Determination of the Most Applicable Precipitable Water Vapour Model for Turkey using GNSS

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Key words: GNSS/GPS;Positioning, GNSS Meteorology, Tropospheric effects, weighted mean temperature, conversion factor Q

SUMMARY

Water vapor plays an important role in modelling atmosphere and climate studies. Moreover, long-term water vapor changes can be an independent source for detecting climate changes. Since Global Navigation Satellite Systems (GNSS) use microwaves passing through the atmosphere, the atmospheric effects should be modelled with high accuracy. Tropospheric effects on GNSS signals are estimated with the total zenith delay parameter (ZTD) which is the sum of the hydrostatic (ZHD) and wet zenith delay (ZWD). The first component can accurately be obtained from meteorological observations; the latter, however, can be computed by subtracting ZHD from ZTD (i.e. ZWD=ZTD-ZHD). Then, the weighted mean temperature (T_m) or the conversion factor (Q) is used for the conversion between the precipitable water vapor (PWV) and ZWD.

The parameters T_m and Q are derived from the analysis of radiosonde stations' profile observations. A number of Q and Tm models have been developed for each radiosonde station, radiosonde station group, countries and global fields such as Bevis T_m model and Emardson and Derks' Q models. Previously, an algorithm was developed using Matlab^{TM} to compute T_m, Q, ZWD, and the PWV from the parameters of radiosonde profile data such as height (h), temperature (T), dew point temperature (T_d), pressure (p) and relative humidity (H). By applying the least squares method to the results procured from the devised algorithm, the PWV models (T_m and Q models) utilized for Turkey have been derived using a year of radiosonde data (2011) from 4,103 radiosonde profile observations of Istanbul, Ankara, Samsun, Erzurum, Diyarbakir, Adana, Isparta and Izmir radiosonde stations. These models depend on different combinations of parameters such as the station temperature, the station latitude, the station height and day of year. In this study, the models developed are tested by comparing PWV_GNSS computed applying T_m and Q models to the ZTD estimates derived by Bernese and GAMIT/GLOBK software at the GNSS stations established in the close vicinity of Istanbul and Ankara radiosonde stations (PWV_RS) from October 2013 to December 2014. The GNSS and meteorological data are obtained from a project (no 112Y350) supported by the Scientific and Technological Research Council of Turkey (TUBITAK). The comparison results show that PWV_GNSS and PWV_RS are in high correlation (86 % for Ankara and 90% for Istanbul). Thus, the most applicable model for Turkey and the accuracy of GNSS meteorology are investigated.

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1. INTRODUCTION

GNNS (Global Navigation Satellite Systems) Meteorology research has gained a momentum with the possibilities supplied by networks of permanent GNSS reference stations offering to determine and monitor precipitable water vapor (PWV) with high positional and temporal accuracies.

The amount of PWV can be estimated with the total zenith delay (ZTD) stemming from GNSS signals passing through the troposphere. This delay is the sum of the hydrostatic (ZHD) and wet zenith delay (ZWD). The first component can be obtained from meteorological observations with high accuracy; the second one, however, can be computed by subtracting ZHD from ZTD (ZWD=ZTD-ZHD). Once ZWD is estimated, PWV can be computed using the weighted mean temperature (T_m) or the conversion factor (Q) models (Askne and Nodius, 1987; Bevis et al. 1992; Emardson and Derks, 2000).

In this study, the PWV models (T_m and Q models) developed in the project (no 112Y350) supported by the Scientific and Technological Research Council of Turkey (TUBITAK) are tested by comparing PWV_GNSS computed applying T_m and Q models to the ZTD estimates derived by Bernese and GAMIT/GLOBK software at GNSS stations established in the close vicinity of the Istanbul and Ankara Radiosonde Stations (PWV_RS) from October 2013 to December 2014 (Mekik et al., 2016).

