AUTOMATIC SYSTEM FOR GPS TROPOSPHERIC DELAY ESTIMATION, ON-LINE GPS PROCESSING USER SERVICE AND ANALYSIS OF THE RESULTS

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1. ABSTRACT

This paper describes automatic system for GPS tropospheric delay estimation developed at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University (WUT) LAC. The system is based on BPE (Bernese Processing Engine) and utilizes UltraRapid orbits and EUREF weekly coordinates. We describe processing strategies used in this application and report various experiences leading to start of NRT tropospheric service. We have made many statistical quality analysis of the resulting solutions. Accurate comparisons with ZTD combined product (EPN and IGS) and radiosounding data has been made. The poster presents also other research areas on the GPS data processing performed especially the Internet based service for an on-line GPS processing of the users data. Finally we present some other ideas of our interest how to use tropospheric delay in meteorology and climatology.

2. NTR TROPOSPHERIC DELAY ESTIMATION

Fully automatic system for Zenith Total Delay (ZTD) estimation in Near Real Time (NRT) has been successfully set up and works for over half a year. The system processes subset of EPN/IGS GPS stations (over 20) in Central Europe.

Solution minutes:

- **Bernese GPS Software v. 4.2,**
- **coordinates of all stations are fixed to EUREF weekly solutions,**
- **IGS Ultra Rapid orbits are used,**
- **no *a priori* tropospheric model, Dry Niell as mapping function, ZTDs estimated every hour,**
- **observation sampling 30 sec, weighting 1/cos (z), cut off: 10°**
- **sliding window: 4 hours, no ADDNEQ, RINEX files concatenated (teqc)**
- **ambiguities are resolved using QIF.**

Test campaign of automated NRT processing which results we present here comprised 22 stations (see map) and timespan od DOY 164-217 in the year 2005.

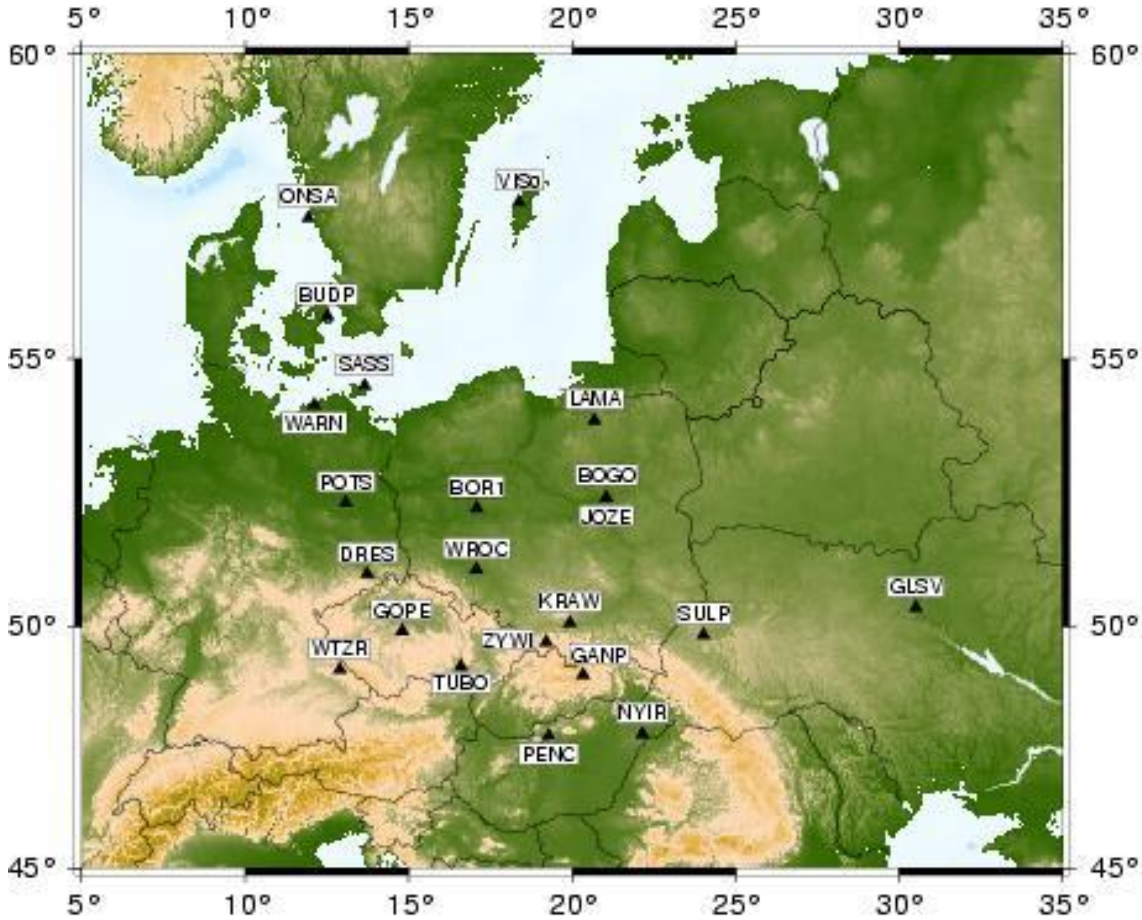


Fig. 1. Map of test NRT campaign stations

We tried several WUT NRT solution validation methods:

- **comparison with final solutions (EPN combined tropospheric product, WUT EPN solution, SIO IGS solution)**
- **IGS rapid tropospheric product**
- **comparison with another NRT solution (made by GFZ in the frame of the GASP project)**
- **radiosounding observations (RAOBs)**

On the figure 2 you can see representative result: generally solutions are harmonized to 1-2 cm levels, final solutions are more stable and sometimes reveal biases. This is a consequence of strategy minutes and poorer reference frame definition in small regional network.

