A Comparative Analysis of Tropospheric Delay Estimates from Network and Precise Point Positioning Processing Strategies

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Abstract

Over the last decade, Global Navigation Satellite Systems (GNSS) have emerged as a precise and cost-effective tool for studying the composition of the atmosphere. The GNSS-derived information about the tropospheric delay on various time scales can be used for improvements in weather forecasts using numerical weather prediction (NWP) models as well as for climate change and variability analysis using long-term reprocessing. The continuous expansion of the ground-based GNSS networks worldwide and the need for near-real time delivery of GNSS-derived meteorological products requires time efficient data processing strategies with an adequate level of accuracy. The two processing strategies, i.e. network double differencing (DD) and precise point positioning (PPP), each have their own strengths and weaknesses. For example, while troposphere delay estimates from the DD strategy are higher in accuracy than from the PPP strategy, the latter is more efficient in the computational burden and allows larger networks to be analyzed in shorter time spans.

The aim of this study is to revisit this topic using the latest IGS products and error models in both strategies in order to assess any differences in the GNSS-derived tropospheric delay estimates. Of particular interest for this comparison will be the results obtained for remote GNSS stations, e.g. mid-ocean islands and high latitudes, when compared to those from dense network areas over Europe and North America.

Introduction

Atmospheric water vapour is the most abundant greenhouse gas and plays a significant role in weather formation, climate change and global warming. Therefore, precise knowledge of the quantity of water vapour in the atmosphere helps in the improvements of weather forecasts and climate monitoring. It is widely known that the propagation delay experienced by GNSS signals, namely the zenith total delay (ZTD), can be converted to integrated water vapour (IWV) using surface meteorological data. As of today, GNSS observations from global networks are available for about the last two decades and this makes it possible to use GNSS as a climate monitoring tool by reprocessing the long-term historical observations and obtaining the IWV trends. Other than its use in climate monitoring, GNSS-derived near real-time ZTD data is assimilated into numerical weather prediction models to improve the short-term weather forecasts. In this application the use of an efficient processing strategy, such as PPP, is of great interest for the processing of dense networks, e.g. the European E-GVAP network which consists of approximately 2000 stations.

PPP and DD are the common strategies in use today for processing of GNSS observations. PPP solutions are based on single station observations and are mainly affected by the quality of orbit/clock products. DD solutions, on the other hand, are based on differenced observations between the stations in a network and while the dependency on the products is much smaller, DD results are somewhat affected by the distance between stations, especially of remote stations at mid-ocean islands.

In this study, the differences between the ZTD estimates obtained through the PPP and DD strategies have been investigated. Two PPP solutions (namely IGFT and PPUL) and one DD solution (namely DDUL) have been used to conduct the comparison. IGFT is the IGS Final Troposphere product[1],[2] whereas PPUL and DDUL are the solutions generated at the University of Luxembourg (UL)[3]. Table 1 lists the processing characteristics of the three solutions. The comparisons are based on 76 globally distributed stations from the IGb08 core network and a time span of one year, i.e. 2011.

