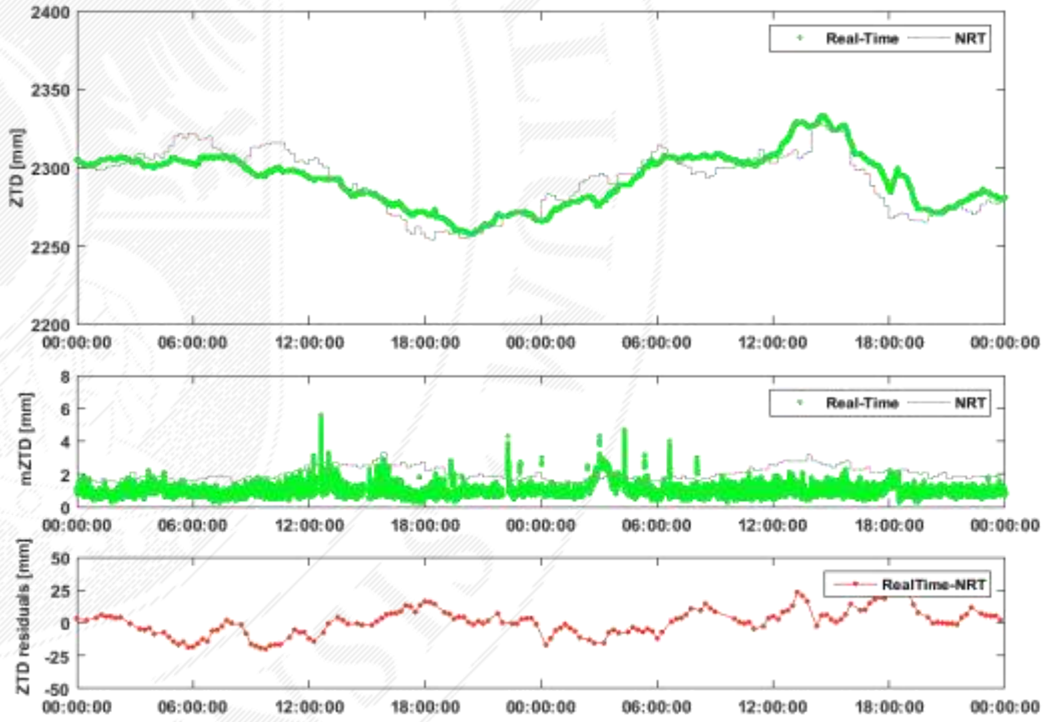


*Station **WTZR***

13-14.06.2015

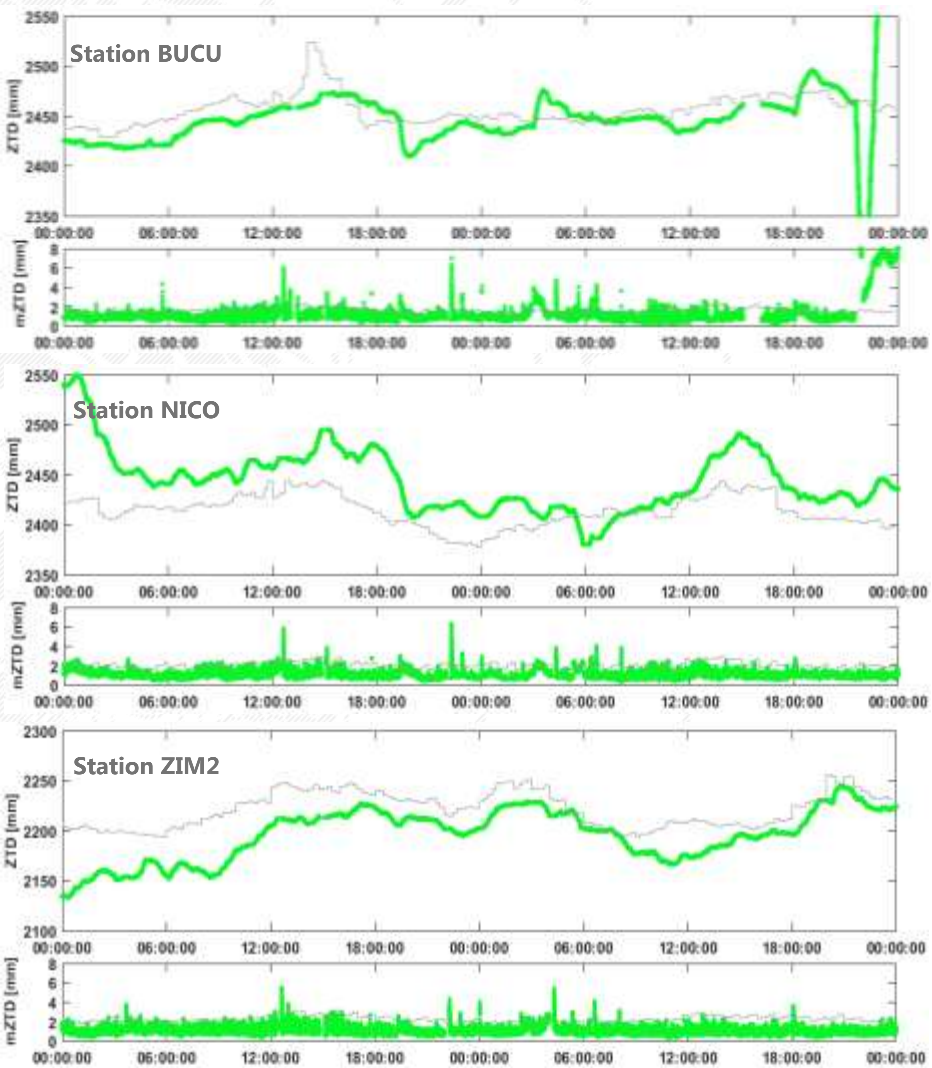
availability: 97%

mean formal error: 1.1mm

mean bias: -1.0mm

