HEIGHT SYSTEM MODERNIZATION AND GEOID MODELLING STUDIES IN TURKEY

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ABSTRACT

The establishment of vertical reference system in Turkey, that is, Turkish National Vertical Control Network (TNVCN) started with the adjustment of the observations at Antalya tide-gauge station between 1936 and1971. In March 2012, Turkey National Geodesy commission held an official meeting at Zonguldak Bülent Ecevit University. In the final declaration of the meeting, the problems with the levelling-based vertical control approach which is currently used in the country and the realization of the vertical datum in Turkey were discussed. The definition of geoid model which is more resistant to geodynamic activity, local crustal uplift or subsidence as well as the deterioration of the benchmarks are specified as the main topics of the realization of the new vertical datum. The problems in levelling-based vertical control approach have led the country to find an alternative approach to vertical control. In this aspect, geoid based vertical datum approach is under consideration as an alternative way. Thus, the Realization of Turkish National Control Network Project has been initiated by the General Command of Mapping. The aim of the project is to obtain a 1-2 cm-accuracy geoid model that will be the new vertical datum of Turkey by using terrestrial and airborne gravity data which were obtained during the realization Project. The maximum accuracy of the regional geoid models achieved in Turkey is 8.7 cm. According to the Large-Scale Map and Map Information Production Regulation of Turkey, though, the accuracy should be at least 5 cm, which means that the result of the accuracy of the latest geoid model in Turkey is not satisfactory. Until reaching the aimed accuracy (1-2 cm accuracy regional geoid model), the local GPS/levelling surface models will be used as a geodetic infrastructure in Turkey. There is an increasing trend of geoid models in the world, and many countries determine them as their vertical datum. An example of this is the GRAV-D (Re-definition of the American Vertical Datum) project of the United States. From this aspect, having a local geoid model which can meet the accuracy demands in Turkey is very important. This study aims to specify the historical perspective of Turkish vertical control approaches, their current situation and current developments.

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1.INTRODUCTION

A geodetic datum is defined as a coordinate system with a reference surface that serves to provide known locations to begin surveys and create maps. **(NOAA, 2017).** There are two types of geodetic datum: horizontal datum and vertical datum. Traditionally, these two datums are established separately. This study will focus on the vertical datum. Vertical datum is a surface of zero elevation to which heights of various points are referred in order that those heights be in a consistent system. More broadly, a vertical datum is the entire system of the zero-elevation surface and methods of determining heights relative to that surface **(NOAA, 2017).** Over the years, many different types of vertical datums have been used. "The geoid, quasi-geoid, reference ellipsoid of revolution (normal Earth ellipsoid) are used as a reference surface (datum) for heights in geodesy. In addition, the mean sea surface, which is assumed to coincide to the geoid/quasi-geoid at one point, is also used as a reference surface for heights.'' **(Erol, 2007)** The zero-height surface defined by Mean Sea Level (MSL), also called vertical datum, is derived from tide-gauge (sea-level measurement) records. "MSL is usually described as a tidal datum that is the arithmetic mean of hourly water elevations observed over a specific 19-year cycle. This definition averages out tidal highs and lows caused by the changing effects of the gravitational forces from the moon and sun.'' **(Fraczek, 2003**) On the other hand, the 3D datum concept shows up with technological developments. Geoid-based height system that will be explained in the paper can be given as an example on the basis of 3D datums.

2.DEFINING VERTICAL DATUM ACROSS A COUNTRY

Most countries use sea level (geoid) as the basic reference surface which is used to measure elevation changes. Because sea level varies along the coasts, the idea of using multiple tide-gauges to define the vertical datum was abandoned, instead of using just one tide-gauge in most countries. Today, countries are no longer limited to separate horizontal and vertical datums thanks to Global Positioning System (GPS) and some other space-based techniques. GPS and other space-based techniques provide access to geometric datums which combine latitude, longitude, height and time information. The height information derived from GPS uses ellipsoidal model of the Earth instead of the sea level. New technologies like GPS helped to improve the accuracy of the current datums.

