Wrocław University of Environmental and Life Sciences

Emerging GNSS based tropospheric products

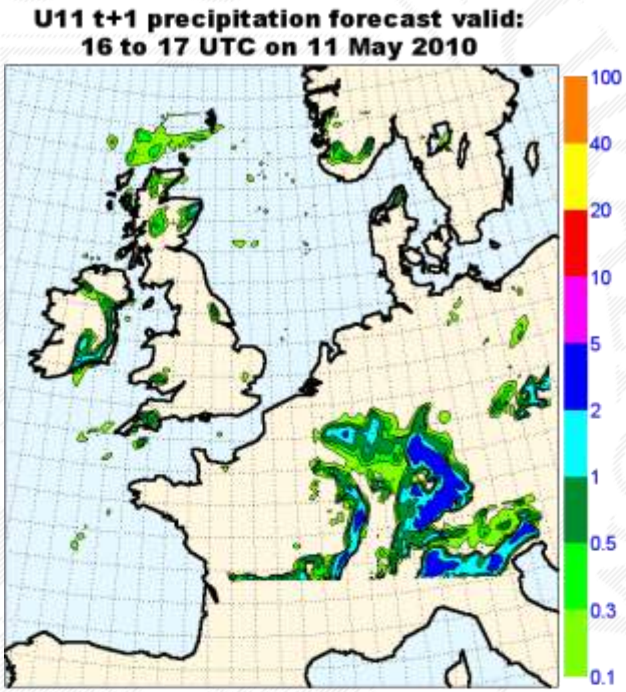
Jaroslaw Bosy, Witold Rohm, Jan Kaplon, Tomasz Hadas, Karina Wilgan, Pawel Hordyniec, Krzysztof Sosnica, Kamil Kazmierski, Jan Sierny

The 7th China Satellite Navigation Conference, May 18-20 Changsha China, Session F3: CSNC – CPGPS PANEL

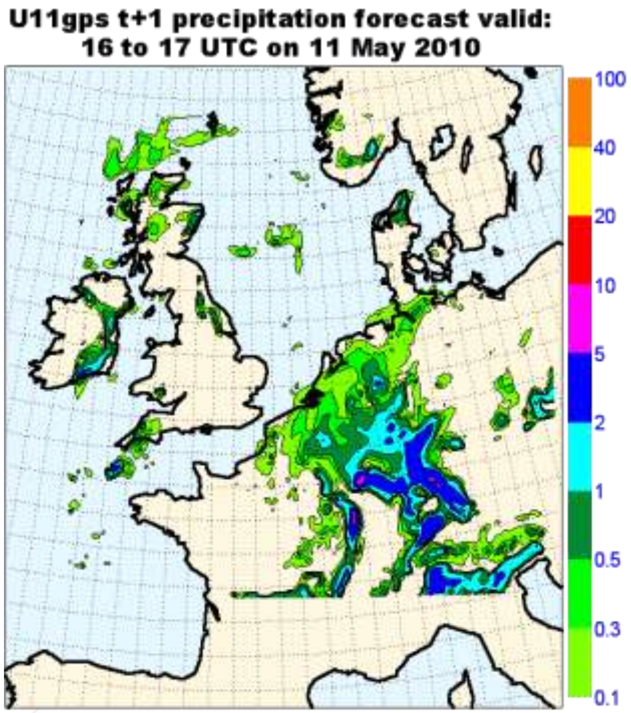
Presentation plan

1. Introduction and motivation
2. Near Real Time PPP GNSS service
3. Real Time PPP GNSS service
4. RO GNSS service
5. GNSS tomography service
6. GNSS and NWP data integration
7. Conclusion

GNSS NRT ZTD assimilation in NWP

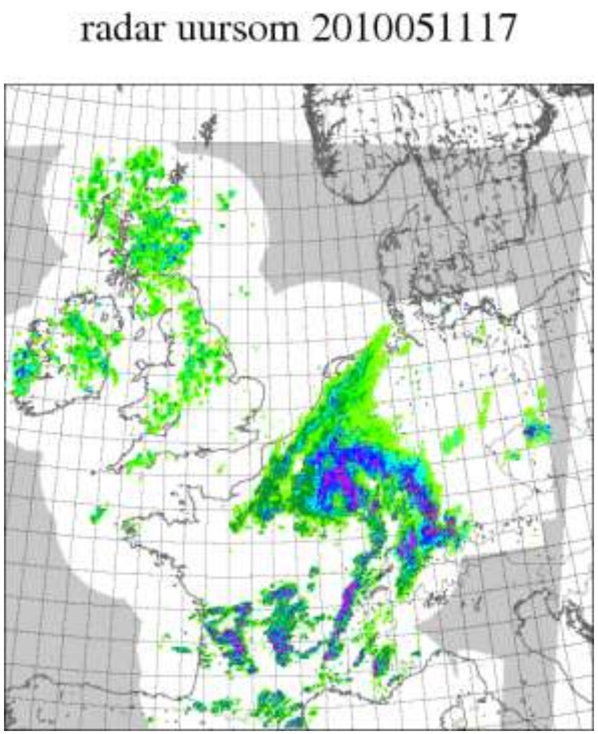


Forecast without GPS



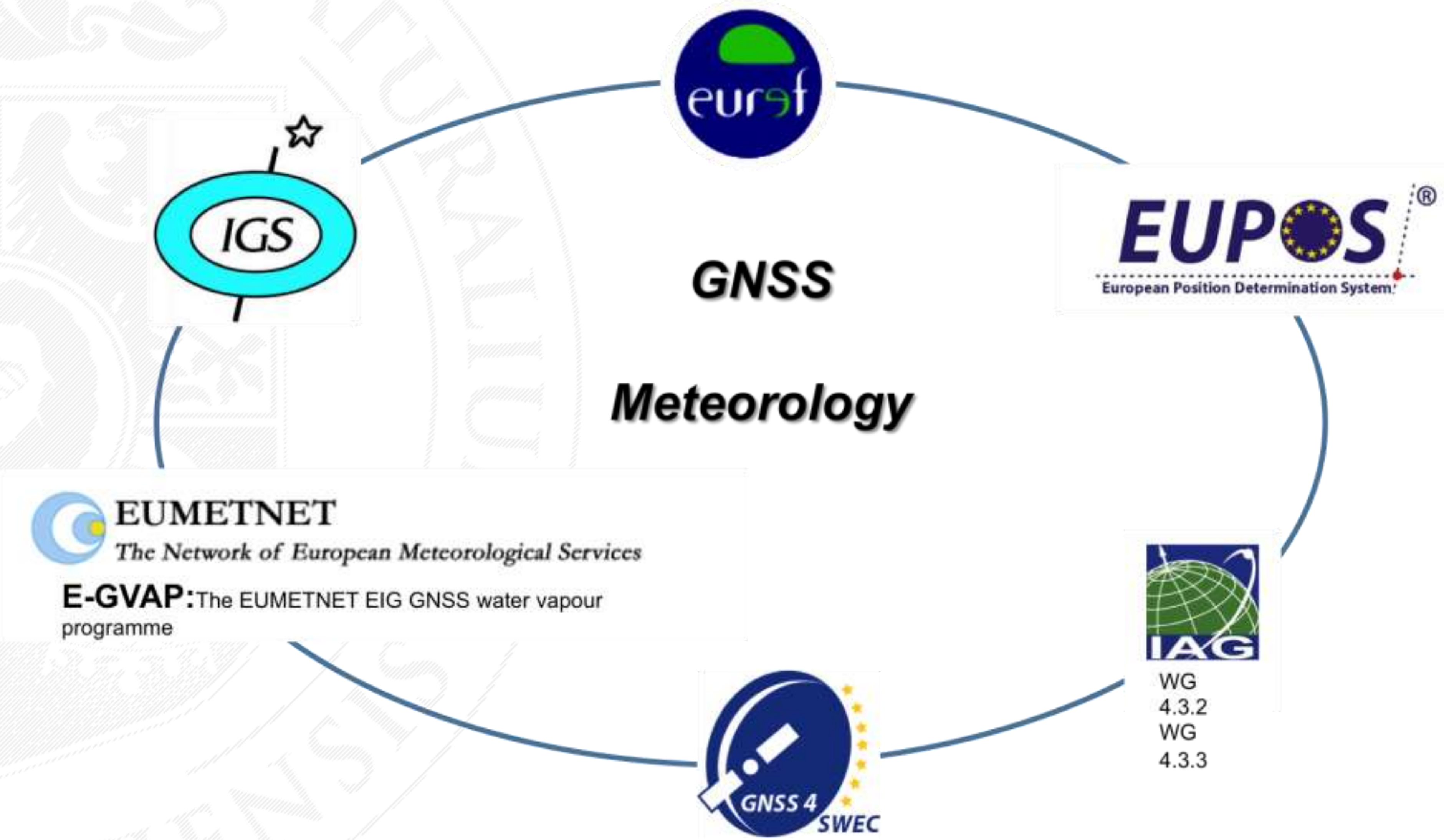
Forecast with GPS

(source Siebren de Haan KNMI)