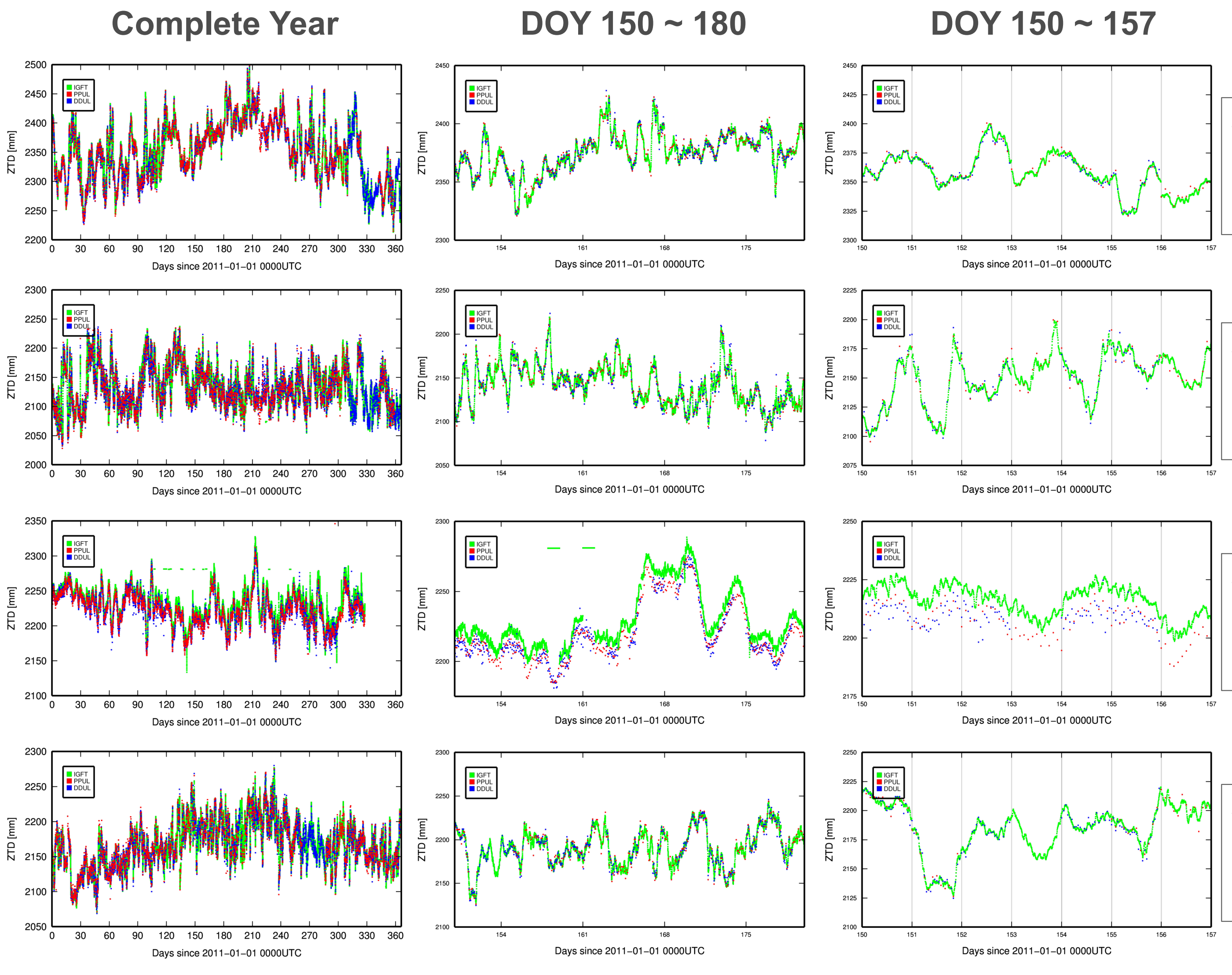
The DDUL solution has been used as the reference and ZTD estimates from the two PPP solutions have been compared to those from DDUL.

Table 1: Processing characteristics of the ZTD estimation systems

Solution Name:	**PPUL**	**DDUL**	**IGFT**
Strategy:	PPP	DD	PPP
Processing Engine:	BSW5.2	BSW5.2	BSW5.0
ZTD Output Interval:	2 hours	1 hour	5 minutes
Observation Window Used:	24 hours	24 hours	27 hours
Processing Session Length:	24 hours	24 hours	24 hours
GNSS Used:	GPS	GPS	GPS
A-Priori ZHD Model:	GPT	GPT	GPT
Troposphere Mapping Function:	Wet GMF	Wet GMF	Wet GMF
Orbit Product Used:	COD Repro1	COD Repro1	IGS Final
Clock Product Used:	COD Repro1	COD Repro1	IGS Final
Antenna Models:	IGS08	IGS08	IGS08
Coordinates Computed:	Yes	Yes	Yes
Elevation Cut-Off Angle:	3°	3°	7°
Ambiguity Resolution:	No	No	No