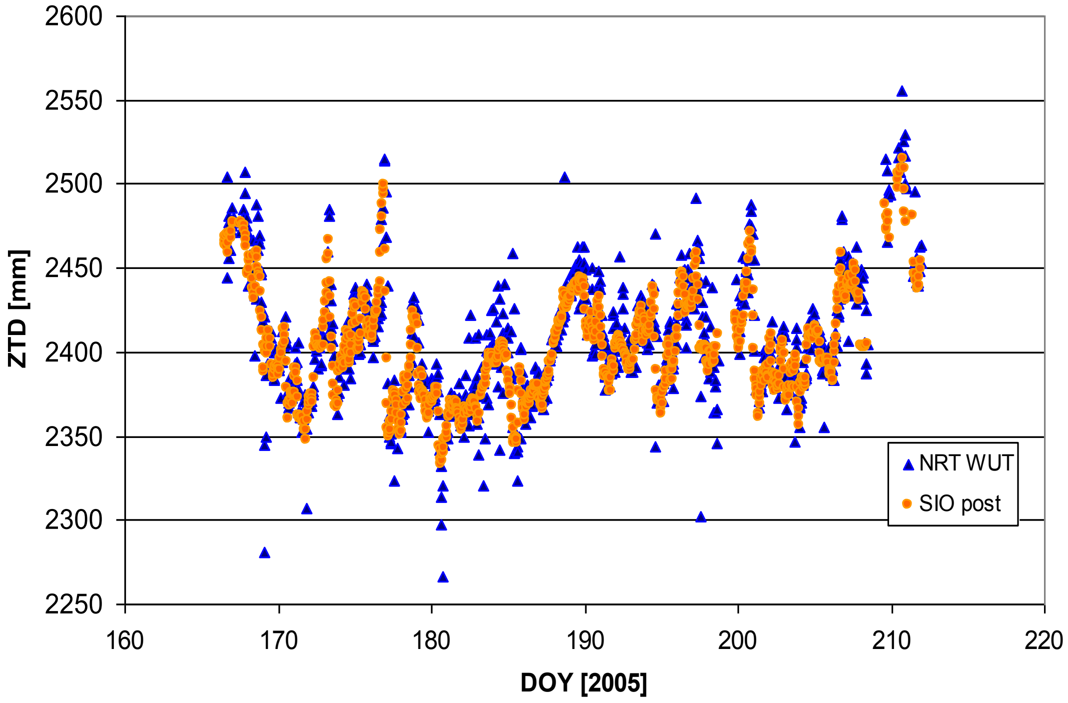


Fig. 2. NRT solution and SIO final solution for LAMA

IGS rapid tropospheric product was also used in the tests. On the figure 3 you can see ZTD values for station HOFN (not included in the map). Our NRT solution is slightly less stable (natural feature as IGS rapid product is a combination of several independent solutions) but shows no significant bias (table 1).

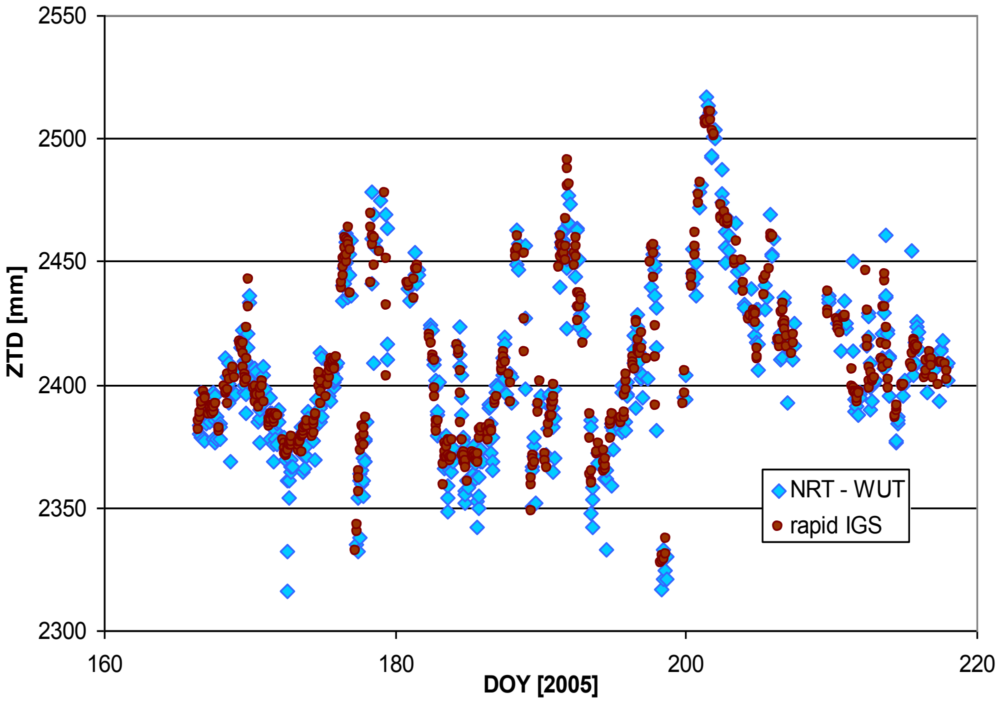


Fig. 3. Results of comparison of WUT NRT solution and IGS rapid tropospheric product for station HOFN

Tab. 1. NTR solution ZTD and rapid IGS solution differences

station	averaged difference (NRT-PW) - (rapid IGS)	averaged absolute difference	No. of points
BOR1	1.82	7.42	626
GOPE	5.15	8.52	529
POTS	1.7	7.43	899
WTZR	1.88	7.06	1027
HOFN	-2.05	7.24	550
ONSA	1.62	6.08	541

In case of comparisons to GFZ (Geo Forshungs Zentrum, Potsdam) solution we have found even more satisfying results. Despite different strategies, networks and software used in this solutions we got very high correlation (table 2). Figures below shows selected typical results of WUT – GFZ inter-comparisons.