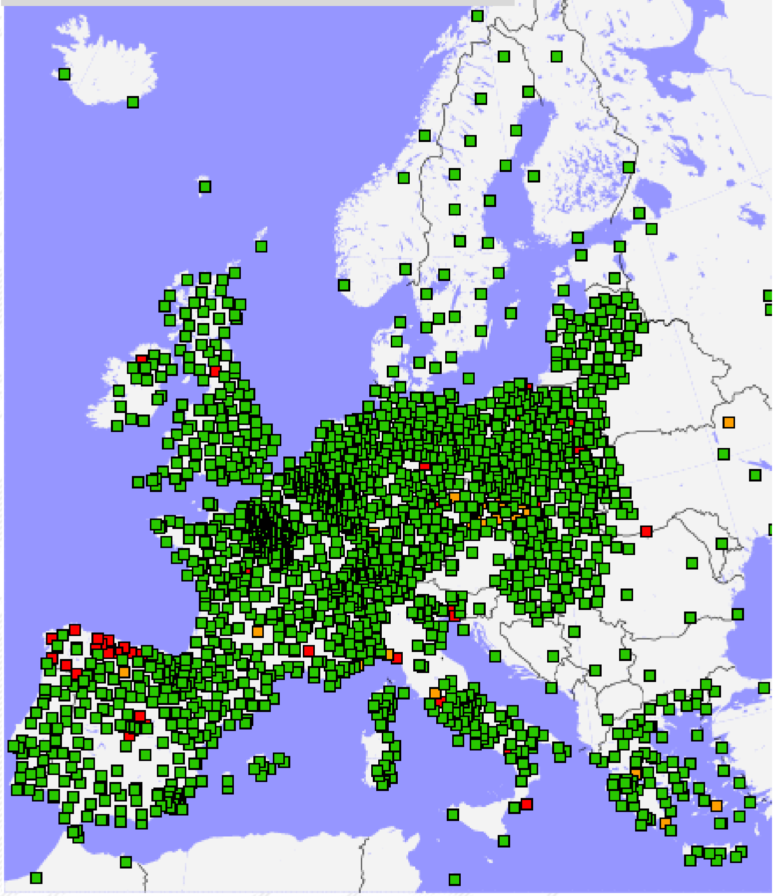
Radar composite

GNSS and METEO comunity integration



Growing ground-based infrastructure – CORS

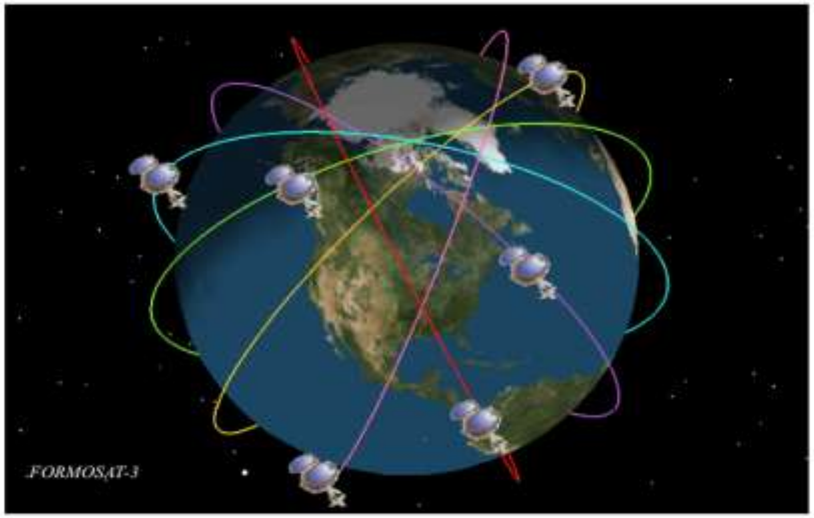
www.egvap.dmi.dk

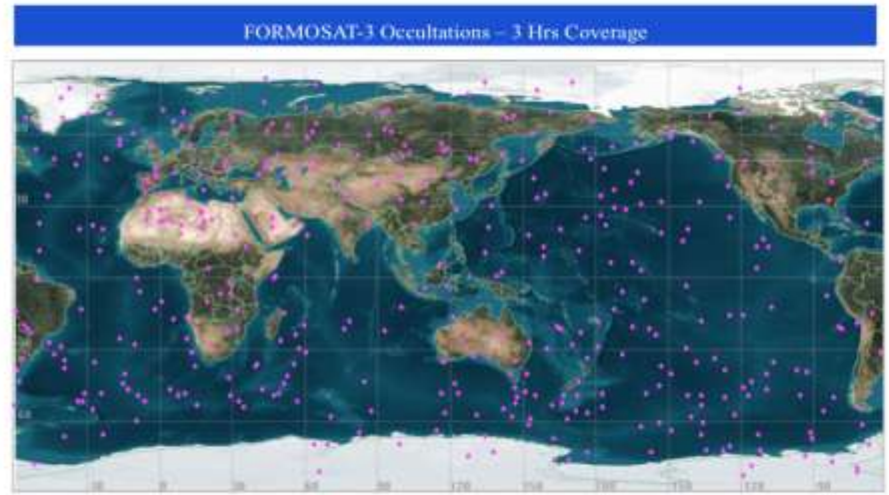


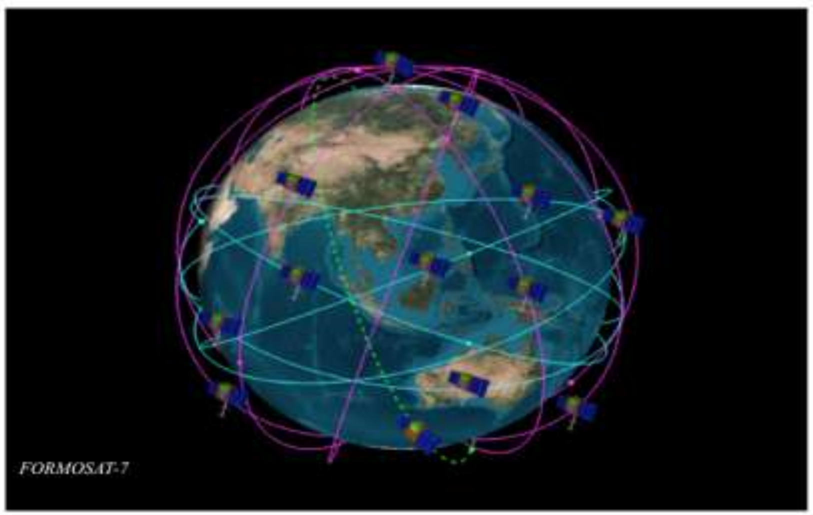
- E-GVAP (~2500 GNSS stations) dedicated processing for meteorology
- Interesting example of geodesy and meteorology collaboration
- Near real-time processing with quality control
- BUFR and COST format export for EUMETNET consortium members
- WUELS hosts GNSS processing centre for Poland

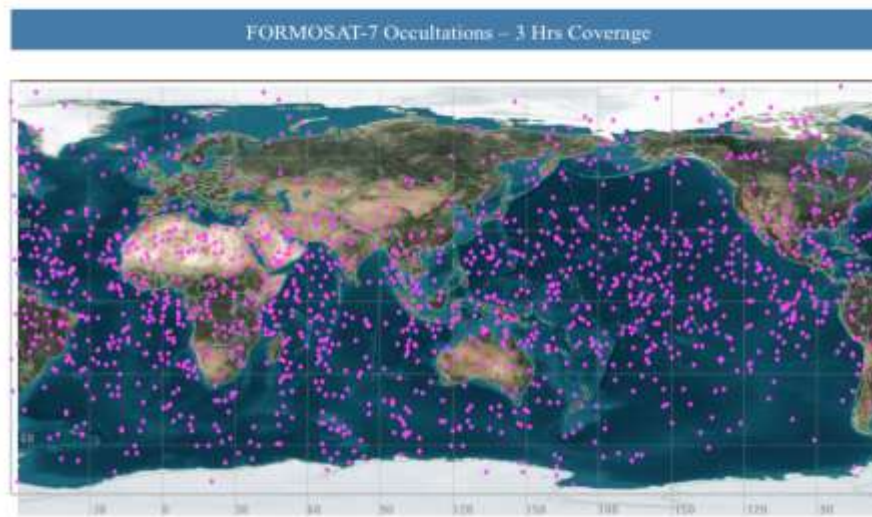
http://www.suominet.ucar.edu/

New satellite mission e.g. COSMIC II









6 satellite on low inclination angle (2016), 6 satellite in high inclination orbits (2018), P NOAA + NSPO programme, 12,000 profiles per day

Źródło: www.cosmic.ucar.edu, credicts: NSPO - Taiwan

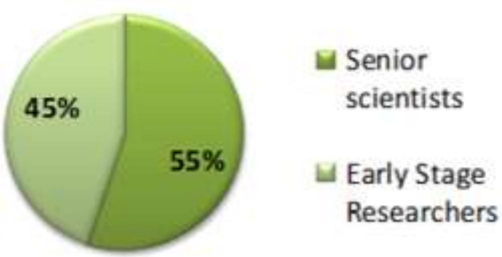
COST Action ES1206 - **GNSS4SWEC - Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate** *(http://gnss4swec.knmi.nl)*

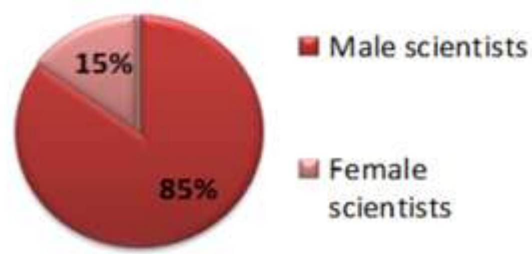
23 COST Countries

55 Participants

25 ESRs (45%)

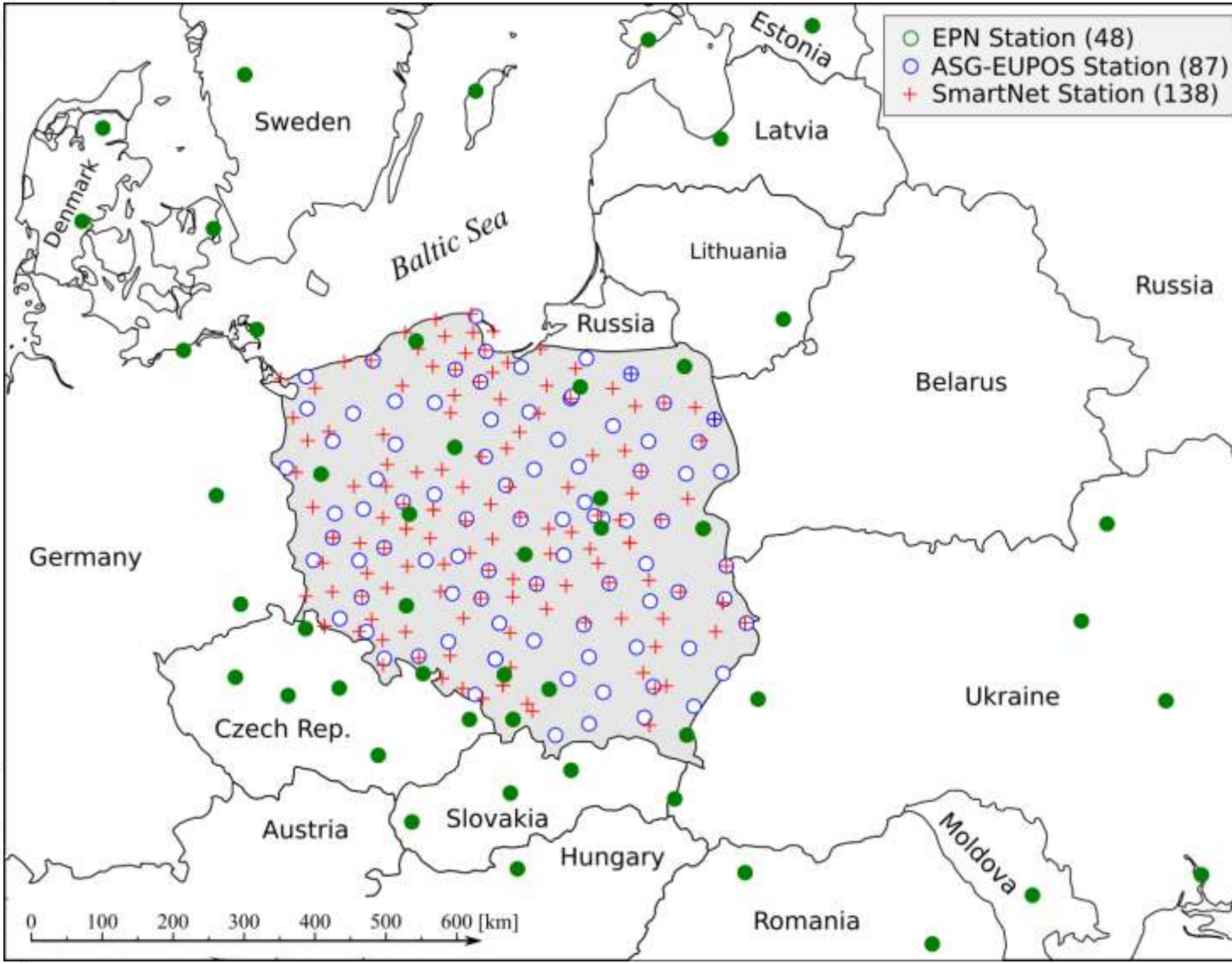
8 Female Scientists (15%)





