Tropospheric delay EPN products and meteorological ZTD and IPW data sources - conformity study

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Abstract

I describe several interesting results of ZTD and IPW time series comparisons and analyses. Temporal changes of individual LAC's ZTD solutions and some simple conformity indexes have been manifold investigated. Greatest attention is paid to IPW (Integrated Precipitable Water) - important meteorological parameter easily derivable from GPS tropospheric solutions (ZTD's). Unfortunately IPW values from various sources can be relatively problematic through various technical shortages. I have made quite many comparisons of different static solutions (mainly IGS and EPN) with three meteorological water vapour data sources: radiosoundings, sun photometer (CIMEL, Central Geophysical Observatory Polish Academy of Sciences, Belsk) and input fields of operational numerical prediction model COSMO-LM (maintained by Polish Institute of Meteorology and Water Management).

Abundance of meteorological data and in accordance with them topospheric delay information makes more and more crucial the question of their usefulness in GPS network processing. Results which lead to the conclusion of IPW coming from GPS high quality will be presented. Some other analyses show value of GPS IPW as a geophysical tool.

Inside standard EPN tropospheric delay products

Final tropospheric solutions of EPN Local Analysis Centers, IGS solutions and EPN combined product should be a subject of minute analysis. Below I show some selected especially interesting results.

Differences between individual LAC solutions (taken from EUR tropo combination made for EPN by Wolfgang Shöene) dramatically diminished in 2007 showing best conformity since the year 2003. Results from 2005 – period of new Bernese software version 5.0 introduction (in some LACs only) show greatest discrepancies. For many stations (e.g. JOZE) we can see quite a strange results. The cause of nice conformity from the GPS week 1400 is in all probability cumulative effect of Bernese 5.0 almost exclusive reign, absolute antenna PCVs and ITRF2005/IGS05.

I have found interesting rule (for the years before 2007) 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. This patterns changed in 2007 and sometimes reversed. The graph on fig.2 shows extreme weekly discrepancies of different LAC's solutions for all GPS stations in Poland.

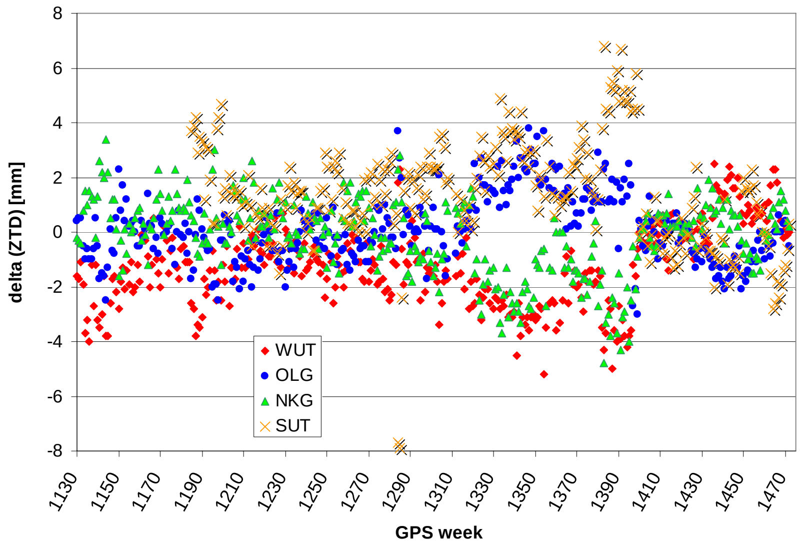

Fig. 1 JOZE (Jozefoslaw near Warsaw) ZTD weekly mean differences (taken from combination file made by W. Söehne): EUR combined product - individual LAC

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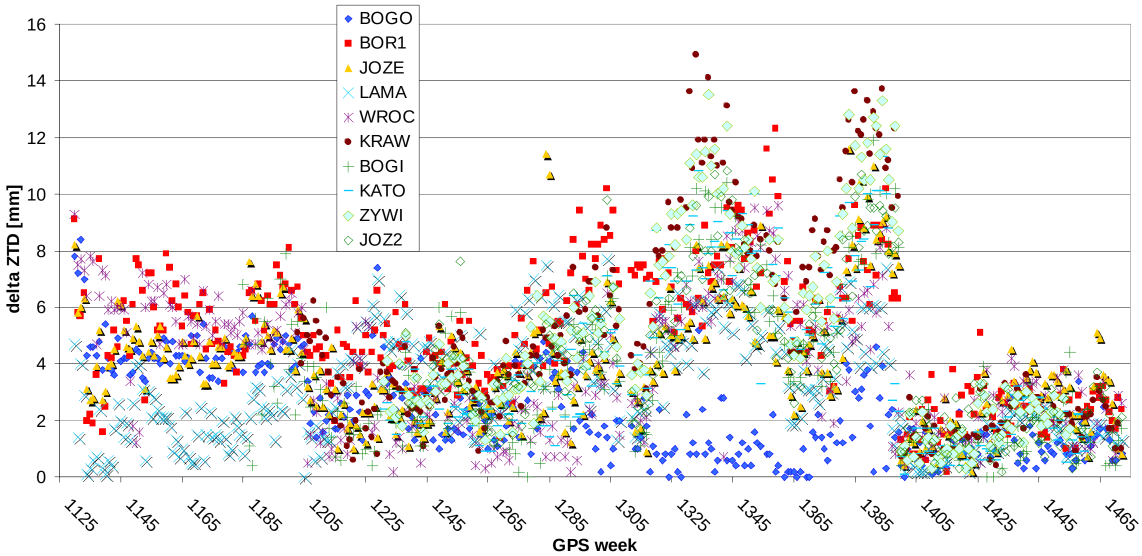

Fig. 2 ZTD weekly mean absolute differences: EUR combined product - individual LAC for all EPN stations in Poland

The same was already reported by me 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 (years 2006 and 2007).