StdDev of residuals: 15.5mm

RT ZTD benchmark 2 - real-time demonstrator (3)



Bugs & errors

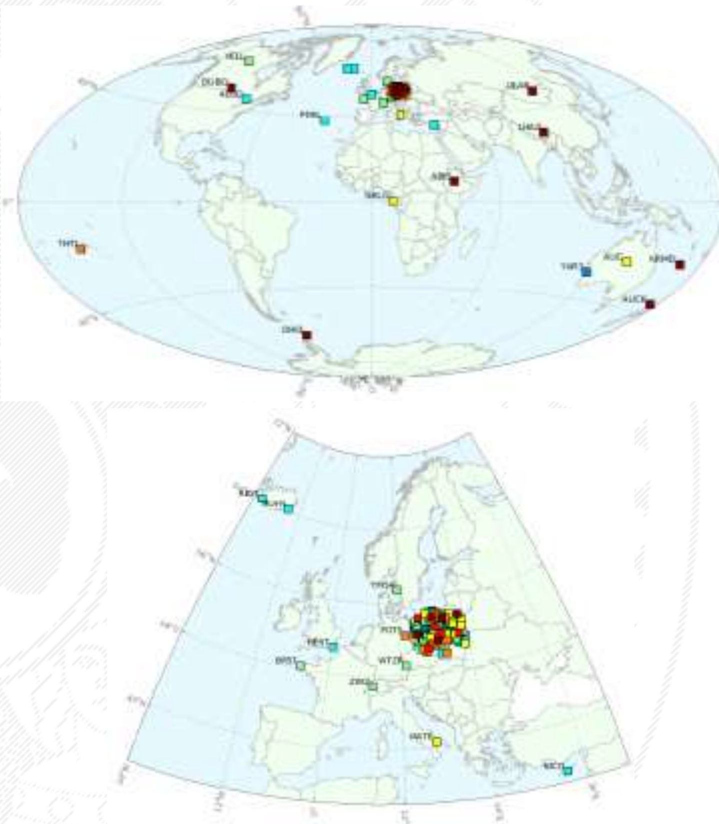
1) Real-time service problems:

