SOME REMARKS ON GPS TROPOSPHERIC DELAY PRODUCTS AND THEIR SIGNIFICANCE

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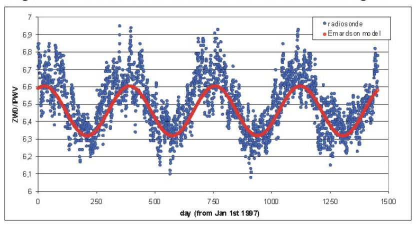
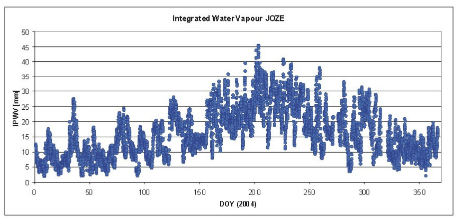
Abstract

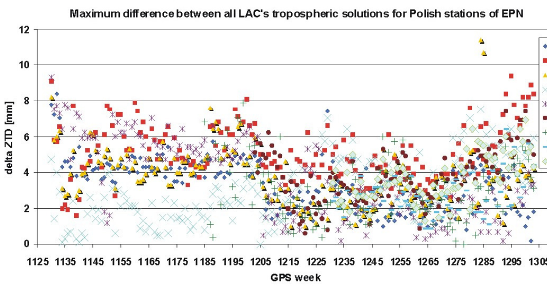
Paper deals with some areas of my interest in ZTD series and research in GPS meteorology.
I have made many statistical quality analysis of the many standard tropospheric solutions and ZTD combined products (EPN and IGS). Special stress is laid on quality of EPN tropospheric delay output. Factors considered as affecting tropospheric solution quality are network geometry (e.g. range), solution minutes (individual AC solutions), latitude (climate), height. This work can be useful not only for persons interested in combined product but also lead to deeper analysis of the strategy guidelines. Next area refers directly to GPS meteorology: IPW derivation, quality comparisons with radiosounding profiles, correlation of IPW series for different stations and other parameters. Finally there are presented some ideas how to use (analyse and visualise in interesting way) tropospheric delay in meteorology and climatology: e. g. long IPW series for different climate conditions.

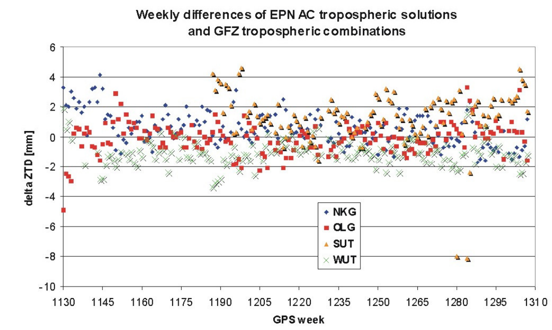
Zenith tropospheric delay from GPS network solution can be separated into hydrostatic part (it is a function of surface pressure) and 'wet' part which can be transformed into IPWV if we can calculate coefficient dependent upon mean temperature in troposphere. I have calculated mean temperature linear regression model (to transform different ZTD series to IPW) using vertical profiles of temperature and humidity from radiosoundings . Below you can see comparison of ZWD/IPW coefficient from the model and other so called Emardson model which is independent from temperature measurements but least precise.
Right below there is the effect - IPWV for JOZE during whole 2004



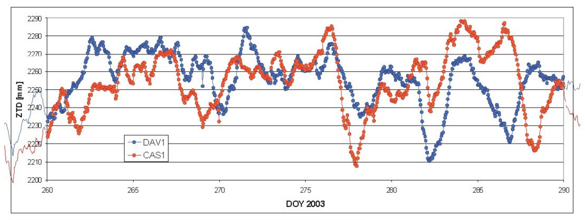


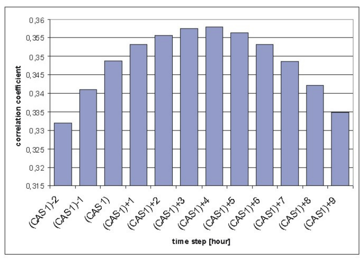
Total Zenith Delay above all stations in the network became one of the standard products of IGS (1998 by GFZ) and EPN (2001 by BKG and GFZ). It is created as a combination of individual AC solutions. Below you can see average (weekly) AC solutions and EPN combination differences for all GPS points in Poland and next the same quantities for JOZE in GFZ combinations.