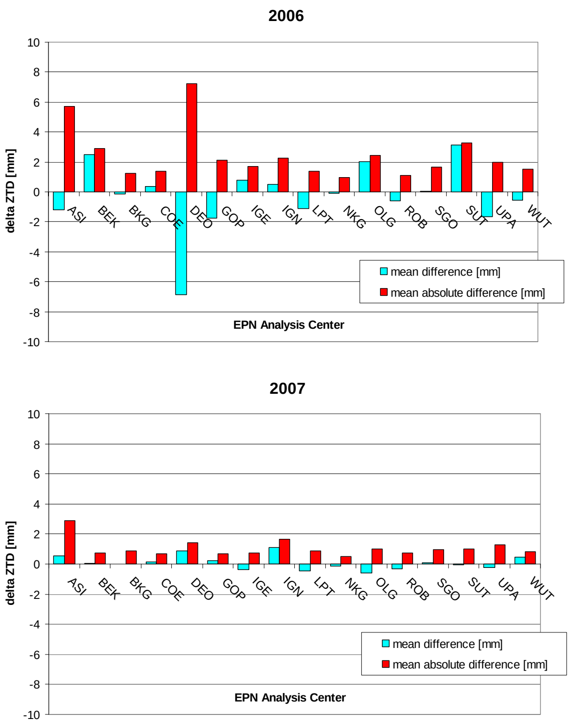

Fig. 3 LAC EPN tropospheric solution statistics in 2006 and 2007: all LACs vs EUR combination; same scale

ZTD IPW data from COSMO-LM NWP model vs. GPS network data

We can treat input fields of numerical weather prediction models (after assimilation/analysis) as a meteorolgical database. I tested this for main synoptic model in Poland: COSMO-LM model maintained by Polish Institute of Meteorology and Water Management in Warsaw (data made accessible by A. Mazur).

The model has a grid of 183x161 points (about 14 km spacing), 36 vertical levels and is restarted twice a day (00 UT and 12 UT); data stored in the GRIB format. Grid has rotated equator and 0 meridian to minimize deformations making typical map projections inadequate – so I prefere to use original grid for mapping results.

For all grid points we can calculate zenith tropospheric delay and interpolate it for 120 EPN stations located in the model area. The ZTD map is of course dominated by topography:

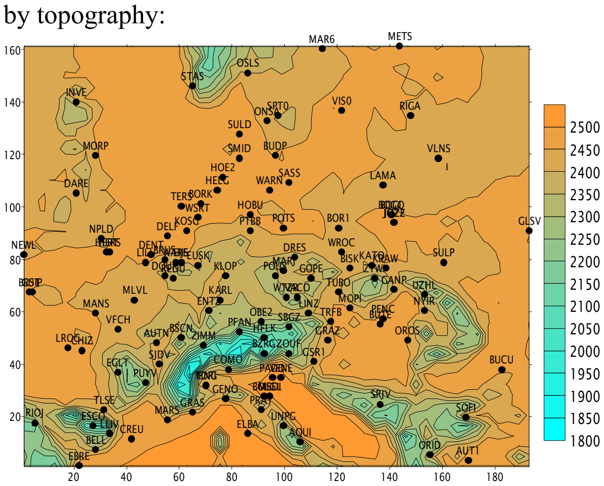

Fig. 4 Map of ZTD calculated from COSMO-LM input fields

Now I can compare ZTD from COSMO-LM model and GPS solutions. On the fig.5 I show the differences: EPN combined tropospheric product - COSMO-LM derived ZTD in 10 months of 2006 and whole year 2007. Both maps are quite similar and have dramatic extremes for mountain stations. I have found these differences dependent on station height. Effect caused surely by relatively poor model topography. Correlation of ZTD differences for respective station and height differences (EPN station height minus interpolated in

COSMO model grid for station coordinates) is amazing. See fig.7

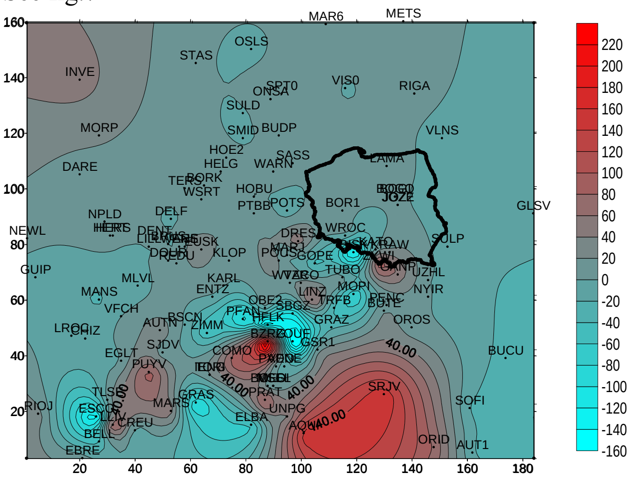

Fig. 5 ZTD differences [mm] map: EPN combined tropospheric product - COSMO-LM input fields derived ZTD averaged in the 10 months timespan (Mar-Dec 2006)