Met Office

New „WUEL" network (ASG-EUPOS + SmartNet)



Since Aug 26, 2015
12:00 UTC (BSW 5.2)

NRT DD processing details

Parameter	Value
Processing type	Post-processing (Double-differenced)
Satellite system considered	GPS only
Observation window	6 hours
Observation cut-off angle	5°
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).
Reference frame for epoch solution	IGS and ARGN IGb08 coordinates and velocities
Method of referencing epoch solutions	Minimum constraining on all reference station positions.

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]

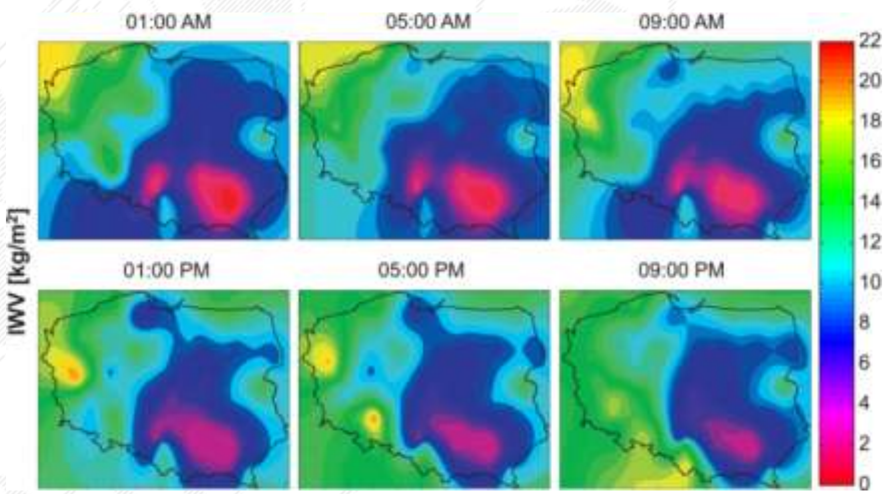
ϕ - point latitude [rad]

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)]



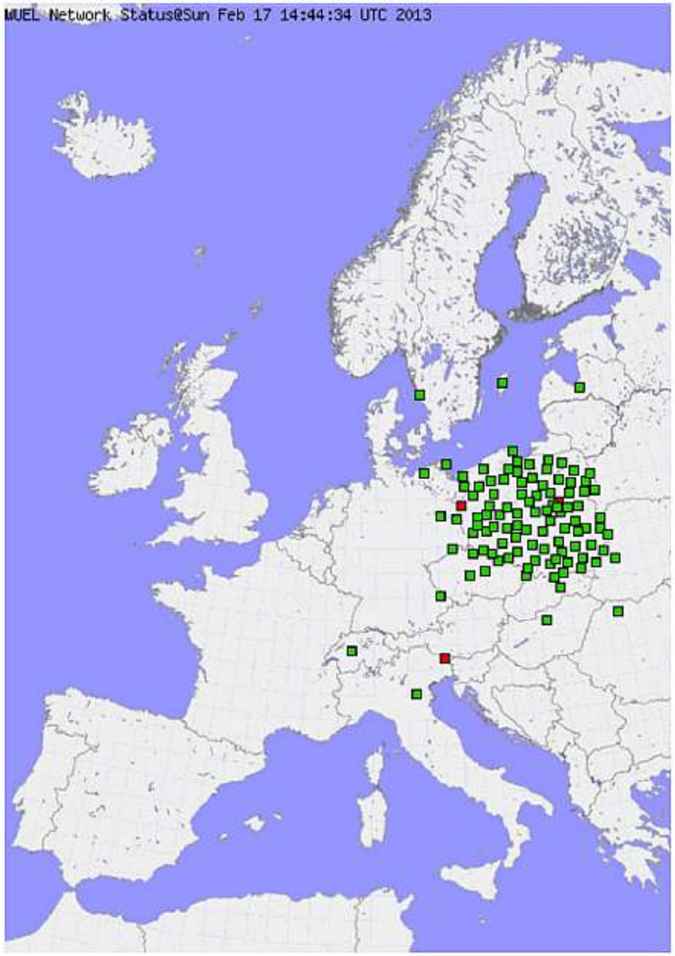
Example of the Integrated Water Vapour (IWV) 2D distribution over the area of Poland calculated for November 7, 2012, shown as a time series with 4 hours interval

COST-716 Format

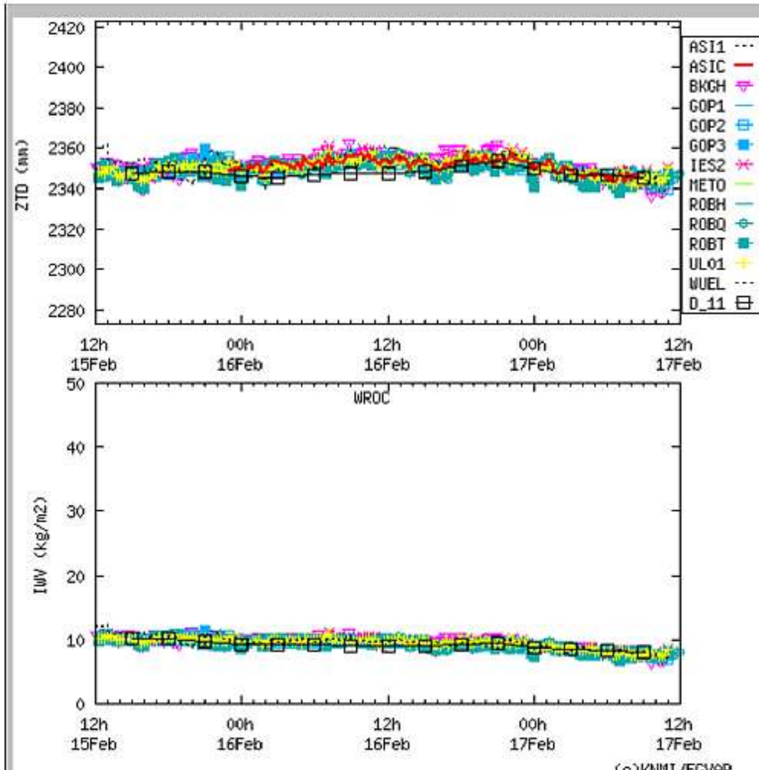
```
--------------------------------------------------------------------------------
COST-716 V2.0a           E-GVAPII
BIAL 12235M001           Bialystok (Poland)
TRIMBLE NETRS            TRM41249.00     TZGD
   53.132083   23.138750     191.393     163.157       0.000
21-NOV-2012 09:00:00     21-NOV-2012 10:39:30
IGIG                     BERN_V5.0                IGSULT                   NONE
   60   60 1440
00000065
-999
 09 00 00 fffffff 2345.4    1.5   -9.9   -9.9   -9.9   -9.9   -9.9 999.99 999.99  -9.99  -9.99 -9.999
   0
 09 59 00 fffffff 2349.5    2.7   -9.9   -9.9   -9.9   -9.9   -9.9 999.99 999.99  -9.99  -9.99 -9.999
   0
--------------------------------------------------------------------------------
```

```
 ZTD     mZTD    ZWD    IWV     P      T     RH  ZTD Gradients  Grad. Errors   TEC
2345.4    1.5   -9.9   -9.9   -9.9   -9.9   -9.9 999.99 999.99 -9.99  -9.99 -9.999
```

E-GVAP „WUEL” - The WUELS contribution



http://egvap.dmi.dk



HIRLAM(KNMI) AN - GPS ZTD

7day stat. 2013/02/09 - 2013/02/17

AC	num	bias	RMS	stddev
ASIC	56	2.0	3.9	3.3
GOP1	56	2.5	3.9	3.0
METO	56	2.6	4.4	3.5
ROBH	56	1.9	4.3	3.9
TEST				
ASI1	56	3.0	4.8	3.8
BKGH	55	5.7	6.6	3.5
GOP2	56	1.9	3.5	3.0
GOP3	55	3.1	4.8	3.7
IES2	56	2.6	4.4	3.5
ROBQ	56	2.0	4.6	4.1
ROBT	56	1.7	4.6	4.3
UL01	56	2.2	4.0	3.4
WUEL	56	4.3	5.7	3.7

Notes

- Statistics are updated daily
- GPS ZTD are interpolated to NWP analysis time

Graphical location of the site

latitude	51.11330
longitude	17.06200
altitude	140.54

Oct 15th, 2012 to Apr 11 2015 (BSW 5.0)

