A MULTI-PURPOSE CONTINUOUS GPS NETWORK WITHIN THE BOUNDARY ZONES OF THE EURASIAN, AFRICAN, AND ARABIAN PLATES

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Abstract

Turkish National Permanent GPS Network (TNPGN) consisting of 27 stations, 4 of which are also included in EPN and IGS networks, is serving for long-term maintenance of TNFGN and provides the integration of national control networks to the global networks. Although TNPGN was preliminarily conceived as a static continuous network, intensive cadastral demands have led to establishing a denser RTK GNSS network which covers the whole country. TNPGN has been currently operated by the General Command of Mapping. Establishment of a new RTK GNSS Network, along with TNPGN, consisting of 150 stations is still under progress and expected to be full functional by the end of 2008 and will provide the basis for various applications and scientific researches. More than half of the stations were installed in meteorological parks of General Directorate of State Meteorology. Precipitable water (PW) data for weather forecasting will be obtained from TNPGN at near real-time with unprecedented temporal and spatial coverage. Assimilation of TNPGN-derived PW values with numerical weather models is still an on-going effort. Moreover, a new project about real-time 3D mapping of ionosphere was initiated with support of Turkish Scientific and Technological Research Council (TUBITAK). The preliminary results are promisingly adequate for most of the RTK operations. The network has also been connected to the Turkish Horizontal and Vertical Control Networks through overlapping leveling and tide-gauge stations. The analysis center for daily processing of data was improved and communications infrastructure was re-designed for real-time processing of data streamed to the center via ADSL and GPRS/EDGE. With the state-of-art hardware, RTCM 3.0 protocol will be used assuring the communications via GSM, GPRS, NTRIP (Network Transport of RTCM through Internet Protocol).

1. Introduction

“Project of Research and Implementation Related to the Establishment of Network Based Stationary Real-Time Kinematic (RTK) GPS Terminals and Determination of Cellular Transformation Parameters (CORS-TR / TUSAGA-Aktif)” has been proposed by Istanbul Culture University (IKU), jointly with the General Command of Mapping (GCM) and the General Directorate of Land Registry and Cadastre (GDLRC). The project’s started at 08 May 2006 and shall be concluded at September 2008.The Objectives of the project are; to provide DGPS and RTK GPS data corrections and determine real time precise coordinates throughout Turkey via establishing approximately 145 CORS-TR stations, to determine datum transformation models and computations between different coordinate systems (ED50/WGS-84) and serve data for geodetic, terrestrial mapping and cadastre applications.

TNPGN will function as a fundamental tool for geodynamics, tropospheric and ionospheric research as well as surveying and cadastral works. While permanent GNSS networks offer the utmost precision obtainable from GNNS studies, they still lack the sufficient spatial resolution required in high-deformation regions. Turkey is located within the boundary of Eurasia, Arabia and African plates and TNPGN forms the southeastern boundary of European Continues Network. TNPGN has the importance of detecting the rigid and deforming boundaries of any ETRS-89 realizations including sites in the southeastern

Europe. In this respect, TNPGN will provide an indispensable geodetic control for monitoring the crustal movements as well as addressing the issues of southeastern boundary in reference frame definition of ETRS-89. On the other hand, continuous networks are still growing with respect to survey-type GPS studies which date back to late 1980s. With more than 80 GPS surveys carried out across Turkey since 1992, survey-type GPS data are still the most important data for long-term maintenance of control networks. A spatial resolution of 30-50 km inter-station distance was achieved upon completion of Turkish National Fundamental GPS Network (TNFGN) in 1999. Following the establishment of TNFGN, revision surveys have been done due to the high seismicity after 1999 (e.g. İzmit Eq., 1999, Mw = 7.5, Düzce Eq., 1999). Consequently, maintenance of continuous GNSS networks still require historical data which are only available from survey-type measurements to detect and quantitatively resolve deforming regions and dispersing effects for reference frame definition. Combining permanent and survey-type GPS measurements is still an on-going effort. Significant progress has been made and preliminary results were obtained. In this study, I introduce real-time Turkish National Permanent GPS Network (TNPGN) and as well as address the possible application areas, integration with EUREF and other issues concerning reference frame definition within boundaries of high tectonic activity with experience from Turkish National Fundamental GPS Network (TNFGN).

