Real-time GNSS and meteorological activities at Wroclaw University of Environmental and Life Sciences

GNSS & Meteo WG

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Abstract

The GNSS&Meteo group at the Institute of Geodesy and Geoinformatics of Wroclaw University of Environmental and Life Sciences (WUELS), Poland is continuously working on GNSS meteorology since 2010. Currently group maintains real-time (RT) service collecting GNSS and meteorological data and near real-time (NRT) services for estimation of Zenith Troposphere Delay (ZTD), Zenith Hydrostatic Delay (ZHD), Integrated Water Vapour (IWV) and GNSS tomography over the territory of Poland. Data are obtained with high resolution from EUREF Permanent Network (EPN) stations and Ground Base Augmentation System (GBAS) called ASG-EUPOS (www.asgeupos.pl). The ground meteorological observations in the area of Poland and neighbour countries are available from: ASG-EUPOS stations included in EUREF Permanent Network (EPN), airport meteorological stations (METAR) and stations managed by national Institute of Meteorology and Water Management (SYNOP).

Ground-based ZTD estimation

The main product of GNSS and METEO group at Wroclaw Univ. of Environmental and Life Sciences are the ZTD estimates obtained during the near real-time double differenced processing (L3/L5 strategy) of ASG-EUPOS network (IGGHZ-G). Product is available since December 2012 via E-GVAP data centre (egvap.dmi.dk) (Fig. 1) as WUEL stream. All ZTD estimations are performed using the Bernese GNSS Software V.5.0 and 5.2, but the service based on 5.2 version is not yet operational All comparisons were made with respect to Military University of Technology Rapid ASG-EUPOS network solution ASR (24 hour sessions, processed using the rapid IGS products).