2.1 Turkey National Sea Level Monitoring System (TUDES)

Turkey National Sea Level Monitoring System (TUDES) records sea level and parameters which affect the sea level such as relative humidity, pressure, and wind (velocity and direction) in every 15 minutes numerically and automatically. TUDES consists of a data center that is located in General Command of Mapping in Ankara and 20 tide-gauge stations located in İstanbul, Şile, Amasra, İğneada, Marmara Ereğlisi, Erdek, Yalova, Gökçeada, Trabzon, Menteş, Bodrum, Marmaris, Antalya, Taşucu, Bozyazı, Erdemli, Girne and Gazimağusa. (See figure 1)

Figure 1: Tide-gauge stations of Turkey National Sea Level Monitoring System **(General Command of Mapping,2015)**

General Command of Mapping observes sea level changes in the coastal zones of Turkey with TUDES stations in long periods of time in order to establish Turkey National Vertical Control Network. On the other hand, Turkish local geoid models use the data of TUDES stations. These stations can observe relative sea level changes based on their location. They can also reveal the elevation changes related to each other by using the related TNVCN (Turkish National Vertical Control Network) point. In this way, for a country surrounded by seas like Turkey, determining sea level changes among the seas (Mediterranean Sea, Aegean Sea, Sea of Marmara, Black Sea) will be possible. A GNSS integrated radar sea-level meter has been set up in İskenderun as part of the tide-gauge modernization project. General Command of Mapping has planned to set up the meter in every station across Turkey **(General Command of Mapping, 2015).**

2.2 Turkey National Vertical Control Network (TNVCN 99)

The vertical datum for the TNVCN-99 is the arithmetic mean of instantaneous sea level measurements of Antalya tide-gauge station between the years 1936 and 1971. The geopotential numbers were used in adjustment. Helmert orthometric heights and Molodensky normal heights were calculated. The precision of point heights varies from 0.3 cm to 9 cm after the adjustment. This result depends on the distance from the datum point. The differences between TNVCN-99 Helmert orthometric heights and currently used Normal orthometric heights were defined between –14 cm and +36.9 cm, and the mean value was found as +9.5 cm with standard deviation of 8.4 cm (National Geodesy Committee still discusses about whether change to height type which is currently used or not). 14 of the first- and second-order leveling lines of 1300 km were re-measured to determine the displacements after the earthquakes in Izmit on August 17, 1999 and the one in Düzce on November 12, 1999[Occurred in the Northwest side of Turkey]. The displacements were performed in Bursa, İstanbul, İzmit, Adapazarı, Zonguldak, and Bolu between May and September in 2002. The differences in Helmert orthometric heights before and after earthquakes vary between -52.7 and +28.8 cm **(Demir and Cingöz, 2002).** Turkey National Control Network is currently in use but it is not sufficient to carry out all the engineering studies in the country. National Geodesy Committee still discusses about whether change to height type which is currently used or not.