2. A Natural Laboratory for Geosciences: Anatolia

Though Central Anatolia has been regarded as deformation-free region in many studies, Anatolia and surrounding regions encompass a wide variety of tectonic phenomena including transform strike-slip faulting (North and East Anatolia Faults), continental collision and major thrust faulting (Bitlis-Zagros, Caucasus), subduction (Nubia, Arabia), contraction (Caucasus, Marmara Sea), extension (Western Anatolia) and numerous relatively small scale processes (McKenzie, 1972; Jackson and McKenzie, 1984; Taymaz *et al.*, 1991; Barka and Reilinger, 1997). Tectonic framework of Anatolia is a result of interaction of Arabian and African Plates with Eurasia (McKenzie, 1982; Jackson and McKenzie, 1984; Şengör *et al.*, 1985; Taymaz *et al.*, 1991). While Eastern Anatolia is characterized by compression due to northward motion of Arabian Plate along Bitlis-Zagros suture zone (Koçyiğit *et al.*, 2001), Western Anatolia is under a north-south extension driven by subduction of Nubia in Hellenic Arc. Central Anatolia bounded by dextral North Anatolian Fault System (NAFS) in the north and sinistral East Anatolian Fault System (EAFS) in the east is a wedge-shaped structure with relatively low seismicity and less internal deformation (Jackson and McKenzie, 1984; Taymaz *et al.*, 1991; Barka & Kandinsky-Cade, 1988). While NAFS is one of seismologically most active fault zones in the world, there has been little seismicity associated with the EAFS in this century although many large earthquakes are known to have occurred within last 500 years (Taymaz *et al.*, 1991). Due to its seismically inactive state, Şengör *et al.* (1985) defined Central Anatolia as “ova” province. However, there were moderate size earthquakes such as 1717 and 1835 Ecemis, 1914 Gemerek (M = 5.6), 1938 Kırşehir (M = 6.8), 21 February 1940 Erciyes (M = 5.3), and 14 August 1996 Mecitözü–Çorum (M = 5.6). Tectonic framework of Anatolia and surrounding regions are shown in Figure 1.

3. GPS Studies in Turkey

The GPS studies in Turkey date back to early 1990’s. At the earlier stage these studies were geodynamics-oriented. They focused on seismically active areas. Especially high concentration was given to Marmara and Western Anatolia region. >80 GPS survey campaigns have been implemented up to now since 1992. Interseismic deformation is monitored by periodic GPS and leveling measurements across Turkey while specific densified networks are established for local and regional secular deformation in certain regions. Velocity solution of GPS data over the interval 1992-2007 gives the information for tectonic nature of Anatolia and its surrounding regions (Figure 2). Analyses of velocity field have been carried out to expose areas of secular deformation and seismic hazard.

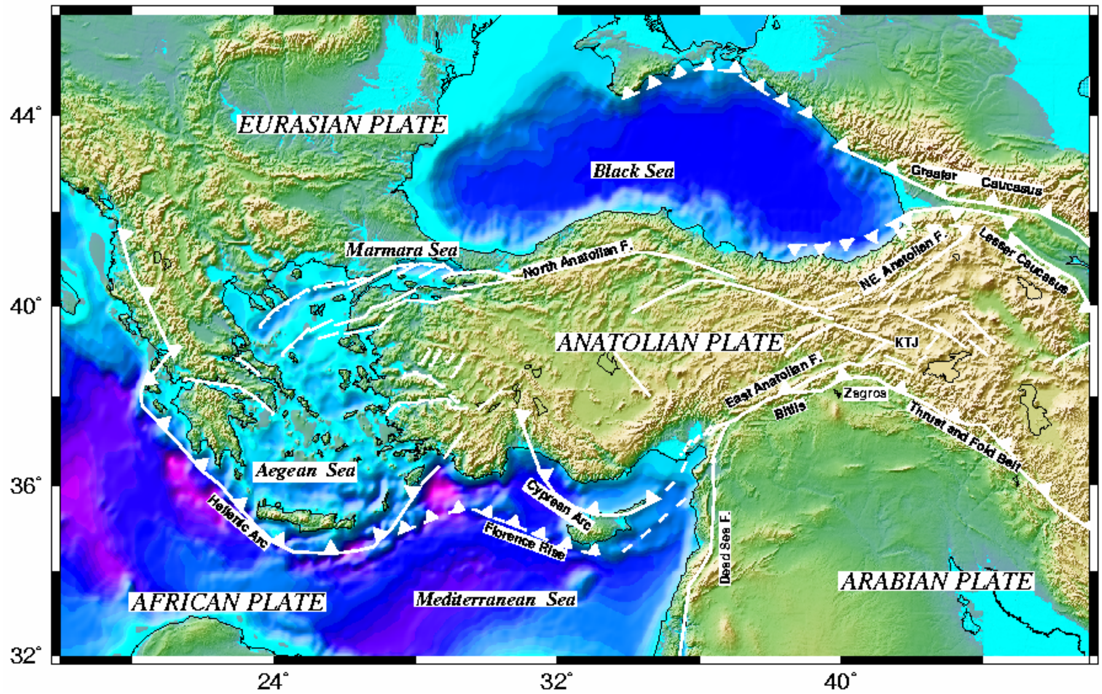

Figure 1. Tectonic framework of Anatolia and surrounding regions.

