Chapter 6

Sensing Precipitable Water Vapor (PWV) using GPS in Turkey – Validation and Variations

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Additional information is available at the end of the chapter

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1. Introduction

In the last two decades, the Global Positioning System (GPS) has been widely used in navigation, positioning, timing and related sciences. However, GPS observations are subject to several sources of error, such as clock biases, multi-path delay, and ionospheric and tropospheric delays. Particularly, the tropospheric delay significantly affects the GPS signals and causes errors of several meters in positioning. Since the GPS signal is sensitive to the tropospheric refractive index, which is dependent on the pressure, temperature and moisture, GPS can be used for sensing these properties in the troposphere, e.g.,tropospheric water vapor [12, 13]. Although studies have demonstrated to successfully estimate PWV from GPS within 1-2 mm of accuracy at 15-minute temporal resolution, a number of factors still affect PWV accuracies, e.g., mapping functions and Earth’s tide models, [14, 11].

The GPS-derived zenith total delay (ZTD) can be split into surface pressure dependent component or so called a hydrostatic (dry) part [23] and a water vapor and temperature dependent component or so called non-hydrostatic (wet) part. Since these delays change with the elevation angle, the signal with low elevation angle has a longer delay through the troposphere than one with high elevation angle. In addition, the mapping functions are needed to transform slant tropospheric delays into the zenith tropospheric delays [4, 17, 27]. Latest mapping functions include GMF (Global mapping function) and VMF1 (Vienna mapping function) obtained from numerical weather prediction models [4], which are widely used as currently the most accurate tropospheric mapping function models [25].

The PWV can be obtained from wet delay, which can be used for climatology and weather forecasting. As for Near-Real Time (NRT) applications, estimation of PWV requires near-real-time observations from ground-based GPS stations and ultra-rapid orbit products. Although radiosounding is the most reliable technique for PWV estimates, it is quite costly and low resolution with twice per day. With the estimation of NRT-PWV from GPS measurements, spatial and temporal resolution of PWV values are improved for applications in climatology and numerical weather prediction models. In this chapter, the first PWV results are obtained from GPS observations in Turkey, which are validated and analyzed with radiosonde observations.

2. Data processing and methods

The tropospheric zenith delay can be computed with BERNESE, GAMIT/GLOBK and GIPSY-OASIS softwares. In this study hourly ZTD, ZHD and ZWD values are computed with GAMIT/GLOBK and corresponding PWV values are validated by radiosonde measurements. Here, two radiosonde stations with co-located GPS stations are used in Ankara and Istanbul (Figure 1). Meteorological parameters (temperature, pressure and humidity) at co-located GPS stations are obtained from the Turkish Met-Office (Meteoroloji Genel Mudurlugu).

In order to investigate various effects on GPS ZTD and PWV estimates, different processing strategies are used, including atmospheric and oceanic tidal and non-tidal models, and the mapping functions. Full list of processing strategies are shown in Table 1 Here GPS data from Sep. 2013 to Aug. 2014 are processed from GPS network in Figure 1, including IGS sites (Zeck, Onsa, Hert, Ramo, Mets, Ankr, Bucu, Drag, Gope, Ista, Medi, Mikl, Nico, Orid, Tubi, Yebe) and EUREF sites (Aut1, Baca, Dub2, Duth, Igeo, Larm, Noa1, Pat0, Srjv, Tuc2, Cost).

Process Strategy	Mapping Function	Ocean Tide	Atmospheric Tide	Non-Atmospheric Tide
A	VMF1	Yes	Yes	Yes
B	VMF1	Yes	No	No
C	VMF1	No	Yes	Yes
D	GMF	Yes	Yes	Yes
E	NMF	Yes	Yes	Yes

Table 1. Processing Strategies

The processing software can resolve or model the orbital parameters of the satellites, estimate the transmitter and receiver positions and ionospheric delays, and solve the phase-cycle ambiguities and the clock drifts as well as for the tropospheric delay parameters of interest