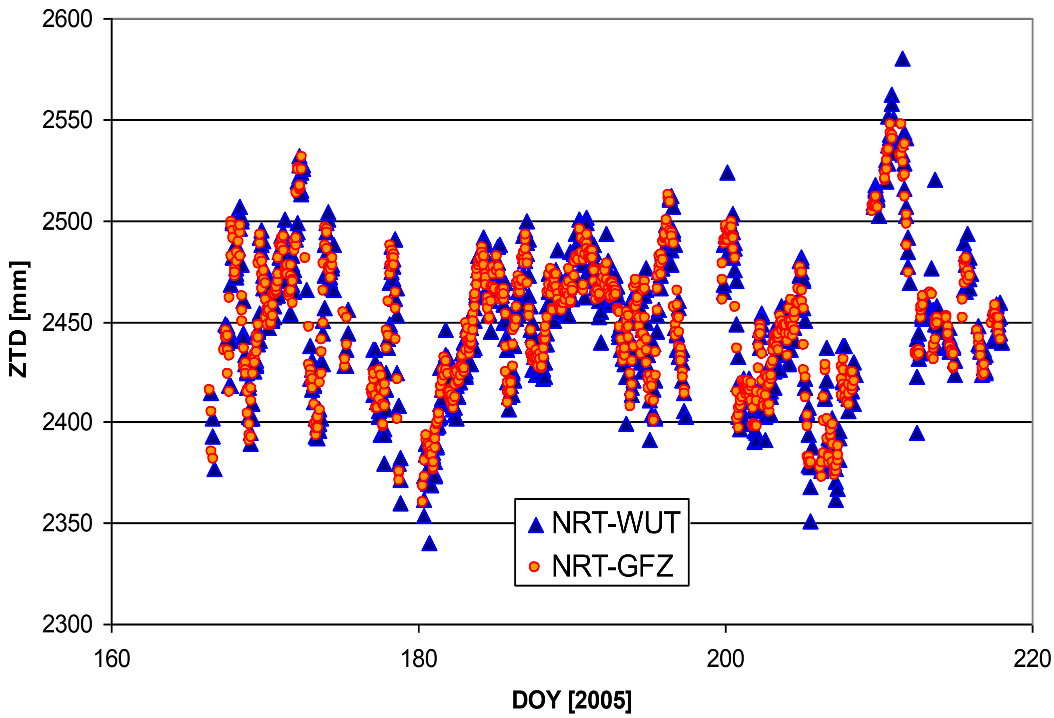


Fig. 4. Two NRT ZTD solution series for ONSA

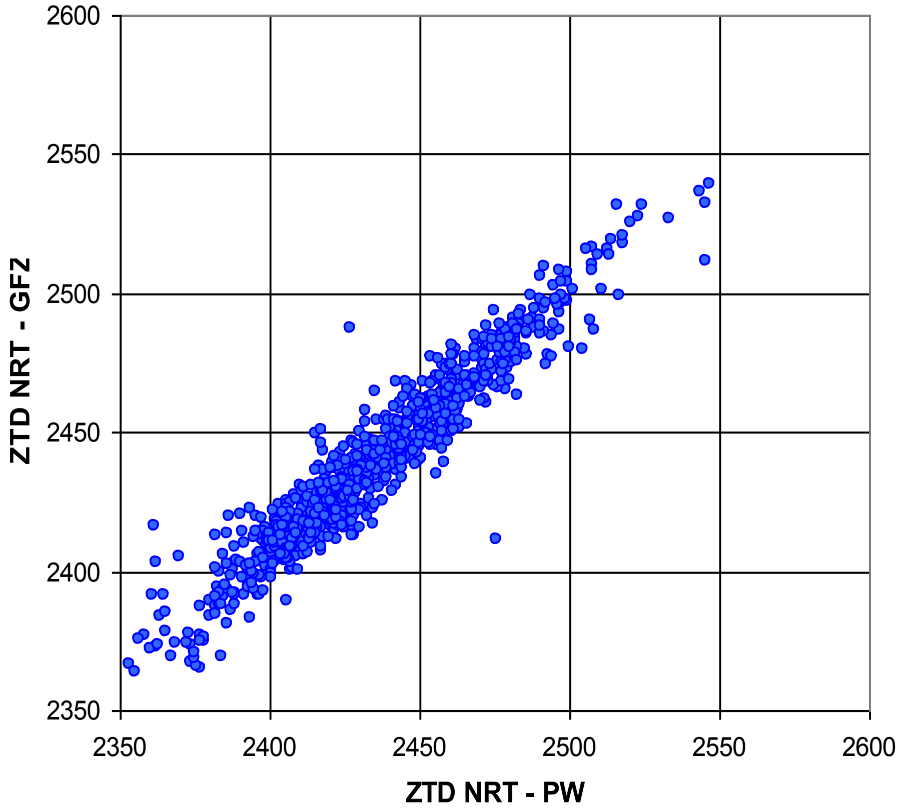


Fig. 5. Two NRT ZTD solution results scatterplot for DRES

Tab. 2. Two NRT ZTD solutions (WUT and GFZ) series correlations

station	correlation	station	correlation
BOGO	0.929	POTS	0.963
JOZE	0.958	PENC	0.954
BOR1	0.956	TUBO	0.962
WROC	0.959	WTZR	0.951
BUCU	0.952	HOFN	0.930
SULP	0.961	ONSA	0.969
DRES	0.958	KRAW	0.955
GOPE	0.953	VIS0	0.951

As a last validation method we used radiosounding results (available thanks to help of Mr Henrik Vedel from DMI). Radiosonde profiles were numerically integrated to obtain both ZTD and IPW/IWV values. We compared both IPWV (for this points we need surface meteorological data to calculate IPW from ZTD), and ZTD (look at the table 3) which makes available more numerous set of points.

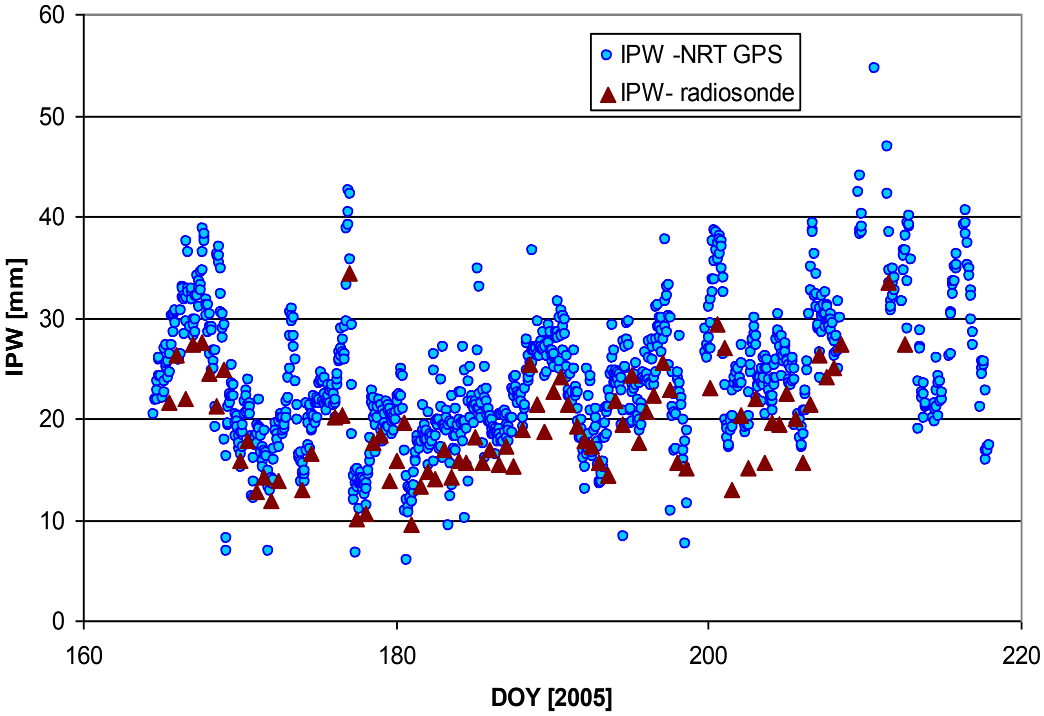


Fig. 6. IPW – radiosonde (Legionowo) and IPW from GPS NRT solution for station BOGO