Strain analyses utilizing secular movements shed light on rigid block rotations, local compression and faulting areas that well conform to the geological and geophysical evidence of Anatolia. Due to high seismic activity, co-seismic and post-seismic deformation is also monitored by independent GPS campaigns. Earthquakes with magnitude equal and higher than M_w 6.0 cause surface displacements that should be taken into account in high-precision geodetic studies. Six such earthquakes have occurred since the establishment of Turkish National Fundamental GPS Network. Co-seismic surface displacements obtained from survey-type pre-earthquake and post-earthquake GPS observations are analyzed and modeled in an elastic isotropic medium. Depending on the time interval, computed inter-seismic deformation is dispersed from observed co-seismic deformations and published to civilian users surveying in the regions under earthquake influence. TUTGA as well as other existing stations comprises a set of precise coordinates along with their velocities and possible co-seismic corrections for the earthquake prone areas. Specifically, certain parts of Anatolia are still investigated through permanent and survey-mode GPS measurements in collaboration with international earth scientists. Shear strain rates and rigid body rotation rates are given in Figure 3 and 4, respectively.

4. Turkish National Fundamental GPS Network (TNFGN)

Turkish National Fundamental GPS Network (TUTGA) consisting of about 600 stations has been established through surveys between 1997 and 1999. General distribution of TUTGA stations is given in Figure 5. Following the establishment of TUTGA, revision surveys have been done due to the high seismicity after 1999 (İzmit Eq., 1999, M_w = 7.5, Düzce Eq., 1999, M_w = 7.2, Çerkeş Eq., 2000, M_w = 6.1, Sultandağ Eq., 2000, M_w = 5.9, Çay Eq., M_w= 6.6 and Bingöl Eq., 2003, M_w = 6.4) and due to the possibility of being destroyed. A revision plan has been put into practice which comprises reconnaissance and revision of all the TUTGA sites. For each station, 3D Coordinates and their associated velocities were computed in ITRF2000 and transformed into ITRF-96 which is the initial reference frame chosen for TUTGA. Definition of a national reference system called TUREF-96 (Turkish National Reference Frame-1996) is still in progress in coordination with the Turkish National Permanent GPS Network. Site distributions of TUTGA are given in Figure 5.

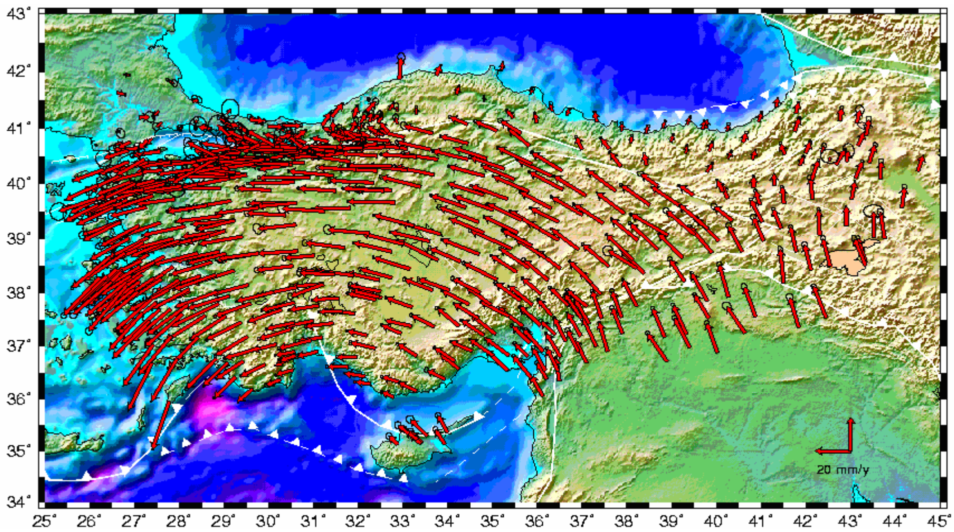

Figure 2. Horizontal velocity field of Turkey and surrounding regions in a Eurasia-fixed frame.