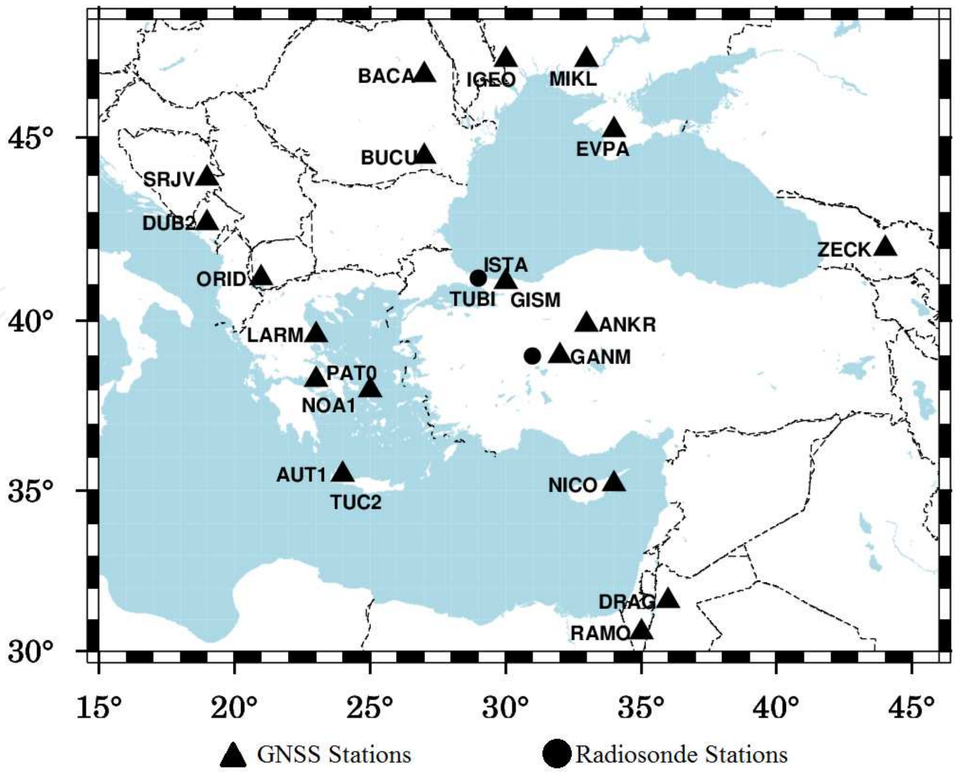

Figure 1. GPS Network and co-located radiosonde stations

(Jin et al., 2007). In this study, the GAMIT/GLOBK software (Herring et al., 1999) has been used to estimate the ZTD and other parameters with the constrained batch last squares inversion procedure. By parameterizing the ZTD as stochastic variation of the [23], a piecewise linear interpolation between solution epochs is done. Additionally, a priori constraint of varying degrees of uncertainty is allowed. Orbit ephemeris are obtained from final International GNSS service (IGS)'s solution. Radiosonde observations are obtained from University of Wyoming Department of Atmospheric Science's website. The coordinates of the stations are computed by processing 7 days of GPS observations of the prior week. Then, these coordinates are fixed, and the wet tropospheric component delays are estimated every hour [22]. The hydrostatic part of the troposphere was calculated from the GPT (Global Pressure and Temperature). After GAMIT/GLOBK computed daily zenith total delays (ZTD), PWV values are computed with Sh_Met_Util (Bevis Tm model). Bevis model was based on the mean temperature of the water vapor and estimates the PWV as a function of the surface temperature formula [2].

3. Results and analysis

3.1. Validation

The one-year available and continious GPS observations from Sep. 2013 to Aug. 2014 are processed using GAMIT/GLOBK software (Herring et al., 2006) with the International GPS Service (IGS) final orbits, the International Earth Rotation and Reference Systems Service

(IERS) Earth orientation parameters, and the elevation antenna phase center models. The unknown parameters are the station coordinates, the ambiguity, the ZTD, and the GPS satellite orbital parameters [15]. Figure 2 shows the results of PWV values using the different strategies at GISM station, which are nearly consistent with each other.

