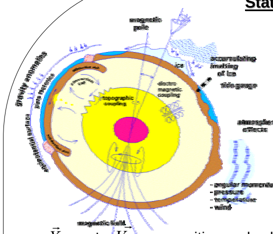
SITE COORDINATES MONITORING FOR NEAR REAL TIME GPS ZENITH TROPOSPHERIC DELAYS

R.Pacione - Telespazio S.p.A – Centro di Geodesia Spaziale, Matera (Italy)

F.Vespe - Agenzia Spaziale Italiana – Centro di Geodesia Spaziale, Matera (Italy)

GPS tropospheric zenith delay is correlated with the site coordinates, especially with the vertical one. For meteorological application there is no need to estimate them when processing GPS data but there is the need to know site coordinates with a certain level of accuracy. In Near Real Time GPS data processing site coordinates are fixed onto weekly or monthly averages and, although this reduces the noise, it may causes small time varying biases. The geodetic reference frame is always being improved; there are occasionally slight changes, which can lead to offsets in the long-term trend of GPS ZTD. In the framework of the EC TOUGH project, the analysis centres use different software packages, analysis strategies and handle the site coordinates in different ways. An overview of the processing options used by the ACs focusing on those differences related to site coordinates handling will be presented and for a subset of IGS/EUREF stations a time series of daily ZTD bias and std between ASI and the other ACs involved in the project will be discussed together with site coordinate time series extracted from the COST hourly files. Guidelines to take into account in GPS ZTD data processing will be discussed as well. A statistical method to assess the degree of reliability of the NRT ZTD and their real uncertainties will be proposed and the results achieved applying the proposed method will be shown.

Station Motion Model



The Earth's surface is perpetually deformed due to a variety of internal and external forces, acting on time scales from seconds to millions of years. In order to avoid contamination of the ZTD or other tropospheric parameters by the station motion, the relevant part of the station motion needs to be accounted for both in the realization of the reference frame and the station motion model used in the analysis. The position of a point on the surface of the solid Earth at a given epoch t is expressed as

$$\vec{X}(t) = \vec{X}_0 + \vec{V}_0(t - t_0) + \sum_i \Delta\vec{X}_i(t)$$

$\vec{X}_0$ and $\vec{V}_0$ position and velocity at the initial epoch t_0 (*secular movement)*

$\sum_i \Delta\vec{X}_i(t)$ corrections due to the various time changing effects, as Earth tide displacement, ocean and atmospheric loading.

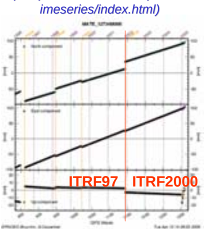
For GPS meteorological applications the station coordinates are fixed (i.e. not estimated) onto weekly and monthly averages in order to get a more stable ZTD time-series. Fixing the site coordinates in the GPS data analysis means that

- the secular movement is taken into account,
- known geophysical phenomena as Earth and pole tides, ocean tidal loading are model,

but although this reduces the noise, it may cause small time varying biases.

Reference Frame Evolution

Matera ITRS time series
(http://epncb.oma.be/_dataproducts/timeseries/index.html)



The International Terrestrial Reference Frame (ITRF) is defined through a set of 3-D coordinates and secular velocities. Transition from one ITRF to the next changes the coordinates of the sites and the velocities associated with them. Such a change introduces a step in the ZTD time series of a given station that has to be investigated. The evolution from ITRF97 to ITRF2000 occurred on December 2nd, 2001 is focused on and for 2-months period (November-December 2001) we point positioning the Italian stations of Cagliari, Matera, Medicina and Venezia with ITRF97 and ITRF2000 coordinates and velocities and we estimate ZTD. The effect of site position difference on ZTD is minor being the 2-months ZTD bias (ITRF97 minus ITRF2000) less than **2 mm** and the related standard deviation of the same order of magnitude. The effect of scale difference may not be negligible and should be considered when 'absolute' antenna phase patterns will be adopted.

TOUGH processing options related to site coordinates

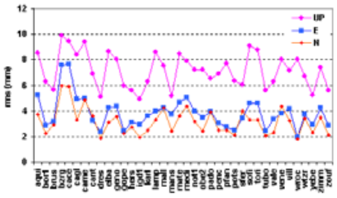
TOUGH analysis centres **ASI (Italy), ACRI (France), GOP (Czech Republic), IEEC (Spain), LPT (Switzerland), NKG (Norway), NKGS (Sweden)** use different software packages (GIPSY, GAMIT, Benese) and analysis strategies and handle the site coordinates in different ways. All the ACs keep the coordinates fixed onto values from ITRF or coordinate solutions computed by post-processing using longer time spans of GPS data. The coordinate solutions are updated regularly, e.g. in monthly intervals using post-processing, or using a multi-day combination of normal equation stacking (GOP). Only IEEC is estimating station coordinates simultaneously with the ZTD parameters in the near real time processing. The adopted terrestrial reference frame is ITRF00, only GOP is using IGS00.