NWM requirements for tropopshere products

EUMETNET

GNSS 4 SWEC

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

RT ZTD: GNSS-WARP software

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

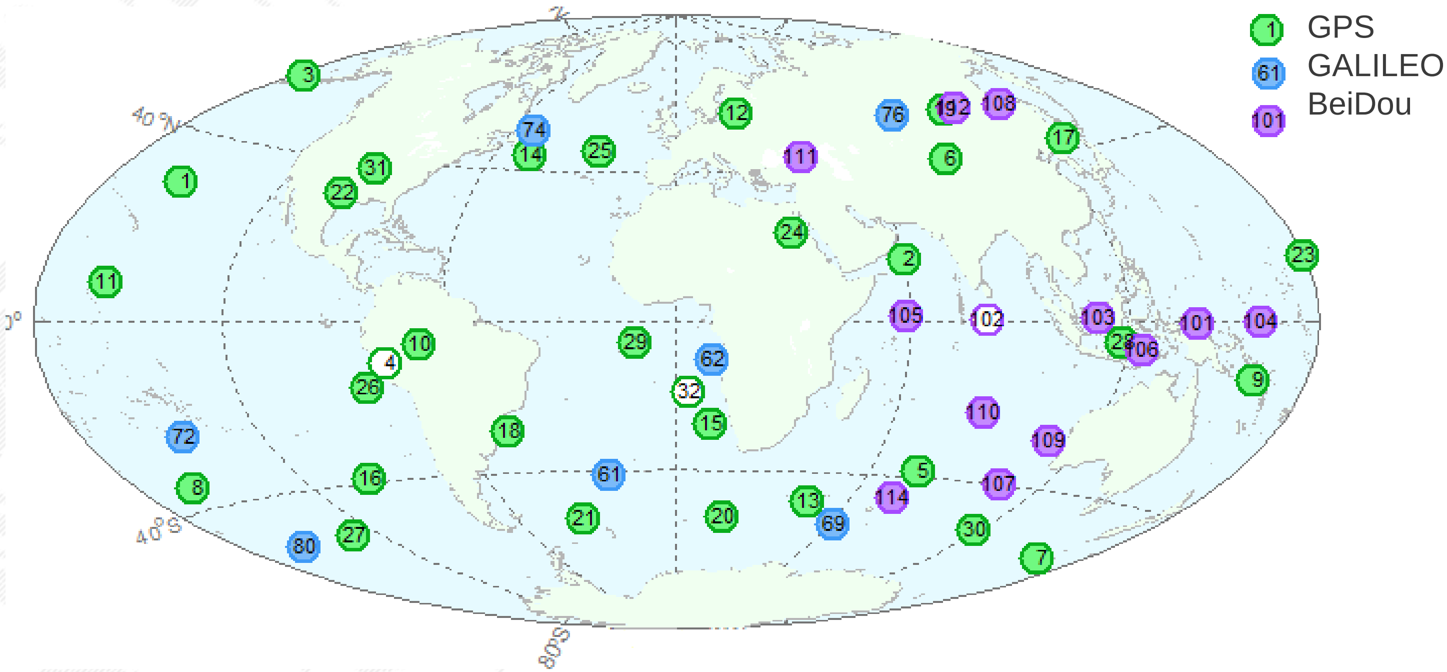
RT-ZTD optimization (GNSS-WARP v2.1m):

- redeveloped and optimized for multi-station, continuous processing
- performance: >10stations / 1 second @1CPU
  (currently: >200 stations every 60 seconds)

Strategy:

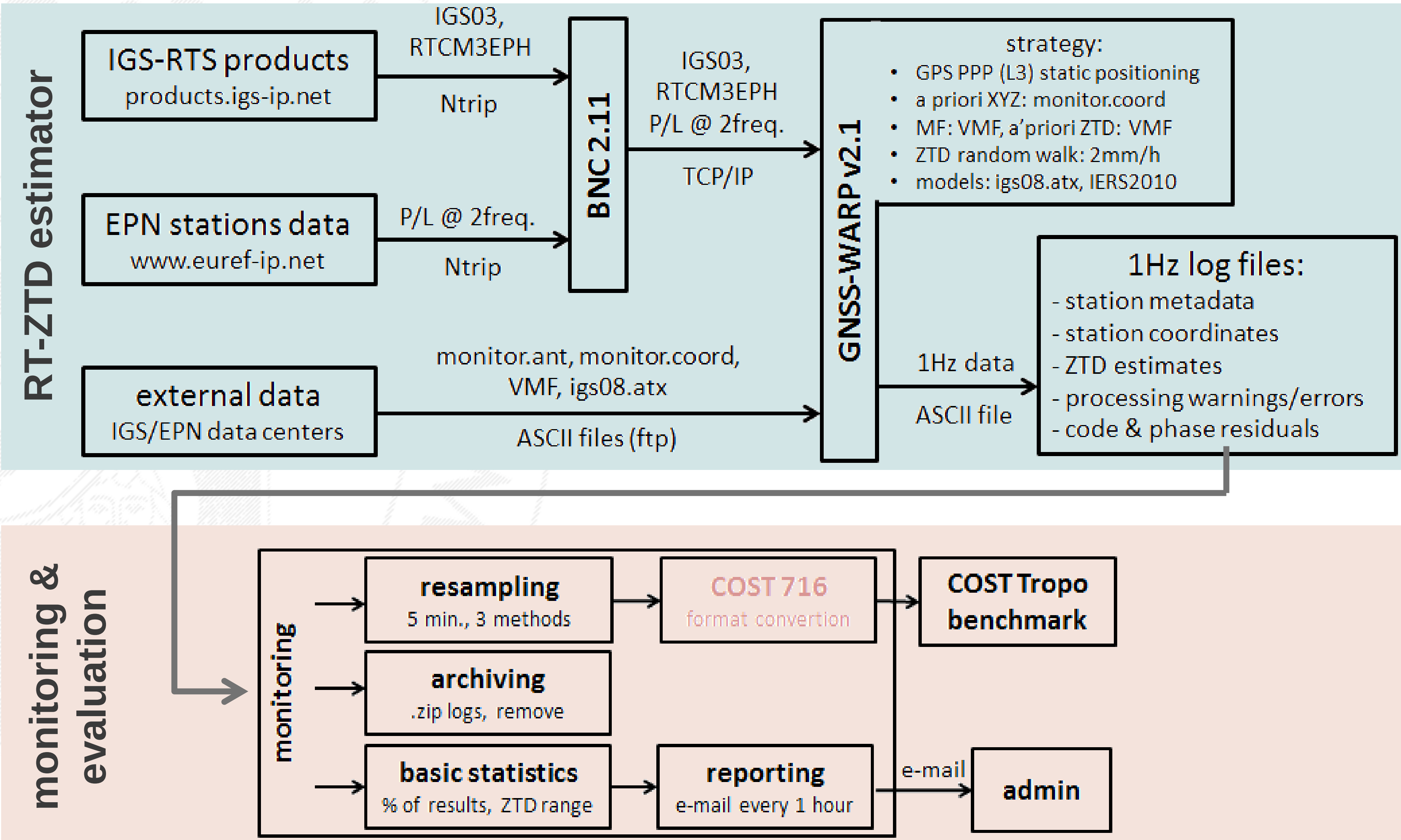
- PPP, static positioning, VMF, IGS03, IERS 2010 models

RT ZTD: GNSS-WARP - multi-GNSS status



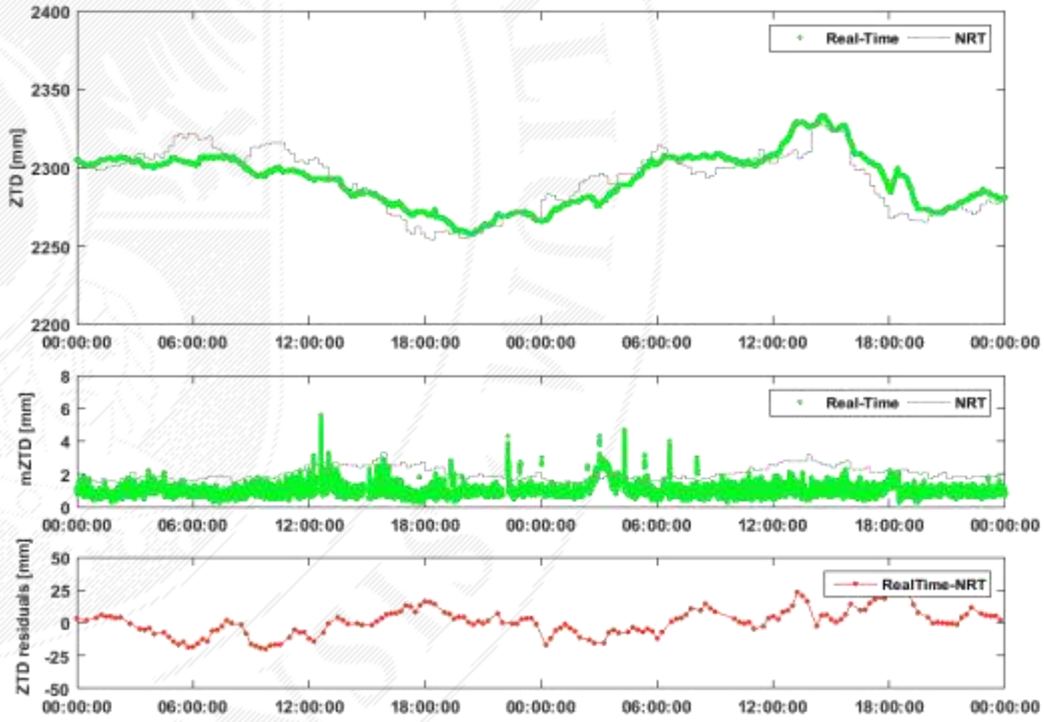
	GPS	GLONASS	Galileo	BeiDou
SP3+CLK	operational	operational	operational	test phase
broadcast	operational	operational	operational	tracked
real-time	operational	IOD problems	test phase	not available