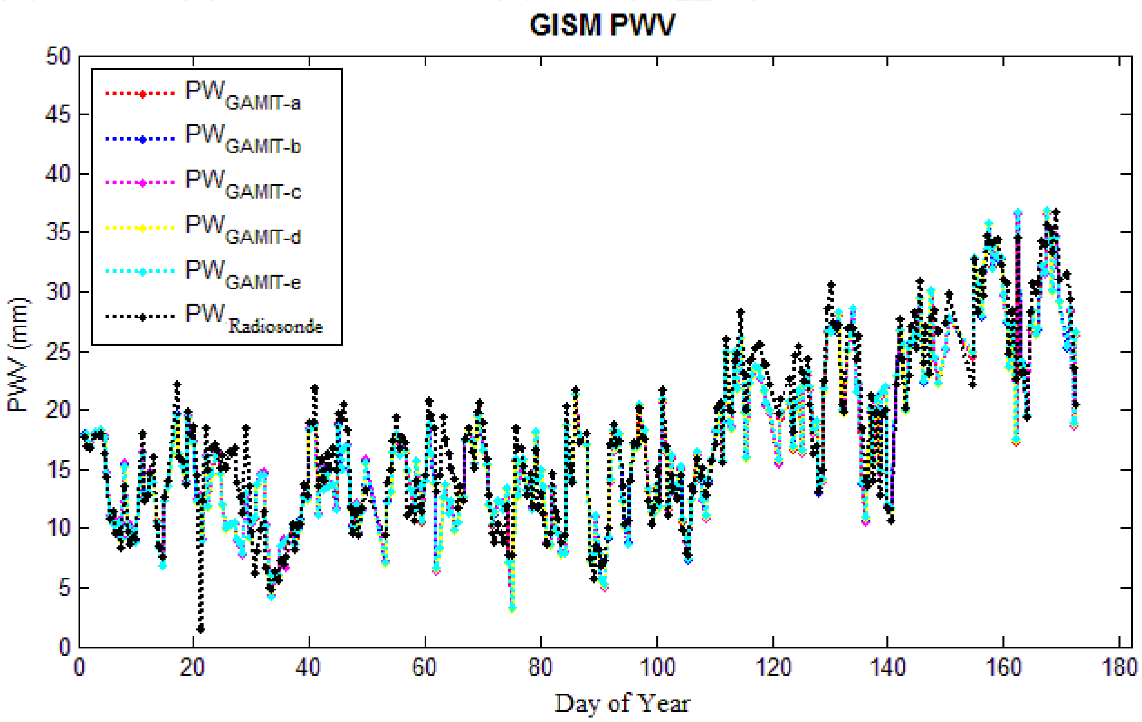

Figure 2. PWV time series at GISM

In Table 2, PWV values obtained from radiosonde are compared to those from GPS observations and the difference is in ±1-2 mm. The results obtained from the Niell Mapping Function (strategy E) are the most accurate with the smallest standard deviation. GPS-derived PWV has a good agreement with radiosone (Figure 3). In addition, note that the temporal resolution of hourly GPS-derived PWV is much higher than the radiosonde measurements with twice per day.

When comparing with the first three strategies (Vienna Mapping Function) without the oceanic and the atmospheric tides corrections, it matches each other at sub-millimetric level. That means that even including these effects in the processing, the impact on the PWV values is small.

The effect of oceanic tide is stronger than the atmospheric tide effects (strategy B and strategy C). When comparing strategy B and strategy C with respect to the radiosonde PWV values, the results show that when atmospheric tide effects are removed, the differences of GPS PWV values with radiosonde results increase at GISM station.