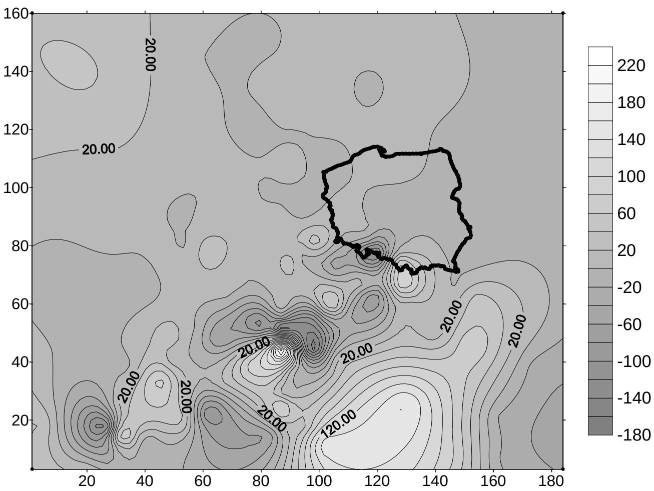

Fig. 6 ZTD differences [mm] map in 2007: EPN combined tropospheric product - COSMO-LM input fields derived ZTD averaged in the 12 months timespan (Jan-Dec 2006)

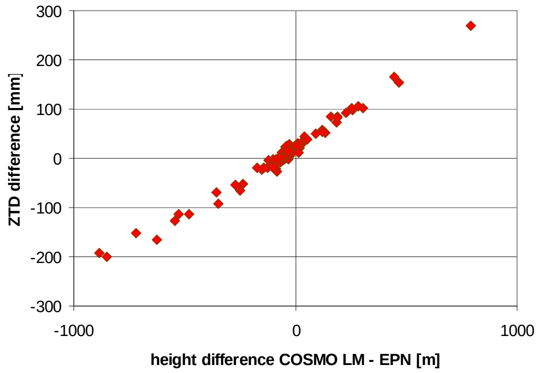

Fig. 7 ZTD differences [mm] for EPN stations inside COSMO model in relation to height difference: EPN height (logs) – height of model ground level for station coordinates

I will develop procedure to take into consideration that phenomena in ZTD and IPW retrieval from numerical weather prediction model. By now I can asses ZTD differences from this two sources by mapping difference RMS which has much less dramatic values. See fig. 8

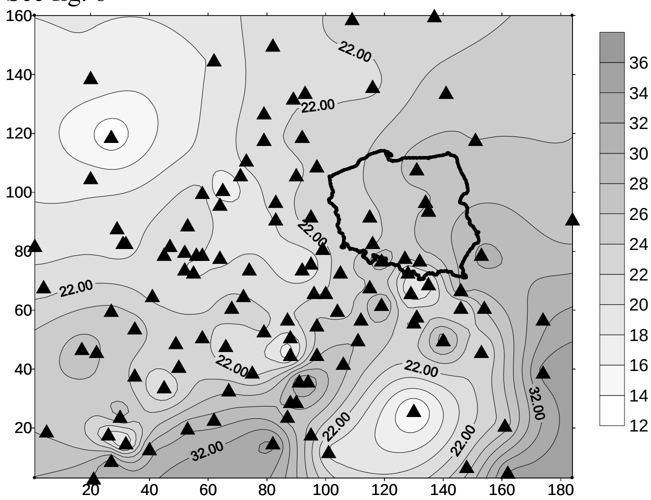

Fig. 8 ZTD differences RMS [mm] map in 2007: EPN combined tropospheric product minus COSMO-LM input fields derived ZTD

In the same way I can get IPW fields by numerical integrating vertical humidity data. Minute comparison of IPW from EPN combined tropospheric product and COSMO-LM input fields is possible only for 22 stations which record meteorological data. On the fig.9 you can see set aside series of IPW for station JOZE in the 2007, XY plot for ORID and the table for all stations. For most stations generally correlation is good (near 0.97) but I got systematic 'scale' difference of 4-7 mm (COSMO model data too big or rather 'too wet'). In this case height difference is not a source of problems because humid air masses travel horizontally, whereas for ZTD pressure is decisive.

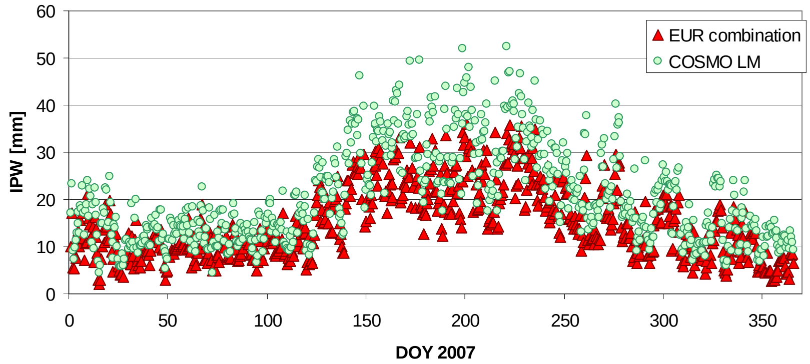

Fig. 9 Integrated Precipitable Water values for TUBO: derived from EPN combination and numerical weather prediction model COSMO-LM input fields – year 2007