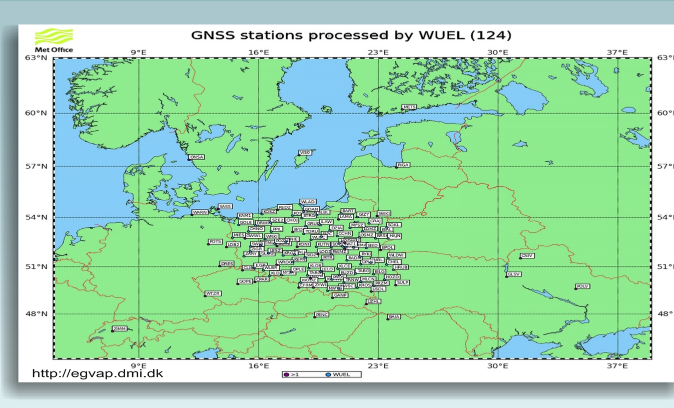


Fig.1

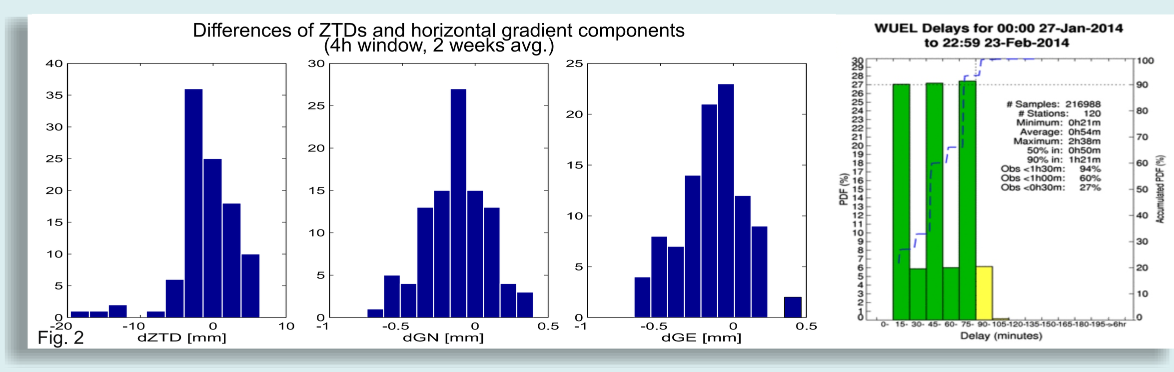


Fig. 2

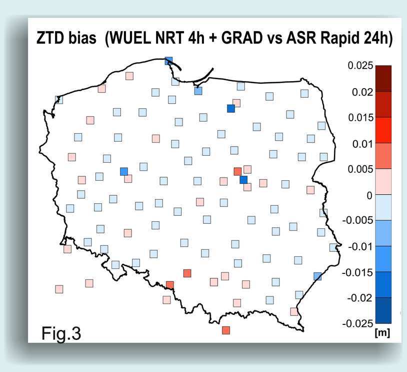


Fig.3

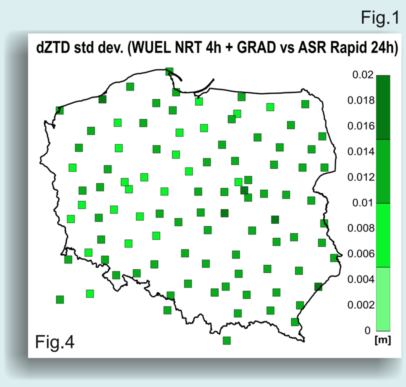


Fig.4

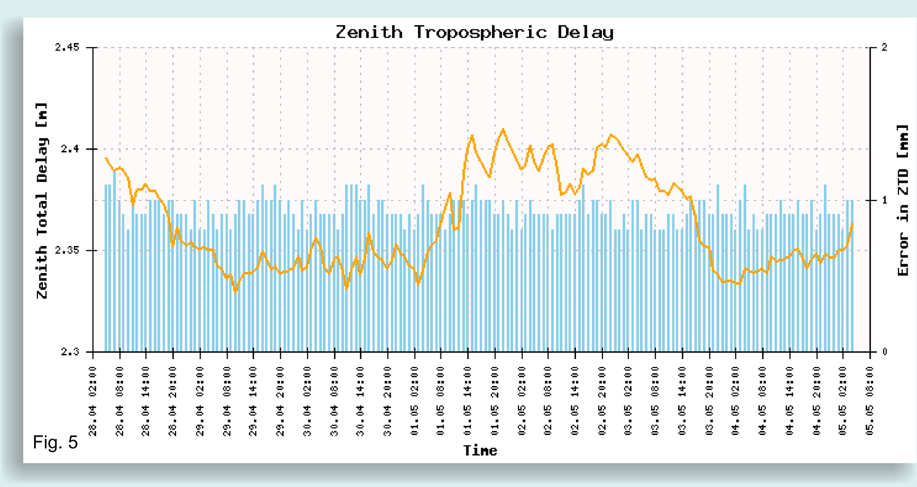


Fig. 5

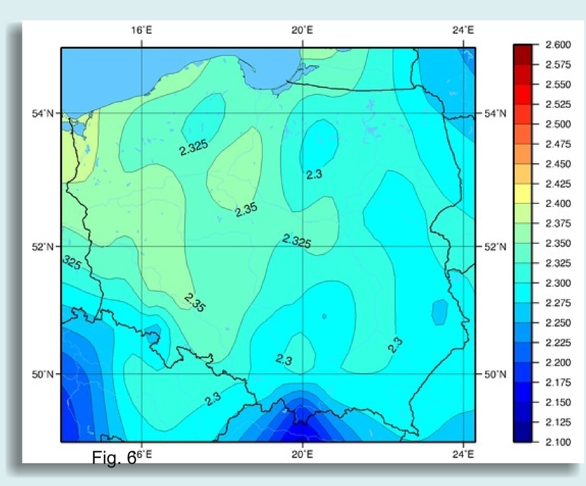


Fig. 6

Figure 2 shows residuals of ZTD and gradients calculated as a difference between ZTD + gradients WUELS and ASR MUT solution. ZTD estimation perfomes within 10mm error (Fig.4) with small negative bias (Fig.3). However gradients estimation needs to be further improved. Exemplary ZTD model for Poland and ZTD time series for station WROC are presented in figures 5 and 6 respectively.

