# Establishment Of Gnss Regional Network For Tropospheric Tomography

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**Key words**: Severe weather, GNSS network, GNSS tomography, Water Vapour, Numerical Weather Model.

**SUMMARY**

In Turkey, severe weather events have increased severely since beginning of years 2000s. In 2015, the numbers of severe weather events, 959, have reached to record level. More than one fourth of these events are flood and heavy rain. Blacksea Region has been affected by hydrological origin severe weather events. Moreover, according to climate change scenarios until 2100, it has been foreseen that East Blacksea Region will be one of the region where severe weather events especially heavily rain and flood will increased related to climate change. This situation states a necessity of reliable weather monitoring and prediction system.

Precipitable water vapor (PWV) can be estimated via GNSS meteorology by using Zenith Tropospheric Delay (ZTD) estimated at GNSS stations and meteorological data. By using a regional network of GNSS reference stations, it is possible to recover estimates of the slant wet delay (SWD) to all satellites in view. SWD observations can then be used to model the vertical and horizontal structure of water vapor over a local area, using a tomographic approach. This study introduces the TUBİTAK research project 116Y186 “Using Regional GNSS Networks to Strengthen Severe Weather Prediction” which has been performed at Department of Geomatics Engineering of Karadeniz Technical University and explain criteria to establish GNSS network for tropospheric tomography. The first aim of the project, to determine of atmospheric water vapor distribution by GNSS meteorology and GNSS tomography software developed by ourselves using observation data of network designed with 4 new constructed GNSS reference station in Trabzon and Samsun, in Blacksea Region of Turkey. Two GNSS stations in Samsun are co-located with Samsun radiosonde site within 10 km. Water vapor distribution derived by GNSS meteorology and GNSS tomography will be compared with water vapor distributions derived by radiosonde. Therefore, it is targeted to perform accuracy analysis of water vapor distributions derived by GNSS meteorology and GNSS tomography.

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## 1. INTRODUCTION

PWV and 3D WV distribution can be estimated by using direct estimation of Zenith Tropospheric Delay (ZTD) or involving more sophisticated processing applying GNSS tomography principle, respectively. The use of GNSS technology to estimate atmospheric water vapour in the troposphere has increased in addition to its use for geodetic positioning (Teke et al. 2011, Teke et al. 2013, Lutz 2009). In recent years a number of research groups in the World have performed researches on development of GNSS meteorology methodologies, including GNSS tomography (Bender and Raabe 2007, Bender et al. 2010, Rohm and Bosy 2010). In Turkey, there have been a few researches on topic of GNSS meteorology and GNSS tomography (Deniz and Mekik 2013, Mekik 2014, Gurbuz et al 2015). The TUBITAK research project titled 116Y186 aims to determine water vapor distribution derived by GNSS Meteorology and GNSS Tomography from a network with new constructed GNSS stations in two cities Samsun and Trabzon of Black Sea Region, TUSAGA-Aktif GNSS stations and IGS/EUREF GNSS stations. At the first part of the project, water vapour distributions calculated by GNSS meteorology and radiosonde data between November 1, 2017 and January 31, 2018 has been compared and accuracy analyses has been performed for water vapor distributions derived by GNSS meteorology and radiosonde data.

This paper presents the estimation of precipitable water vapour (PWV) from GNSS observations over four new constructed GNSS stations in Samsun and Trabzon cities of Black Sea Region, Turkey, radiosonde data in Samsun and meteorological data over GNSS stations calculated by spatial interpolation methods. Samsun GNSS stations are co-located Samsun radiosonde with WMO (World Meteorology Organization) ID 17030 site is located at 41.28 °N, 36.33°E, 4 m above mean sea level in Samsun and have been launched twice daily at 00:00 UTC ve 12:00 UTC. The data used for external validation of GNSS derived PWV are radiosonde derived PWV at Samsun radiosonde site.