RT ZTD: GNSS-WARP software – real-time troposphere service



RT ZTD: COST 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 **WTZR***

13-14.06.2015

availability: 97%

mean formal error: 1.1mm

mean bias: -1.0mm

StdDev of residuals: 15.5mm

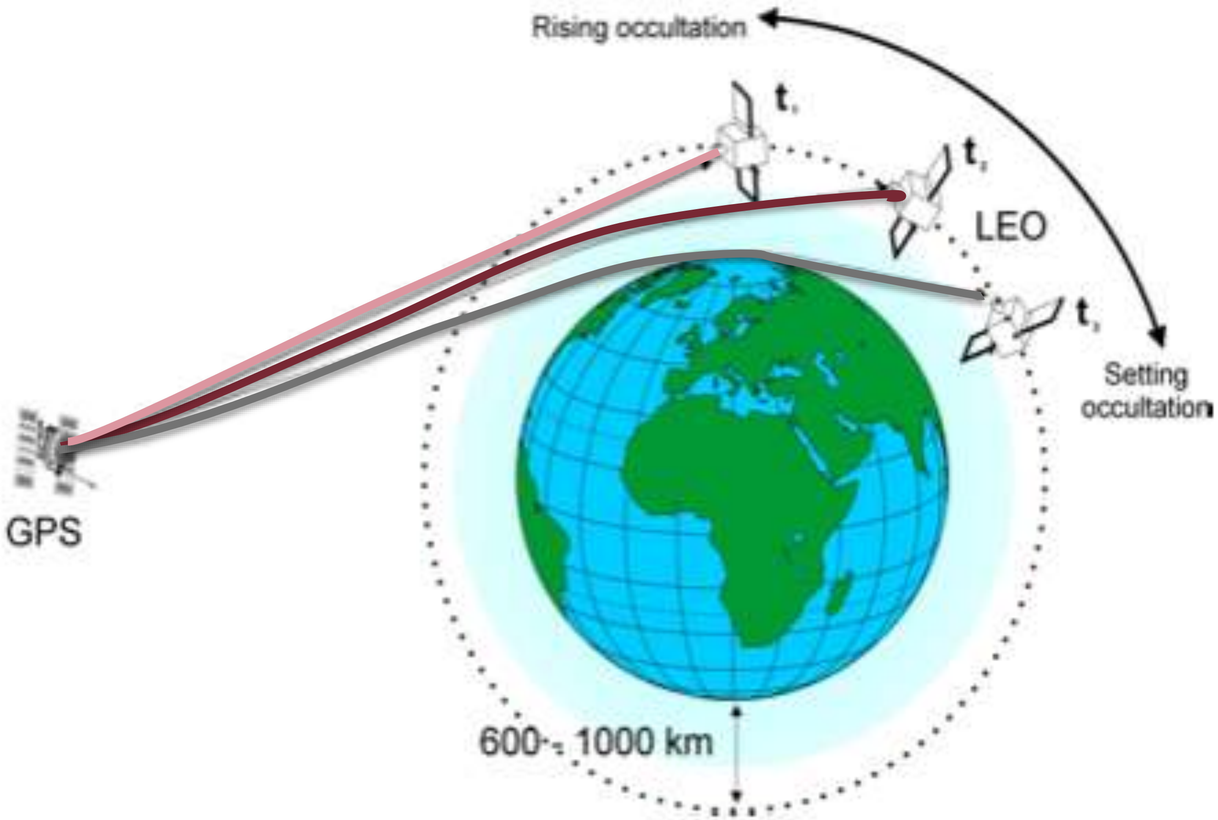
Towards RT-ZTD monitoring service in Poland (3)

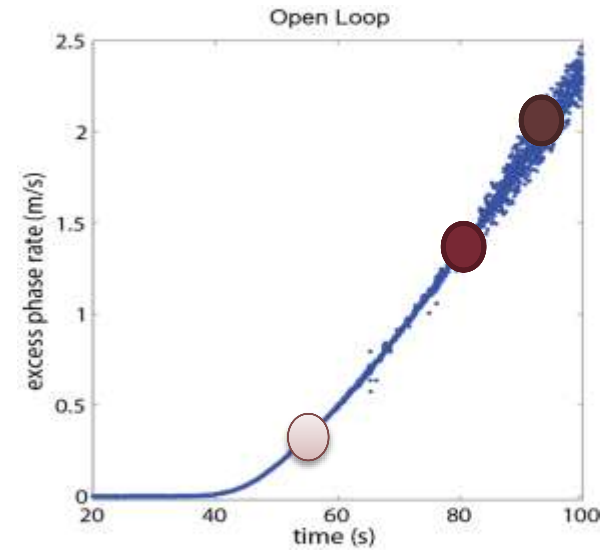
RT ZTD service (under development, improvements required)

- 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

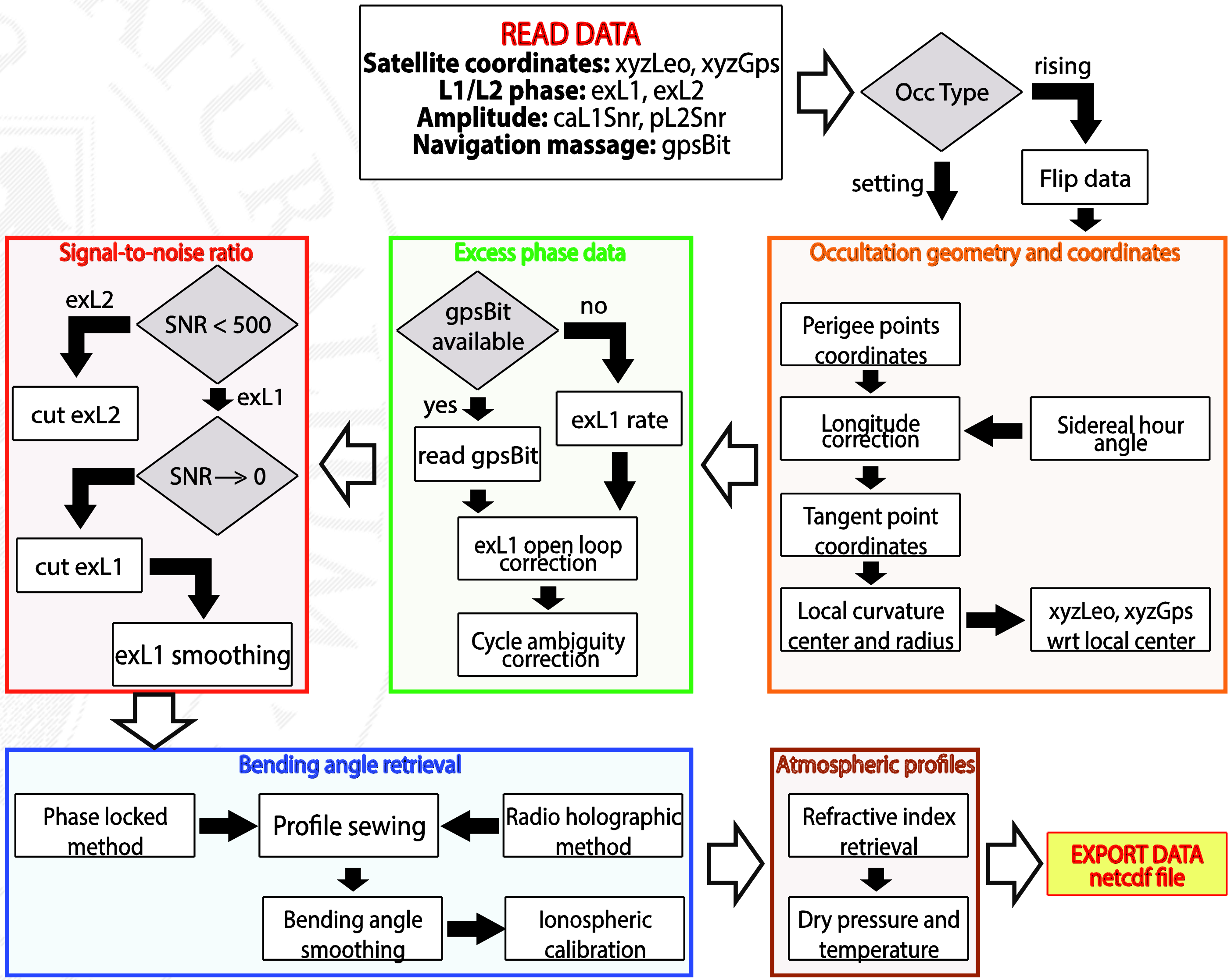
Radio occultation



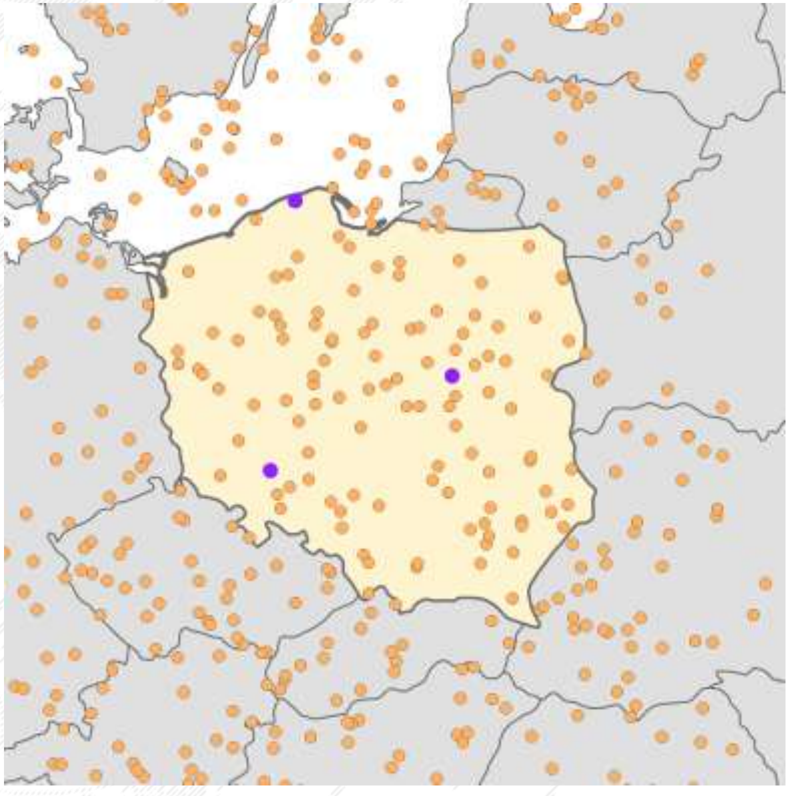


Syndergaard, S., 1998. Modeling the impact of the earth's oblateness on the retrieval of temperature and pressure proles from limb bounding. Journal of Atmospheric and Solar-Terrestrial Physics 60 (2), 171{180.