PW/IWV as a water vapour data source,

The information about contents of water vapour (2-D model) above GNSS stations, represented by Integrated Water Vapour (IWV), is obtained directly from ZWD. The relation between ZWD and the water vapour content in the atmosphere is expressed by IWV and given by the equation (Bevis et al., 1992, 1994; Kleijer, 2004). The pressure, temperature and water vapour parameters are interpolated from neighbour in-situ stations (SYNOP, METAR).

$$IWV = \frac{ZTD - ZHD}{10^{-6} R_w}\left(k_2' + \frac{k_3}{T_M}\right)^{-1}$$

where:

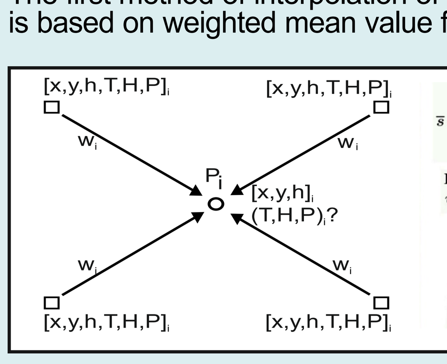
R_w = 461.525±0.003 [J kg^{-1} K^{-1}] is the specific gas constant for water vapour

k'_2 = 24±11 [K hPa^{-1}], k_3 = 3.75±0.03 [105 K2 hPa^{-1}] are refraction constants (Boudouris, 1963)

T_M ≈70.2±0.72 · T is weighted mean water vapour temperature of the atmosphere

T - is the surface temperature

The first method of interpolation of meteorological parameters is based on weighted mean value from four nearest stations:



$$\overline{s} = \frac{\sum_{i=1}^{n} s_i w_i}{\sum_{i=1}^{n} w_i}$$

Temperature: $s \longleftarrow T$
$w_i = (h - h_i)^{-4},$

Humidity: $s \longleftarrow H$
$w_i = [(x-x_i)^2 + (y-y_i)^2 + (h-h_i)^2]^{-2},$

Pressure: $s \longleftarrow P$
$w_i = [(x-x_i)^2 + (y-y_i)^2]^{-2}$

$$\log P_i = \log P_{COA_i} + \frac{h_i - h}{18400(1 + \frac{T+T_i}{546})}$$

The second method have updated pressure interpolation:

$$P = P_i\left(\frac{T_i - \gamma(h - h_i)}{T_i}\right)^{\frac{g \cdot M}{R \cdot \gamma}}$$

$$g = 9.8063 \cdot \left(1 - 10^{-7}\frac{h_i + h}{2}\left(1 - 0.0026373 \cdot cos(2\phi) + 5.9 \cdot 10^{-6} \cdot cos^2(2\phi)\right)\right)$$

Pi [T,P,h,ϕ] P ?

The quality of IWV varies between 0.19 mm for GNSS station with mounted, meteorological sensors, to almost 3 mm for stations with no collocated meteorological observations (data source UNB3m, GPT2).