Tab. 1 IWV values from EPN combined tropospheric product and COSMO-LM weather prediction model comparison statistics in 2007

station	mean difference: EUR comb IPW - COSMO IPW [mm]	difference RMS [mm]	number of points
BACA	-7.35	4.66	720
BAIA	-5.40	3.84	661
BBYS	-1.62	2.30	203
BOGI	-6.62	3.88	686
BOGO	-7.00	3.99	662
BOR1	-5.95	3.45	346
BORK	-5.34	2.56	290
DEVA	-3.59	3.24	676
DRES	-5.63	3.28	432
EUSK	-5.00	3.07	679
GOPE	-6.32	3.89	672
HELG	-5.94	3.39	643
HERS	-6.51	2.96	700
HOE2	-6.28	3.18	720
JOZE	-6.69	4.03	667
JOZ2	-6.75	4.09	644
KARL	-6.19	3.42	442
KRAW	-5.64	3.40	670
MOPI	-9.95	4.90	385
MORP	-3.31	2.25	88
ORID	-3.75	3.85	634
POTS	-7.10	3.61	689
PTBB	-4.75	2.92	703
SASS	-7.64	3.42	715
SOFI	-5.80	3.98	574
TUBO	-5.60	3.44	720
WROC	-4.67	1.49	139
WTZR	-5.39	3.29	702
ZIMM	-5.55	3.24	689

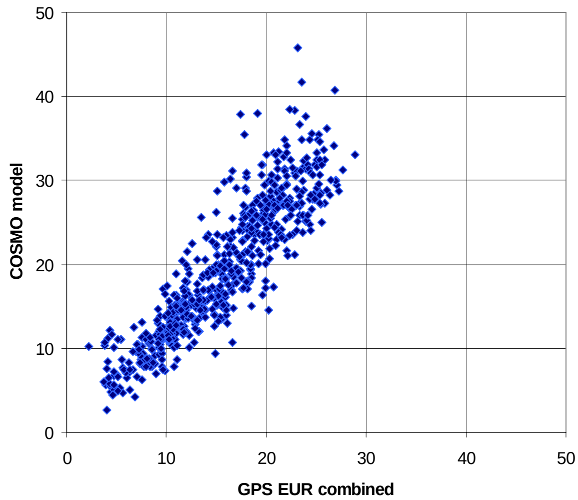

Fig. 10 IPW values [mm] from EPN combination and COSMO model for ORID in 2007

IWV/IPW verification by aerological data

Integrated Precipitable Water values are for some points can be validated by independent techniques: radiosounding observations (in Poland: Legionowo and Wrocław) and sunphotometer CIMEL CF-318 (Central Geophysical Observatory, Belsk near Warsaw, 33 km from JOZE) – results shown below for 2002 and 2005.

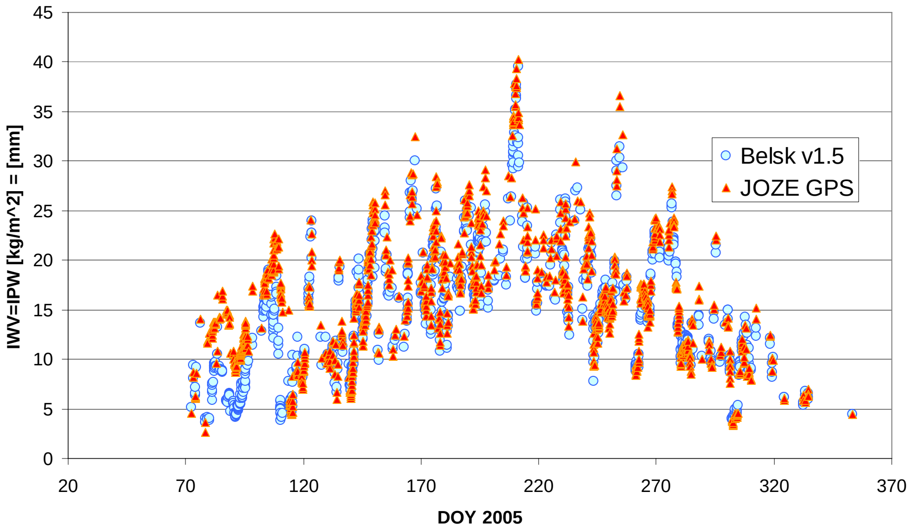

Fig. 11 Integrated Precipitable Water values validated by independent technique: sunphotometer CIMEL CF-318 (Central Geophysical Observatory, Belsk near Warsaw, 33 km from JOZE) – results shown for 2005