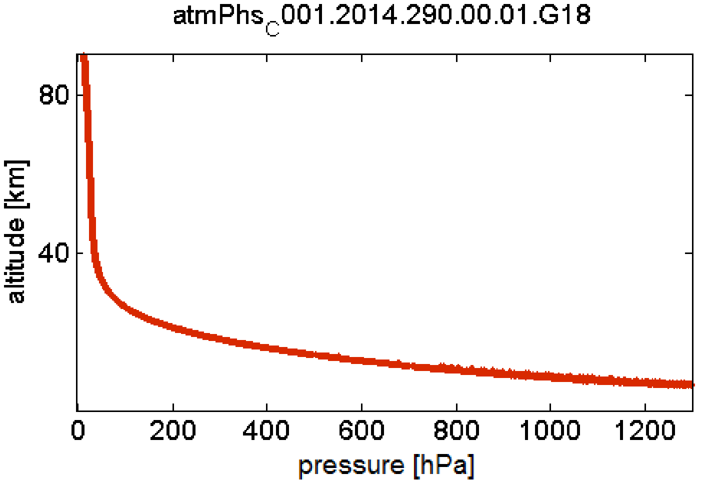
RO WUELS software (1)

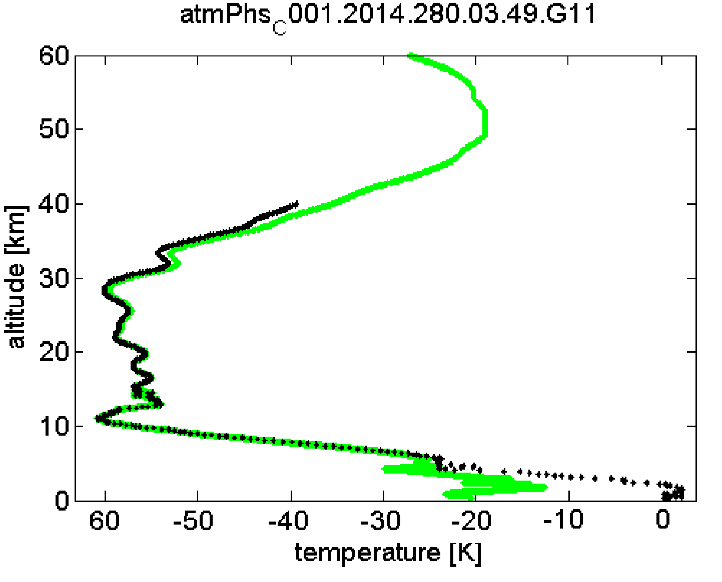


RO WUELS software (2)



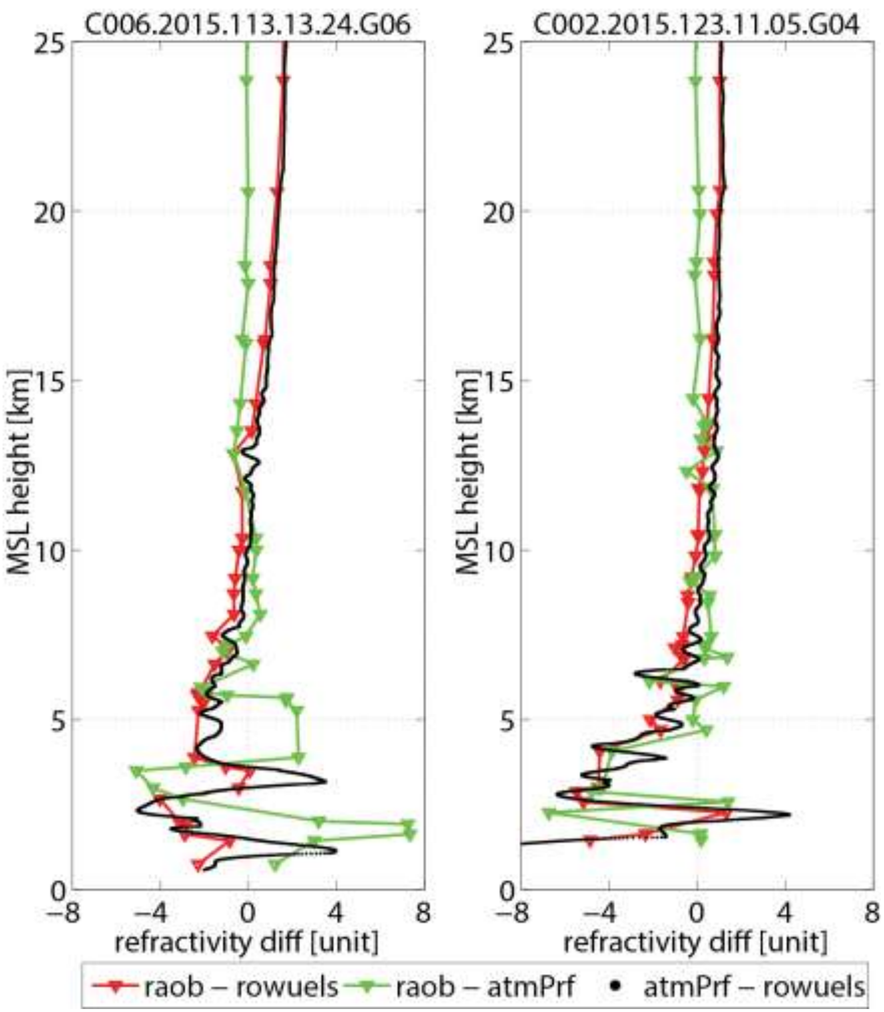
$$N = (n-1) \times 10^6 = k_1 \frac{P_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$





RO WUELS software(3)

Near-real time FORMOSAT-3/COSMIC atmospheric profiles

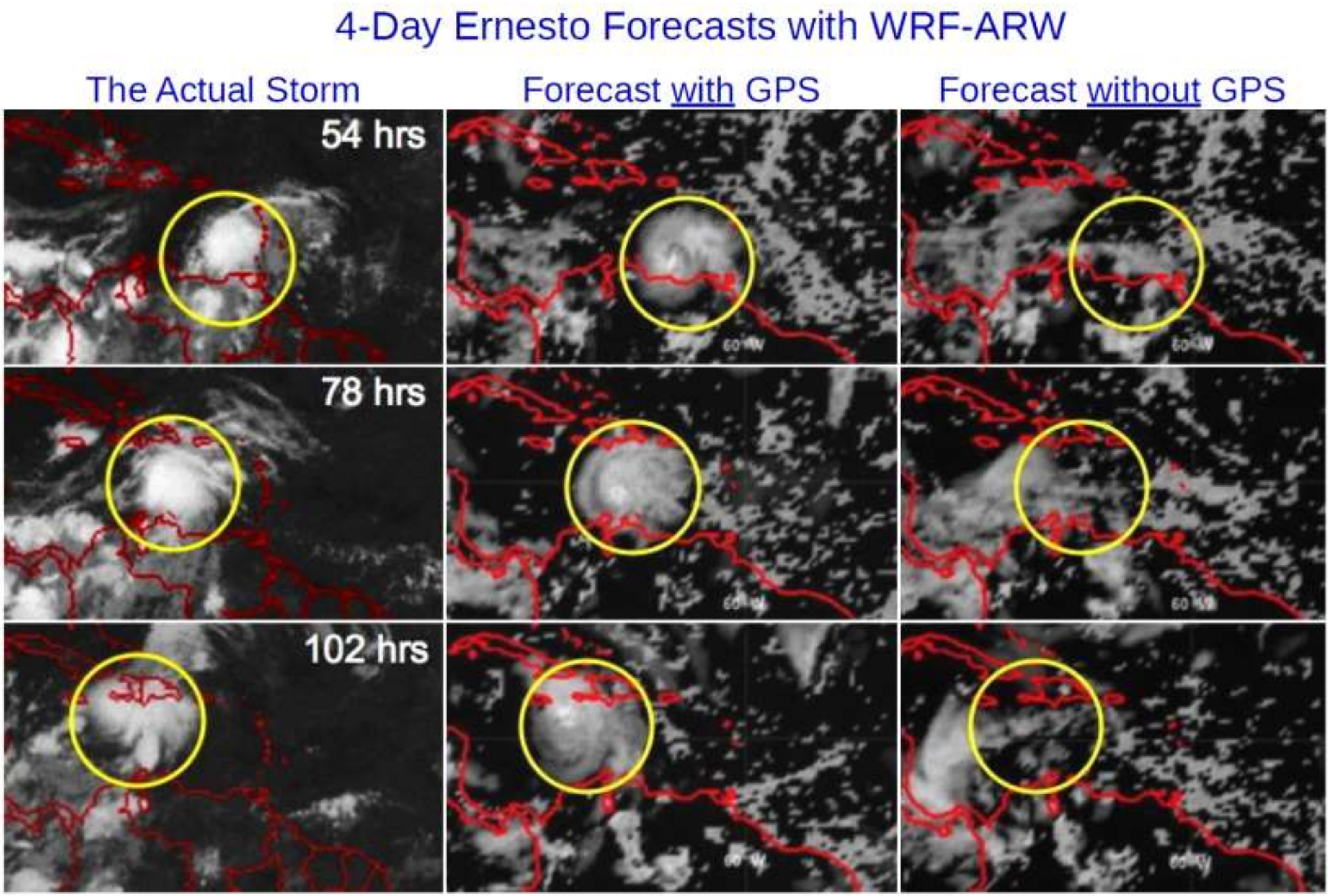


1. **Excess phase processing to dry atmospheric profiles**

- Open Loop correction in the troposphere
- Radioholographic methods to resolve signal multipath:
  - Full Spectrum Inversion (FSI) and Phase Matching (PM)
- Inverse Abel transform to retrieve refractive index profile
- Forward operator to bending angle
- Validation with respect to CDAAC atmPrf and radiosonde profiles:
  - ± 100 km collocations
  - up to 4 units residuals for refractivity

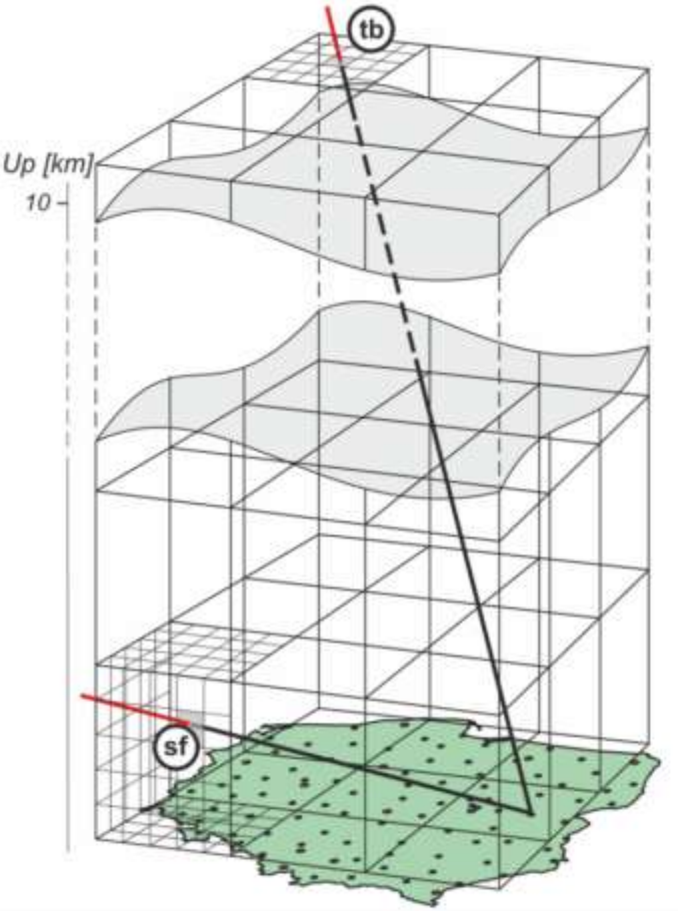
Data from Taiwan Radio Occultation Process System (TROPS) will be included.