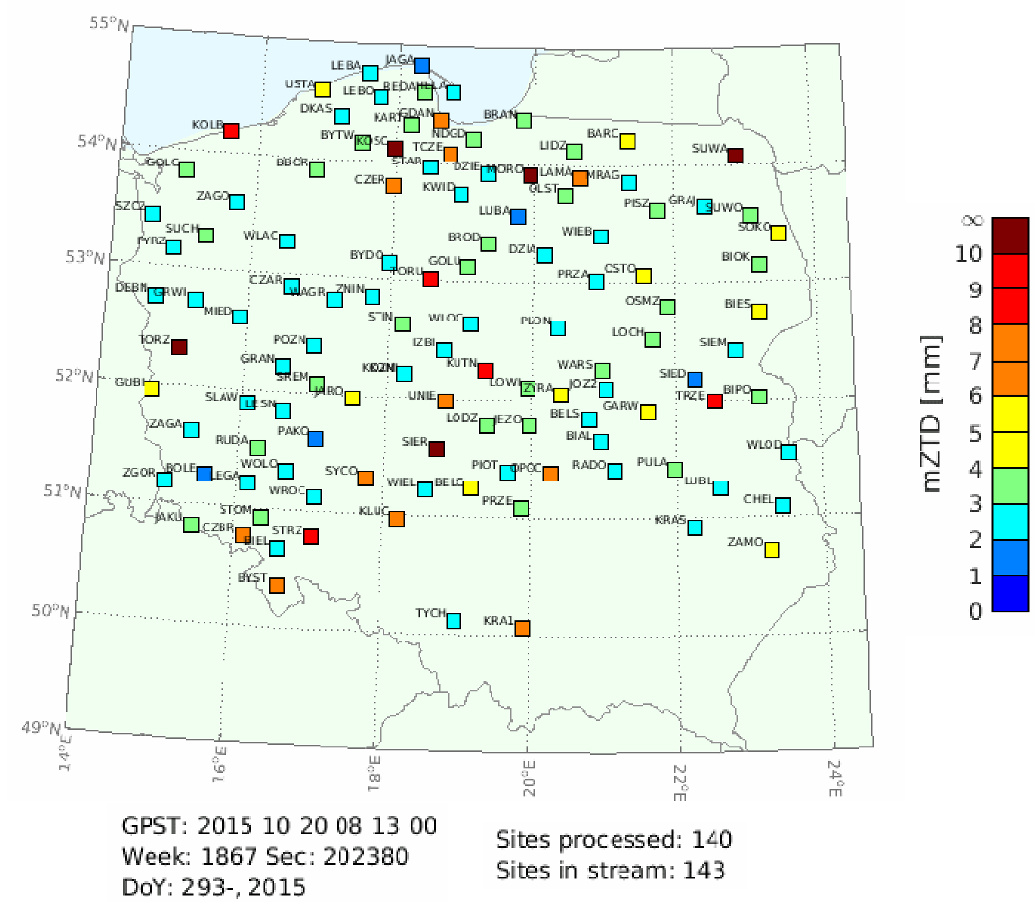
- IGS03/RTCMEPH stream failure (e.g. mismatching IOD's)
- stream recovery failure in BNC (solved: use Ntrip 1, not Ntrip 2)
- long gaps in streams availability (re-initialization of the solution)

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 RT-ZTD monitoring service in Poland (1)