2. THE DERIVATION OF PWV_GNSS

As GNSS signals pass through the troposphere, it causes tropospheric delay in GNSS observations. The total tropospheric delay in the zenith direction (ZTD) can be divided into two parts: the hydrostatic (ZHD) and wet zenith delay (ZWD). The first one is the function of the atmospheric pressure while the latter mostly consists of water vapor. ZHD can be computed with the meteorological observations accurately whereas ZWD cannot be computed due to the dispersed and unpredictable water vapor content in the atmosphere, therefore ZHD is first calculated, and then it is subtracted from the total zenith delay:

$$ZWD=ZTD-ZHD \quad (1)$$

Once ZWD is estimated, PWV can be computed using the weighted mean temperature (T_m) or the conversion factor (Q) models (Askne and Nodius, 1987; Bevis et al., 1992; Emardson and Derks, 2000) by

$$PWV = \frac{ZWD}{Q} \quad (2)$$

where PWV is the precipitable water vapor in mm, ZWD is the wet zenith delay in mm (Hogg et al., 1981; Askne and Nodius, 1987; Bevis et al., 1992; Mendes and Langley, 1994; Tregoning et al., 1998; Emardson and Derks, 2000; Mendes and Langley, 2002; Troller et al., 2005). The conversion factor Q is given as:

$$Q = 10^{-6}\left(k_2' + k_3 / T_m\right)R_w \tag{3}$$

where $k_2' = 64,8\left(KhPa^{-1}\right), k_3 = 3,776.10^5\left(K^2 / hPa\right), R_w = 461.524\left(JK^{-1}kg^{-1}\right)$ (Bevis et al., 1992). T_m is the weighted mean temperature depending on the surface temperature T_s.

The relation between Q and T_m is as follows:

$$Q = 4,61524 \times 10^{-3}\left(\frac{3,739 \times 10^5}{T_m} + 22,1\right) \tag{4}$$

In our previous studies, the PWV models (T_m and Q models), applicable for Turkey developed in the project (no 112Y350) supported by the Scientific and Technological Research Council of Turkey (TUBITAK), were derived using a year of radiosonde data (2011) of 4,103 radiosonde profile observations at Istanbul, Ankara, Samsun, Erzurum, Diyarbakir, Adana, Isparta and Izmir radiosonde stations. These models depend on different combinations of parameters such as the station temperature, the station latitude, the station height and day of year.

The annual T_m model for Turkey is developed in the project with a root mean square error of 2.566 K (Mekik and Deniz, 2017):

$$T_m = 48.546 + 0.796 T_s \tag{5}$$

where T_s is the surface temperature.

In addition, the conversion factor model is developed with a root mean square error of 0.0684:

$$Q_{BEU} = \left[5.7053 - 0.0067(T_s - 287.7620\right] + 0.0130\ \theta + 0.0833\ H + 0.0709 \sin\left(2\pi \frac{t_D}{365}\right) + 0.1195 \cos\ (2\pi \frac{t_D}{365}) \tag{6}$$

where θ is the station latitude, H the station height, and t_D day of year (the subscript BEU in Q_{BEU} stands for Bulent Ecevit University).

In order to test the developed models developed, PWV_GNSS computed applying T_m and Q models (Eq. 5 and 6) to the ZTD estimates derived by the Bernese and GAMIT/GLOBK software at GNSS stations established at Istanbul and Ankara are compared with those from the co-located radiosonde stations (PWV_RS) from October 2013 to December 2014

In this study, the ZTDs are estimated by the Bernese and GAMIT/GLOBK software at GNSS stations established in Istanbul and Ankara. The processing strategies of both softwares are given in Table 1. Moreover, the geodetic network consisting of 29 GNSS stations utilized in the processing can be seen in Figure (Rozsa, 2012).

Table 1 The processing strategies of Bernese GNSS Software v5.0 and GAMIT/GLOBK softwares

Processing parameters	**Processing strategies**	
	Bernese GNSS Software v5.0	*GAMIT/GLOBK*
Input data	Daily	Daily
Network design	OBS-MAX	RELAX
Elevation angle	10˚	10˚
Sampling rate	30 saniye	30 saniye
Antenna phase center offset	PHAS_COD.I08	RCVANT.DAT
Ionosphere	Ionospheric free linear combination (L3)	AUTCLN
Ambiguity solution	Quazi-ionosphere free (QIF) and SIGMA strategies	AUTCLN
A priori model	Saastamoinen model with the dry Niell mapping function	Saastamoinen model with the dry Niell mapping function
Mapping function	wet Niell mapping function	wet Niell mapping function
ZTD interval	1 hour	1 hour