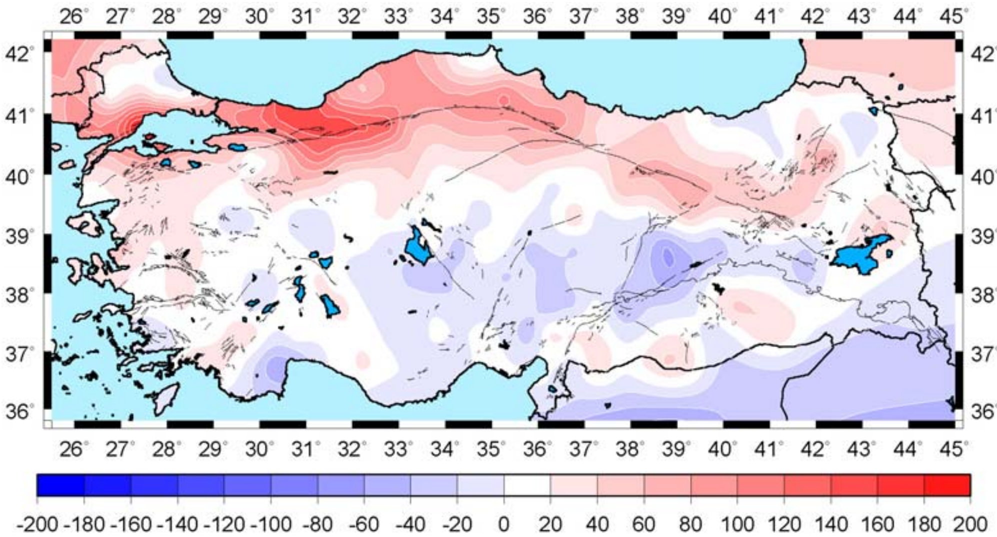

Figure 3. Shear strains in nanostrain per year

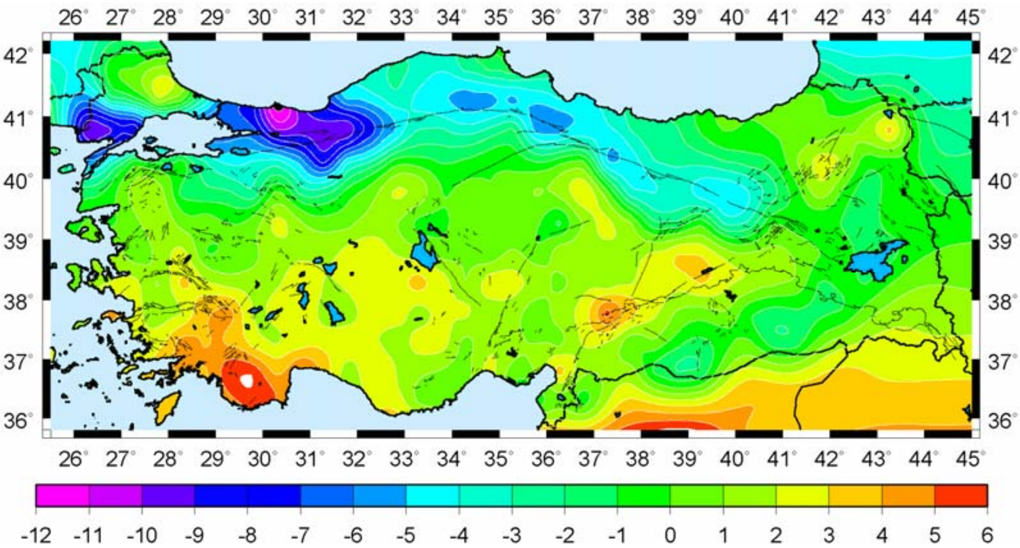

Figure 4. Rigid-body rotations in ^{0}/Myr

Positional accuracies of the stations are about 1-3 cm whereas the relative accuracies are within the range of 0.1 - 0.01 ppm. Besides, the network has been connected to the Turkish Horizontal and Vertical Control Networks through overlapping stations and time-dependent coordinates of all stations are being computed in the context of the maintenance of the network with repeated GPS observations. Also appropriate models for coordinate transformation from ED-50 system into the WGS84 have been defined in the context of TUTGA. Detailed information about TUTGA can be found at official web of General Command of Mapping. Combining permanent and survey-type GPS measurements is still an on-going effort. Significant progress has been made and preliminary results were obtained.

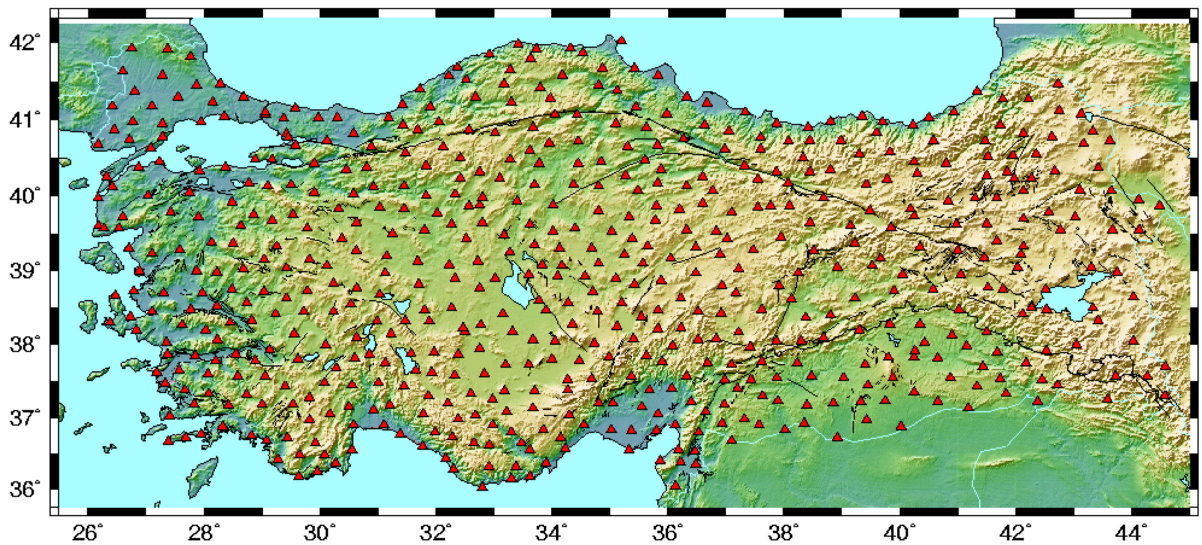

Figure 5. Distribution of TNFGN stations.