### 1.1.Determination of Water Vapour From Regional GNSS Network

The location for this study over two cities Samsun and Trabzon of Blacksea Region of Turkey is given in Table 1. We use the GNSS data from two stations in Samsun: SOMU-On Dokuz Mayıs University Department of Geomatics Engineering, SAME- Samsun Regional Office of Turkish State Meteorological Service and two stations in Trabzon: TRAB-Karadeniz Technical University Department of Geomatics Engineering, MACK- Karadeniz Technical University Maçka Vocational School with Ashtech Proflex 800 receiver. The observations of Samsun stations are available from 15 November 2017, while for TRAB and MACK from December 2017 and TRAB from February 2015.

Table 1. Samsun GNSS stations and co-located radiosonde station

| **Station Name** | **Latitude** | **Longitude** | **Height (m)** | **Place** |
|---|---|---|---|---|
| SAME | 41.3438 | 36.2555 | 42.7 | Samsun |
| SOMU | 41.3645 | 36.1846 | 267.5 | Samsun |
| MACK | 40.8048 | 39.6181 | 416.2 | Trabzon |
| TRAB | 40.9947 | 39.7756 | 99.3 | Trabzon |

ZTD has been estimated by processing of GNSS data using the Bernese 5.2 software (Table 2).

Table 2. GPS processing parameters.

| | |
|---|---|
| Processing method | Double Differencing Network solution |
| Processing Strategy | Obs-Max |
| Satellite and receiver antenna phase center calibration | IGS14 |
| Apriori Tropospheric model | Dry VMF |
| Zenith Path Delay | Wet VMF |
| Mapping functions | Vienna mapping functions (1-h interval) |
| Elevation cut-off angle | 10◦ |
| Observation interval | 30 seconds |
| Ambiguity Resolution | Quasi-Ionosphere Free (QIF)<br>MW/L3, L5/l3, L1&l2 |
| Reference Coordinates and epochs | ITRF 2014 -2010 |
| Ionosphere Model | CODE Daily Global Model |
| Antenna Phase Center Variations | IGS (igs14.atx) |

| | |
|---|---|
| Observation data interval | Daily |
| Orbit Files | CODE Final 15 min. GPS+GLO orb/clk |

To process the GNSS data using Bernese 5.2 software with network solution, we construct a network with 52 stations, including 4 stations in Samsun and Trabzon, 15 stations of TUSAGA-Aktif, and 33 stations from IGS/EUREF (Figure 1).


Figure 1. Distributions of GNSS Network Stations

In order to retrieve PWV based on GNSS derived ZTD estimation, meteorological data such as pressure and temperature are necessary. Since our GNSS stations in Trabzon and Samsun are not equipped with meteorological instruments, a method is used to interpolate temperature and pressure at GNSS sites with measurements from 302 surroundings meteorological sites of Turkish Meteorological Office at Blacksea Region (Figure 3).


Figure 2. Meteorological Sites of Turkish Meteorological Office at Blacksea Region

Because pressure is sensitive to the station height, the pressure and temperature measurements given at different heights ($P_{SL}, T_{SL}$) have to be converted to mean sea level as follow;

$$P_{MSL} = P_{SL}/(1 - 2.26 * 10^{-5} * H)^{5.225}$$

$$T_{MSL} = T_{SL} + 0.0065 * H \qquad (1)$$

Thus, the interpolated temperature and pressure at GNSS sites refer to mean sea level ($P_{MSL}, T_{MSL}$). In order to calculate PWV at GNSS site, interpolated temperature and pressure at mean sea level have to be converted to station height level (Baltink et al 1999, Böhm 2007).

There are many interpolation methods available in spatial geodetic applications. In our analyses, Inverse Distance Weighted (IDW) which is one of the most commonly used techniques for interpolation. IDW interpolation method in this work is configured w.r.t. the power parameter and the search radius to improve accuracy of interpolated temperature and pressure at GNSS sites (Zengin Kazancı and Tanır Kayıkçı 2016a; Tanır Kayıkçı and Zengin Kazancı 2016b). We compare the interpolated pressure and temperature for some meteorological site using the observed pressure and temperature to evaluate the accuracy of interpolation results. The optimal interpolation results in terms of RMS values which are calculated from the differences between interpolated and observed pressure and temperature will be used to derive PWV calculations.