Tab. 3. Comparison of NRT test campaign with RAOB (radiosounding observations) - June 2004

GPS station	radiosounding point		distance [km]	points	ZTD difference (NRT-RAOB) [mm]	absolute difference
GLSV	33345	Kiev	4	38	14,62	17,72
GANP	11952	Poprad/Ganovce	4,2	81	36,38	36,87
VIS0	2591	Visby	7,2	57	21,02	21,42
GOPE	11520	Praha-Libus	29,2	167	-36,58	39,31
SASS	10184	Greifswald	48,6	83	19,18	21,82
POTS	10393	Lindenberg	72,8	164	35,45	36,09
WTZR	10771	Kummersruck	76,5	120	-12,15	25,61

In the end of this section let us look at some interesting features of ZTD series obtained in the NRT mode. Figure 7 shows ZTD series of two stations (Wroclaw and Dresno) located on the same parallel. We can notice that in most cases rapid ZTD changes occur first in Dresno and then (after 3-4 hours) in Wroclaw. This effect of dominant western circulation in our climate was already demonstrated by the author (Kruczyk) for IPW. IPW – Integrated Precipitable Water is a valuable source of information concerning the whole water vapour content in the atmosphere above given GPS station. As we can see on the figure 8 this information is something independent to absolute humidity measured (or rather calculated by psyhrometric formulas from temperature and humidity) on the surface.