5. Turkish National Permanent GPS Network (TNPGN)

The Turkish Permanent GPS Network (TNPGN) is still growing up with the addition of new stations (Figure-6). The number of the sites forming TUSAGA is 25 as of 2007. Other than that of those stations, the data from 10 stations around Marmara Sea, established under a private project with TUBITAK Marmara Research Center (TUBITAK – MAM) is being utilized by scientific community. The time-series analyses of TNPGN stations are performed at General Command of Mapping on a daily basis.

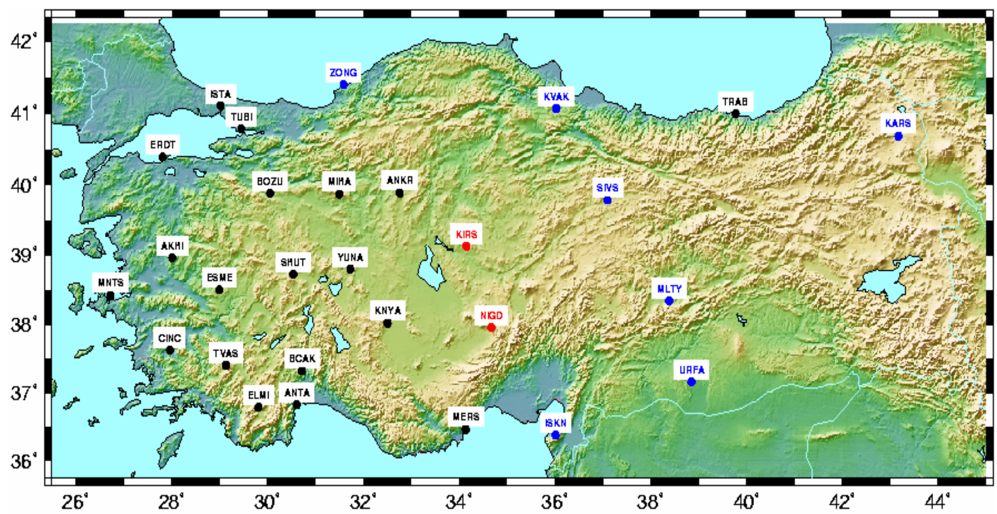

Figure 6. Distribution of TUSAGA and TUSAGA-Active stations (as of Jun 2008). Red Circles TPGN sites-27; BlueTriangles: TPGN-ACTIVE stations(145).

Collaborate works in and abroad Turkey for geodetic, geodynamic and engineering surveying purposes are increasingly contributing to the development of the static network. Furthermore, TNPGN stations are going to be utilized as geodetic control and for monitoring the crustal movements in geodynamical activities within their continuous data collection and analyses cycle. Most of the TNPGN stations have been functional for more than 5 years. 4 of them (Ankara (ANKR), İstanbul (ISTA), Trabzon (TRAB), Gebze (TUBI)) are included in IGS and EPN (Figure 7). TNPGN is still geodynamics-oriented and not supplying real-time data.

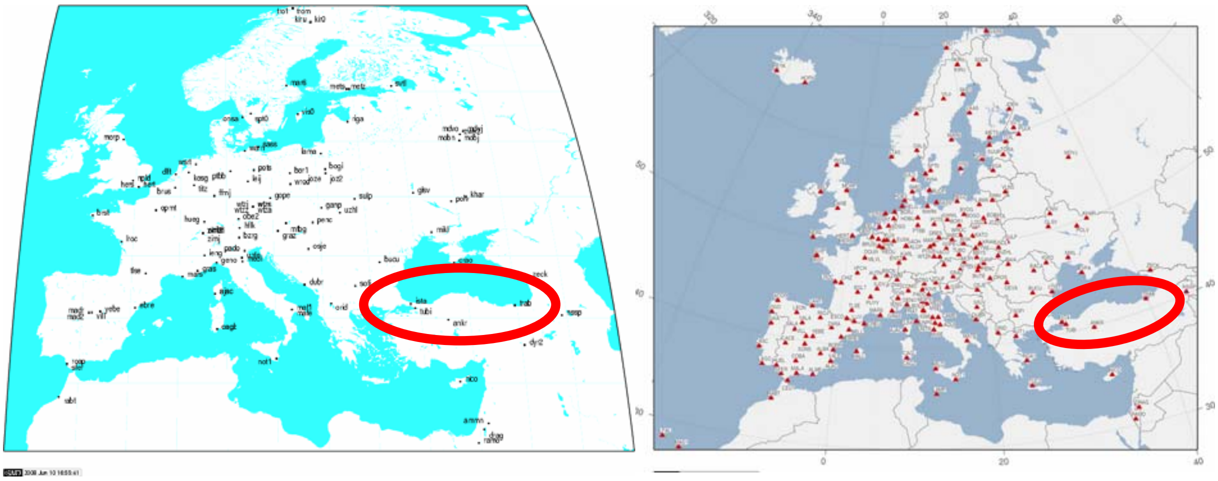

Figure 7. IGS/EPN stations in Turkey

6. Turkish National Permanent GPS RTK Network

Although TNPGN was preliminarily conceived as a static continuous network, intensive cadastral activities have led to establishing a RTK network which is supposed to cover the whole country. A RTK Network of 145 sites is financed by Turkish National Scientific and Technological Council) and İstanbul Culture University has taken over the responsibility of making the network fully operational by the end of 2008 under the supervision of General Command of Mapping and General Directorate of Registration and Cadastre. The distribution and of current and future stations is given in Figure 8.