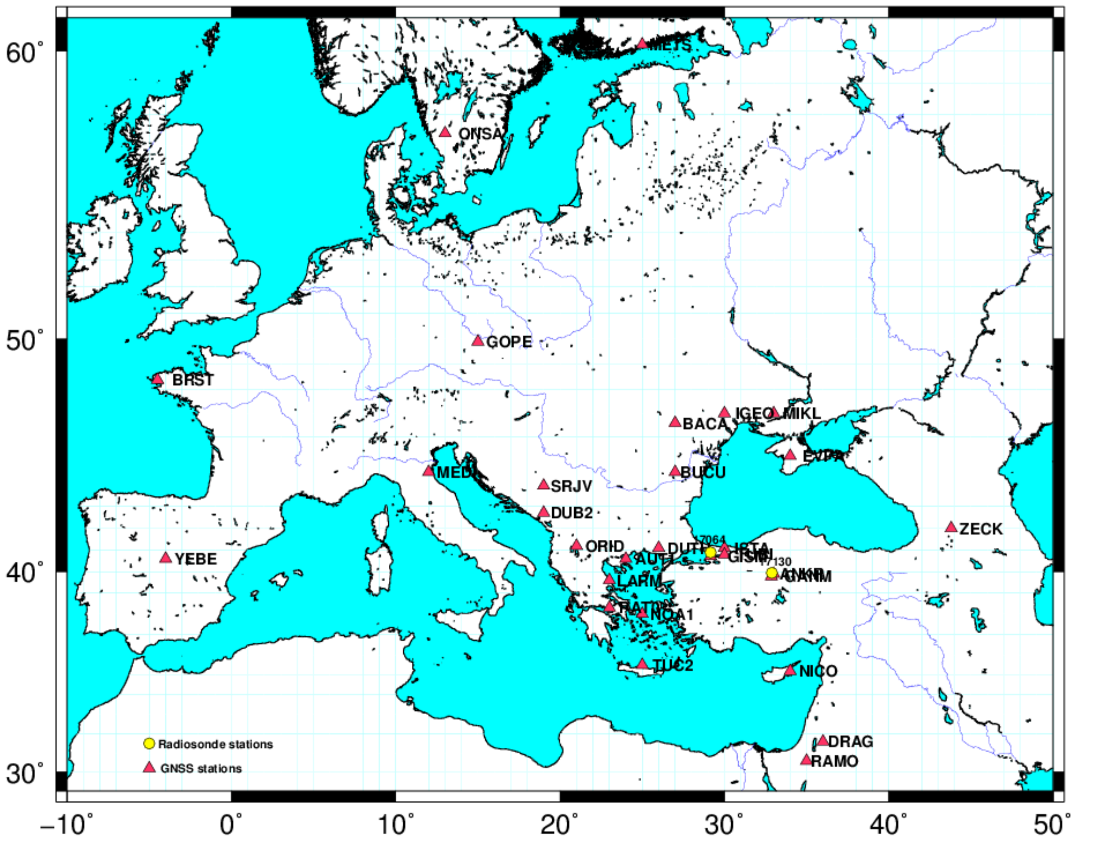


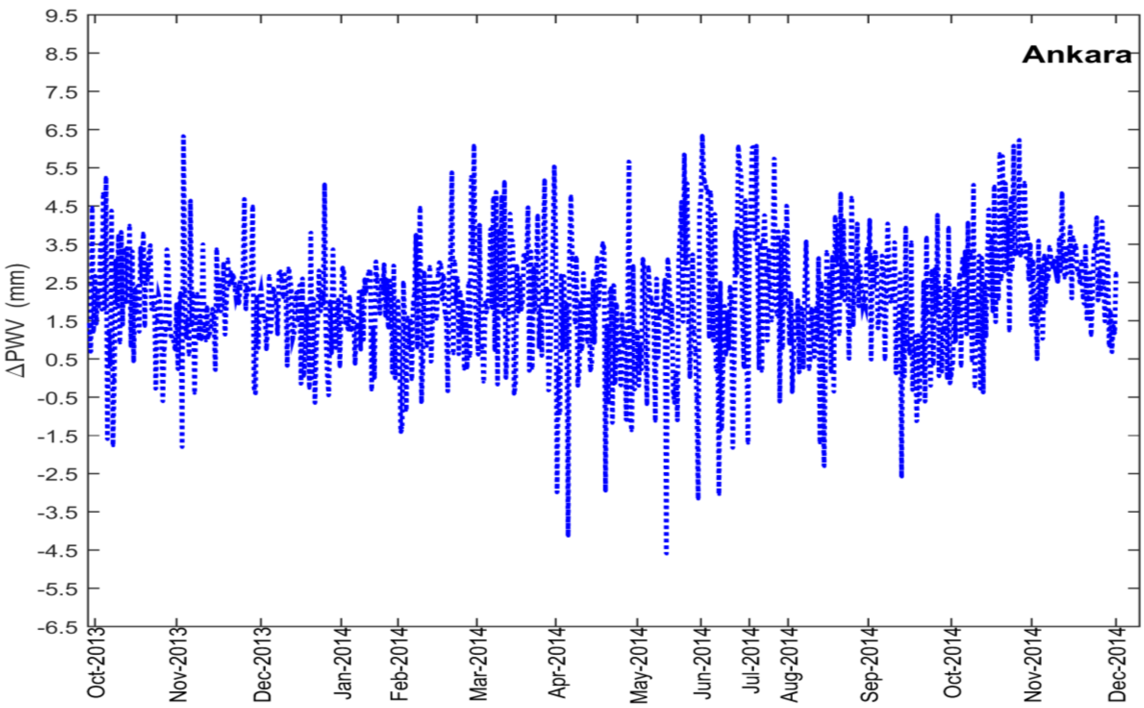
Figure 1. The GNSS network for ZTD estimation