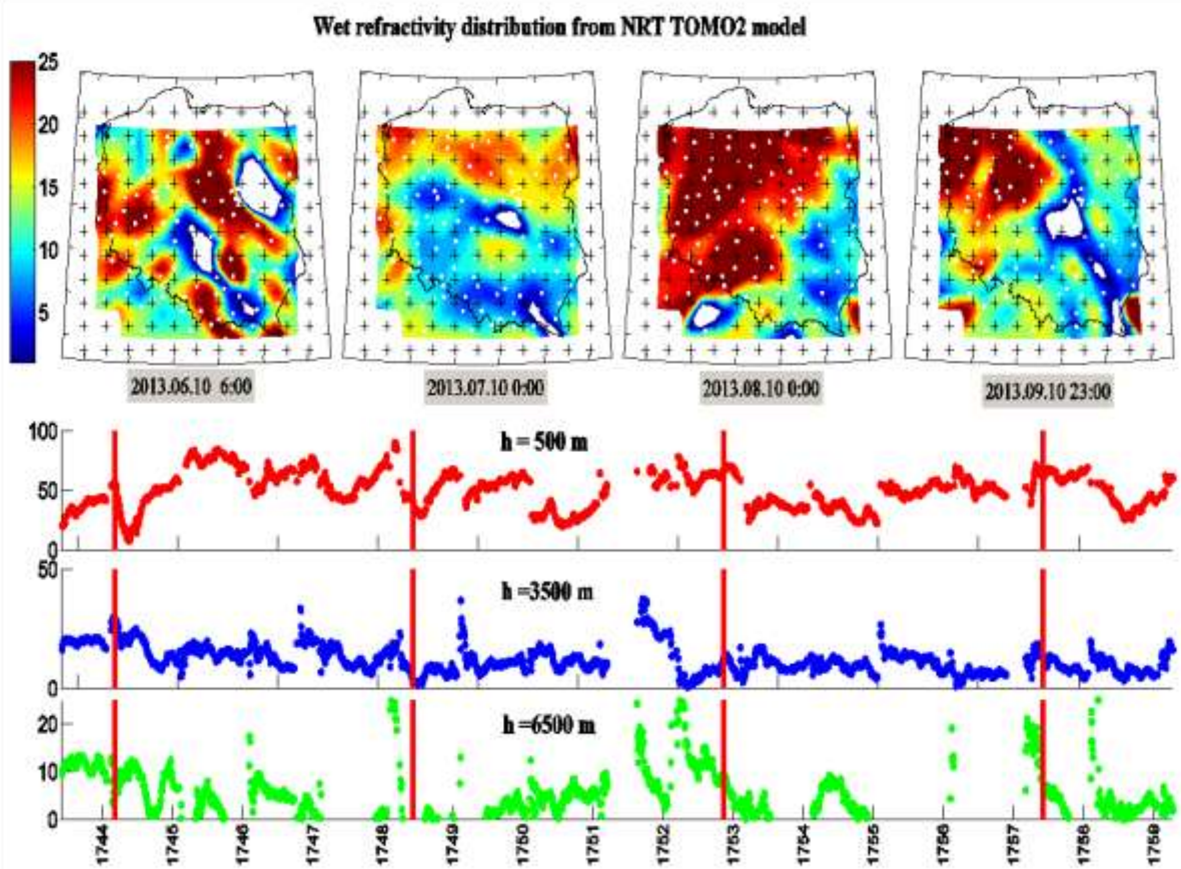
Impact of RO data assimilation



źródło: The Impact of GPS Radio Occultation Data on the Analysis and Prediction of Tropical Cyclones Bill Kuo and Hui Liu UCAR COSMIC

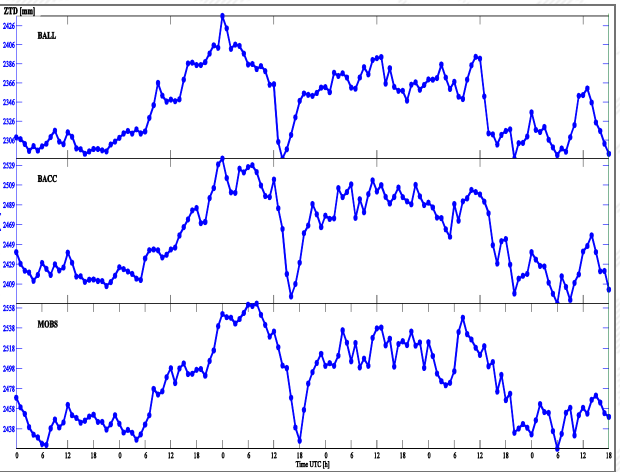
TOMO2 : 3D NRT GNSS tomography model for area of Poland





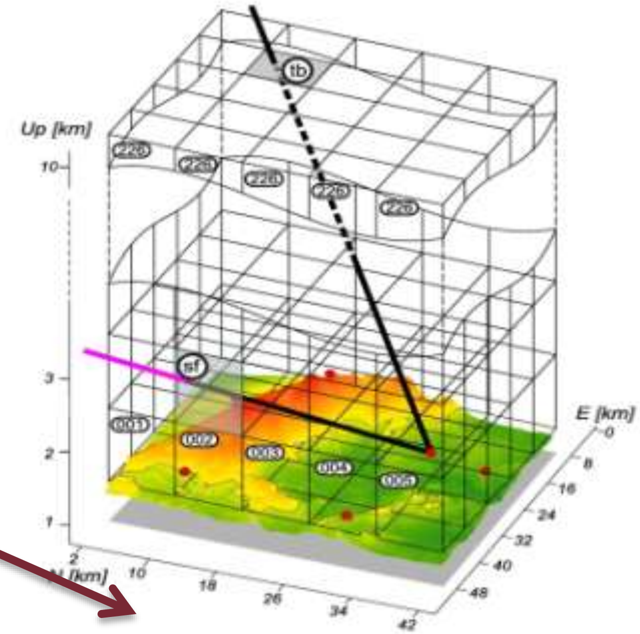
GNSS tomography STD assimilation / convection studies

TOMO2



Inversion of Radon transform

1D ZTD/STD 3D IWV/N_w



$$x = inv(A) \cdot y$$

Zenith total delay -> refractivity

$$N_w = \left(A^T \cdot P \cdot A\right)^{-1} \cdot A^T \cdot P \cdot SWD$$

I Observations operator

$$y_m = Hx_m$$

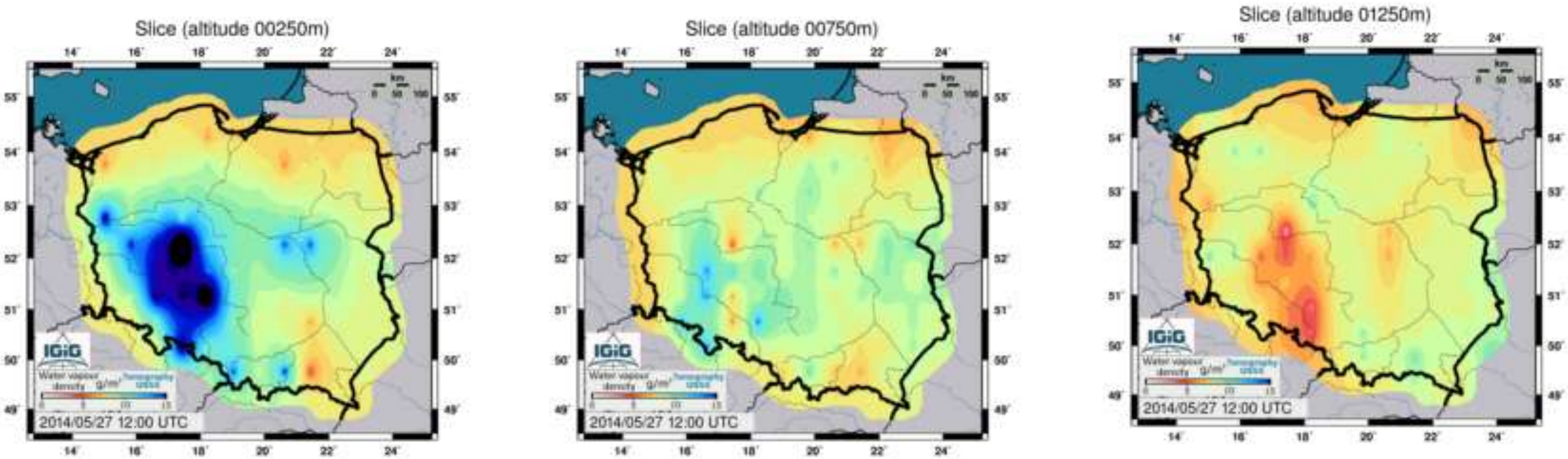
N_{wm} Refractivity from NWP

Working Group 2, Task TOMO – GNSS tomography data assimilation

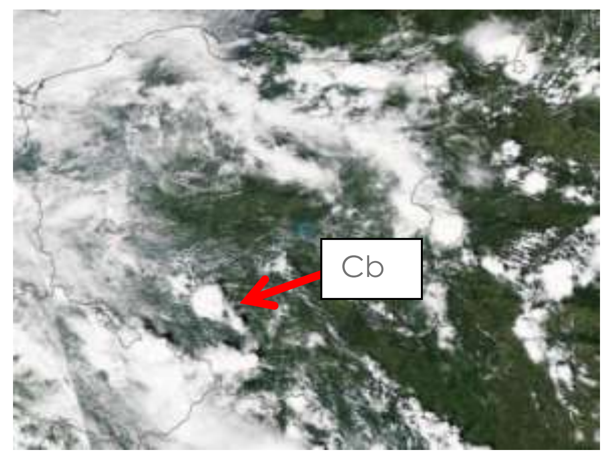
GNSS 4 SWEC

GNSS tomography 03.08.2014 – intensive rainfall

Torrential rain associated with strong movements of the ascending air within the large convection cells



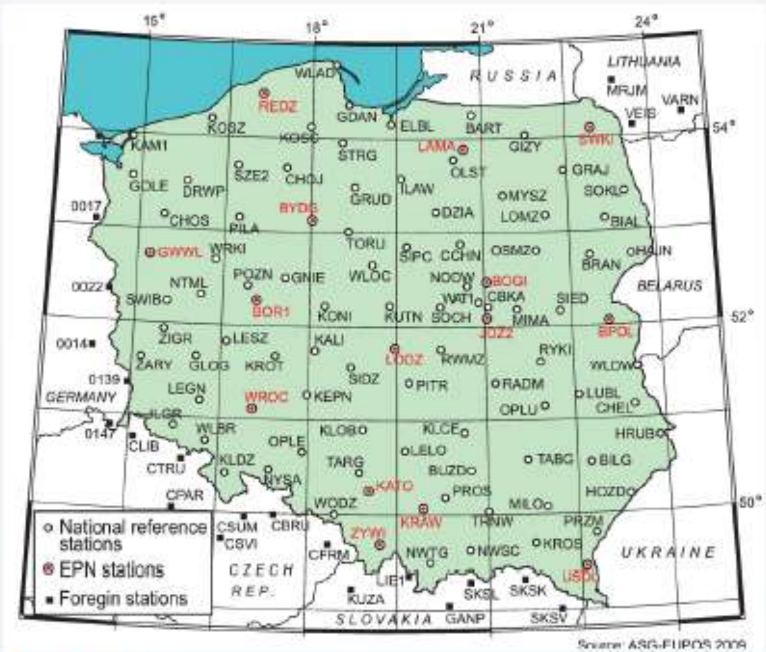
Tomography retrieved water vapour densities on 3 consecutive levels, convection cores should match with the increase of water vapour in bottom part (pool) and with sudden decreas of WV in cloud section (rain).



