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IGS Combination of Tropospheric Estimates - Experience From Pilot Experiment

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Introduction

The existing global and regional networks of permanent GPS receivers installed for geodetic and navigational applications can be used with marginal additional cost for determination of atmospheric water vapor with high temporal and spatial resolution. In different countries projects are under way in which the impact of GPS derived water vapor on the improvement of weather forecast are studied. Within the IGS a network of 100 globally distributed sites are analyzed on a daily basis. The zenith path delay (ZPD) values obtained should be converted into precipitable water vapor (PWV) and should be made available to the scientific community.

This IGS product could meet the demands for climatological studies. Here a time resolution of 2 hours (this is what IGS will provide) is sufficient, because long-term characteristics are of interest only, and a time delay of a few weeks for product delivery is acceptable.

In the past some experiments had demonstrated the capability of IGS (Gendt,1996,1997) and on 26 January 1997 (GPS week 890) the Pilot Experiment for the determination of IGS Combined Tropospheric Estimates has started.

Generation of the combined IGS Trop Product

Since the beginning of the Pilot Experiment six of the global IGS Analysis Centers (ACs) have regularly contributed. Different mapping functions and elevation cutoff angles of 10, 15 or 20 degrees are implemented (see Table 1.). Two of the ACs, CODE and GFZ, have made changes in these parameters during 1997. The number of sites per AC varies from 30 to 85, and we have ~100 sites in total (Fig. 1.). More than 60 sites are used by at least three ACs, so that sufficient statistical information about the quality of the tropospheric estimates can be gained. For the other sites poor or no quality checks are possible, only some conclusions from neighboring sites may be drawn.

Input to the weekly combination are seven daily files from each AC with the estimates of ZPD and station coordinates from all sites (in the format TRO-SINEX), as well as the weekly AC SINEX file from which the site description blocks are taken. The combination (details see Gendt 1997) starts with the derivations of 2h mean values for each AC. The mean is formed epochwise taking into account AC dependent biases not to get jumps by missing data. Additionally, the mean daily station coordinates are computed. Here a homogenization of all used antenna heights and types is performed, so that all coordinates refer to the same physical point. Vital for this step is that the daily coordinates from the AC TRO-SINEX files are based on the site descriptions given in the weekly SINEX file. Unfortunately, as checked by Helmert transformation residuals this is not always the case. The product from the combination is a weekly file for each site containing the ZPD estimates and precipitable water vapor if conversion is possible. Additionally, a combination report will summarize some statistics on the differences to the IGS Mean (bias, standard deviation), for the global mean of each AC and separately for all sites.

Table 1. Contributing Analysis Centers with some relevant parameters

	ZPD [minutes]	Cutoff [deg]	Mapping Function	No.Sites	No.Sites 1 AC only
CODE (week 926)	120	20 10	Saastmoinen Dry Niell	85	14
EMR	60	15	Lanyi	30	2-4
ESA	120	20	Saastmoinen	50	
GFZ (week 929)	60	20	Saastmoinen Dry Niell	55	3-6
JPL	5	15	Lanyi	37	1-5
NGS	120	15	Niell	55	1-3

Comparisons, Results

The results from 48 weeks in 1997 are used to estimates the achieved consistency. No information about the absolute accuracy could be obtained, with the exception of POTS - the only site for which water vapor radiometer (WVR) data were available.

In Figs. 3, 4 some statistics on the differences between individual AC estimates and the IGS Mean are shown. The information is given separately for about 60 sites, more or less classified into sites with smaller (left) and larger (right) standard deviation (stddev). For most sites and ACs the stddev is ±6 mm ZPD (which corresponds to ±1 mm PWV) and it approaches in many cases the ±3 mm level. The magnitude of the stddev is of course highly correlated with the magnitude in the repeatability of the estimated station coordinates. In Fig. 2 the geographical distribution of the magnitude for the stddev is shown. The largest stddevs can be found in the equatorial region. The bias for most sites is below ±3 mm. Even for sites with a larger bias its repeatability is very high.