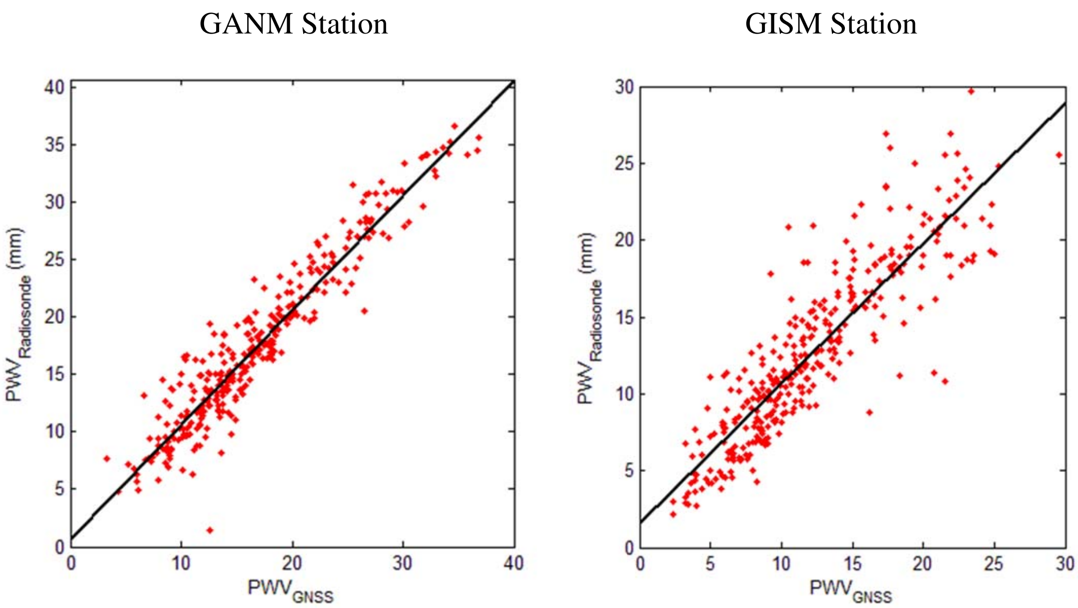

Figure 3. PWV distribution of GPS with respect to radiosonde

GANM	A	B	C	D	E
Sdt.dev.	1,835	1,826	1,832	1,797	1,794
Mean	0,188	0,195	0,208	0,217	0,147
Min.	-4,580	-4,580	-4,480	-4,480	-4,460
Max.	5,090	5,100	5,140	5,060	4,990
GISM	A	B	C	D	E
Sdt.dev.	2,224	2,232	2,221	2,222	2,221
Mean	0,192	0,086	0,094	0,117	0,052
Min	-4,530	-4,500	-4,470	-4,410	-4,410
Max	6,080	5,960	6,100	6,040	5,960

Table 2. Statistics of PWV (mm) in 2013 at GISM and GANM

The results in 2014 show that all processing strategies can provide reliable PWV values either at GISM or GANM station with the function of the latitude, the longitude and climatic differences. From the results, it can be seen that the most accurate strategy is from the the Niell Mapping Funciton (strategy E) with the smallest RMS and standard deviation (Figure 4).

From the statistics shown in Figures 5, 6, 7 and 8, the strategy E (Niell Mapping Function) has the highest accuracy among all the strategies here used. By using meteorological measurements instead of the GPT model (Global pressure and temperature), the results will clearly improve.