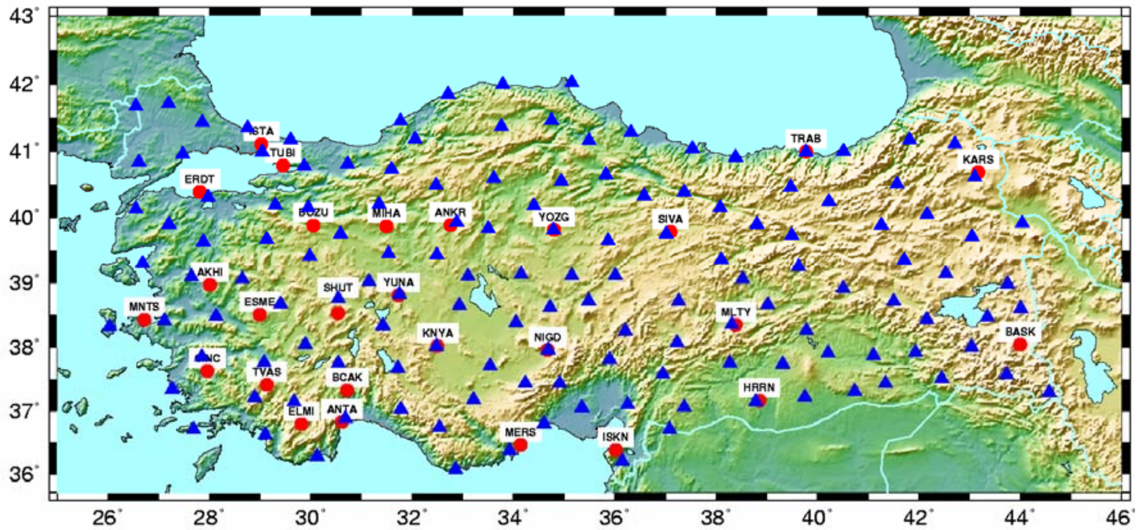

Figure 8. Distribution of TNPGN and TNPGN-Active stations (as of Jun 2008). Red Circles TPGN sites-27; Blue Triangles: TPGN-ACTIVE stations(145).

While the RTK Network is planned to serve the mapping community, daily GPS data will also provide an indispensable tool for earth science community investigating the tectonic and seismic activity of a very active region like Anatolia and surroundings. The feasibility of TUSAGA for DGPS operations and a homogeneously distributed high-precision GPS network enable civilian end users to work at ease in variety of applications ranging from large-scale mapping, GIS and cadastral applications. Particularly for the applications ranging from large-scale mapping, GIS and cadastral surveys, new project under the name TUSAGA-Active has been initiated collaboratively with governmental institution and funded by TÜBİTAK. The stations will serve as real-time kinematics basis enabling all users to get differentially corrected positional information as well as updated geoid and datum transformation parameters. There will be many applications which exploit Turkish National Permanent GPS RTK Network. Some of related with them are; surveying/cadastre, geodynamics/earthquake hazard assessment, meteorology, communications, long-term earthquake prediction etc. In addition there are on-going studies about short-term earthquake prediction by utilizing TNPGN-Active.

7. GPS Meteorology

The Global Positioning System (GPS) consists of a constellation of satellites that transmit radio signals to large numbers of users engaged in navigation, time transfer, and relative positioning. The radio signals of GPS are delayed, in part, by atmospheric water vapor as they travel from GPS satellites to ground-based GPS receivers, and then techniques have been devised to estimate time-varying "wet delay" by geodesists. GPS-derived precipitable water (PW) has many applications, including satellite and reanalysis data, validation of radiosonde, monitoring climate change and numeric weather prediction (Wang et all 2005). A ground-based GPS receiver has some advantages as an atmospheric sensor. It is increasingly economical and it provides continuous measurements (better than costly and intermittent radiosonde launches). Unlike observations with other instrument types, such as the water vapor radiometer (Rocken et al. 1995), the GPS measurement is largely weatherproof; that is, it is unaffected by rain or thick clouds. Furthermore, the GPS technique can potentially provide a dataset that is consistent both temporally and spatially, making it ideal for detecting climate changes. More than half of the GPS stations of TNPGN-Active installed in meteorological parks of General Directorate of State Meteorology. For a preliminary test at selected stations, radiosonde measurements supplied by Turkish State Meteorological Service and GPS measurements maintained by Turkish National Permanent GPS Network operated by General Command of Mapping were employed. In the first stage, to test the efficiency of empirical transformation equations, weighted-average mean temperatures from radiosonde profiles for one-year data were computed. Best-fitting regression coefficients are obtained as 0.7149 and 70.5539 for ANKR CGPS station and 0.8790 and 24.2860 for ISTA CGPS station and given in Figure 9 (Özdemir et al. 2007).