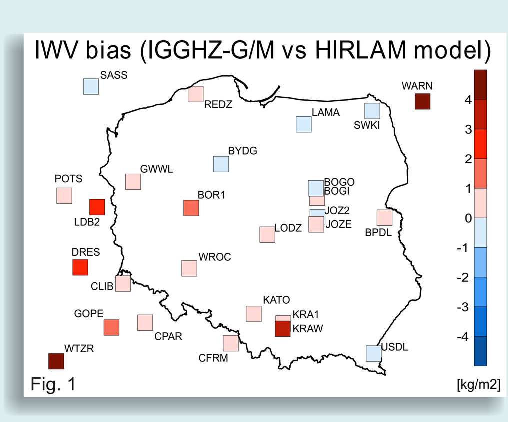


Fig. 1

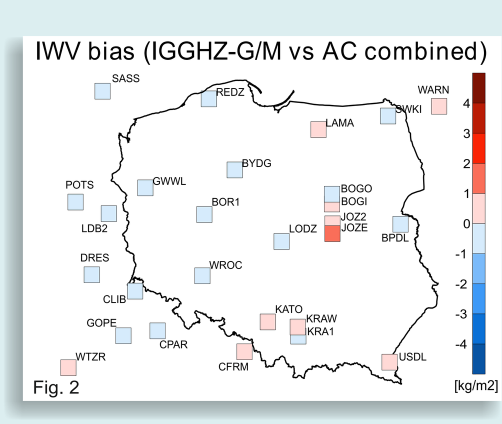


Fig. 2

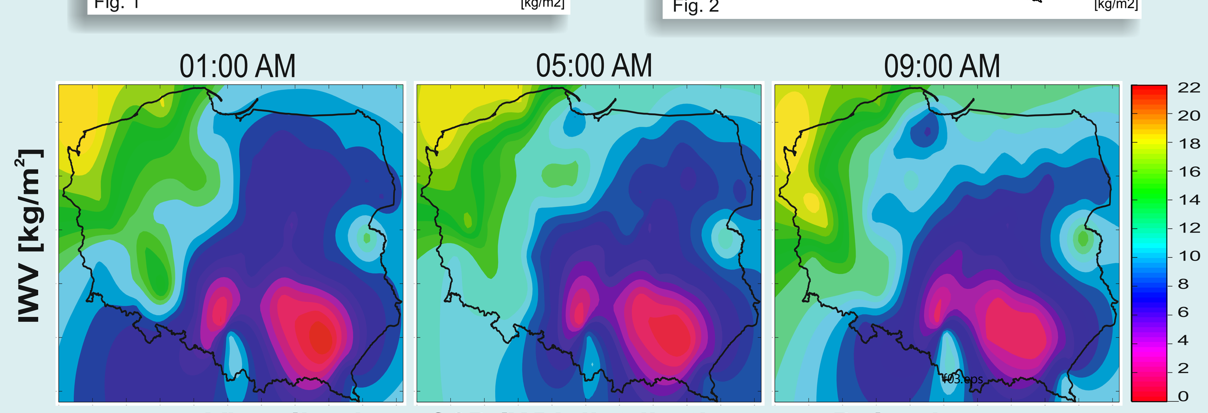


Fig. 3 **Visualization of 2D IWV distribution over Poland**

GNSS tomography and as a non-NWP nowcasting product

The TOMO2 GNSS tomography model (Fig.1) developed at WUELS combine the a priori NWP data with GNSS troposphere delay observations to obtain the 4D wet refractivity model over the GNSS network. TOMO2 is now used within the frame of COST ES1206 Action: GNSS4SWEC to severe weather monitoring. Currently it is working in NRT mode (1hour interval with 10 minutes delay) over the area of ASG-EUPOS network in Poland. The TOMO2 model has unique features: use of Kalman filters instead of ordinary least squares method, model nesting (Fig 2.a) to account for low satellites signal, flexible setting of voxel number and layer thickness (Fig 2.b) and choice of different methods to find Kalman gain matrix. The tomography technique has been applied to study severe storm in Australia. The refractivity fluxes (Fig. 3 color-coded red increase and blue decrease of water vapour content) show strong correlation with radar reflectivites (black line). This coincide well with the development, maturity and dissipation of severe storm caused by Mesoscale Convection System. Profiles of wet refractivity (Fig.5 RG2SAD, M2NSAD, M1NSAD) from GNSS tomo-graphy model TOMO2 show good agreement with NWP data especially in the troposphere layer between 2 and 6 km.

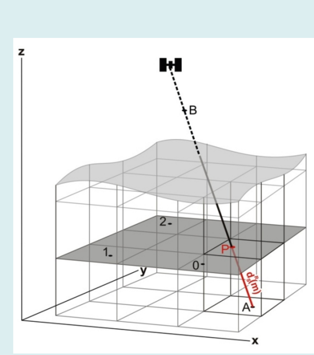
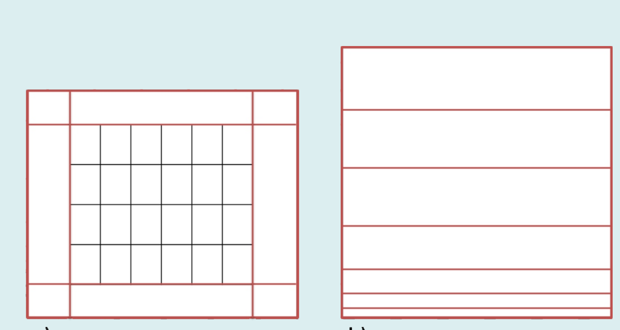