ZTD Time Series

Figure 1 shows the ZTD time series for four stations (HOFN, KOKB, MCM4, and YEBE) obtained from the three solutions as examples. To observe any differences closely, the time series have been shown for three time periods i.e. 2011, a month (DOY 150 – 180) and a week (DOY 150 – 157). It can be seen that the ZTD time series from all three solutions follow the same pattern, however, some stations show a bias and some PPP solutions have a jump in ZTD at the day boundaries where the latter is a known effect of the daily processing batch.



Station: HOFN
Lat: 64° Lon: -15°
Mean(IGFT–DDUL) = -1.40 ± 3.63 mm
Mean(PPUL–DDUL) = 1.03 ± 3.75 mm

Station: KOKB
Lat: 22° Lon: -159°
Mean(IGFT–DDUL) = -0.25 ± 4.74 mm
Mean(PPUL–DDUL) = -0.12 ± 6.06 mm

Station: MCM4
Lat: -77° Lon: 166°
Mean(IGFT–DDUL) = -8.52 ± 5.10 mm
Mean(PPUL–DDUL) = 0.03 ± 4.54 mm

Station: YEBE
Lat: 40° Lon: -3°
Mean(IGFT–DDUL) = -0.42 ± 3.57 mm
Mean(PPUL–DDUL) = 1.13 ± 5.06 mm

Figure 1: Comparison of ZTD time series from DDUL, IGFT and PPUL for the stations HOFN (row 1), KOKB (row 2), MCM4 (row 3) and YEBE (row 4). Column 1: Time series for whole year 2011, Column 2: Time series for a month, Column 3: Time series for a week, Column 4: Station location and mean difference. The week plot shows gray lines at day boundaries.

References
[1] Byun S H and Bar-Sever Y E (2009) A new type of troposphere zenith path delay product of the International GNSS Service. J Geodesy, 83(3-4), 1–7
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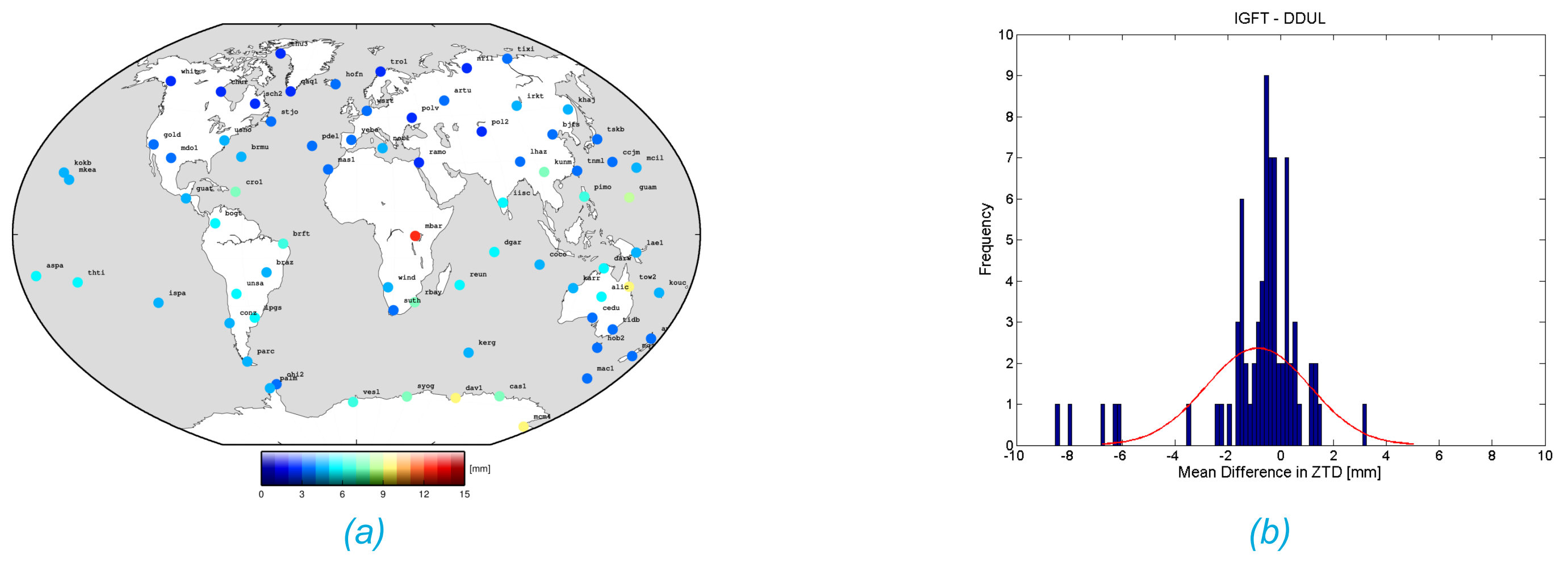
ZTD Comparison Results