Geo satellite cloud image

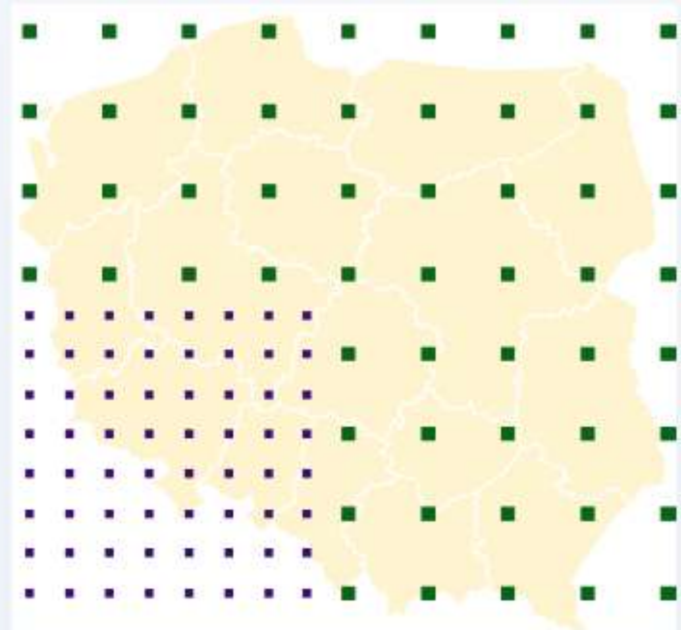
APPLICATION OF TROPOSPHERE MODEL FROM NWP AND GNSS DATA INTO RT PPP - Data

GNSS



- 277 Polish stations
- near-real time
- ZTD with 1 h resolution
- product of Bernese software v5.2
- post-processing
- double-differenced

NWP WRF



- WRF – Weather Research and Forecasting
- 219x237 horizontal nodes
- 4x4 km² grid
- 47 vertical levels
- 24-hour forecasts at 0:00 UTC
- p, T, e with 1 h resolution

APPLICATION OF TROPOSPHERE MODEL FROM NWP AND GNSS DATA INTO RT PPP – Collocation - ZTD results

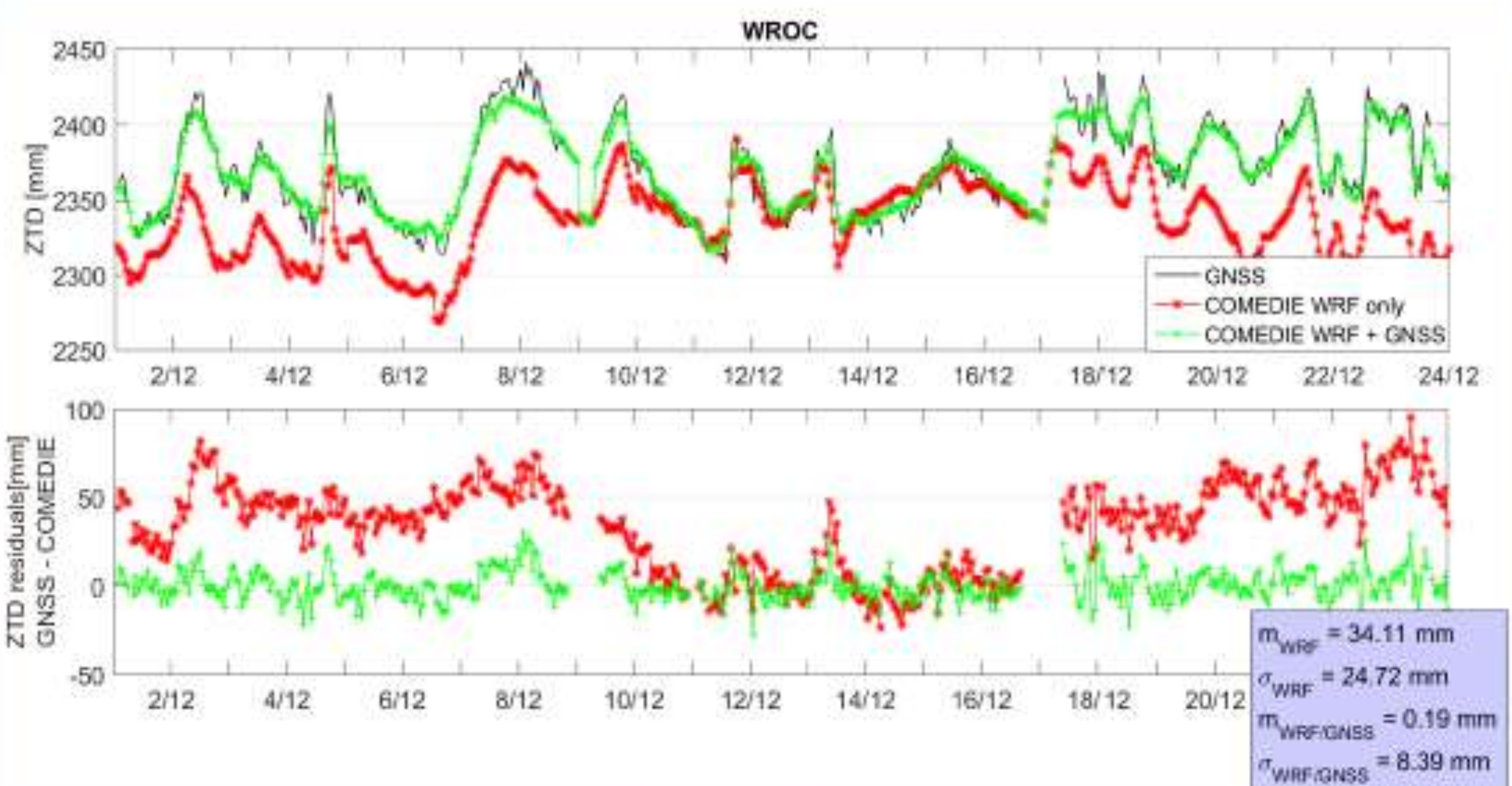


Fig.1. Comparison of COMEDIE models w.r.t. reference GNSS data

Conclusion

1. The NRT ZDT service is operational and stable in DD for 1h timeliness and will be developed to PPP and 15 min. timeliness.

2. The RT PPP is the alternative technique in GNSS meteorology and will be developed in future.

3. The RO service give us in future more profiles for calibration of 4D GNSS models of troposphere

4. The GNSS tomography is the next step of assimilation of 4D GNSS data in NWP models.

5. The integration of GNSS outputs and NWP models data is very important for support of RT positing services and meteorology.

GNSS&Meteo WUELS working group

Prof. Jarosław Bosy
Chair of WG
Vice-Chair of IAG Sub-Commission 4.3:
Atmosphere Remote Sensing

Dr. Witold Rohm
Chair of Meteo section
Chair of IAG WG 4.3.6
Troposphere Tomography

GNSS meteorology

Positioning

SLR&GNSS

Pawel Hordyniec
PhD student
ROWUELS software

Dr. Jan Kaplon
GNSS and Meteo
NRT services

Dr. Tomasz Hadas
GNSS-WARP software
Chair of IAG WG 4.3.4
Ionosphere and Troposphere
Impact on GNSS Positioning

Dr. Krzysztof Sosnica
Chair of IAG JSG0.21:
Fusion of multi-technique
satellite geodetic data

Karina Wilgan
PhD student
GNSS and meteo integration

Jan Sierny
PhD student and IT support
GNSS and meteo data base

Kamil Kaźmierski
PhD student
Multi-GNSS

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


igig.up.wroc.pl

International Association of Geodesy (IAG), Commission 4 Symposium

September 04-07, 2016, Wroclaw, Poland

POSITIONING AND APPLICATIONS

IAG

- GENERAL INFORMATION
- PROGRAMME
- SCIENTIFIC COMMITTEE
- ORGANIZING COMMITTEE
- DEADLINES
- ABSTRACT SUBMISSION
- REGISTRATION
- VENUE LOCATION
- ACOMMODIATION
- TRANSPORTATION

Sponsors:

Media partners:

GEODETA

» GENERAL INFORMATION

The Institute of Geodesy and Geoinformatics, Wroclaw University of Environmental and Life Sciences, in a collaboration with the **Institute of Geodesy, University of Warmia and Mazury in Olsztyn**, would like to cordially invite you to the

IAG Commission 4 Positioning and Applications Symposium,

that will be held in **Wroclaw, Poland**, on **September 4-7, 2016** (Sunday to Wednesday).

We are looking forward to seeing you all in Wroclaw!

Wroclaw University of Environmental and Life Sciences

Institute of Geodesy and Geoinformatics

IGiG

University of Warmia and Mazury in Olsztyn

UWM

Institute of Geodesy

Abstract submission: **June 15, 2016**

Notification of acceptance: July 1, 2016

Registration: July 31, 2016

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

Emerging, GNSS based tropospheric products

WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Thank You!

jaroslaw.bosy@up.wroc.pl

Presenting author:
Professor Jaroslaw Bosy
Institute of Geodesy and Geoinformatics
Wroclaw University of Environmental and Life Sciences

www.up.wroc.pl