Fig.1


a) b)
Fig. 2

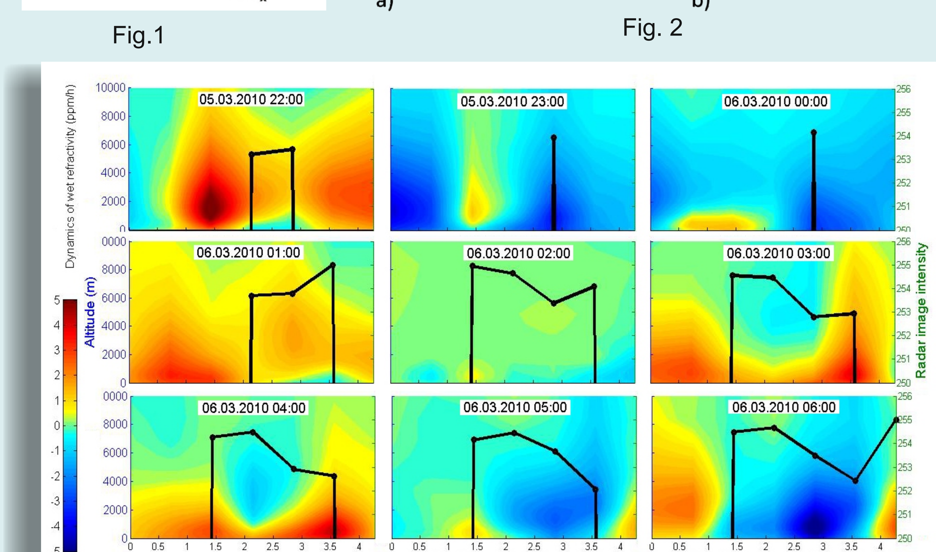


Fig.3

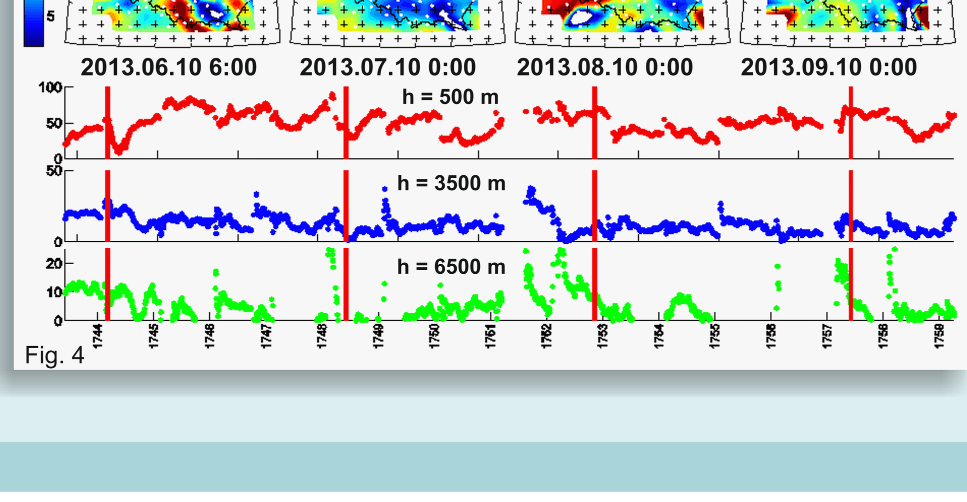


Fig. 4

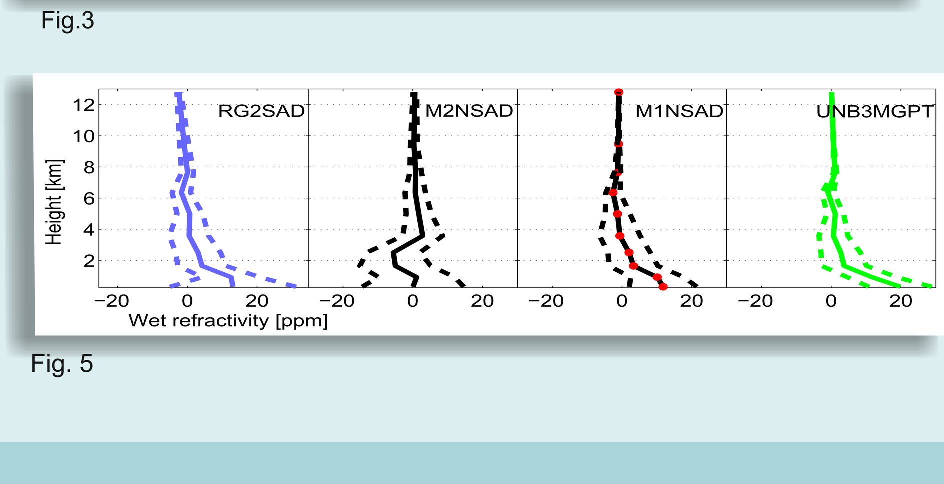


Fig. 5

Predictions of ZTD for nowcasting

Time series (Y_t) is an autoregressive (AR(r)) process, if it is stationary and satisfies (for every t):

$$Y_t = \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \ldots + \alpha_r Y_{t-r} + Z_t$$

where (Z_t) is a white noise and $(\alpha_i)_{i=1,..r}$ are coefficients.
Time series (Y_t) is an autoregressive moving average (ARMA(p,q)) process, if it is stationary and satisfies (for every t):

$$\begin{aligned} Y_t &= \alpha_1 Y_{t-1} + \alpha_2 Y_{t-2} + \ldots + \alpha_p Y_{t-p} \\ &+ \beta_0 Z_t + \beta_1 Z_{t-1} + \beta_2 Z_{t-2} + \ldots + \beta_q Z_{t-q} \end{aligned}$$

where (Z_t) is a white noise, $(\alpha_i)_{i=1,..p}$ and $(\beta_i)_{i=1,..q}$ are coefficients.

Here are depicted the results of 1h predictions using AR and ARMA methods compared to COAMPS and GPT2 models.