Tab. 2 GPS (EUR ZTD combination) and CIMEL sunphotometer (CSPHOT) IPW comparison; lev 15 - indicates application of corrections due to clouds, lev 20 also instrument corrections made by NASA (AERONET)

year	CSPHOT Belsk	JOZE GPS solution	IPW average difference [mm]	IPW average absolute difference [mm]	GPS estimates	CPHOT measurements
2002	lev15	EUR comb	-1.738	1.962	696	1807
2002	lev20	EUR comb	-1.694	1.930	661	1758
2003	lev15	EUR comb	-1.121	1.140	95	265
2003	lev20	EUR comb	-1.173	1.193	83	242
2004	lev15	EUR comb	-1.680	1.861	966	2583
2004	lev20	EUR comb	-1.649	1.827	835	2283
2005	lev15	SIO global	-1.255	1.827	1116	3235
2005	lev20	SIO global	-1.270	1.828	1068	3157
2006	lev15	WUT LAC	-1.772	1.961	968	2842
2006	lev20	WUT LAC	-1.199	1.217	41	110
2007	lev15	EUR comb	0.041	1.065	681	1811
2007	lev15	WUT LAC	-0.067	1.130	681	1811
2007	lev15	SUT LAC	0.052	1.066	678	1806

Conformity of sunphotometer and GPS derived IPW in 2007 (after periodic calibration) is really excellent. Even for the more distant station (BOGI – distance to Belsk nearly 64 km) we can see quite good results with slightly bigger dispersion (see fig.12 and 13).

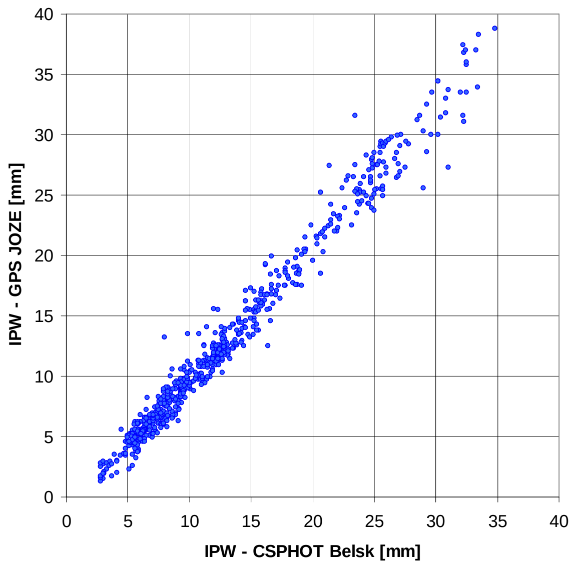

Fig. 12 Belsk CSPHOT vs. GPS JOZE (EPN comb.) in 2007

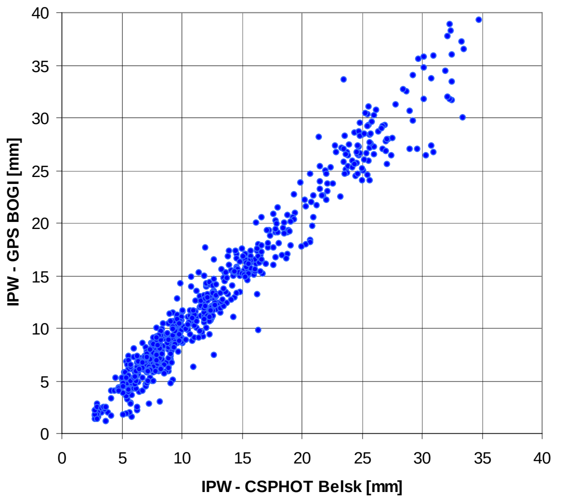

Fig. 13. Belsk CSPHOT vs.GPS BOGI (EPN comb.) in 2007

Radiosundings are regularly performed in 3 points in Poland 2 of them are close to GNSS stations. In my previous works I have calculated IPW from radiosounding profiles by myself this time I used values made available by Department of Atmospheric Sciences University of Wyoming. Here I show two examples of GPS (EPN) derived IPW and results of radiosounding performed twice a day at Legionowo (34 km from JOZE but only 9.5 km from BOGO/BOGI) compared. For both observatories IPW differences are at 1 mm level.