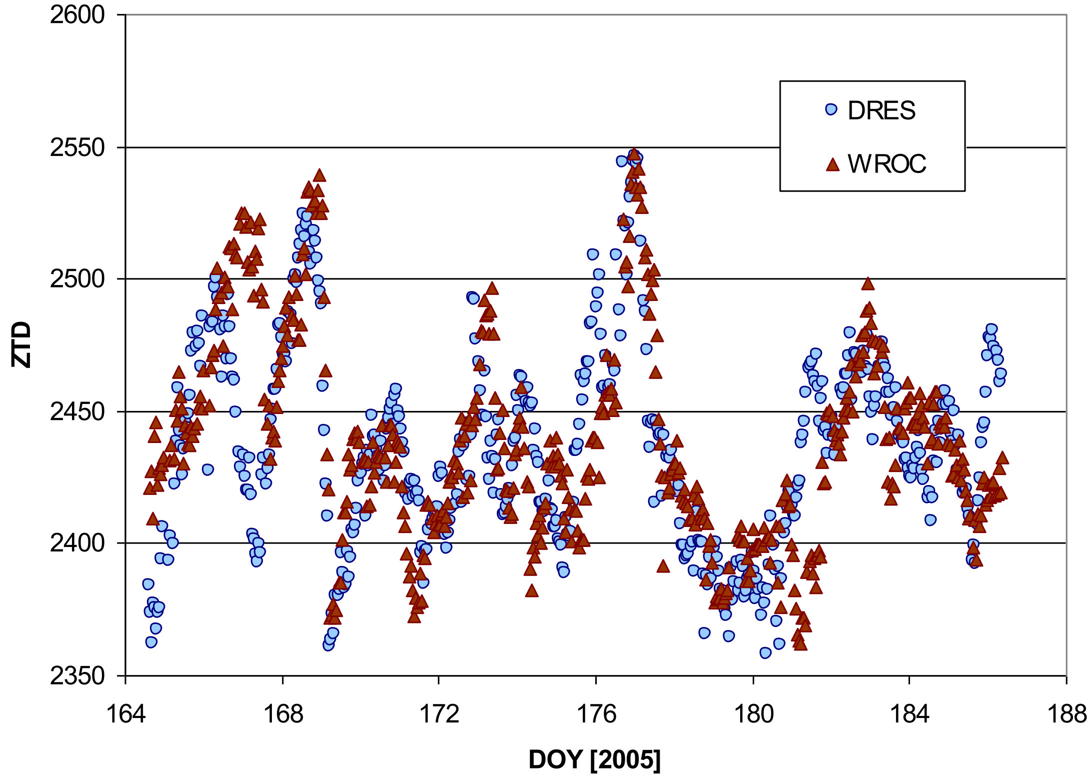


Fig. 7. ZTD from NRT solution for stations DRES and WROC

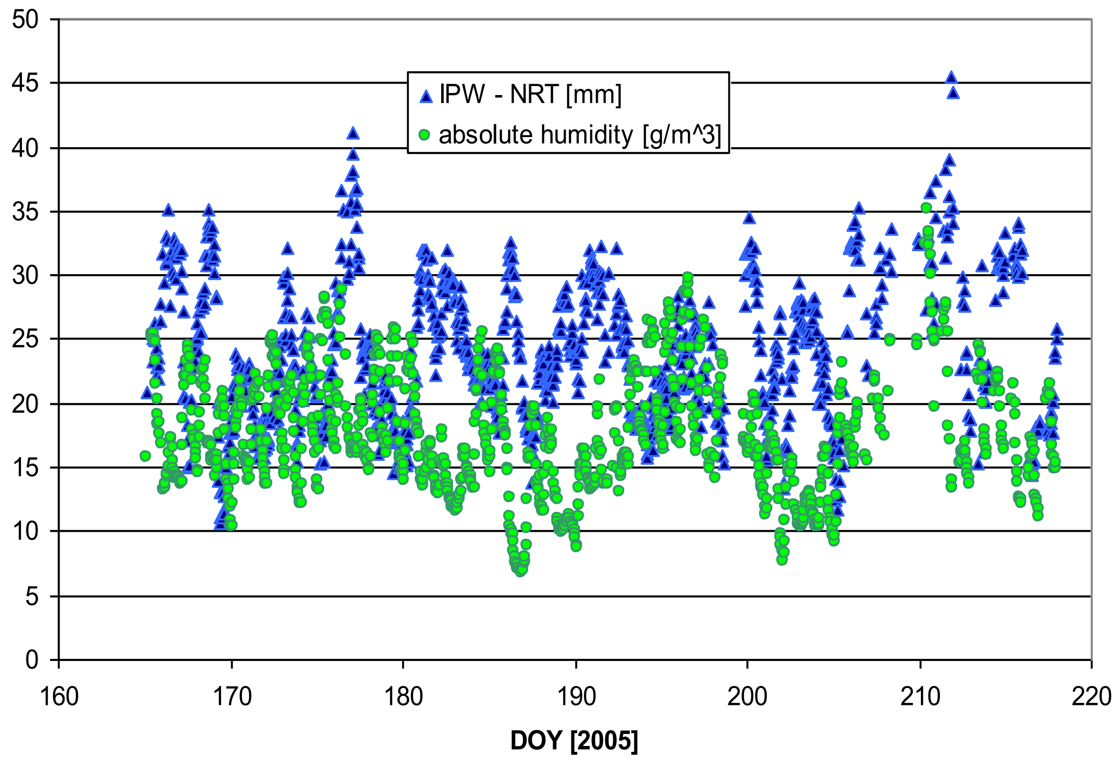


Fig. 8. IPW obtained from NRT ZTD solution and surface absolute humidity for GOPE

3. USER AUTOMATIC ON–LINE SERVICE OGPSP

The system (individual work of T. Liwosz) uses subset of EPN/ IGS GPS stations in Central Europe and is based on Bernese GPS Software version 4.2 (Linux platform) but original panels and BPE are not used. All necessary scripts for preparation input files -I, -F, -N, processing control, data download, error/exception handling etc. have been written in Perl language. System uses EUREF weekly coordinate solutions and IGS cumulative solutions for reference frame realization. System utilises the most precise IGS orbits which are available at the time of the user data submission (final, rapid, ultra-rapid).

The choice of the IGS/EPN stations can be performed in 3 ways:

- **system automatically will choose 3 nearest stations,**
- **user will specify 1 to 4 stations,**
- **system automatically will choose 3 optimal stations evenly distributed around the user station (in testing)**

Communication with the user is arranged via webpage (below) for observation file upload and e-mail to send the results back

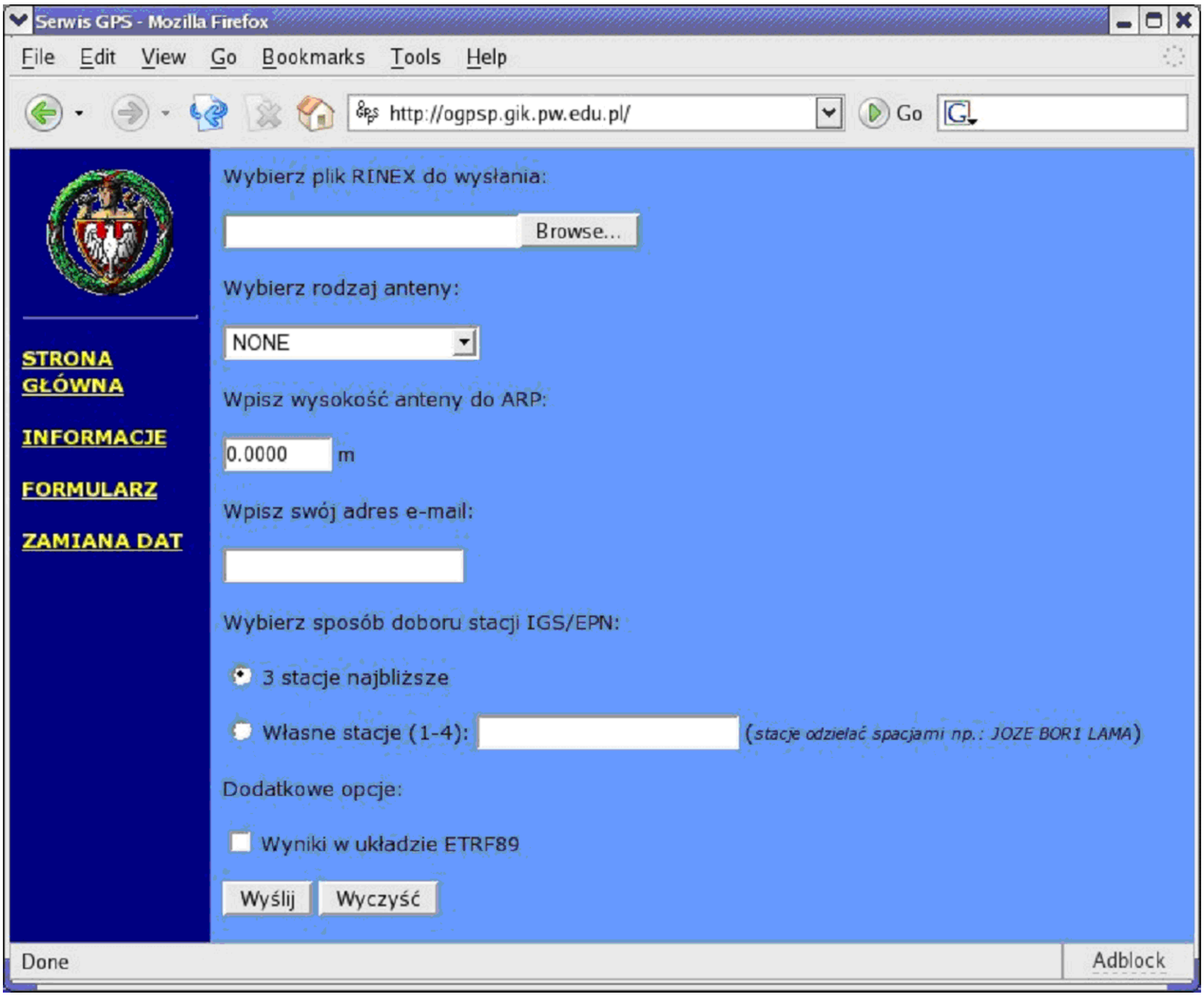


Fig . 9. OGPSP service - main webpage

Note you can also choose the datum: ITRF (standard) or ETRF89. Immense numerical tests has been performed. Tested parameters include:

- **network arrangement**
- **session length (1-24h)**
- **solution scheme:**

  S15 strategy - Saastamoinen troposphere model as 'a priori', 1/cos(z) mapping function, 15° cut off angle

  N10 strategy - no 'a priori' tropo model, Dry Niell mapping function 10° cut off angle, observation weighting (1/cos2(z))

Quantities analysed as a solution quality indicator:

- **height component RMS**
- **percent of resolved ambiguities**
- **tropospheric solution vs. IGS final**