Firstly the ZHD is computed with surface meteorological parameters provided by the General Directorate of Meteorology, and then the ZWD is computed by Eq 1. The PWV_GNSS are computed applying T_m and Q models to the ZWD estimates, and then are compared with those from the co-located radiosonde stations (PWV_RS). PWV_RS used in this paper are downloaded from the University of Wyoming web site (University of Wyoming, 2014).

The results of the comparison for T_m model can be seen in Table 2, and are depicted in Figure 2 and 3. It can be seen that the PWV_GNSS and PWV_RS are in high correlation (86 % for Ankara and 90% for Istanbul).

Processing software	**GNSS station**	**min. (mm)**	**max. (mm)**	**mean (mm)**	**std. (mm)**
Bernese	Ankara 743 profiles	-4,60	6,35	2,02	1,60
	Istanbul 671 profiles	-4,74	6,45	2,33	1,72
GAMIT	Ankara 484 profiles	-4,67	9,37	1,37	1,17
	Istanbul 460 profiles	-4,90	6,13	1,48	1,31

Table 2. The statistics of the comparison of PWV_RS and PWV_GNSS computed by applying the annual T_m model to the Bernese ZTD and GAMIT ZTD estimates



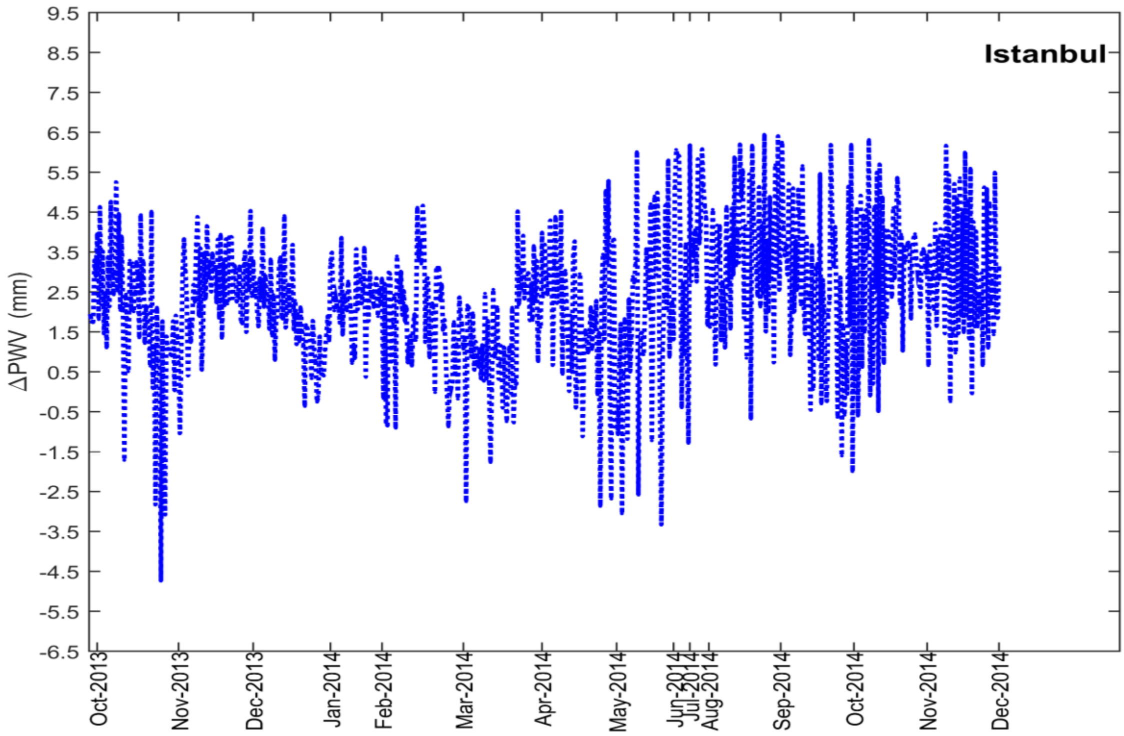
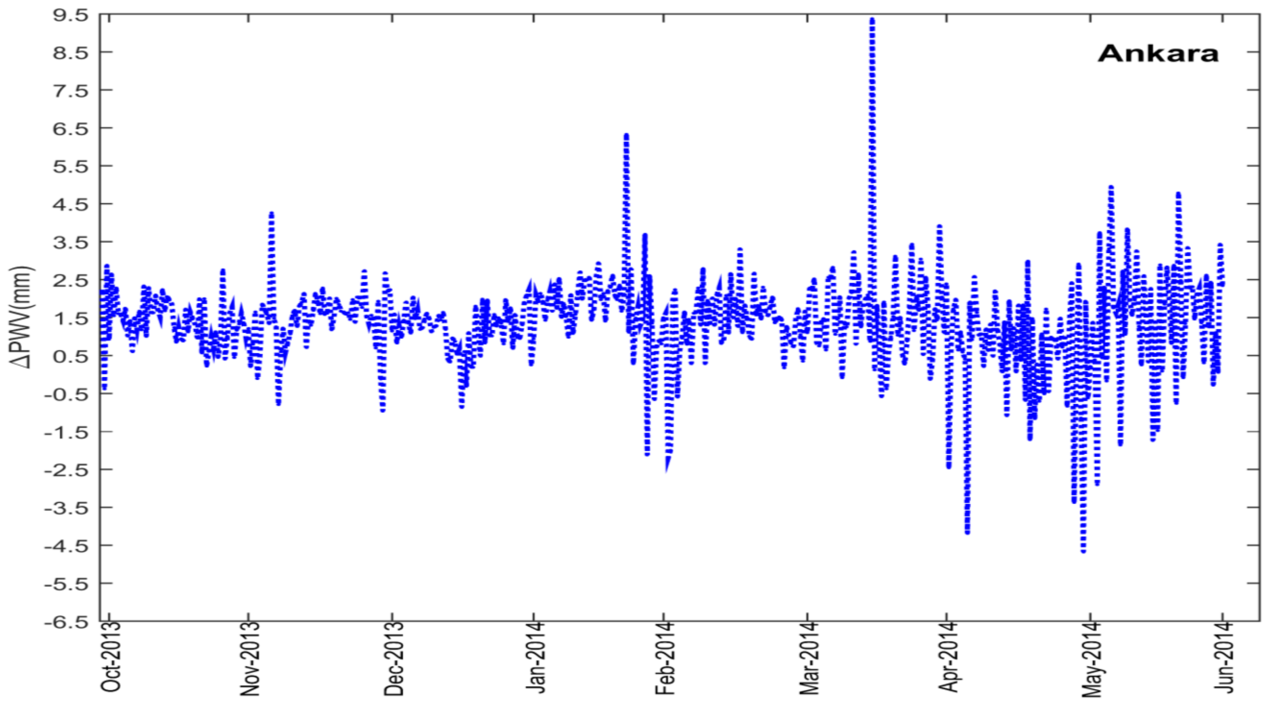


Figure 2. The differences of PWV_{GNSS} derived using Bernese ZTD estimates and the annual T_m from PWV_{RS} at Ankara and Istanbul stations