### 1.2. Determination of Water Vapour From Radiosonde Data

There are 8 radiosonde stations in Turkey launched twice a day, and are located hundreds of kilometers from each other (Figure 3). Samsun radiosonde site is the only one radiosonde in Black sea region. The two Samsun GNSS stations are co-located with Samsun radiosonde site within 10 km. The radiosonde data are avaliable the University of Wyoming on a website with radiosonde observations (http://weather.uwyo.edu/upperair/sounding.html). Samsun radiosondes are launched twice a day at epoch 00:00 and 12:00 UTC only. The radiosonde data used in this study covered the period from 1 November 2017 to 31 January 2018.


Figure 3. Radiosonde Sites in Turkey

The total amount of water that accumulates in the vertical column from the earth to the upper surface of the atmosphere is called precipitable water vapor. Because it can not be measured directly, it is possible to calculate the meteorological data obtained from ravinsonde observations. One of the approaches used to determine the amount of water vapor in the air is the mass of water vapor in a unit of dry air mass. This approach is expressed as follows

$$\omega = \frac{m_v}{m_a} = \left(\frac{\text{Water Vapour(kg)}}{\text{Dry Air(kg)}}\right) \tag{2}$$

The mixing ratio (ω) is defined as the specific humidity or humidity ratio, according to the ideal gas law can be expressed as follows

$$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = \frac{P_v/R_v}{P_a/R_a} = 0.622\frac{P_v}{P_a} \tag{3}$$

Here, P is total pressure, $P_v$ partial water vapor pressure and $P_a$ dry air partial pressure. Finally, ω can be expressed as follows

$$\omega = \frac{0.622 P_v}{P - P_v} \cong 0.622 \frac{e}{p} \qquad (4)$$

where e is partial water vapor pressure, can be calculated from the dew point temperature (Td) as follows

$$e = 6.11 * 10^{\left(\frac{7.5 * Td}{237.3 + Td}\right)} \qquad (5)$$

The precipitable water vapour, PWV, contained in layer bounded by pressures $p_o$ and p can be calculated from the equation expressed in equation as follows (Raudkivi 1979).

$$PVW = \frac{1}{g} \int_{p}^{p_0} \omega \, dp = \frac{1}{g} \int_{p}^{p_0} 0.622 \, \frac{e}{p} \, dp = \frac{0.622}{g} \int_{P}^{P_0} e \, d(\ln p) \qquad (6)$$

where g is the accelaration of gravity. If unit of pressure is in millibar and unit of dew temperature is in ℃, dimensionally

$$PWV = \frac{0.622}{9.81 (kg/ms2)} 100 (kgm/sn2m2) \int_{P}^{P_0} e \, d(\ln p) \qquad (7)$$

In this work, PWV calculated from eq.(7) are compared to the PWV results which are be obtained from URL1 in advance to compare GNSS derived PWV (Figure 4, Figure 5).