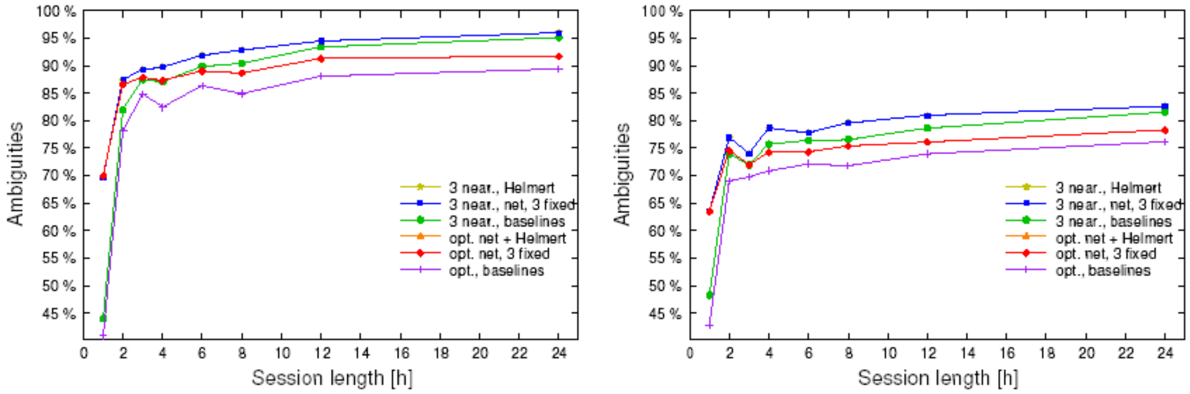
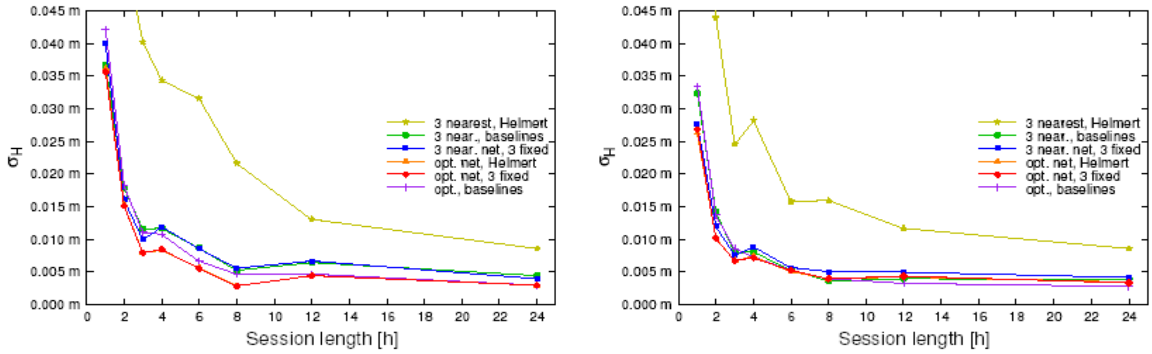


Fig. 10. Percentage of resolved ambiguities for 2 strategies and different network construction scheme



(a) strategy S15 (b) strategy N10

Fig. 11. Height component RMS for 2 strategies and different network construction scheme

Web site address of the OGPSP system is http://ogpsp.gik.pw.edu.pl
We encourage everybody to test it (English webpage version will be soon ready).

4. STANDARD TROPOSPHERIC SOLUTIONS ZTD ANALYSIS AND IPW DERIVATION

Final tropospheric solutions of EPN Local Analysis Centers, IGS solutions and EPN combined product are subject of minute analysis. Below we show some selected especially interesting results. Differences between individual LAC solutions (taken from EUR tropo combination) show best conformity in the year 2003. Results from 2005 – period of new Bernese software version 5.0 introduction show growing discrepancies. For some stations (e.g. KRAW) we can see especially strange results.

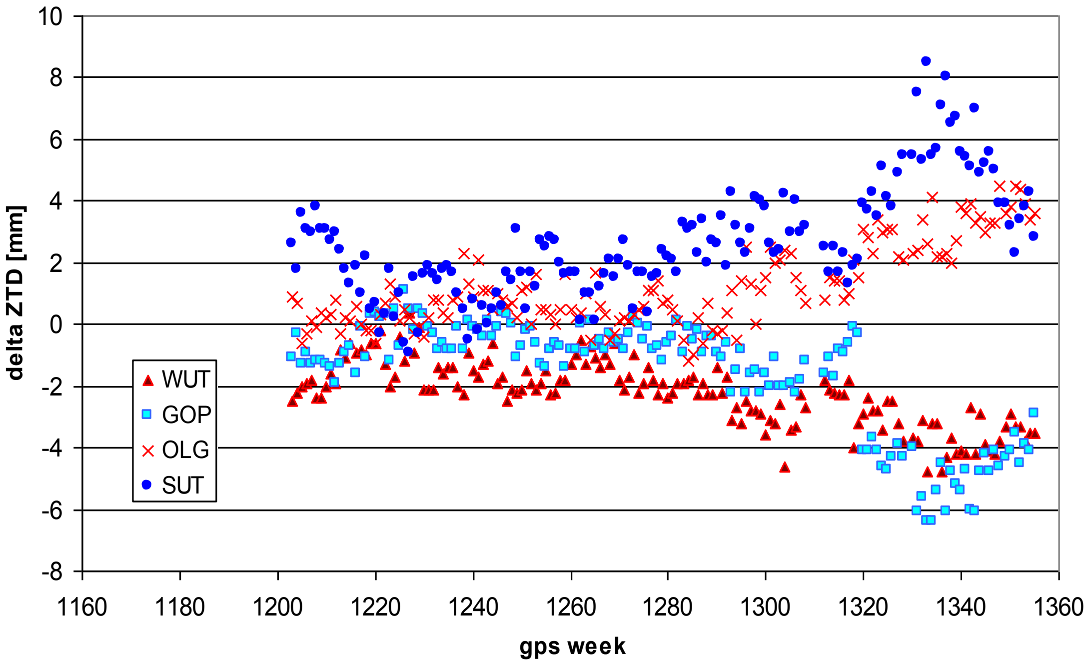


Fig. 12. Differences of EPN LAC solutions and EPN combined product for KRAW

We have found interesting rule that every LAC solution has its characteristic bias relatively to the others nearly constant in time. Probable cause is different strategy and coordinates taken as fixed. Below You can see it for station ZYWI, at the right there are average differences in mm ZTD presented.