The statistics for this comparison were computed by using the epochs that are common in all the three solutions while rejecting outliers. The overall mean difference between the ZTD estimates from IGFT and DDUL was found to be -0.86 ± 1.98 mm with an RMS of 2.12 mm and the overall mean and RMS difference between the PPUL and DDUL ZTD estimates was found to be 0.01 ± 0.70 mm and 0.68 mm, respectively. Table 2 shows some more statistics for these differences.

Table 2: Difference between the ZTD estimates from PPP solutions and the DDUL solution

Solution	**Minimum [mm]**	**25th %tile [mm]**	**Median [mm]**	**75th %tile [mm]**	**Maximum [mm]**	**STD [mm]**
IGFT	-8.52	-1.29	-0.47	0.15	3.25	1.96
PPUL	-3.10	-0.41	-0.01	0.46	1.58	070

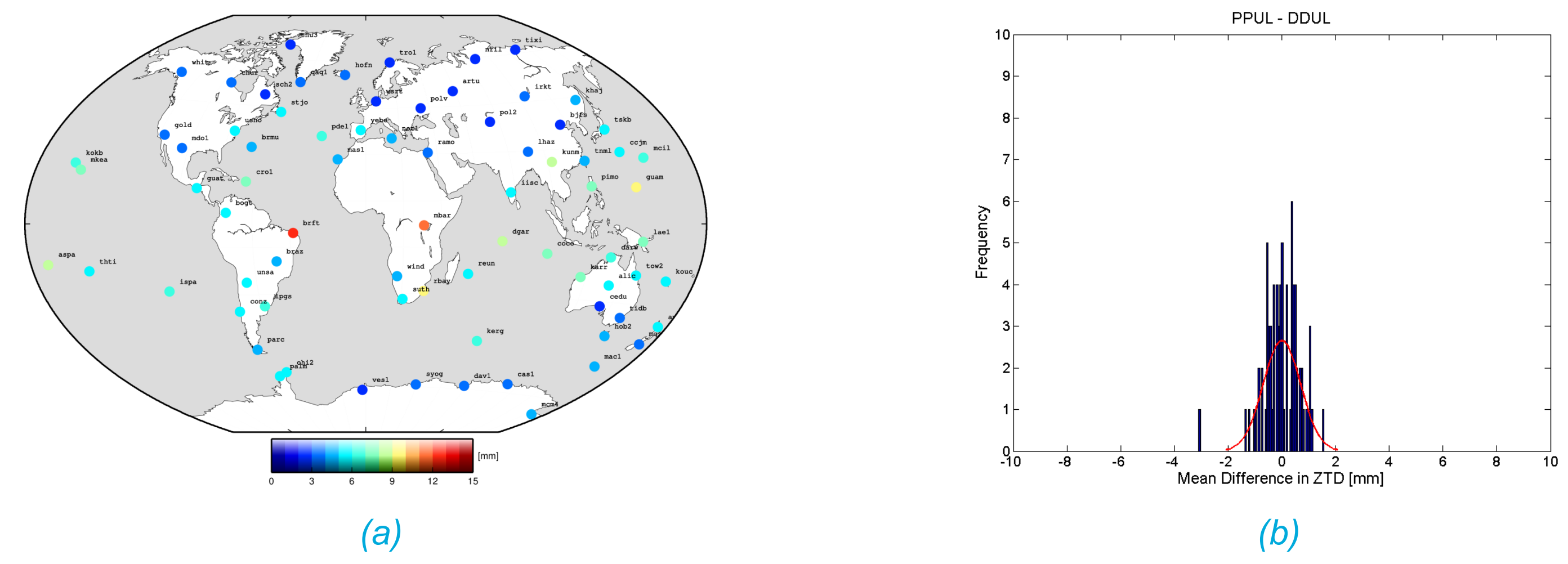
Figures 2 and 3 show the global distribution of the station-wise RMS difference and the histograms of the station-wise mean difference between the two PPP solutions and the DDUL solution. For mid- to high latitudes the RMS values (2-4 mm) are smaller than those for the low latitudes (4-7 mm). The high RMS values for the stations MBAR and BRFT are due to data issues at MBAR, which affected IGFT and PPUL differently than DDUL, and bad PPUL solutions for BRFT for which not all outliers were removed.