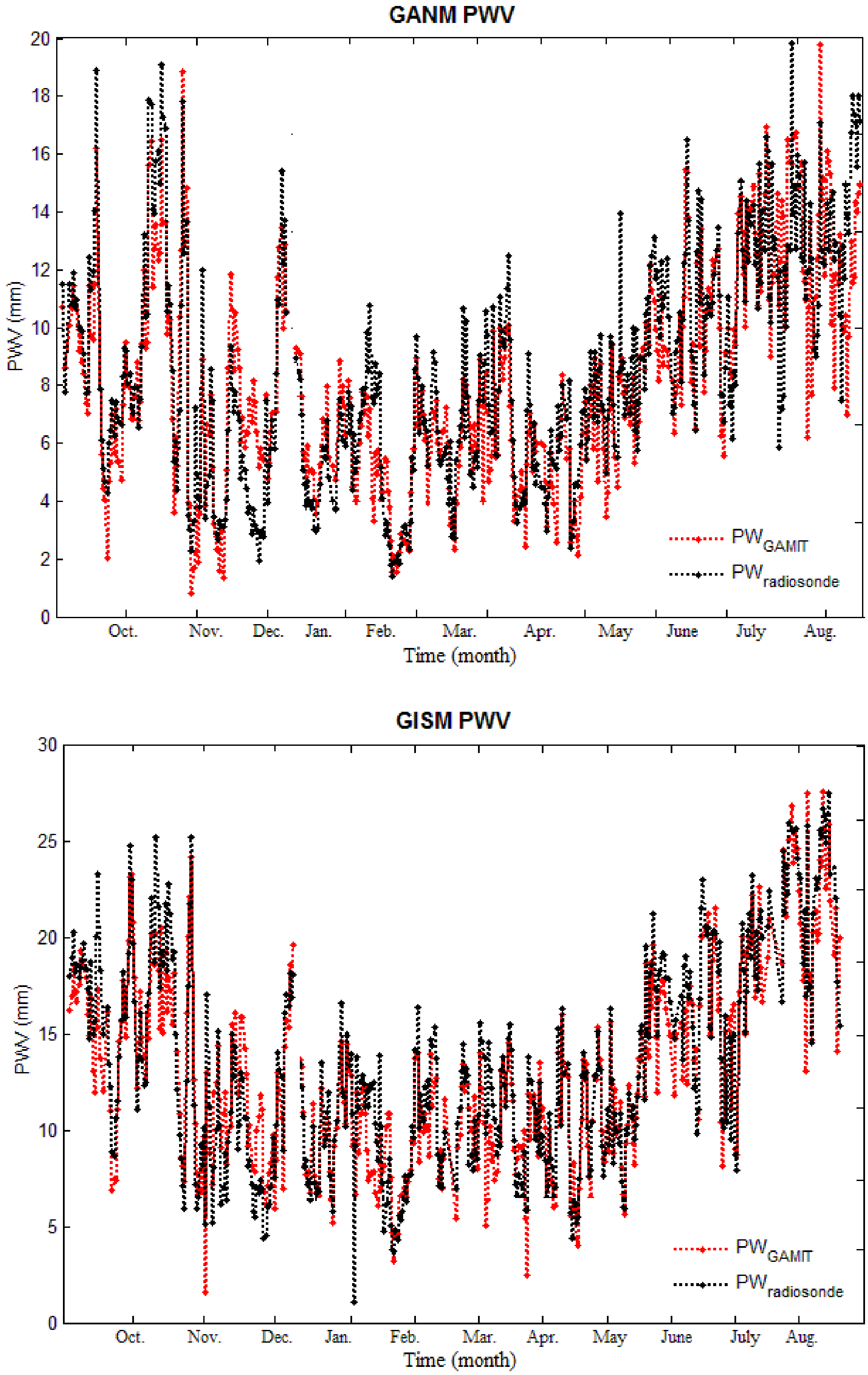

Figure 4. PWV values obtained from GNNS using the Niell Mapping function and radiosonde at GISM and GANM stations.

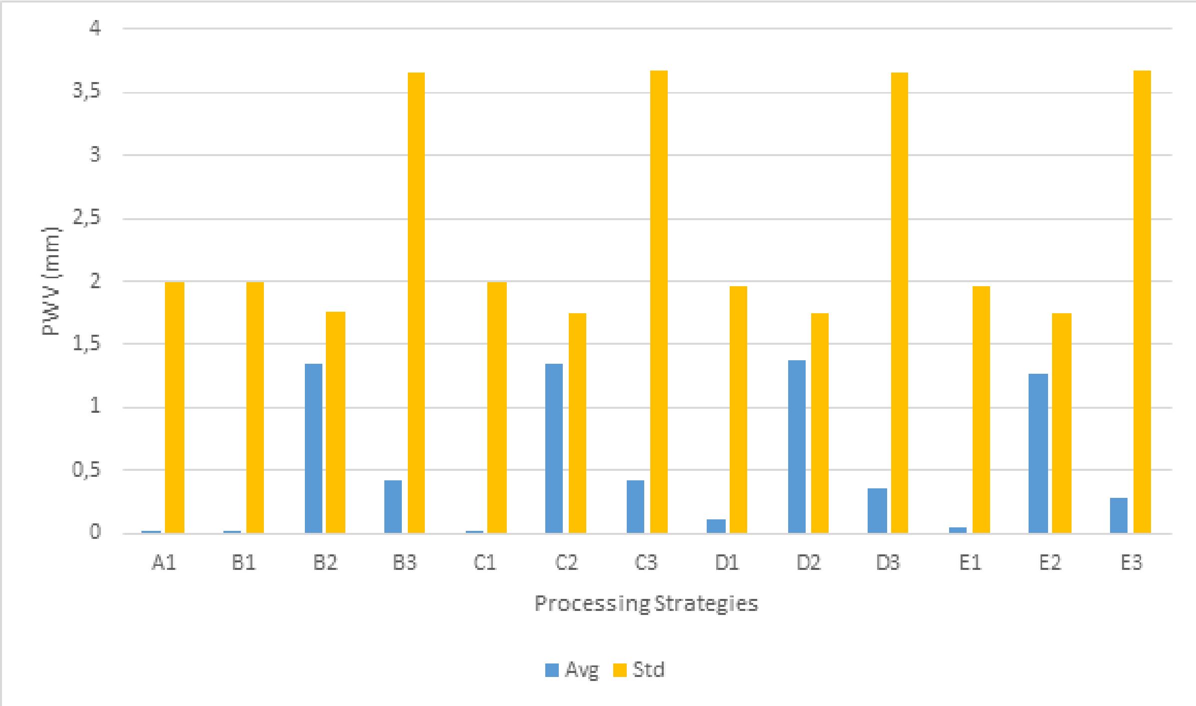

Figure 5. Average and standart deviation of PWV from GANM station for each strategy (Table 1). Values are divided in three time span of 60 day interval since Jan 1st of 2014