The TOUGH recommendations concerning the site coordinates used in the COST files are:

- the ZTD COST files must report the coordinates used in the processing;
- it is recommended to fix the coordinates in the processing and not to estimate them together with ZTD. The COST format says:" *The values should be stable, long-term means, not just for the period of the vfile*";
- the site location should be stable and long term stability is required;
- 'long-term' should be site-dependent and would be a trade-off between station velocity and its repeatability;
- height coordinate repeatability should be lower than 10 mm;
- site coordinates should be updated at least every month.

Targeting Optimal Use of GPS Humidity Measurements in Meteorology

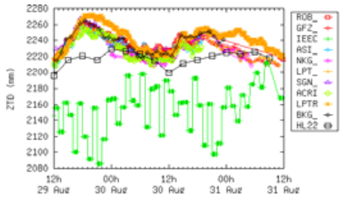
http://tough.dmi.dk/



Height coordinate repeatability as indicator of ZTD quality

9mm H → 3mm ZTD → 0.45 mm PWV

ZIMM 24-h ZTD series
http://www.knmi.nl/samenw/egvap/validation/ztd_iwv.html

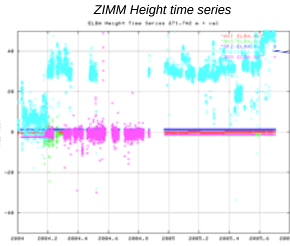


Inter Comparison of TOUGH results

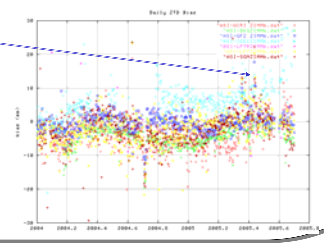
http://geodaf.mt.asi.it/html_old/GPSAtmo/WP9300/TOUGH_WP9300.html

On a subset of IGS/EUREF stations a daily monitoring of the site coordinates reported in the header section of the COST files is done as well of the ZTD bias and std between ASI and the other ACs.

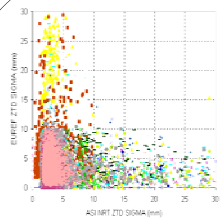
ZIMM Height time series



ZIMM Daily ZTD bias



Assessment of the uncertainties of NRT estimates



When comparing ZTD solutions coming from different ACs we realize that while the ZTD estimates are very high correlated there is a poor correlation between the related sigma. This means that the quality indicator for the ZTD, obtained by the GPS processing, is not perfect. A statistical method to assess the degree of reliability of the NRT ZTD and their real uncertainties is proposed and the results achieved applying it to the ZTD estimates provided by the ACs involved in the project are discussed.

ZTD sigma correlation between ASI NRT and EUREF solutions. Each colour is a station.

If we have have different data sets x_i and y_i, measurements of the same observable in time and space, it is possible to assess the real uncertainties of that intrinsically less precise. If y_i is more precise than x_i, we can define the a-dimensional data set z_i as:

$$z_i = \frac{(x_i - y_i)}{\sqrt{\sigma_{x_i}^2 + \sigma_{y_i}^2}} \qquad (1)$$

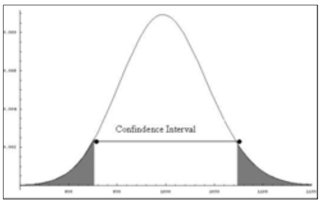
If x_i and y_i are unbiased and if their internal (formal) error is not underestimated z_i behaves like a Gaussian with μ=0 and σ=1. μ behaves according to the Normal distribution with

$$\sigma_\mu = \frac{\sigma_z}{\sqrt{n-1}} \qquad (2)$$

μ is significantly $\neq$0, if x_i are affected by a bias (first 4 columns of Table 1). The variance $\boldsymbol{\sigma^2}$ behaves according the $\boldsymbol{\chi^2}$ function with n-1 degree of freedom. To assess the real values of the uncertainties we should test if $\boldsymbol{\sigma^2_z}$ is equal to 1 within its confidence interval. The new parameter to study is