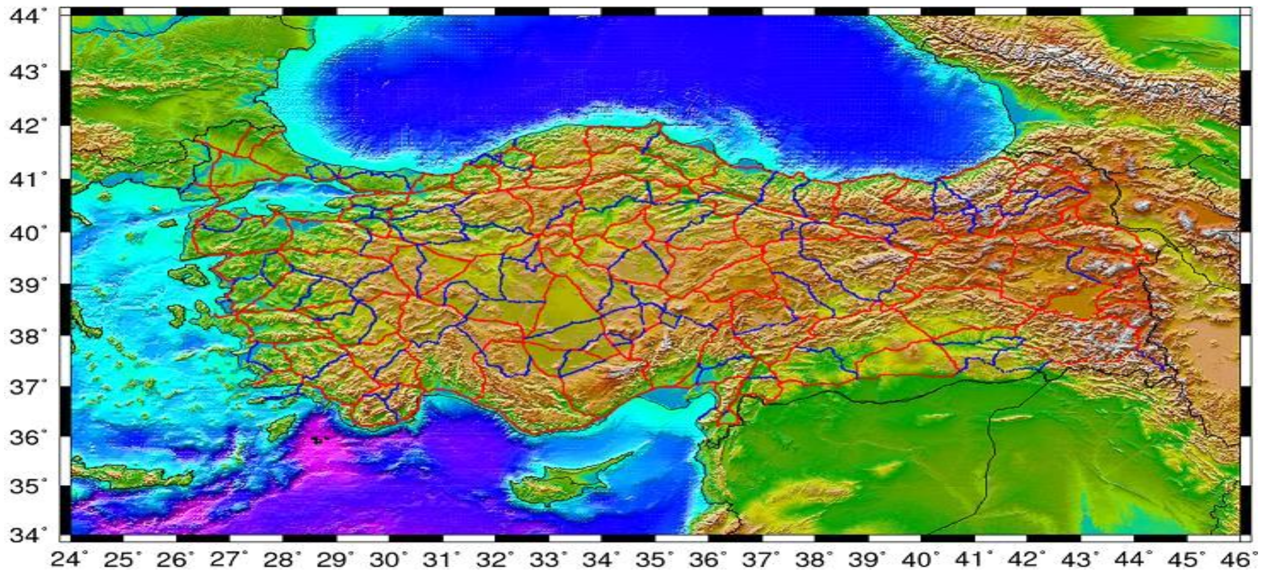

Figure 2: TNVCN 99 Network **(General Command of Mapping, 2016)**

3.TURKISH HEIGHT SYSTEM MODERNIZATION PROJECT

The determination of the vertical reference system of a country through classical geodetic networks comes with a lot of restrictions since the geodetic networks consist of benchmarks established on the ground at certain intervals which are easily affected by geodynamic activities and local crustal uplift or subsidence. Because the benchmarks are physically located on the Earth's surface, the horizontal and vertical coordinates of the benchmarks change in time. Also, the urbanization and human effect are other reasons to benchmarks to be destructed. One of the main restrictions of determining vertical datum by benchmarks (geodetic networks) is inconsistency problem in reference system. The benchmarks are established on hard, low pitched surfaces such as highways. Thus, the vertical datum information is not available on the seas, lakes and other parts of the country. The leveling measurements are needed to get information about the vertical datum in other parts of the country which do not have height benchmarks. The leveling measurements have high costs (especially in long distances, >10 km) and those measurements are hard to obtain. In addition, observations depend on weather conditions, which means that they can only be carried out on the daylight and in proper seasons. The leveling observations have some systematic errors correlated with the base length. Geodetic vertical control networks which are realized by height benchmarks cannot serve the real time positioning applications. Determining the height of the benchmarks can take days or even weeks especially in long distances. The General Command of Mapping of Turkey still discusses whether the height benchmarks will be used in the future or not.Determining the vertical reference system by using geoid modeling approach is better than the geodetic control network approach. Thus, a modernization project is needed to determine a geoid model with sufficient accuracy. Consistent vertical datum information will be available in surrounding seas of the country by using geoid modeling approach. Since geoid is a model, it is not established physically on the surface of the Earth. For this reason, the geoid model will never be exposed to the destruction effects that height benchmarks cause. Geoid models are more resistant to geodynamic activity, local crustal uplift or subsidence because they are not physically established on surface of the Earth. A 1 cm-change in geoid height can only be possible with very big mass motions. By combining GNSS, RADAR and LIDAR with the geoid models, physical height information can be achieved in every weather condition, everywhere and every time in a short period of time. The main restrictions of geoid models are identified as data distribution and data accuracy. Theoretically, more than 1 mGal gravity accuracy is needed to compute a cm accuracy geoid height on a point**. (Simav,2015)**