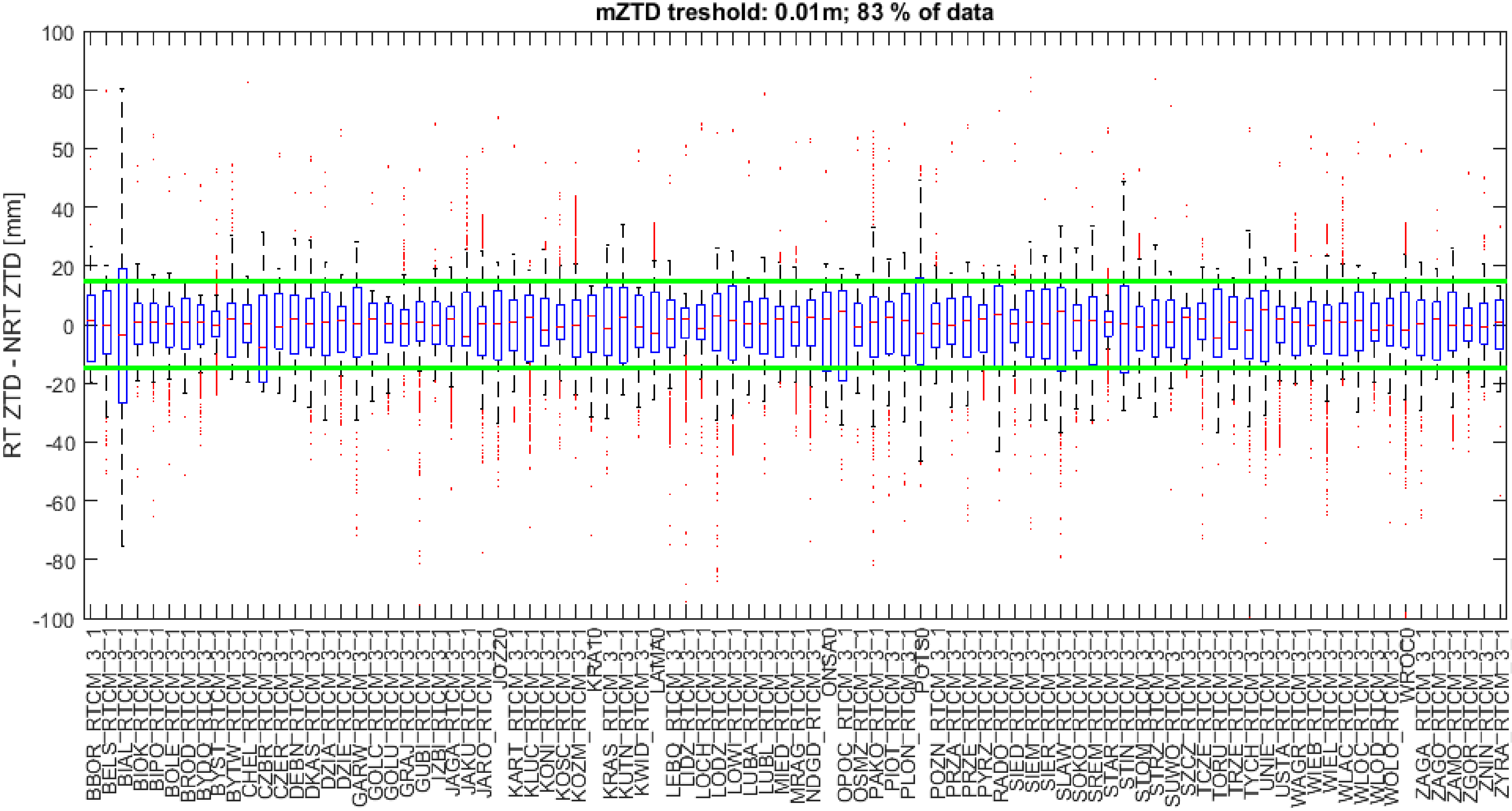


Recent problems:

- 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 (3)

RT ZTD service (under development, improvements required)