I have shown in the previous posters some interesting meteorological regularities. Setting aside parameters for two stations with the same latitude we ca discern similar IPW time changes shifted by a few hours. It is caused by dominant western atmospheric circulation in Europe. The effect is quite clear for pairs: POTS-JOZE and WROC-DRES. Now I have found the same for two Antarctic stations CAS1(Casey) and DAV1 (Davies) placed near the polar circle but with 30 deg latitude change.

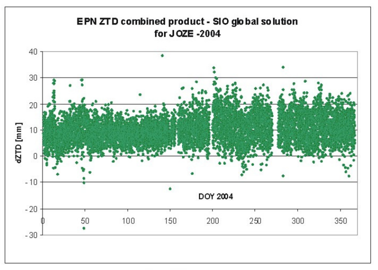




Closer look at some statistical aspects of separate Analysis Centers solutions and combinations for various stations can disclose many interesting regularities.

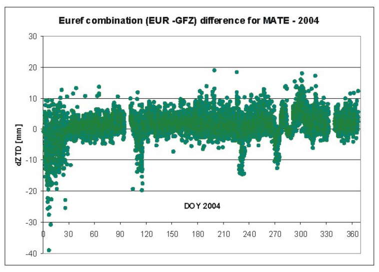
Below differences of European combination and global IGS solution made by SIO and (EUR -SIO) for 30 stations and difference series for JOZE during 2004. Note clear and always positive bias.

	averaged ZTD (EUR-SIO) difference [mm]	mean absolute difference		averaged ZTD (EUR-SIO) difference [mm]	mean absolute difference
BOR1	6.716	6.903	MEDI	7.445	8.215
BRUS	6.292	6.509	METS	5.644	5.969
BUCU	6.855	7.112	NOT1	5.847	6.579
CAGL	4.819	6.524	NYA1	3.379	4.099
GLSV	4.737	5.425	ONSA	4.265	4.850
GOPE	9.197	9.426	POTS	5.692	6.501
GRAS	4.335	4.955	RABT	6.028	6.493
GRAZ	5.978	6.742	REYK	1.821	4.119
HERS	5.131	6.166	THU3	5.075	5.635
JOZE	10.207	10.272	TRO1	3.799	4.871
KELY	3.511	5.606	VENE	10.325	10.669
KIRU	5.421	5.883	VILL	2.295	3.730
KOSG	4.035	4.609	WSRT	2.874	4.356
LAMA	6.121	6.373	WTZR	4.892	5.781
MATE	7.638	8.857	ZIMM	6.330	6.655

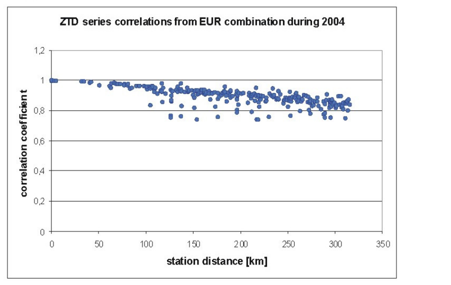


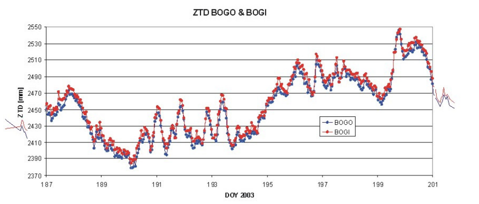
To chose optimal solution of given network (even in case of post processed solutions of EUREF Analysis Centre) still presents some problem. Comparing various solutions we get on the average 1-2 mm IPW differences. Even two available EUREF ZTD combined products show clear discrepancies. Differences for one of the stations (MATE) for which they are quite expressive are illustated on the right.