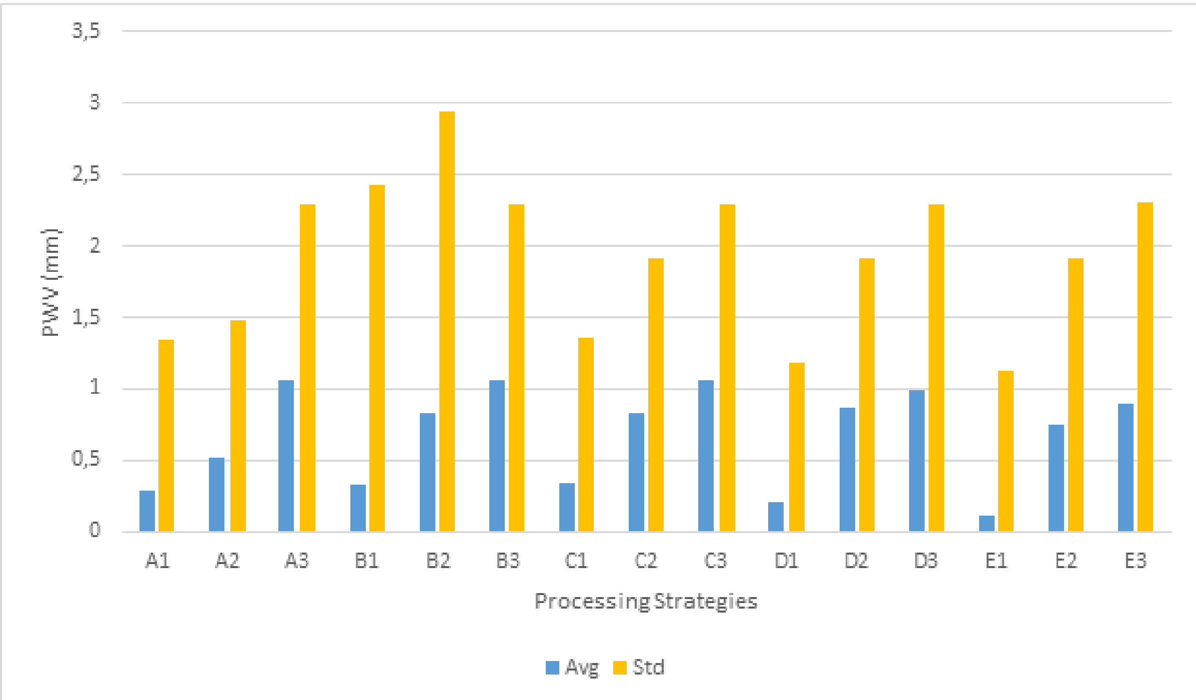

Figure 6. Average and standart deviations of PWV at GISM station for each strategy (Table 1). Values are divided into three time spans with 60 day interval since Jan 1st, 2014

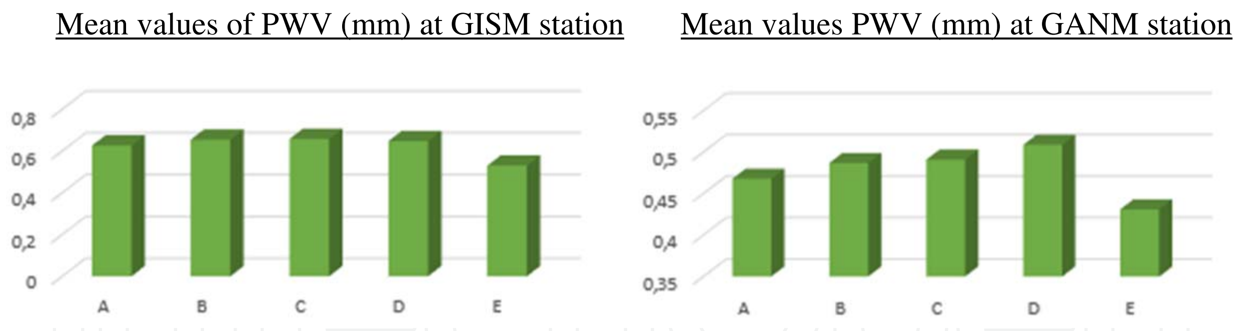

Figure 7. Mean values of PWV at GISM and GANM stations from each strategy (Table 1)