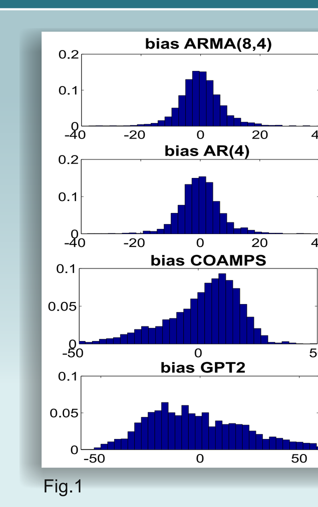


Fig.1

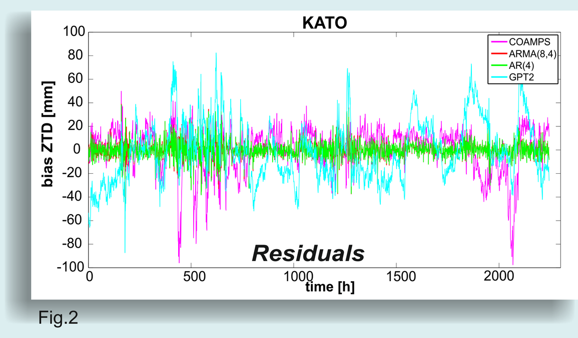


Fig.2

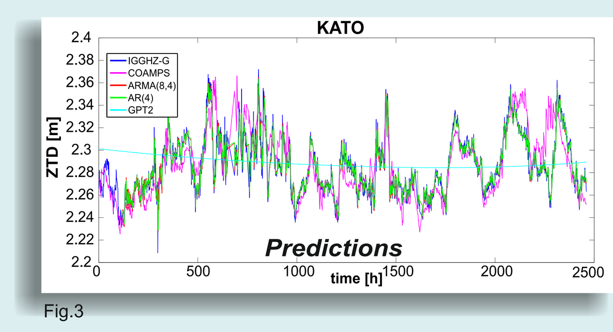


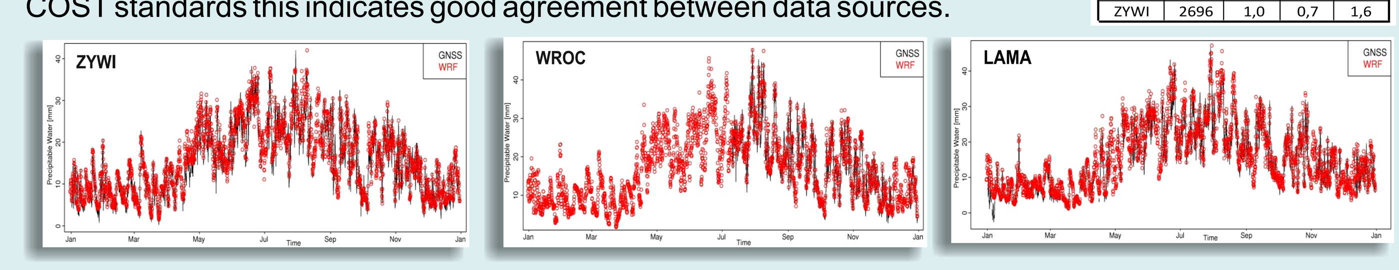
Fig.3

Assimilation of GNSS troposphere parameters in NWP

Currently, all major meteorological agencies through the Europe are, either operationally or for testing purpose, using GNSS troposphere estimates (IWV/PW or ZTD). Through the close collaboration with University of Wroclaw we are actively investigating the use of GNSS derived ZTDs and STDs as a assimilation data source for NWP models. In our studies we are using WRF model. Here we show initial results of WRF/IWV comparison. Most of the stations perfoms well with low bias (Table 1) (below 1 mm and std of 1.6 mm). According to COST standards this indicates good agreement between data sources.

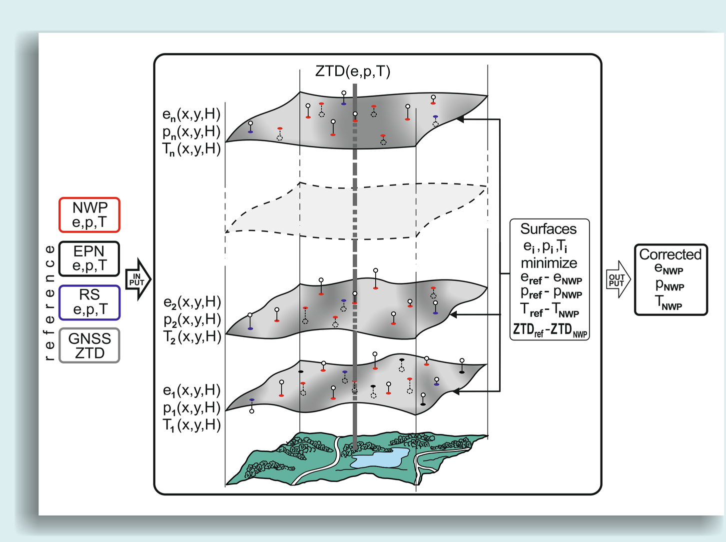
Table 1

Station	Count	R^2	Bias [mm]	STD [mm]
WROC	1237	1,0	0,4	1,6
BOGI	780	0,3	-16,8	20,3
BOR1	2732	1,0	-1,0	1,7
BPDL	2821	1,0	0,7	1,6
BYDG	156	0,9	0,6	1,3
GWWL	2764	1,0	0,7	1,4
JOZ2	611	1,0	1,6	2,2
KATO	2620	1,0	0,3	1,5
USDL	2396	1,0	0,8	1,6
LAMA	1701	1,0	0,5	1,5
ZYWI	2696	1,0	0,7	1,6



3D integrated troposphere model

The integrated model will provide values of meteorological and GNSS parameters at any point and any time with known accuracy. First step in building this model is to inter-compare all available data sources and to establish the accuracy of parameters. The main data sources were compared: ground-based GNSS products on ASG-EUPOS stations, NWP model COAMPS (Coupled Ocean/ Atmosphere Mesoscale Prediction System), vertical profiles from radiosonde (RS) and surface meteorological parameters from ground-based stations: EUREF Permanent Network (EPN) stations, airport meteorological sensors and synoptic Institute of Meteorology and Water Management stations.