(a) (b)

Figure 2: a) Station-wise RMS of the difference between the IGFT ZTD and DDUL ZTD b) Histogram of the station-wise mean of the difference between the IGFT ZTD and DDUL ZTD along with a normal distribution fit (red)

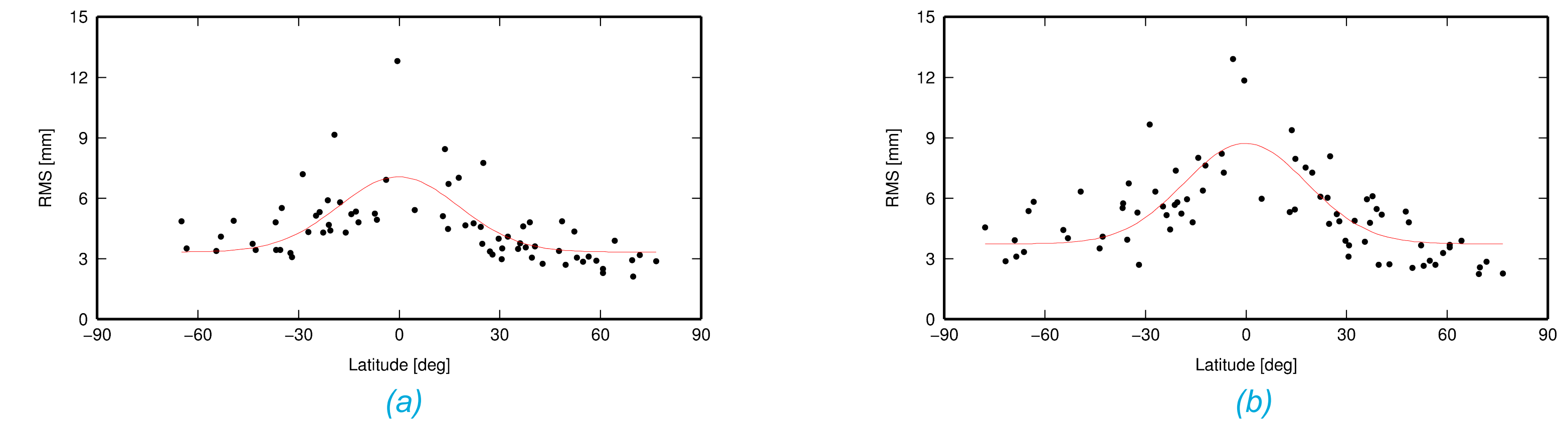
It can be seen from Figures 2 and 3 that for most of the Antarctic stations, IGFT solution shows a larger difference to DDUL as compared to PPUL. This could be an effect of the lower elevation cut-off angle (3°) used in PPUL. To investigate this, a new PPP solution was run for the 6 stations (cas1, dav1, mcm4, palm, ohi2, syog) and the year 2011 with an elevation cut-off angle of 7°. This new solution showed a better agreement to the DDUL solution and the overall RMS of the ZTD differences for these 6 stations was reduced by 1.44 mm while the height coordinate repeatability was improved.