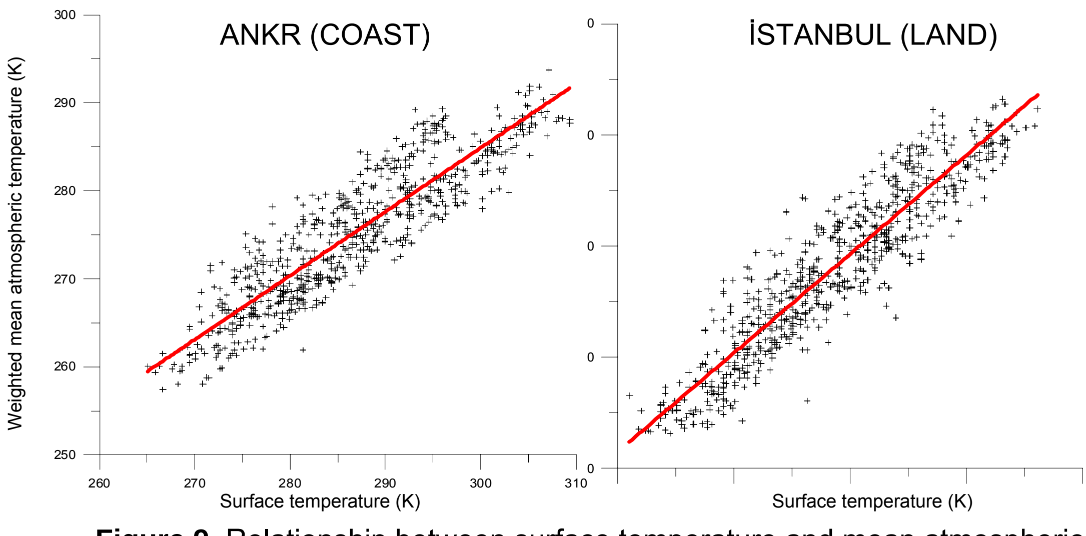

Figure 9. Relationship between surface temperature and mean atmospheric

Time series analysis of GPS and radiosonde derived PWs for ANKR station have been implemented (Figure 10). There is a good agreement at PW values between radiosonde and GPS (Figure 11). Similar results were presented for TNPGN for longer time series by Ayhan et al. (2007).

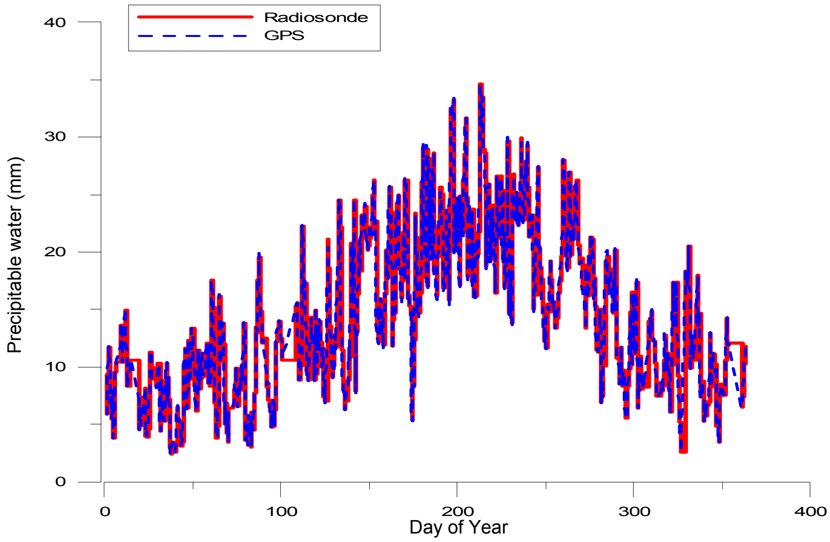

Figure 10. Time series comparison of GPS and Radiosonde derived PWs for ANKR station

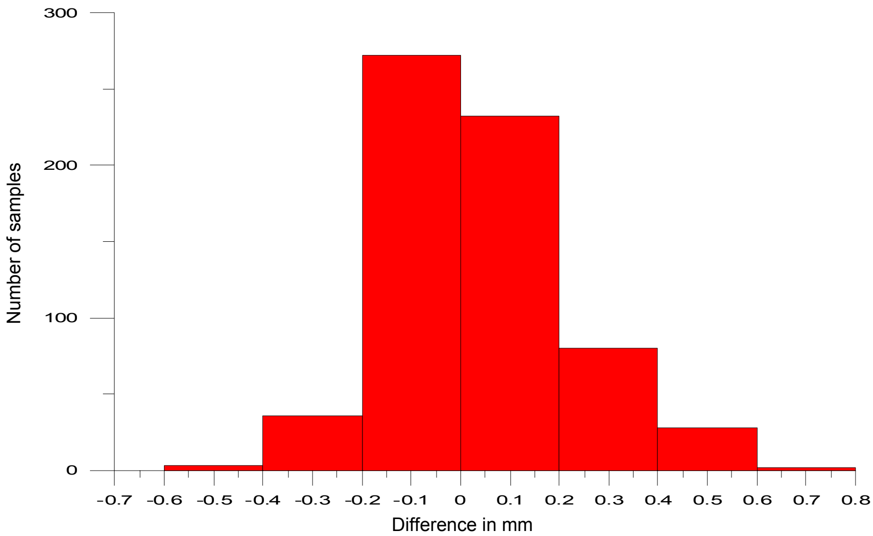

Figure 11. Histogram of differences between GPS and Radiosonde derived PWs at ANKR station