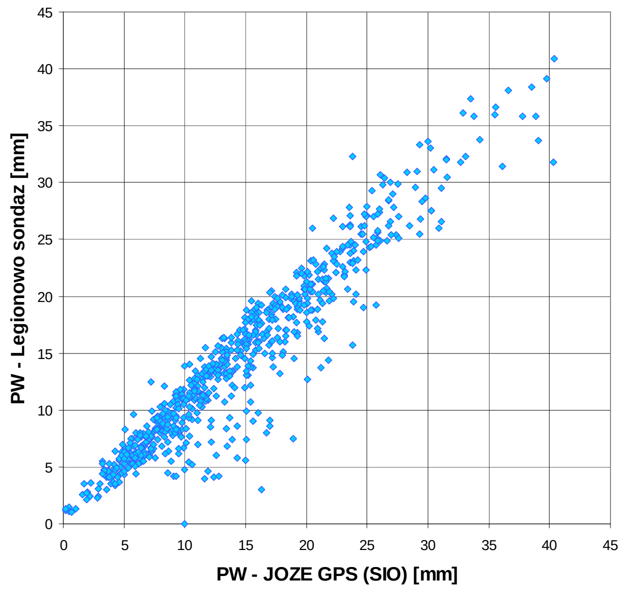

Fig. 14 Legionowo radiosundings vs. GPS SIO IGS global solution for JOZE in 2005

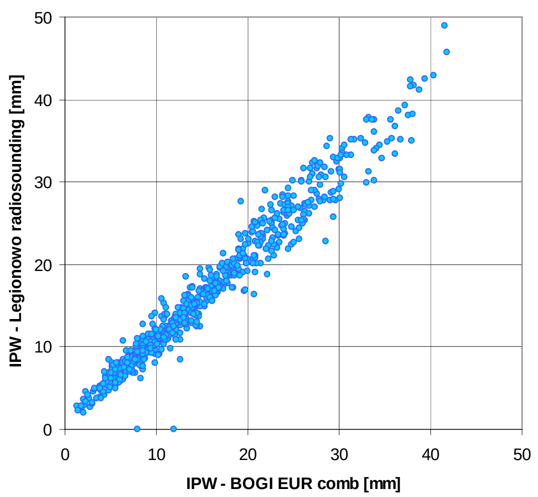

Fig.15 Legionowo radiosundings RAOBS vs. GPS EPN combination for BOGI (Borowa Gora) in 2007

For the midday soundings we can try to validate also meteorological techniques until now treated as more credible than GPS derived values. The next graph compares radiosounding and sun-photometric IPW values – thus the area around Warsaw can serve as some inter-technique test area.

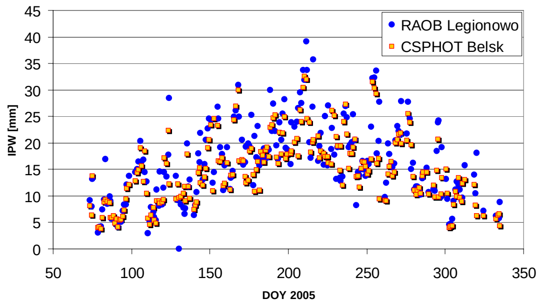

Fig.16 Legionowo radiosundings RAOBS and Belsk CSPHOT in 2005

ZTD and IPW derivation and analysis

ZTD and IPW series have been analysed in many ways in search for some geophysical effects. Among other conclusions I have found decrease of correlation coefficient as a function of distance: ZTD series correlations have been calculated for 2004, IPW for 2007 – less stations with meteo sensor.

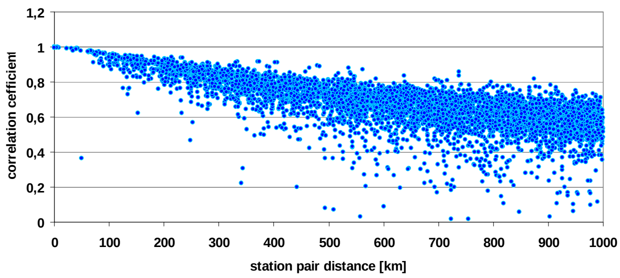

Fig. 17 Correlations of annual ZTD series correlations related to stations distance

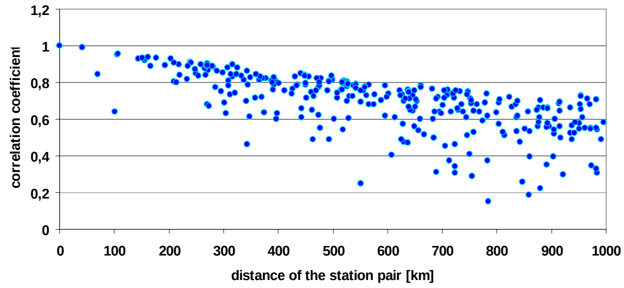

Fig. 18 Correlations of annual IPW series correlations related to stations distance

In EPN we have 5 pairs of very close stations (distance several metes to over 100m) which are of course most correlated stations. BOGO & BOGI are very close (100 m) and correlated but show also systematic difference caused by 10 m height difference (BOGO – on the building roof). Analogical JOZE and JOZ2 pair shows also some periodic variations probably due to problems with JOZ2 receiver (Ashtech Z18). Similar situation exist for HERS and HERT (first on the 8 m mast). Rather trivial illustration of this situation shows fig.19. Case of two very close Italian double sites CAGL-CAGZ and MEDI-MSLM is very puzzling: points on the same level but different antenna-receiver sets. (see Tab 3)

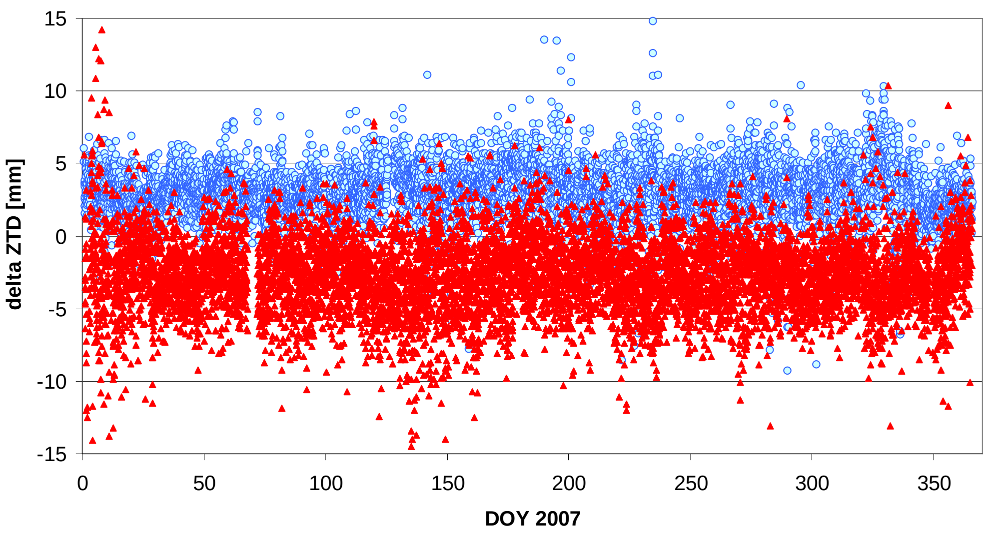

Fig. 19 ZTD differences for close stations: BOGO – BOGI (full triangles); HERS – HERT (empty circles)