Future step is to correct NWP model outputs according to the reference data. The main idea is to fit the mathematical surfaces into the NWP models, RS profiles, GNSS data and AWS observations considering the statistical information linked with each observation tech-nique and station. The mini-mization techniques will be exploited to make the diffe-rences between reference data (meteo-rological parameters as well as ZTD) and NWP the smallest. The final result will be corrected meteorological parameters from NWP model.

RO COSMICII data as the NWP data source

We first evaluate the quality of GPS-RO profiles; collocated occultation events were found for radiosonde retrievals, which serve as reference data. Observations from weather balloons for three Polish stations were compared to wetPrf product of CDAAC/TAAC processing center. The analysis was performed in terms of various spherical distances with respect to radiosonde location using the parameters of pressure, temperature and refractivity. The comparison for GPS-RO profiles located between 50 to 100 km (Fig. 1) far from radiosonde station at altitudes over 8 km showed an agreement of 0.45 units for refractivity, 0.35 hPa for pressure and 2 Kelvin for temperature expressed as standard deviations. If the spherical distance is increased to 300 km or higher (Fig. 2), the uncertainties will reach 0.78 units, 1.37 hPa and 2.84 K, for refractivity, pressure and temperature respectively. At lower troposphere (8 km and below) significant residuals occur for refractivity (5 unit) and pressure (3 K). The temperature RO profiles for the distance below 50 km show negligible discrepancy to RS ones, whereas ROs obtained more than 450km show significant differences (9 K) (Fig. 3).

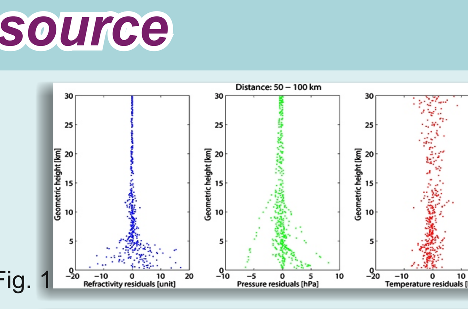


Fig. 1

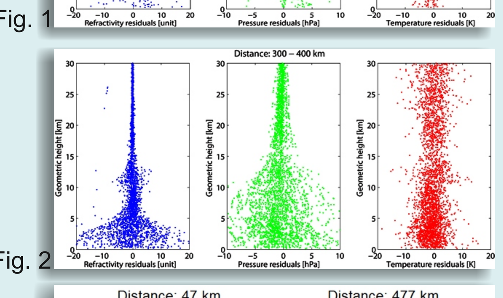


Fig. 2

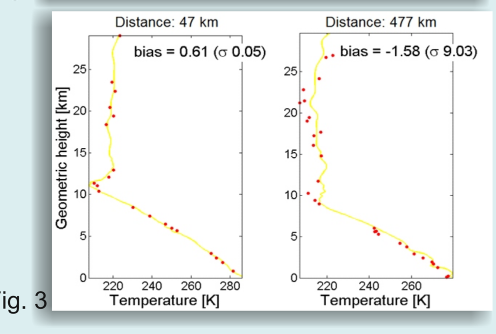


Fig. 3

Summary

All mentioned above activities of WUELS are performed to produce the most reliable NRT troposphere product for meteorology and positioning. The next step is to develop the ultra-fast (5 min) ZTD processing with Bernese GNSS Software V.5.2 and operationally combine this product with ZHD obtained from meteorological data to achieve IWV in 5 min. intervals as well.

The GNSS&Meteo group at WUELS carries out research in the frame of COST Action ES1206 - GNSS4SWEC Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (gnss4swec.knmi.nl/), E-GVAP: The EUMETNET EIG GNSS water vapour programme (egvap.dmi.dk/) and Working Groups 4.3.2 Inter-comparison and cross-validation of tomography models and 4.3.3 Integration of GNSS atmosphere models with NWP models of Sub-Commission 4.3: Remote Sensing and Modelling of the Atmosphere in COMMISSION 4: Positioning & Applications of International Association of Geodesy

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