(a) (b)

Figure 3: a) Station-wise RMS of the difference between the PPUL ZTD and DDUL ZTD b) Histogram of the station-wise mean of the difference between the PPUL ZTD and DDUL ZTD along with a normal distribution fit (red)

A latitude dependence of the bias between the PPP and DD ZTD estimates was observed and is shown in Figure 4. The bias seems to be largest at the equator and smaller closer to the poles. A possible reason for this latitude dependence of the bias could be the higher concentration of column water vapour at the equator.



(a) (b)

Figure 4: Distribution of the RMS difference (Gaussian fit in red) with respect to latitude a) between the IGFT ZTD and DDUL ZTD b) between the PPUL ZTD and DDUL ZTD

During the computation of the DDUL solution, baselines of up to approximately 6000 km were used. An attempt was made to study the relation between the ZTD bias of PPP solutions to the DDUL solution and the mean of the length of all the baselines used to process each station. This analysis yielded a very small dependence of the PPP-DD bias on the mean baseline length i.e. 0.00025 mm/km for IGFT and 0.0003 mm/km for PPUL. However, this topic still remains under investigation.

Conclusions

The ZTD estimates from two PPP solutions namely IGFT and PPUL were compared to those from the DDUL solution using a global network of stations and a time period of one year. Both the PPP solutions showed good agreements with the DD solution and the ZTD time series from all three solutions were observed to follow the same pattern.

When compared to DDUL, the IGFT solution showed a mean bias of -0.86 ± 1.98 mm in ZTD (≈ -0.14 ± 0.33 kg/m^2 IWV) with an RMS of 2.12 mm (≈ 0.36 kg/m^2 IWV) whereas the PPUL solution showed a mean bias of 0.01 ± 0.70 mm (≈ 0.001 ± 0.12 kg/m^2 IWV) with an RMS of 0.68 mm (≈ 0.11 kg/m^2 IWV). The larger differences of the IGFT solution are due to the different processing settings.

The RMS of the bias between the PPP and DD solutions was observed to have a latitude dependence and was found to be largest at the equator and smaller in high latitudes. This is believed to be due to the higher concentration of atmospheric water vapour at the equator than in mid-to-high latitudes. Aligning the processing strategy of PPUL to IGFT (7° elevation cut-off angle) improved the RMS agreement for Antarctic stations by 1.44 mm.

The effect of the mean baseline lengths used during the DD processing on the bias between the PPP and DD ZTD estimates was investigated. Initial results showed that the mean baseline lengths have very little effect on the bias between the PPP and DD ZTD solutions, i.e. 0.00025 mm/km for IGFT and 0.0003 mm/km for PPUL, indicating a bias of 1.5 and 1.8 mm for a baseline of 6000 km, respectively.

This preliminary study confirms previous results in that ZTD estimates derived from PPP are of high quality and are largely comparable to those from DD network solutions. However, a small latitude dependency and a small dependency on the baseline length have been suggested, which will need to be further investigated.

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