Tab. 3 ZTD series (from EUR comb) differences for closest stations

station 1	station 2	mean ZTD differrence	mean absolute ZTD differrence	difference RMS [mm]	number of points	station 1 height [m]	station 2 height [m]
BOGO	BOGI	-2.71	3.13	2.74	8536	149.6	139.9
JOZE	JOZ2	0.17	2.05	3.02	7767	141.4	152.5
CAGL	CAGZ	5.66	5.74	2.53	7366	238.4	238.0
HERS	HERT	3.06	3.17	3.61	8518	76.5	83.3
MEDI	MSEL	-6.27	6.38	3.09	6011	50.0	49.3

We can treat series of Integrated Precipitable Water obtained from ZTD values as interesting meteorological parameter coming from purely geometrical solution (so called GPS meteorology). The parameter shows weather patterns in the other manner than pressure or humidity.

Long series of IPW (daily averaged) can serve as 'climatological' information. On the next figure you can see 11 years for JOZE. I tried to adjust sinusoidal model the series (LS method), every year separately – different not only amplitude but also phase. Figure 21 illustrates the results for 5 year period when I got +0.6 mm/year IPW trend. For the following years not visible. By the way +0.1°C/year trend for temperature keeps for the whole 11 year period.

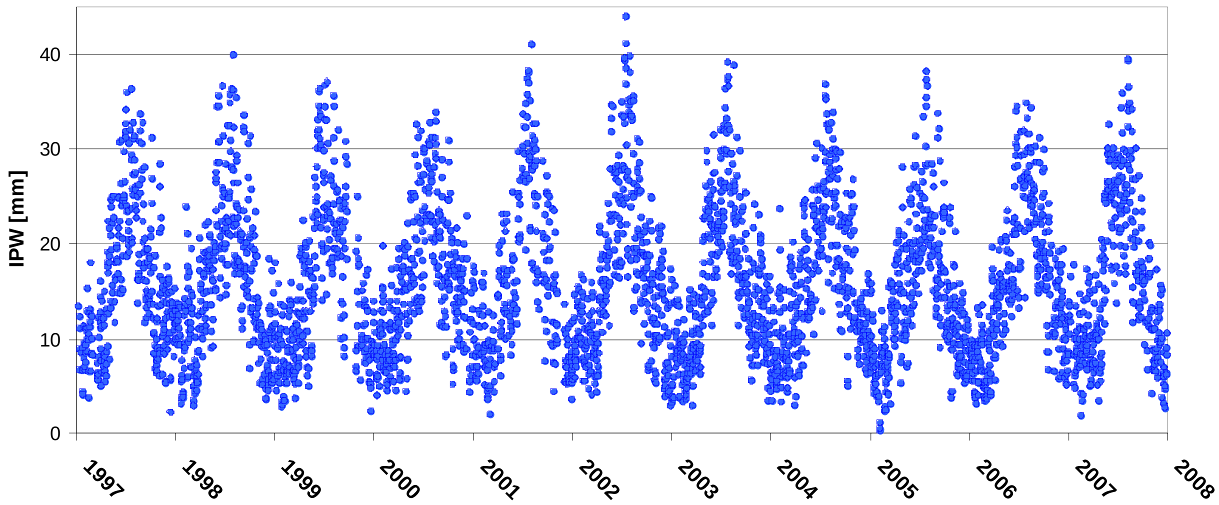

Fig. 20 Long series of daily averaged IPW values derived from EPN ZTD for JOZE

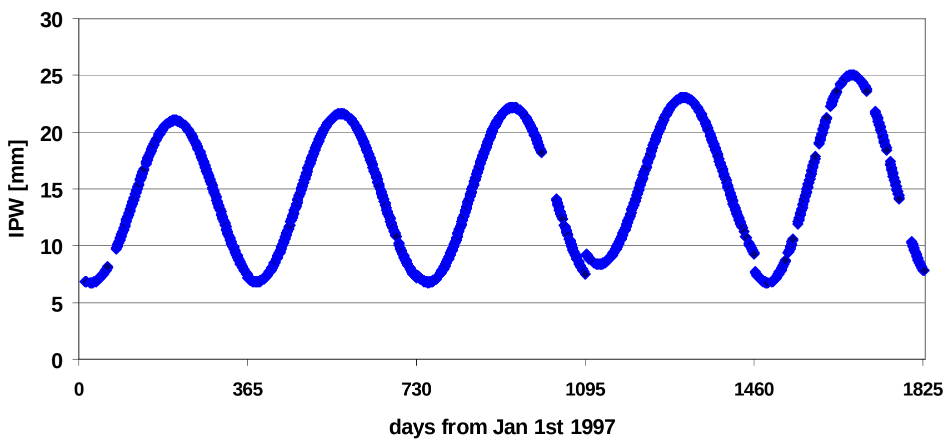

Fig. 21 Simple model of daily IPW values series (sinusoid + const) derived from IGS CODE ZTD solution for JOZE 1997-2001

Some different climate features are visible in IPW series derived from EPN solutions.
E.g. PDEL (Azores) oceanic climate is especially distinct in the spring compared to rather continental WTZR (Bayern).

