IVS Rapid Tropospheric Parameter Re-combination and Comparison with GNSS Products

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Abstract Within the International Very Long Baseline Interferometry (VLBI) Service for Geodesy and Astrometry (IVS), the combination of the tropospheric zenith total delays (ZTD) and zenith wet delays (ZWD) is done for the rapid turnaround sessions IVS-R1 and IVS-R4 on a weekly basis. In this paper, the combination method is discussed. The re-combination of data sets from January 2002 to December 2013 submitted by eight IVS ACs is presented and the various submissions are compared with each other. A discussion on inhomogeneity is done and a possible future extension is treated as well. Furthermore, the combined IVS zenith delays are compared with products provided by the International Global Navigation Satellite System (GNSS) Service (IGS) for co-located stations.

Keywords VLBI, GNSS, tropospheric parameters, recombination

1 Introduction

The IVS rapid tropospheric product is a combination of ZTD and ZWD provided by various IVS Analysis Centers (ACs). Such a combination allows identification and exclusion of outliers of the individual solutions submitted by the ACs and assessment of the internal precision of tropospheric parameters derived from VLBI. The rapid combination is carried out weekly with a delay of about four weeks after the observation files were released on the IVS Data Centers [2]. Recently, the IVS tropospheric parameters rapid combination service has been migrated from DGFI [3] to GFZ. The release of the re-combined data sets from January 2002 to December 2013 has been completed (`kg6-dmz.gfz-potsdam.de/ivs/php/tropospheric_combination.php`).

There are three main user groups of the IVS tropospheric product. The first one is the IGS Troposphere Working Group (IGS TWG) [1], which aims at monitoring GNSS tropospheric parameters and comparing them with available co-located techniques. The Chair, Christine Hackman (USNO), has asked for an extension of the IVS tropospheric product to include gradients and more co-location sites [4]. The second user is EU COST Action ES1206 – GNSS4SWEC: Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate. This action is designed to address new and improved capabilities of monitoring severe weather from concurrent developments in both the GNSS and meteorological communities. As reported in the work plan of its Working Group 3 (WG3) – GNSS for climate monitoring, one of the main tasks is to validate GNSS ZTD data by comparison with data from other techniques, e.g., VLBI [5]. The third user group is the European Permanent Network (EPN) of EUREF. One responsible EUREF AC (BKG), uses the IVS rapid troposphere product for routine comparison and achieves quite good results (`http://www.epncb.oma.be/_networkdata/siteinfo4onestation.php?station=WETT`).

In this paper, the re-combination of data from 2002 to 2013 is reported, and the results are presented. The

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combination method, including the outlier elimination process and the weighting scheme, is also re-visited. Furthermore, a discussion on inhomogeneities is done, and the effects of earthquakes and inconsistencies in the meteorological data are treated as well. Finally, the combined IVS ZTD are compared with ZTD from the IGS at several co-locations.

2 Re-combination and Results

Currently, there are six contributing ACs, as listed in Table 1. Three other ACs (OSO, IGG, and GFSC) also participated in the past and are still welcome to re-join. Other IVS groups are invited for participation as well.

Table 1 Analysis Centers that are currently making contributions.

IVS Analysis Centers	Institutions
BKG	Bundesamt für Kartographie und Geodäsie, Leipzig, Germany
CGS	Centro di Geodesia Spaziale, Matera, Italy
DGFI	Deutsches Geodätisches Forschungsinstitut, Munich, Germany
IAA	Institute of Applied Astronomy, St. Petersburg, Russia
INA	Istituto di Radioastronomia, Istituto Nazionale di Astrofisica, Bologna, Italy
MAO	Main Astronomical Observatory, National Academy of Sciences of Ukraine, Kiev, Ukraine

The tropospheric parameters are combined on the parameter level, and the current inputs are ZTD/ZWD parameters and their formal errors. The combination strategy is a two-step approach as described in detail by Schuh and Böhm (2003) [6]. However, since the effect of inhomogeneous meteorological data is not taken into account in the combination, a further improved scheme will be considered in the future. For instance, the new ZWD can be derived by subtracting from the combined ZTD unique zenith hydrostatic delays (ZHD) that are obtained with homogeneous meteorological data instead of the directly reported ones used before.

In the re-combination, the submissions of various ACs are combined and compared with each other as well as with the combined solution. Figure 1 shows the weekly biases and standard deviations of ZTD of each AC and the combined solution at Westford, USA.