In Fig. 5 global mean values (mean over all sites) of the difference to the IGS Mean are given. The mean stddev of the best ACs is at the 4 mm level. Only a small global bias at the 1 mm ZPD level can be stated. However, significant effects of ±1-2mm from AC to AC exist. An interesting effect can be noticed in the biases of CODE and GFZ (extracted in the graph at the bottom; JPL is included for comparison). CODE has a large jump at week 926 where changes both from Saastamionen to Niell mapping function and from 20 to 10 degree cutoff angle were introduced. Three weeks later GFZ also switches to Niell mapping function, leaving the elevation cutoff angle at 20 degrees. The resulting jump in the GFZ series brings the biases of CODE and GFZ to the same level again, but now 2 mm higher than before week 926. From this one may conclude that the influence of the mapping function on the bias seems to be higher than the influence of the elevation cutoff angle.

In Fig.6 the biases for all weeks and each AC for selected sites are shown. In the top typical examples for fiducial (or other well determined) sites are displayed. The biases are very small, and the repeatability is at the 2 mm ZPD level. Larger systematic effects can be found for some sites as given in the bottom. Here systematic effects of about ±6 mm exist with single peak to peak differences in the weekly biases of 20 mm. The bias differences could be reduced by taking into account the well-known correlation between the station height and the ZPD estimates. This works rather good for some sites, but not for all. However, such a procedure will be not recommended because any corrections to the estimates are dangerous. It is better to reduce the scattering in the determined station heights. One step in this direction will be the enlarged set of 30 to 50 fiducials, which will be constrained to a certain extent by all the ACs. The introduction of a smaller elevation cutoff angle may also help to reduce the bias.

Conversion into precipitable water vapor

The ZPD estimate must be converted into PWV. The directly estimated ZPD values are of interest for some special applications only, such as atmospheric corrections for collocated VLBI or two-color SLR instruments.

For the conversion meteorological surface measurements are needed. At the moment 19 sites report regularly their met data to the global data centers. Ten further sites have announced the installation of met packages, but the data are not yet available. The met data must be of high precision (1 mbar corresponds to 0.35 mm in PWV) and reliability (continuous time series). In Fig. 8 all sites with met sensors available in 1997 are given. For some sites too many missing days or larger gaps must be stated. In those cases no meaningful series of PWV could be produced. Unfortunately, only 10 to 15 reliable sites with met sensors exist at the moment (a small percentage of all analyzed sites).

The GPS derived PWV estimates can be compared with WVR measurements to get a measure for the absolute accuracy. Only at POTS measurements of a collocated WVR were available. A WVR-1100 of Radiometrics Corporation is operated by Meteorological Observatory Potsdam of the German Weather Service, and is located 400m apart from the GPS receiver. In Fig. 10 the time series from WVR, CODE and GFZ are extracted for 90 days at the end of 1997. Due to a lot of rainy days the WVR series has many gaps. The agreement of the GPS results (both CODE and GFZ) with the WVR is at the 1 mm level (Fig. 9). The stddev of the difference approaches ±0.5 mm, the bias has a level of ±1 mm and shows some long-periodic behavior for both GPS results. The difference between the two GPS solutions is smaller than their differences to the WVR measurements. The changes in the parameters of CODE (day 926.0 is 97/278) and GFZ (97/299) have obviously not caused any significant changes, neither in the difference between both solutions nor in their differences to WVR, although with 10 and 20 degrees rather different elevation cutoff angles are used.

Summary

During the one year experiment all components involved in the combination have performed well and timely. Some small inconsistencies concerning the description of the station coordinate solutions must be avoided in future. It would be also more effective if the planed short SINEX version, containing no matrices, could be introduced soon.

The ZPD estimates have a high quality for all the weeks. The consistency is at the 4 to 5 mm level both for the bias and for the stddev. For sites in the equatorial region the quality is not as good - by a factor of 1.5 to 2 worse. The bias is highly correlated with the station height. A lower elevation cutoff angle and the enlarged set of fiducials can help to reduce the bias by smaller scattering in the daily station height solutions.

The importance of the IGS contribution to climate research will not only depend on the quality of the ZPD estimates but also on the number of sites which could be equipped with met packages. The number of instruments available now is not sufficient.

To get a better insight into the behavior of the bias more collocated WVR should be made available, either at existing IGS sites or at non-IGS sites which then should be analyzed by all IGS ACs for some test periods.

References

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