8. Real-time Ionospheric Tomography

IONOLAB is a group of electrical engineers and scientists of various study areas, getting together to handle challenges of the earth's ionosphere. This project has been initiated between GCM and Hacettepe University and is being supported by Turkish Scientific and Technological Research Council (TUBITAK). With this project, real-time 3D mapping of ionosphere is being implemented (Aysezen et al., 2007). Ionosphere is the layer of the atmosphere that has high electron concentration. Ionosphere has an important affect on both HF and satellite communication systems. Due to long term and short term variations caused by the sun, ionosphere causes errors on communication systems.

Total Electron Content (TEC) which is a measure of the total number of electrons along a path of the radio wave can be used to further investigate the ionospheric variability. TEC is defined as the number of free electrons along the ray path above one square meter on the ionosphere and its unit is represented as TECU (1 TECU = 1016 el/m2). TEC measurements can be derived from the delay of the traveling time of the signals transmitted from the Global Positioning System (GPS) satellites and recorded at the earth-based receivers. Due to a lack of a complete forward ionospheric model, and sparse and/or irregular distribution of GPS receivers, TEC cannot be directly estimated everywhere on the ionosphere.

Due to the high variability of the ionosphere in space and time, the electron density distribution and TEC can be regarded as spatiotemporal random functions similar to their counterparts in geostatistics, hydrology, meteorology and environmental sciences. The Global Positioning System (GPS), due to its availability for civilian use in the last 10 years, provides a cost-effective means for estimating TEC. Since GPS-TEC can be estimated only for a limited and mostly sparsely distributed number of receiving stations, a suitable interpolation both in space and time representing the nature of ionosphere is necessary. IONOLAB-TEC is a regularized estimation algorithm which combines signals from all GPS satellites for a given instant and a given receiver for a desired time period or for 24 hours with 30 s time resolution. In Figure 12, one can see the VTEC values both acquired by IONOLAB and Jet Propulsion Laboratory (JPL) for ANKR station.

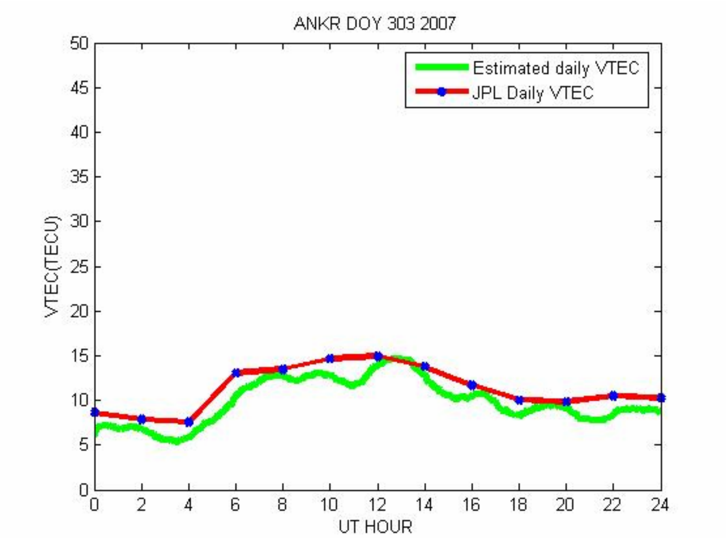

Figure 12. VTEC values acquired from IONOLAB and JPL for ANKR station.

9. Conclusion

As a consequence of the issues described above, new Turkish National GPS RTK Network (TNGRN) will provide; a spatial resolution of ~75 km with 145 stations, real-time cm-level positioning for survey community, invaluable data for weather forecasting, real-time TEC data for ionospheric mapping, a network for studying earthquake hazard assesement in a very active geography, insights about the unresolved issues within the boundary zones of Eurasian, African, and Arabian plates. TNPGN will function as a fundamental tool for geodynamics, tropospheric and ionospheric research as well as surveying and cadastral works. While permanent GNSS networks offer the utmost precision obtainable from GNNS studies, they still lack the sufficient spatial resolution required in high-deformation regions. Turkey is located within the boundary of Eurasia, Arabia and African plates and TNPGN forms the southeastern boundary of European Continues Network. TNPGN has the importance of detecting the rigid and deforming boundaries of any ETRS-89 realizations including sites in the southeastern Europe. In this respect, TNPGN will provide an indispensable geodetic control for monitoring the crustal movements as well as addressing the issues of southeastern boundary in reference frame definition of ETRS-89.

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