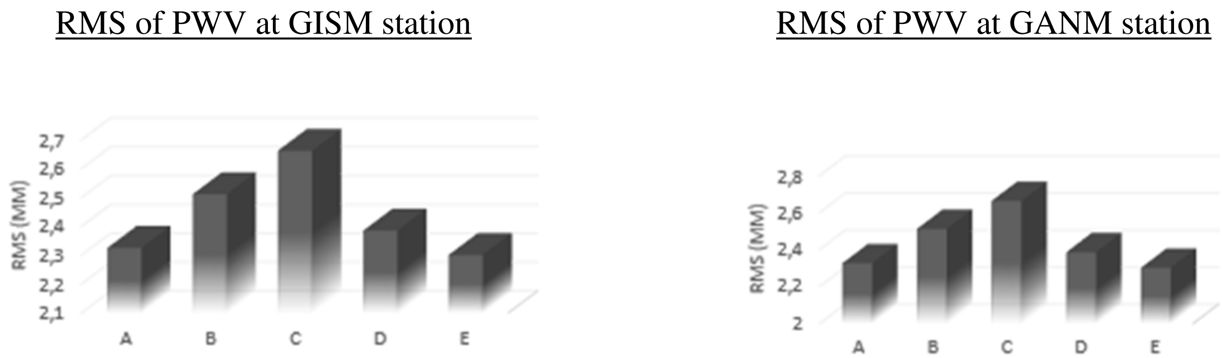

Figure 8. RMS of PWV values at GISM and GANM stations from each strategy (Table 1)

3.2. Seasonal variations

The monthly standard deviation in the ZTD increases from about 5 mm in winter to about 15 mm in summer. Apart from that, Tuchband and [22] compared the results from summer and winter periods and clearly showed that the residual wet delays were smaller in winter periods. We also evaluated the seasonal behaviour of the PWV values for both GISM and GANM stations in Turkey, which have different geographic locations and climates. As we can see in Figure 8, PWV at the GANM station is closer, excluding summer time. On the other hand, at the GISM station, which is near to the coast and has very humid climate, the mean PWV values changes drastically from winter to summer (Figure 9).

Tuchband and [22] stated that this wet delay difference can be explained by the fact that the troposphere contains a low amount of water vapour in the winter period and the weather conditions is more stable in the winter than the summer period.

3.3. Influence of oceanic and atmospheric tides on ZTD and PWV

A permanent GPS station is subject to movements due to the ocean tides [24], which leads to diurnal and semidiurnal variations in station coordinates. Since the GPS site heights and the ZTD are strongly correlated, the ocean tide effects on GPS site heights must be carefully

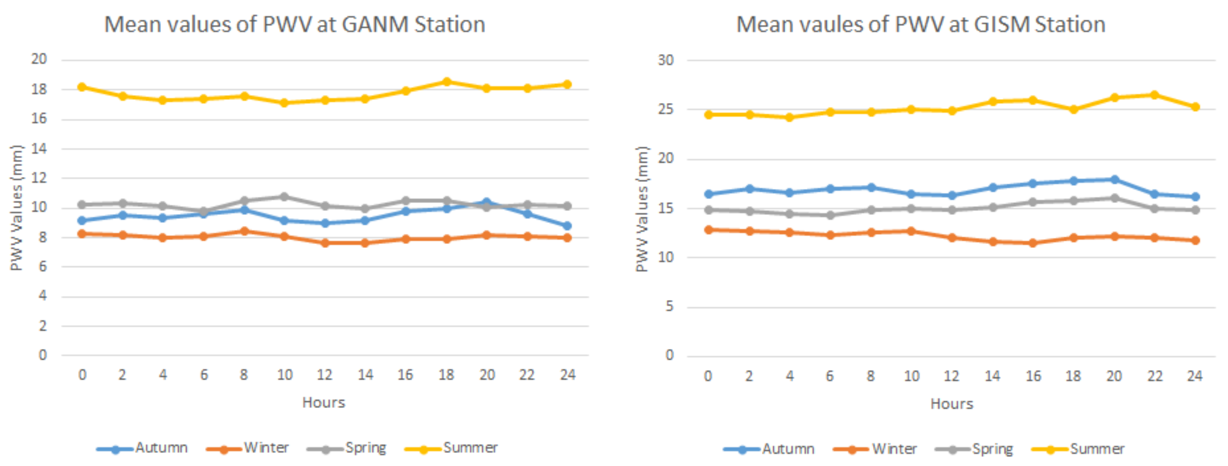

Figure 9. Mean PWV values of GISM and GANM stations

modeled to obtain reliable ZTD [16, 19]. Here the oceanic tide influence is investigated, with and without ocean tide corrections. Tregoning and van Dam (2005) investigated the application of tide and non-atmospheric pressure tide (ATML) at observation level against daily-averaged correction. Their results concluded that applying the ATML at observation level produces significantly better reduction in height RMS than applying daily-averaged corrections. They also showed that still it was not possible to produce a reliable "non-tidal" ATML model by removing diurnal and semi-diurnal atmospheric tides by using the approach of [21].