	averaged ZTD (EUR-GFZ) difference [mm]	mean absolute difference		averaged ZTD (EUR-GFZ) difference [mm]	mean absolute difference		averaged ZTD (EUR-GFZ) difference [mm]	mean absolute difference
AJAC	0.166	0.393	KIRU	0.058	0.171	REYK	0.079	0.359
BOGO	0.023	0.062	KOSG	0.213	0.280	RIGA	0.188	0.323
BOR1	0.164	0.246	KRAW	0.149	0.238	SJDV	-0.027	0.397
BRST	-0.260	0.674	LAMA	0.098	0.138	SODA	0.097	0.250
BRUS	0.087	0.217	LLIV	-0.578	0.753	SOFI	0.041	0.392
BUCU	0.032	0.192	MANS	-0.154	0.344	THU3	0.010	0.068
BUDP	0.019	0.064	MATE	1.240	2.925	TORI	4.224	4.858
CAGL	0.021	0.492	MEDI	-0.185	0.545	TRO1	-0.059	0.105
DELF	0.007	0.031	METS	0.039	0.139	VAAS	0.086	0.179
DOUR	-0.035	0.082	MOPI	0.210	0.333	VALE	-0.849	1.345
DRES	2.489	3.318	NOT1	0.222	0.649	VENE	1.918	2.667
DUBR	0.270	0.724	NICO	0.027	0.507	VILL	-0.106	0.457
GLSV	0.051	0.084	NYA1	0.002	0.045	VIS0	0.058	0.117
GOPE	0.069	0.186	ONSA	0.000	0.090	WARE	-0.036	0.334
GRAS	0.064	0.512	PADO	1.610	2.670	WROC	0.022	0.177
GRAZ	0.030	0.311	PENC	0.050	0.237	WSRT	0.020	0.038
HERS	0.020	0.073	PFAN	0.128	0.331	WTZR	0.122	0.349
JOZE	0.070	0.214	POTS	0.058	0.092	ZIMM	0.151	0.300
KELY	0.015	0.344	RABT	-0.718	1.191	ZYWI	0.141	0.271



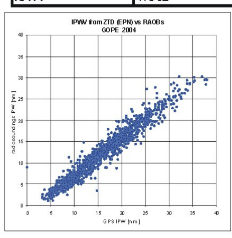
IPW values of two permanent points show apparent similarity depending on spatial separation. Below you can see 300 correlations of annual EPN ZTD combined product for selected stations related to their distance.
The course of ZTD series for two nearby(and strongly correlated) Polish stations BOGI and BOGO show also clear bias which can be explained as the result of 10m height difference (BOGI is located on the building's roof).

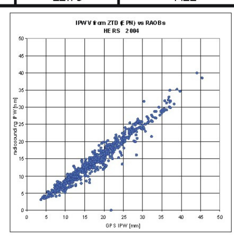


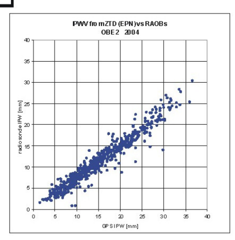


Radiosounding observations (RAOBs) are carried out in about 30 sites relatively close to EPN stations. Unfortunately there are only 8 stations fitted with meteo sensors to calculate precisely zenith wet delay and IPW. Below I present results of IPW series comparisons for this stations. Its worth to note I have got mostly positive values of GPS-RAOBS.
I would like to warmly acknowledge the help of Mr Henrik Vedel from DMI (and also TOUGH project) who made radiosounding data available to me.

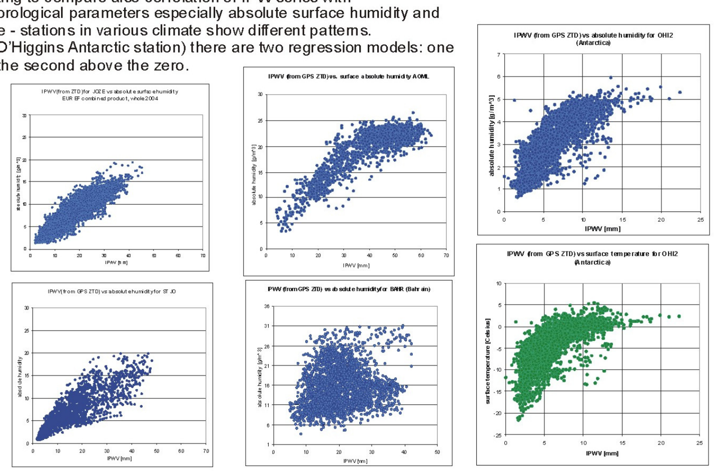
GPS station	radiosounding site	distance [km]	averaged absolute IPW difference 2004 [mm]
WROC	12425	18.34	3.81
JOZE	12374 (Legionowo)	34.83	3.26
GOPE	11520 (Praha Libus)	29.21	3.67
HERS	3882	4.44	3.30
SOFI	15614	9.16	3.93
OBE2	10864 (Munchen)	18.54	3.76
ANKR	17130	3.80	2.84
ISTA	17062	22.79	7.22