- 14 IGS + 19 EPN + 110 Leica SmartNet

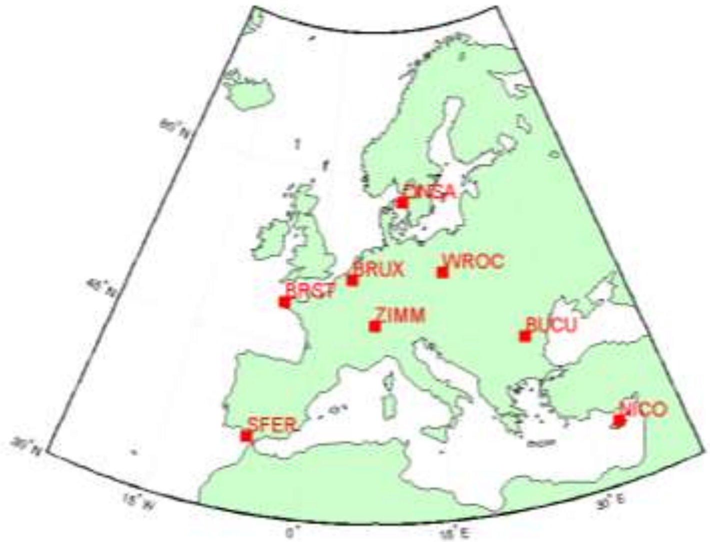
Sub-hourly ZTD	Treshold	Target	Optimal
Accuracy	**15 mm**	10 mm	5 mm
Timeliness	1 h	30 min	**15 min**
Spatial coverage	Europe	Europe to **National**	Regional to **National**
Horizontal Sampling	100 km	**50 km**	20 km

RT tropospheric gradient estimation

Calculation parameters	
Products	RT-IGS RT-CNES
Mapping function	VMF
Model	Chen & Herring $$\delta\kappa \quad \varepsilon,\alpha \quad = \frac{1}{\sin \quad \varepsilon \quad \tan \quad \varepsilon \quad + C} \quad G_N \cos\alpha + G_E \sin\alpha$$
Interval	every epoch
Random walk	0.0003 m/sqrt(h)

RT tropospheric gradient estimation - validation

RT tropospheric gradients
(GNSS WARP)
vs
PPP tropospheric gradients
(GIPSY 6.2)