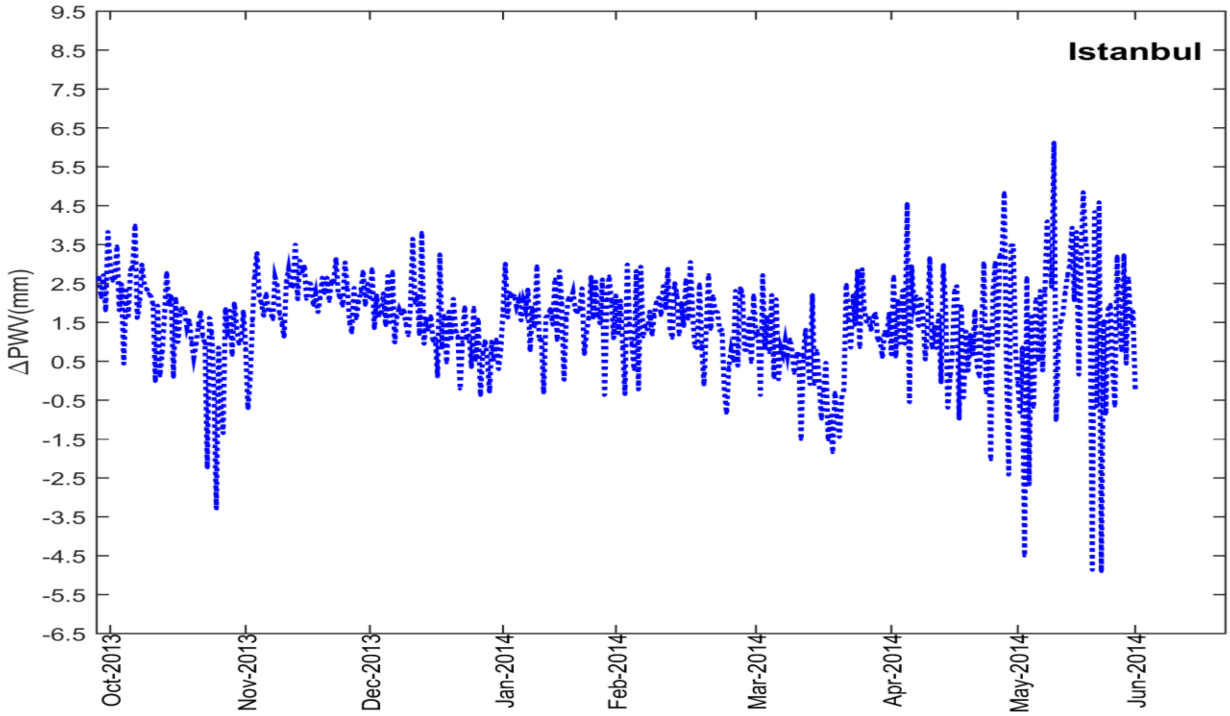


Figure 3. The differences of PWV_{GNSS} derived using GAMIT ZTD estimates and the annual T_m from PWV_{RS} at Ankara and Istanbul stations

The results of the comparison for Q_{BEU} model can be seen in Table and are depicted in Figure 4 and 5. It can be seen that PWV_GNSS and PWV_RS are in high correlation (86 % for Ankara and 90% for Istanbul).

Processing software	GNSS station	min. (mm)	max. (mm)	mean (mm)	std. (mm)
Bernese	Ankara 743 profiles	-5,44	6,09	1,52	1,71
	Istanbul 671 profiesl	-5,72	6,07	1,59	1,78
GAMIT	Ankara 484 profiles	-6,05	8,92	0,92	1,24
	Istanbul 460 profiles	-6,21	5,20	0,82	1,38

Table 3. The statistics of the comparison of PWV_RS and PWV_GNSS computed by applying the Q_{BEU} model to the Bernese ZTD and GAMIT ZTD estimates