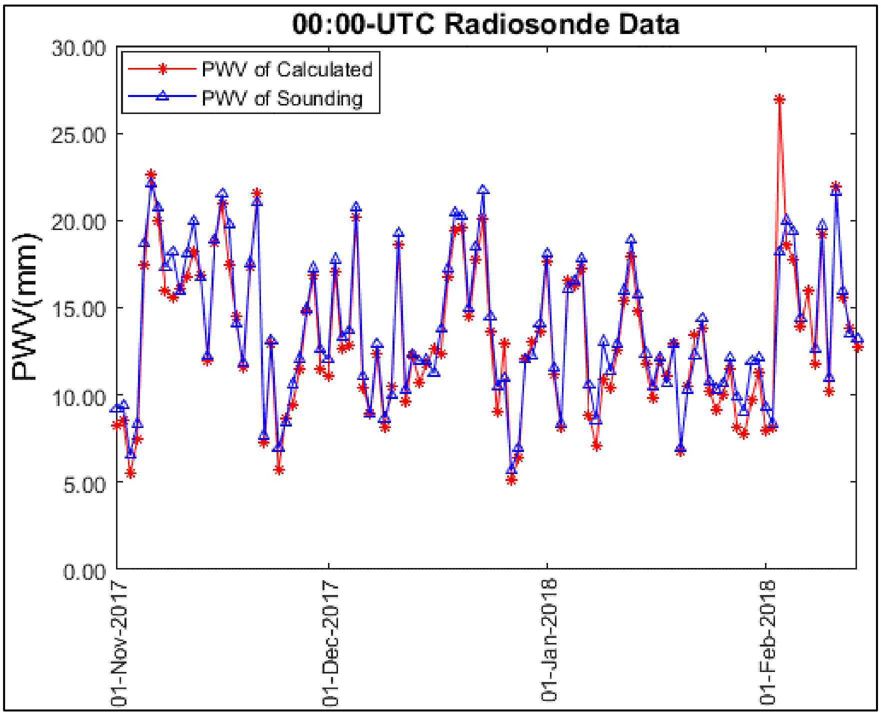


Figure 4. PWV Results from radiosonde profiles and sounding for 00:00-UTC Data

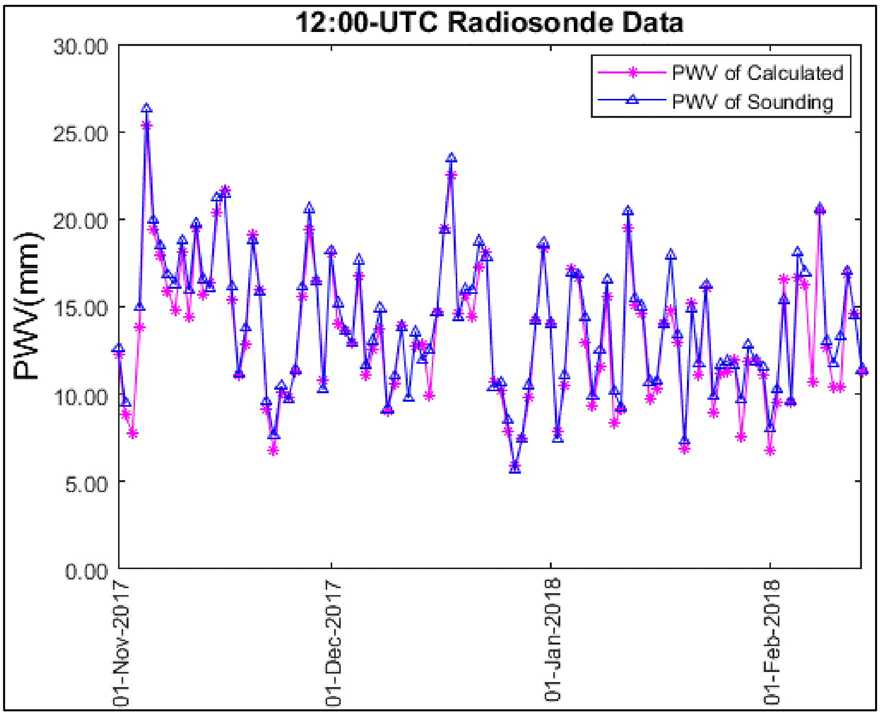


Figure 5. PWV Results from radiosonde profiles and sounding for 12:00-UTC Data

## CONCLUSION

In this study, four permanent GNSS stations over Samsun and Trabzon (SAME, SOMU, MACK and TRAB) and one co-located radiosonde site over a period of November 2017 to January 2018 were established to monitor PWV. SAME and SOMU GNSS stations have data archive since November 2017, MACK since December 2017 and TRAB since (since February 2015, established outside the project) and there have been still some problems in collecting GNSS observation and data processing procedures. Therefore, estimation of PWV and 3D WV distribution using direct estimation ZTD from GNSS processing or involving more sophisticated processing applying GNSS tomography principle has continued.

In this work, radiosonde derived PWV calculations were evaluated. The results have shown that PWV estimates calculated from eq.(7) agree with PWV solutions obtained URL 1 data at an average mean difference of 0.45 mm and 0.57 mm and respectively for 12:00 UTC and 00:00 UTC.

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