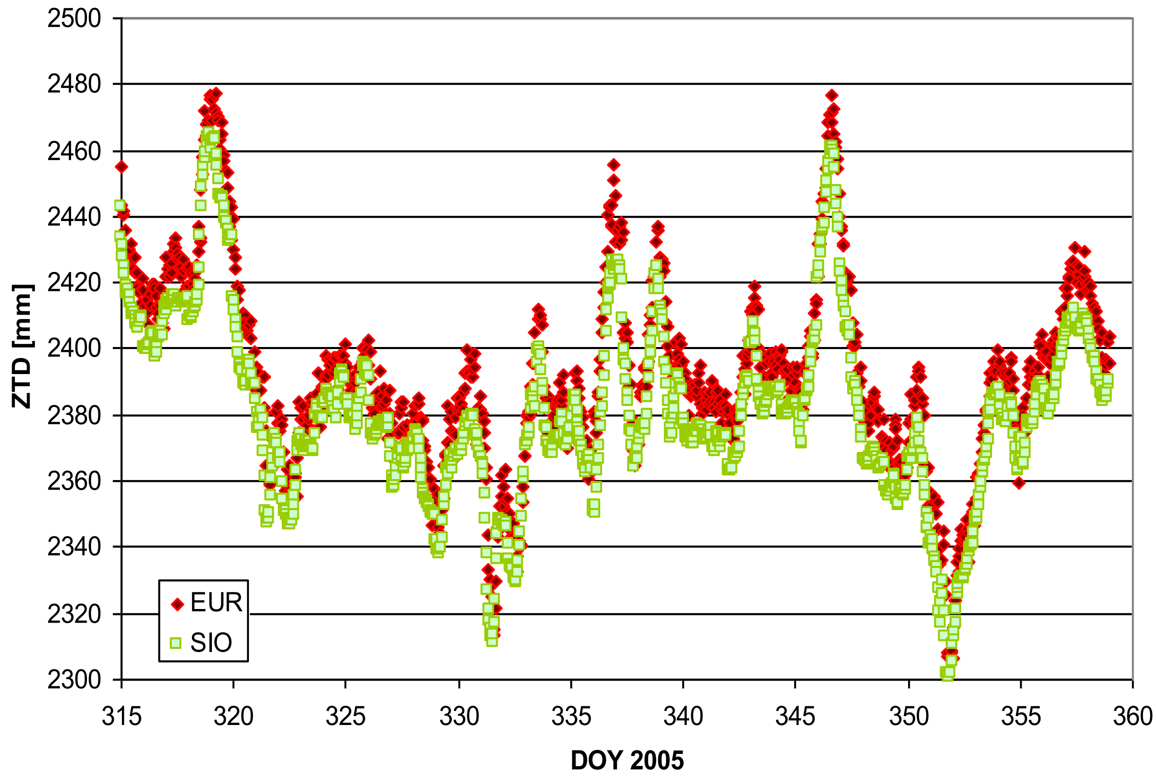


Fig. 13. Differences of EPN LAC solutions and EPN combined product for KRAW

The same was already reported by authors (M. Kruczyk) when compare IGS and EPN solutions. We find slight but durable bias for stations solved by several centers. For EPN Local Analysis Centers we can create some kind of quality-conformity indicator shown below.

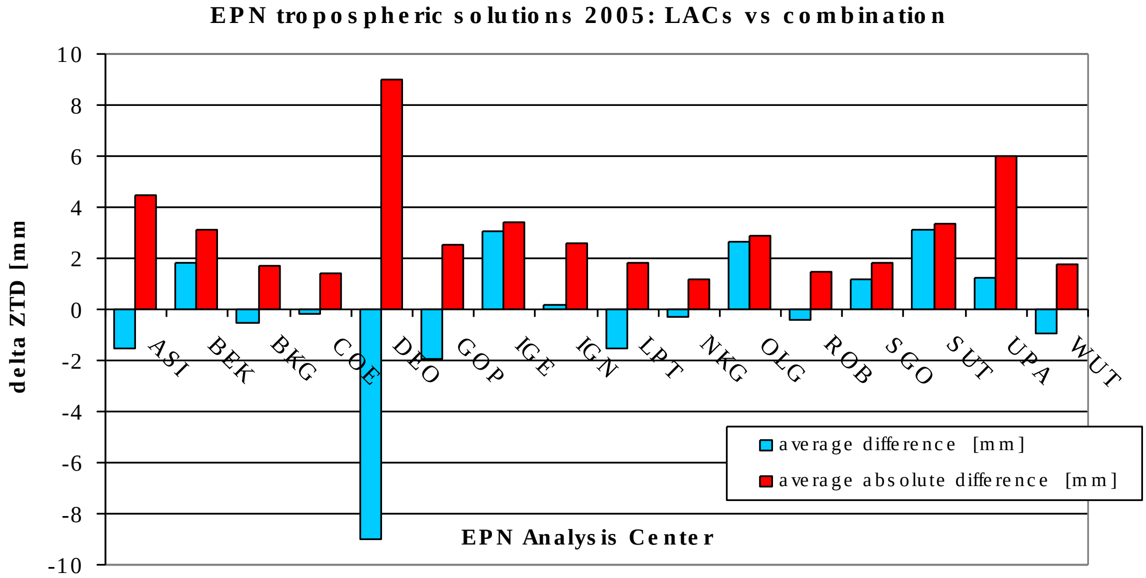


Fig. 14. Averaged differences of EPN LAC solutions and EPN combination during 2005

We use ZTD series to obtain Integrated Precipitable Water values – interesting meteorological parameter coming from purely geometrical solution (so called GPS meteorolgy). The parameter shows weather patterns. Long series of IPW (daily averaged) can serve as 'climatological' information. Below you can see 9 years for JOZE.