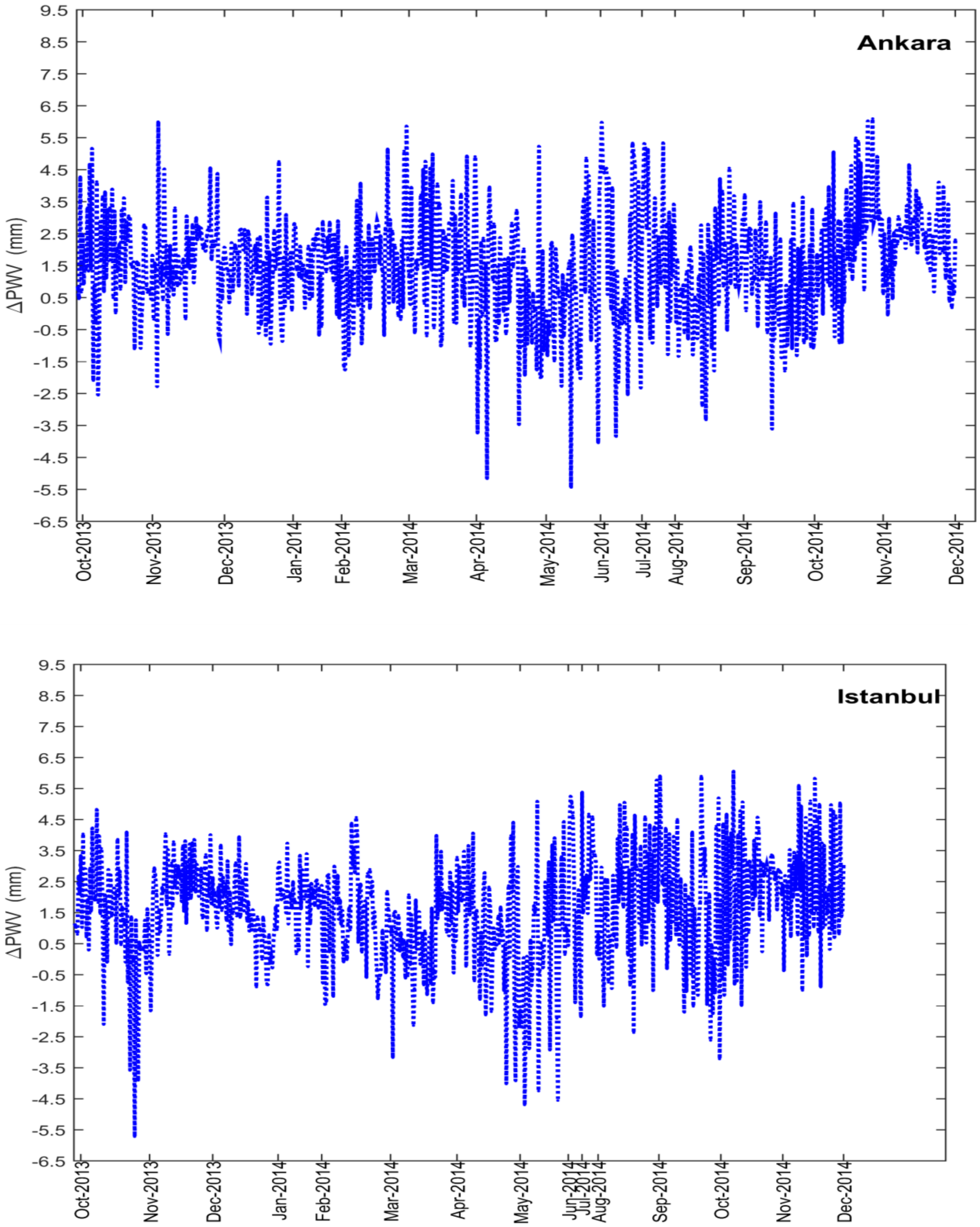


Figure 4. The differences of PWV_{GNSS} derived using Bernese ZTD estimates and Q_{BEU} from PWV_{RS} at Ankara and Istanbul stations