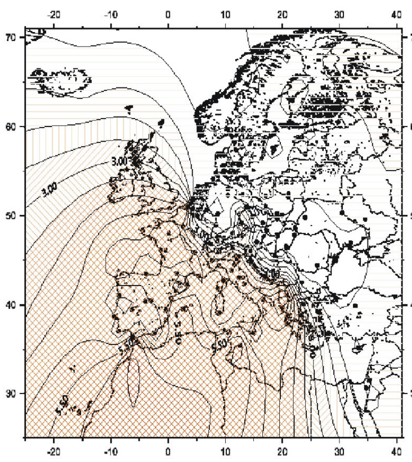




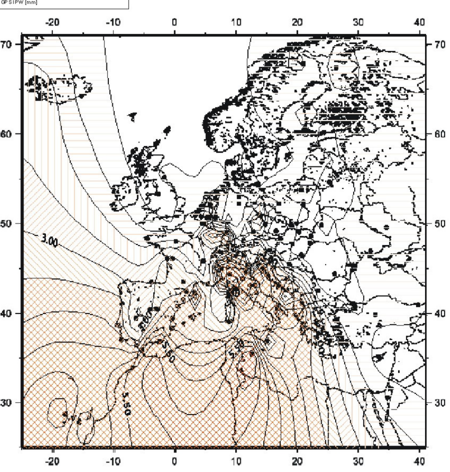
It is interesting to compare also correlation of IPW series with other meteorological parameters especially absolute surface humidity and temperature - stations in various climate show different patterns.
For OHI2 (O'Higgins Antarctic station) there are two regression models: one below and the second above the zero.



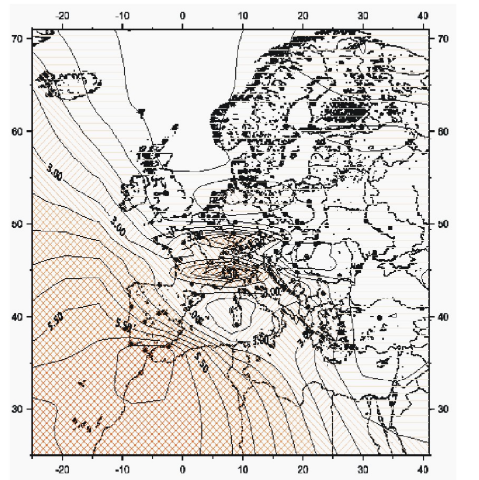
We used differences generated in EPN combination files to calculate averaged differences of ZTD solution for different stations and Analysis Center. We can also assess changes of this discrepancies in time. On the right you can see maps of ZTD differences between EUR combination and all AC's solutions for the whole years 2002 and 2003.
Below you can compare averaged differences and absolute differences for all Analysis Centers in the subsequent four years.



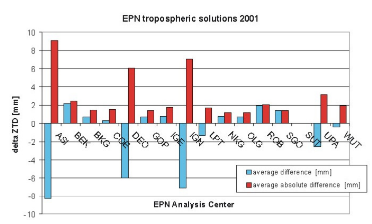
2002

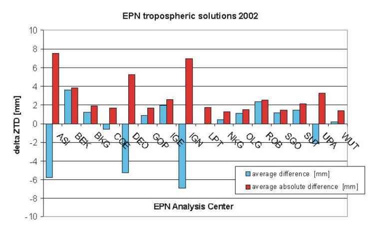


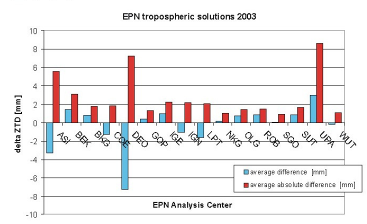
2003

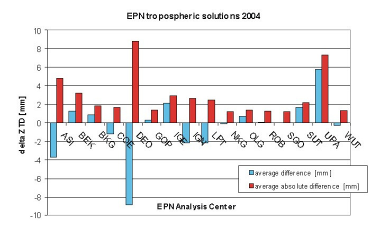


2004









To demonstrate value of IPW as climatological parameter (e. g. global warming indicator) we have calculated daily averaged values of IPWV in the course of 7 years for JOZE, in the course of 6 years for ZIMM, 5 years HERS and METS and nearly 4 years for MATE and REYK. Average temperature values in JOZE and REYK are also showed on the left. First conclusions: seasonal period with summer IPW maximums dominates all european series; ocean climate has smaller seasonal extremes (HERS, REYK, MATE);
greater station height implicates lower values; subpolar and polar stations series show notably lower values. For some stations shape of annual cycle is quite different (e.g. AOML), and even nearly invisible (BAHR) or reversed on southern hemisphere (OHI2).