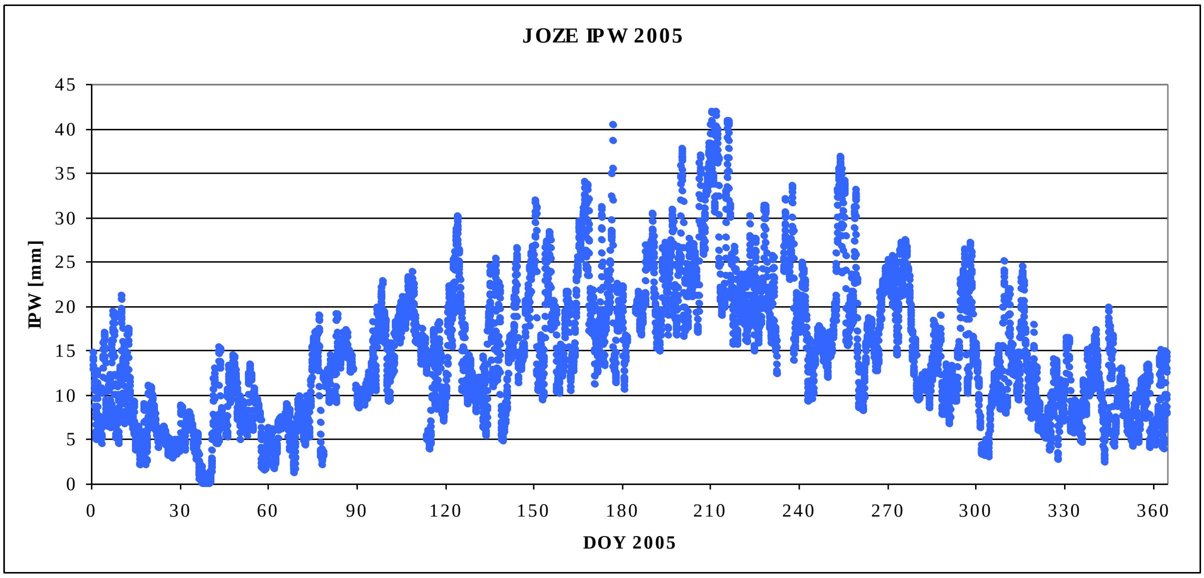


Fig. 15. IPW values for JOZE during 2005

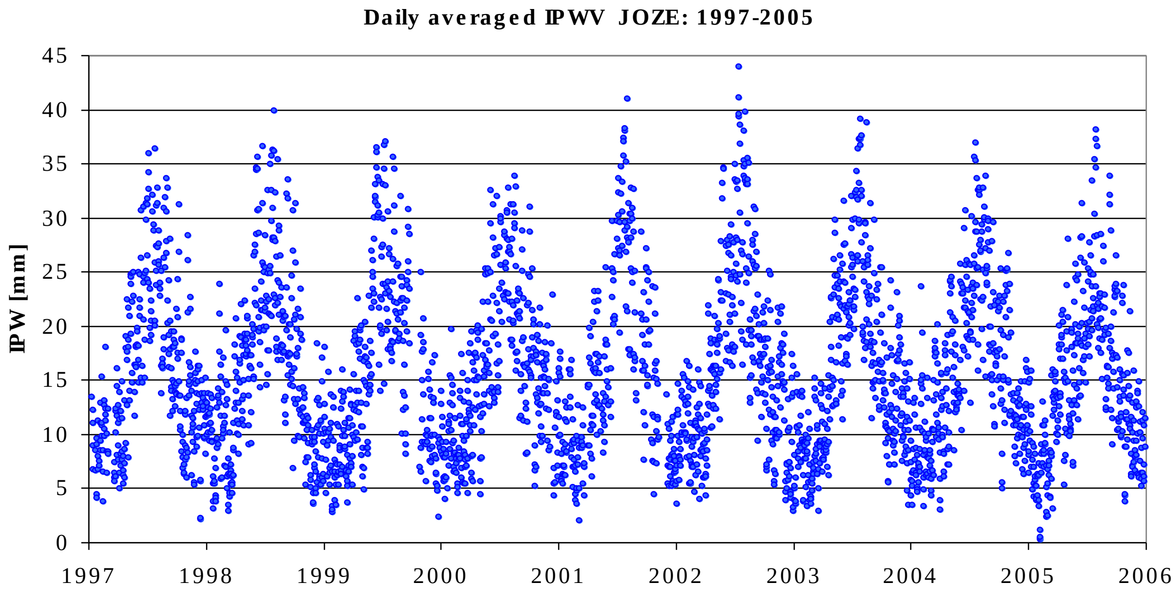


Fig. 16. Averaged daily IPW values from EPN solutions 1997- 2005

Some different climate features are visible in IPW series derived from EPN solutions. E.g. PDEL (Azores) oceanic climate implicates greater values which is especially distinct in the spring.

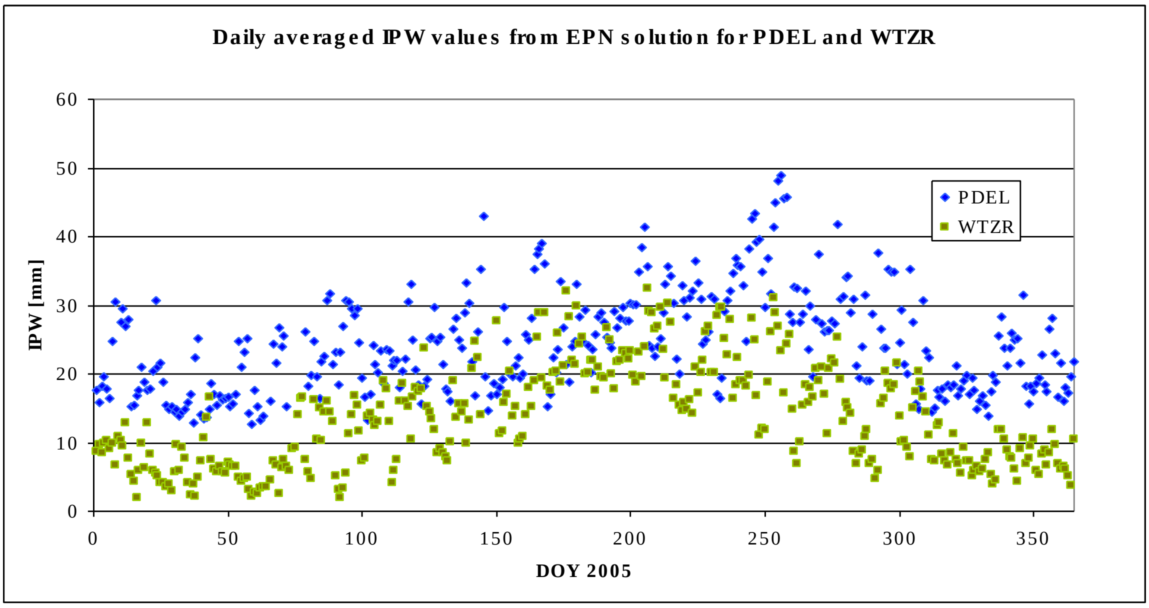


Fig. 17. IPW daily averaged values for WTZR (Bayern) and PDEL (Azores)