$$V = \frac{\widetilde{D}(n-1)}{D_{\exp}} \qquad (3)$$

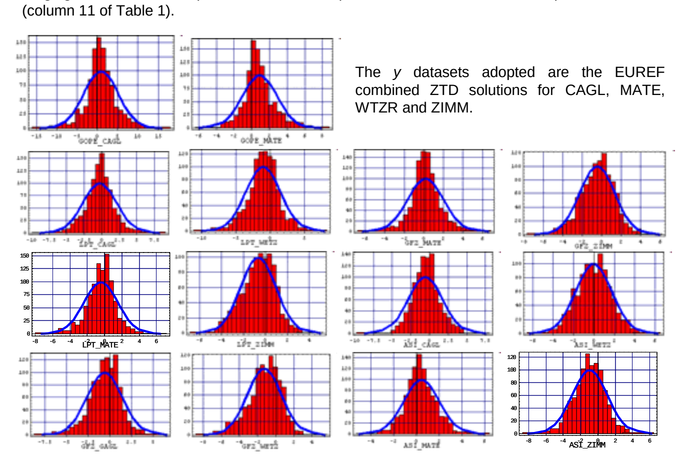
where $\boldsymbol{D_{exp}}$ is the expected variance (=1); while $\widetilde{D}$ is the "***z"*** estimated variance. If ***V*** is out from the interval then the variance of the ***x*** dataset is underestimated (or overestimated) and that the formal error must be scaled using the sigma-value of the z dataset (column 11 of Table 1).



χ^2 function with 999 degree of freedom (n=1000). The Confidence Interval has been computed for a probability of 0.90.

TOUGH
USER WORKSHOP
September, 2005
Met Office, Exeter, UK

Histograms of the "z" datasets (Eq. 1) compared with the Gaussian distribution (blue line) having the same μ and σ of the series. The $\boldsymbol{\chi^2}$ test is applied between the histogram and the Gaussian distribution. The ***y*** datasets adopted are the EUREF combined ZTD solutions for CAGL, MATE, WTZR and ZIMM while the ***x*** datasets are ASI, GFZ, GOPE and LPT NRT solutions. The $\boldsymbol{\chi^2}$ test failed for most of the dataset as outlined in Table 1, due to the presence of "coloured" noise in the ZTD time series. The analysis outlines that all the formal errors are underestimated of a factor ranging from 1.6 to 4.2 (column 7 of Table 1) and the scaled errors are up to 8 mm level (column 11 of Table 1).



The *y* datasets adopted are the EUREF combined ZTD solutions for CAGL, MATE, WTZR and ZIMM.

Table 1

AC_STATION	μ	$\overline{x}_{min}$	$\overline{x}_{max}$	Bias	$\overline{\sigma}_{int}$ (mm)	σ_z	$\sigma - CI$		σ-Bias	Scaled σ_z	χ^2 C-I		χ^2	χ^2 Test
ASI_CAGL	-0,5617	-0,7656	-0,3577	yes	3,4008	2,2975	2,1612	2,4506	yes	7,8136	8,6718	27,5871	151,7546	Fail
GFZ_GAGL	-0,5953	-0,7755	-0,4151	yes	0,8538	2,0298	1,9093	2,1650	yes	1,7331	10,1170	30,1435	151,6955	Fail
GOPE_CAGL	0,9254	0,5476	1,3032	yes	0,9166	4,2561	4,0034	4,5396	yes	3,9012	11,5913	32,6706	224,2260	Fail
LPT_CAGL	-0,2880	-0,5011	-0,0749	yes	1,0033	2,4006	2,2581	2,5605	yes	2,4086	9,3905	28,8693	133,1523	Fail
ASI_MATE	0,4523	0,3143	0,5904	yes	3,3771	1,5552	1,4629	1,6588	yes	5,2520	8,6718	27,5871	99,5617	Fail
GFZ_MATE	0,1767	0,0155	0,3379	yes	0,9917	1,8161	1,7083	1,9371	yes	1,8011	10,1170	30,1435	153,1895	Fail
GOPE_MATE	0,9085	0,7347	1,0824	yes	0,9599	1,9585	1,8423	2,0890	yes	1,8801	10,1170	30,1435	205,2952	Fail
LPT_MATE	-0,4362	-0,6100	-0,2625	yes	1,0776	1,9574	1,8413	2,0878	yes	2,1094	8,6718	27,5871	135,2436	Fail
ASI_WETZ	-0,0297	-0,1877	0,1283	no	2,4498	1,7800	1,6743	1,8985	yes	4,3605	10,1170	30,1435	27,7277	OK
GFZ_WETZ	-1,2458	-1,4141	-1,0775	yes	0,8824	1,8961	1,7835	2,0224	yes	1,6730	10,1170	30,1435	117,3274	Fail
LPT_WETZ	-1,0209	-1,2453	-0,7965	yes	0,8544	2,5280	2,3779	2,6964	yes	2,1599	10,1170	30,1435	123,2262	Fail
ASI_ZIMM	-0,9442	-1,1248	-0,7636	yes	3,5379	2,0342	1,9134	2,1697	yes	7,1966	8,6718	27,5871	56,6513	Fail
GFZ_ZIMM	-0,4649	-0,6256	-0,3043	yes	0,9070	1,8101	1,7027	1,9307	yes	1,6418	10,8508	31,4104	63,4362	Fail
LPT_ZIMM	-0,6470	-0,7899	-0,5042	yes	0,8458	1,6094	1,5139	1,7166	yes	1,3612	10,1170	30,1435	42,7551	Fail