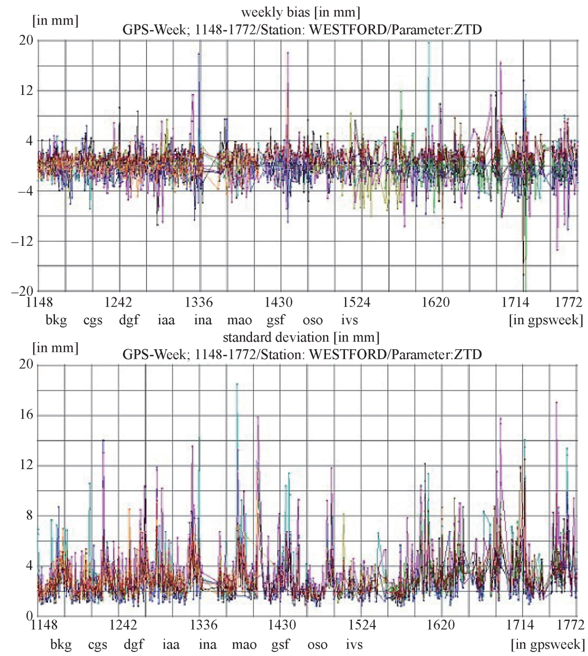

Fig. 1 Weekly bias (top) and standard deviation (bottom) of ZTD of each AC compared to the combined solution at Westford, USA.

It can be noticed that the ZTD submitted by various ACs agree well within a few millimeters, and the standard deviations are at the millimeter level. The combined series is much more smooth, stable, and robust. However, the solution from IAA shows a little larger standard deviation, which may be caused by the usage of Kalman filtering instead of the least squares adjustment adopted by the other ACs, or other differences in the software package. For this case, a factor could be applied to account for this kind of offset during the combination process.

For modeling the ZHD at the stations, the surface air pressure is needed. Thus, consistent meteorological data are of great importance to achieve the goal of homogeneous tropospheric parameters. Figure 2 gives the weekly biases of ZWD at Wettzell, Germany. A significant part of ZWD difference occurs for the DGFI solutions, where the mean value of the local pressure records are shifted to the European Centre for Medium-Range Weather Forecasts (ECMWF) mean value, while the other ACs do not apply this shift. This effect cannot be seen in the ZTD series. Therefore, more attention should be focused on the homoge-

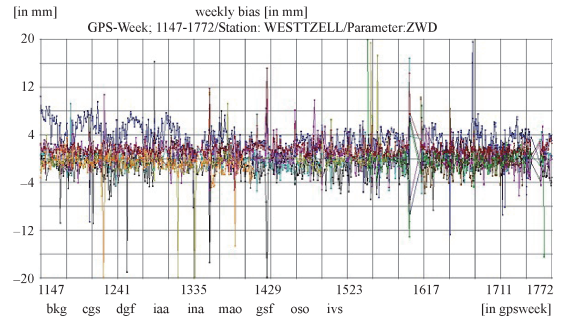

Fig. 2 Weekly bias of ZTD at Wettzell, Germany.

neous meteorological data to obtain a more consistent and stable tropospheric product.

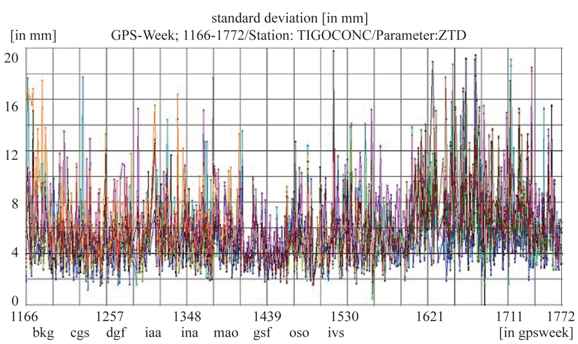

Fig. 3 Standard deviation of ZTD at Tigoconc, Chile.

An indirect effect of earthquakes on the tropospheric product can be seen in Figure 3: for TIGO/Concepción, an increase of the standard deviation from 3 mm to 6 mm happened in GPS week 1560, which is right after the 2010 Maule Earthquake in Chile. This effect results from worse a priori station coordinates. To prevent this type of distortion in the product, revised station coordinates would have to be derived and distributed among the ACs right after a major earthquake.

3 Comparison with IGS ZTD

The IVS combined ZTD are available at each UTC hour within an IVS observing session, while the IGS ZTD (`http://www.igs.org/components/dcnav/cddis_products_trop.html`) are given at UTC hours as well, but with a sampling interval of two hours. Therefore, only data at the common epochs at co-location sites are considered. Figure 4 shows the ZTD time series of both the IVS combined solution and the IGS solution at co-location site Westford, USA.