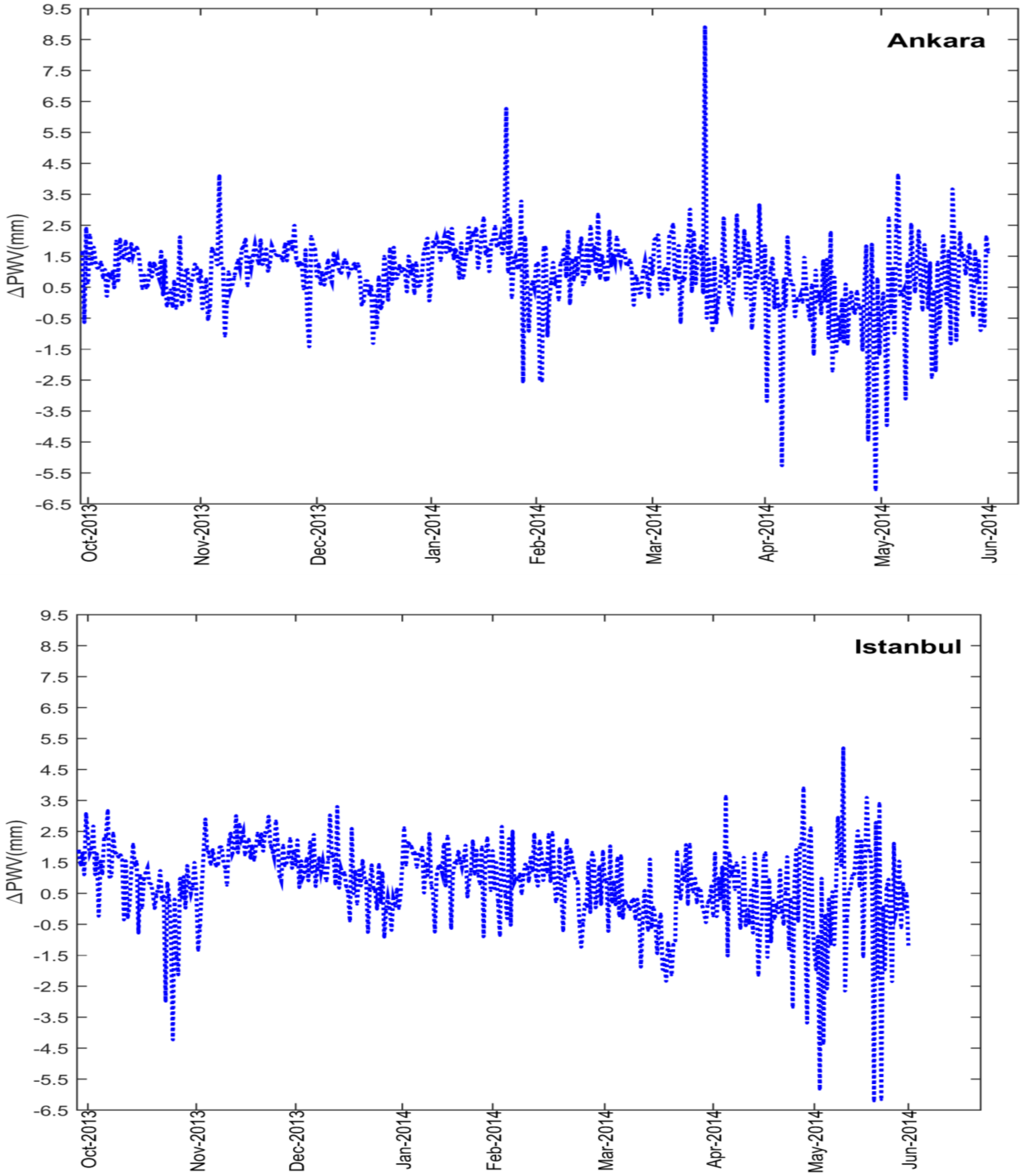


Figure 5. The differences of PWV_{GNSS} (GAMIT and Q_{BEU}) from PWV_{RS} at Ankara and Istanbul stations

3. CONCLUSIONS

GNNS provides high temporospatial accuracy for determining and monitoring precipitable water vapor. It can improve the weather forecast, determining severe weather events and climate studies.

Two PWV models are tested by comparing PWV_GNSS values computed applying T_m and Q models to the ZTD estimates derived by Bernese and GAMIT/GLOBK software at GNSS stations established at Istanbul and Ankara with those from the co-located radiosonde stations (PWV_RS) from October 2013 to December 2014. PWV_GNSS estimated by PWV models show high agreement with PWV_RS.

The differences of PWV_{GNSS} from PWV_{RS} results demonstrated that the annual T_m model is so close to Q_{BEU} and both models can be used in the determination of PWV.

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BIOGRAPHICAL NOTES

Dr. Cetin Mekik was born in 1967. He graduated from Istanbul Technical University in 1988 as Geodesy and Photogrammetry Engineer. He obtained M.Phil. and Ph.D. degrees from Newcastle University, United Kingdom. He is currently working as an Associate Professor and the Head of Geomatics Engineering Department at Bulent Ecevit University in Turkey. He has specialized in GNSS, Network RTK (CORS networks) and GNSS Meteorology, and has recently completed a COST Project called "Water Vapor Estimation using GPS" sponsored by the Scientific and Technological Research Council of Turkey TUBITAK). He has been a member of Executive Committee of Earth and Environmental Support Group of TUBITAK since 2014.

Dr. Ilke Deniz is a research assistant at Department of Geomatics Engineering at Bulent Ecevit University, Turkey. She graduated from Yildiz Technical University in 2004 as Geodesy and Photogrammetry Engineer. She obtained M.Sc. degree from Geodesy Department of Bogazici University and recently PhD degree from Geomatics Engineering of Bulent Ecevit University. Her research interests are GNSS, tropospheric parameter estimation by academic processing softwares, tropospheric delay, GPS Meteorology and strain analysis.

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