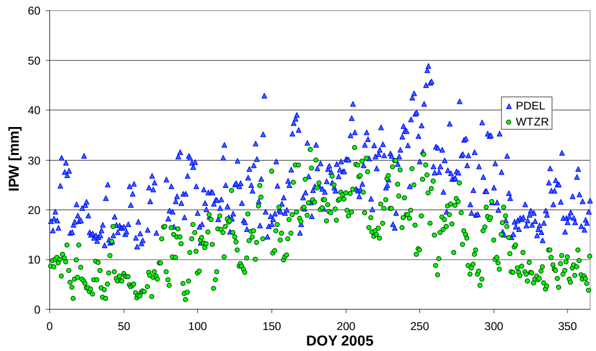

Fig. 22 Daily averaged IPW values for PDEL and WTZR in 2005

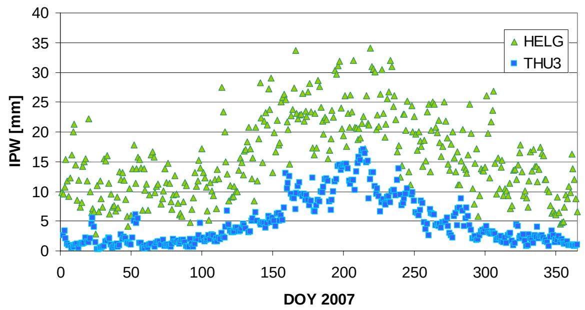

Fig. 23 Daily averaged IPW values for HELG and THU3 in 2007

Unique value of IPW as a meteorological information source can be seen when we try to model Integrated Precipitable Water by means of using surface meteorological data. Best we can got is to calculate (using psychrometric formulas) absolute humidity on the surface. This parameter is loosely correlated (periodically even anticorrelated) to IPW but there is no analytic model to calculate wet atmospheric refraction (see fig 24). Situation is worse for southern stations what shows scatter plot for analogical values obtained from EPN combination for Lagos (fig 25).

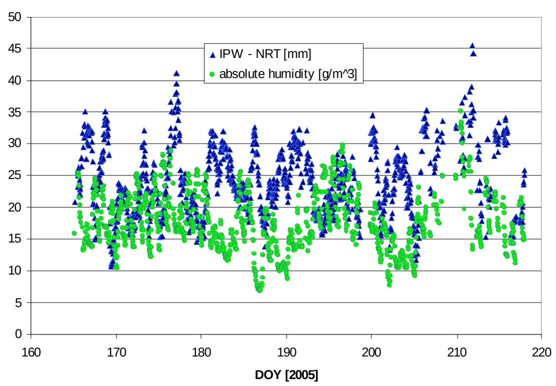

Fig. 24 IPW obtained from WUT NRT ZTD solution and surface absolute humidity for GOPE in 2005

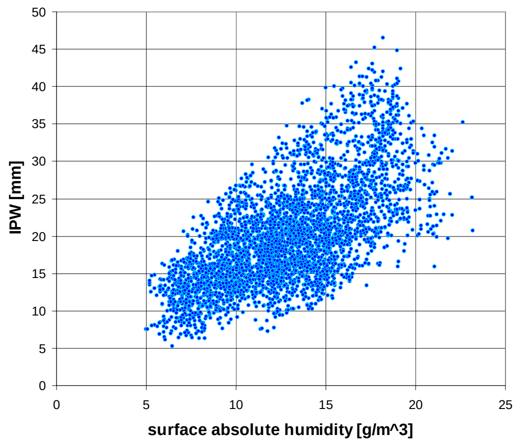

Fig. 25 IPW [mm] vs. surface absolute humidity for LAGO (Lagos, southern Portugal) in 2005

Conclusions

- IPW (Integrated PrecipitableWater, also IWV) is important meteorological parameter easily derivable from GPS tropospheric solutions (ZTD's)
- IPW coming from GPS (different static solutions mainly EPN) is of reliable quality compared with three meteorological water vapour data sources: radiosoundings, sun photometer and input fields of operational numerical prediction model (NWP) COSMO-LM
- Only CIMEL sunphotometer data seems more genuine source. IPW values from other sources can be much more problematic through various technical shortages
- It is worth to emphasize that while inter-technique comparisons of directly measured IPW is attainable only for best equipped observatories, from NWP models treated as meteorological database we can obtain calculate ZTD and IWV for all stations independently from sparse RAOB network. Unfortunately procedure is not so straighforward
- Other research show value of GPS IPW as a geophysical tool: clear physical effects evoked by station location (e.g. height and, ZTD series correlation coefficient as a function of distance) and weather pattern; especially intriguing are also long (climatologic?) IPW series.
- Deficiency of surface humidity data to model IPW extremely encourages to investigate information exchange potential between Numerical Model and GPS network derived values – which is needed for future development of weather prediction but also less laborious methods of GNSS precise positioning.

Acknowledgements

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