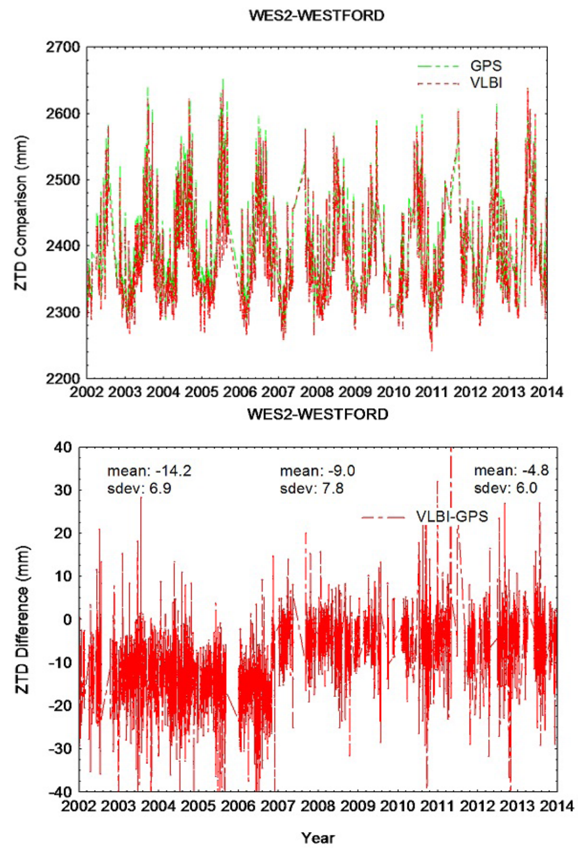

Fig. 4 ZTD time series of VLBI combined solution and IGS product (top) and the difference (bottom) at co-location site Westford, USA.

It can be seen from the top figure that the two time series show a good overall agreement. However, a significant shift of the running mean value in the ZTDs' difference (bottom figure) appeared at the end of 2006 when the mean bias decreased from -14.2 mm to -4.8 mm. The shift was caused by the change of phase center model, i.e., the adoption of absolute phase center offsets/variations (PCO/PCV) model since 5 November 2006 by the IGS. Generally, the absolute antenna model shows a significant effect on the station position, troposphere, and clock parameters [7], resulting in smaller ZTDs in this case. Similar effects of variable size occurred at all the other co-located sites.

Table 2 ZTD comparison of the VLBI combined solution and IGS product for several co-location sites.

site	IGS acronym	height diff. [m]	bias1 [mm]	bias2 [mm]	bias3 [mm]	std1. (IVS –IGS)[mm]	std2. (IVS –IGS)[mm]	std3. (IVS –IGS)[mm]
Algopark	algo	23.0	−15.0			6.3		
Kokee	kokb	10.2	−8.9	−1.6	−3.8	7.5	6.5	7.8
Nyales20	nya1	3.1	−3.8	−0.2	−1.4	4.2	3.9	4.6
Westford	wes2	1.8	−14.2	−4.8	−9.0	6.9	6.0	7.8
Wettzell	wtzr	3.1	−2.7	−0.9	−1.5	5.0	4.8	5.2
Tigoconc	conz	−9.8	−8.0	0.4	−2.1	9.0	8.4	10.4

Table 2 shows the statistics of the ZTD comparison between the IVS combined solution and IGS product at several co-locations with a breakpoint at the epoch when the IGS sites' antenna model changed (November, 2006). Bias1 and bias2 refer to the mean bias before and after the breakpoint, respectively; bias3 denotes the overall mean bias for the whole duration. The standard deviations are described in a similar way (std1, std2, and std3). In general, the IGS mean ZTDs are larger than the IVS rapid combination except for Tigoconc, which needs to be explained. The IGS ZTDs may present a systematic error regarding the PCO/PCV effect, but much better agreement can be achieved after the antenna model change of the IGS sites. The mean bias is usually smaller than 2 mm, except for Westford, where additional inhomogeneities may come from equipment changes such as an antenna receiver change or the usage of a radome of the GPS antenna. The standard deviations are about 5 mm. Such inhomogeneities do not occur in reprocessed products. However, the scope of rapid combination products is not to avoid these kind of inconsistencies but to detect and quantify them to enable them to be considered through the reprocessing. Furthermore, the height difference between GNSS and VLBI reference points will be considered in future studies.

4 Summary and Conclusions

The service of the IVS tropospheric parameter rapid combination has been recently migrated from DGFI to GFZ. At GFZ, we did a consistent re-combination of the complete IVS troposphere rapid combination product starting with the IVS-R1 and IVS-R4 sessions in January 2002. A quite good agreement and consistency can be seen between individual submissions by various ACs. The mean agreement of all AC biases at all sites are within ±1.5 mm, and standard deviations are around 3 mm. The combined solution is more robust and stable. A possible improvement of the combination strategy has been discussed. Also, both the effects of inhomoheneous meteorological data and earthquakes on the product were investigated. The results of comparison with IGS ZTDs show better agreement after the antenna model change of the IGS sites. To avoid the influence of inhomogeneous IGS zenith delays, reprocessed data are suggested for further analysis.

In future studies, we would like to extend the IVS rapid troposphere combination product to include not only IVS-R1 and IVS-R4 sessions but also the other current session types. Another goal is to decrease the time delay from four weeks to two weeks or one week between the release of the database and of the troposphere products. Besides, more information from individual ACs about their submissions are required, e.g., if the parameters are provided right at integer hours or at ±30 min. Better communication about missing or outlying results between the troposphere combination center (GFZ) and the contributing ACs are needed. Furthermore, the joint contribution of all the IVS ACs is proposed to supply the tropospheric gradients, due to the call for participation from IGS TWG for comparison with GNSS data. Ultimately, a new homogeneous IVS tropospheric long-term series at GFZ is in planning and preparation.

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