In fact, applying the tidal models of [21], and the associated "non-tidal" ATML, it yielded a worse solution than applying the ATML convolved from the raw National Centers for Environmental Prediction (NCEP) pressure data with a partial sampling of S1 and S2 tides.

The effect is significant in tropospheric delay estimates, when the ocean tide is not applied. The diurnal and semidiurnal frequencies have a combined effect on the ZTD, within the order of few millimeters. However, if they were not modeled, a periodic and undesired signal in the ZTD time series (not due to the atmospheric refraction) would be induced [19]. So, ocean tide corrections cannot be neglected, even in areas near the Mediterranean Sea [5, 6, 9].

Results of the PWV show that atmospheric tide effects vary with not only the latitude and longitude of the GPS station but also the regional climatic conditions. The oceanic tide effect varies with the geographic location of the GPS stations. Figure 10 shows no significant changes in the PWV values of the A1-C1 values at GANM station or the A1-C1 at GISM station. Since Istanbul is subject to both Black Sea and Sea of Marmara ocean tide effects, the impact on PWV values reaches several millimeters. While Ankara has no such effect since it is located in the middle of Turkey. The atmospheric tide effects have not been specifically applied in the strategy B, neither at the GANM station nor the GISM station. As we can see in Figure 10 that effects on PWV values using strategy B (GISM station) are bigger than 5 millimeters.

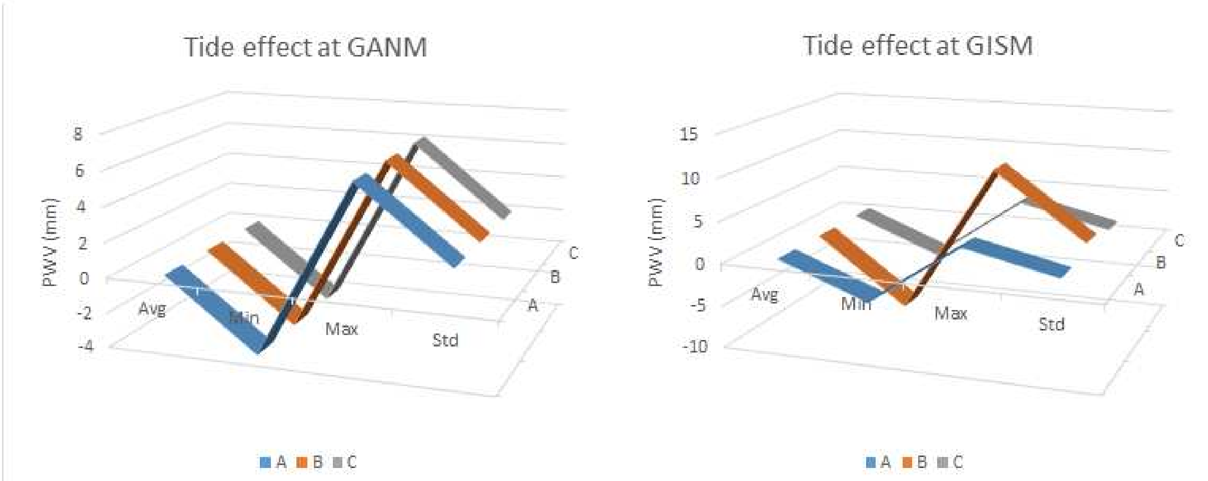

Figure 10. Statistical description of the tide effects in GANM and GISM stations for the first 60 days of 2014 (Processing strategies are listed in the Table 1)

4. Summary

In this study, ZTD values have been calculated by GAMIT/GLOBK software with a resolution of 1 hour at 30 stations from IGS and Turkey. The PWV values at 2 GPS stations (Istanbul GISM and Ankara GANM) in Turkey are obtained and validated by co-located radiosonde PWV measurements. From our results we can see that the ZTD and the PWV by using GAMIT/GLOBK software and GPT model, the Niell Mapping Function gives the best results when compared to radiosonde PWV measurements. The seasonal variations of PWVs at GISM and GANM stations are studied. The larger PWV is found especially in summer periods, and the mean values of PWV are higher than in the other seasons. This difference can be explained by the fact that the troposphere contains lower amount of water vapour in the winter than in the summer and weather conditions are more variable in the summer than in the winter. In addition, oceanic tide effects must be considered for ZTD and PWV estimates, while the effects of atmospheric tide should not be neglected in humid climates.

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