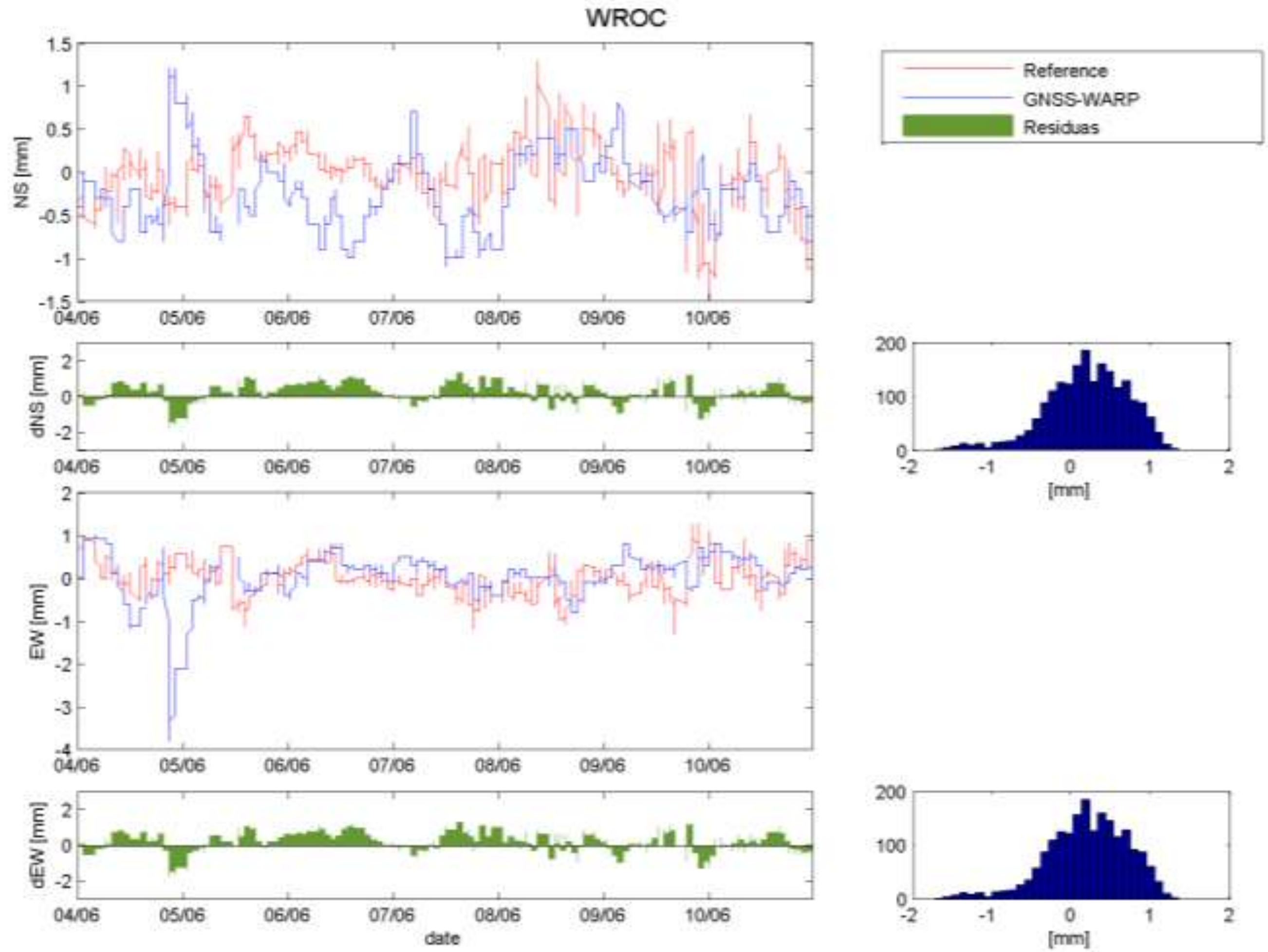


- 8 European station
- 5min sampling
- DoY 155-161 2013
- GPS
- Real-time

	BIAS [mm]		Std.Dev. [mm]		RMSE [mm]	
	NS	EW	NS	EW	NS	EW
'BRST'	-0,03	-0,13	0,97	0,67	0,99	0,72
'BRUX'	0,07	-0,06	0,54	0,48	0,62	0,50
'BUCU'	0,11	-0,26	0,69	0,70	0,75	0,73
'NICO'	0,05	0,01	0,60	0,72	0,65	0,74
'ONSA'	-0,01	-0,01	0,55	0,78	0,86	1,08
'SFER'	0,15	0,05	0,60	0,72	0,66	0,73
'WROC'	-0,02	0,00	0,53	0,68	0,56	0,68
'ZIMM'	-0,07	0,09	0,61	0,55	0,64	0,55
	0,06	0,08	0,64	0,66	0,72	0,72

RT tropospheric gradient estimation - validation

BIAS [mm]	
NS	EW
-0.02	0.00
Std.Dev. [mm]	
SN	EW
0.53	0.68
RMSE [mm]	
SN	EW
0.56	0.68



Conclusion

1. The RT IGS and other AC centres are the Multi-GNSS products
2. The RT PPP is the alternative technique in GNSS meteorology and will be developed in future.
3. The gradients estimated in RT are significant information for the meteorology and should be developed in future.
4. The PPP positioning technique by external RT ionosphere and troposphere models gives a stable solution and research in this area should be continued.

IAG Commission 4 Positioning and Applications Symposium
Wroclaw Poland, September 4-7, 2016

Abstract submission: **June 15, 2016**
Notification of acceptance: July 1, 2016
Registration: July 31, 2016

http://www.igig.up.wroc.pl/iag2016/

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Thank You!

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