With the establishment of leveling department in General Command of Mapping, the studies related with the Turkish Height System started in June 1, 1935. In the same year, the first spirit leveling measurements were carried out between Antalya and Dinar after the establishment of Antalya tide-gauge station. The first period spirit leveling measurements among the benchmarks on the main roads were completed until 1970. In order to renew the destructed lines due to the infrastructure works, the second period leveling measurements were conducted between 1972 and 1991.Then, Turkish National Vertical Control Network (TNVCN 92) was established by the adjustment of the geopotential numbers. The arithmetic mean of the Antalya tide-gauge sea level observations of 1936-1971 was specified as the reference surface for TNVCN 92. TNVCN 99 on the same reference surface was established after the remeasurements of the leveling lines that were accepted as outliers in TNVCN 92 adjustment. The levelling lines were located along the main roads and these marks were destructed due to various roadworks. Furthermore, crustal movements change their vertical coordinates steadily. It is considered that 80% of the benchmarks of the first-order national leveling network are destroyed especially on the grounds of the double road projects started after 2003 in Turkey. National height system modernization including an up-to-date, reliable, time dependent height system meeting the requirements of the 21st century is needed to overcome these problems. As said before, a modernization Project has been started to overcome these obstacles and have a precise and stable height system in the country. **(Türkezer et al., 2011)**

3.1 The Reasons for Implementing Turkish Vertical Reference System Modernization Project

-The number of Turkish Vertical Control Network benchmarks are decreasing because of the destruction.

-The vertical and horizontal coordinates of the TNVCN (Turkish National Vertical Control Network) benchmarks change due to ground dynamics.

-The accuracy and resolution of the gravity and GNSS/Leveling data are not enough to compute a Turkey Geoid Model with a sufficient accuracy.

-The computed Turkey Geoid Models could not reach the sufficient accuracy so far; thus, they cannot be used in determination of the physical heights.

-The current Turkey Vertical Reference System cannot be used in real-time applications such as CORS.

-To leave the classical geodetic network approach which has a lot of obstacles technically, and begin to use the geoid modeling approach which provides users a number of advantages in space-based techniques**. (Simav et al, 2015)**

3.2 The Project Calendar

The Turkish Vertical Reference System Modernization Project started in April 2015 and aimed to be completed in April 2020. The first 3-4 months of 2016, 2017, 2018 and 2019 are specified for the planning process and the preparations of the field work. The conversion, delivery and analysis of the data and meetings are planned to be in November and December from 2016 to 2020.The results and reports will be published between January and April 2020 and the new Turkish Vertical Reference System will be announced to the users officially. **(Simav et al., 2015)**

In total, 10 packages of work plan consisting of field and office works are planned to carry out the project.

First package includes the supply of gravimeters and portable meteorological sensors which will be used in field works.

Second package includes the standardization of relative gravity measurements, evaluation, test and calibration works.

Third and fourth packages include field and office works, respectively, consisting of relative absolute gravimetry reconnaissance, point establishment, point measurements and analysis.

Fifth package includes reconnaissance, establishment, measurements and analysis of GNSS/Leveling points which will be used in testing the completed product.

Sixth package includes quality control of the available gravity data.

Seventh package includes making the national gravity database to store gravity values.

Eighth package includes geoid modeling.

Ninth package includes making the correlation with TUSAGA-Aktif (CORS-TR).

Tenth package includes reporting and announcing the new Turkish Vertical Reference System to the users. **(Simav et al., 2015)**

The first package is planned to be carried out in the first 10 months from the beginning, and the second package is planned to be completed by the end of next year. The first 3-4 months of 2016, 2017, 2018 and 2019 are conveyed to the third, fourth and fifth packages. The sixth and seventh packages are expected to be completed in 2017 and 2018. It is planned that the preparations for the eighth package will begin in the first months of 2018, and the package is to be completed in January 2020. By the end of 2019, the preparations for the ninth package will also begin. **(Simav et al., 2015)**

4.TURKEY GEOID

Regional geoid modeling studies in Turkey go back to 1976 by the computation of Astrogeodetic Geoid. A chronological order of geoid modeling studies in the country can be seen below:

- Astrogeodetic Geoid **(Ayan 1978)**

- South-West Anadolu Doppler Geoid **(Ayhan et al.,1987)**

- Turkey Gravimetric Geoid – 1991 (TG-91) **(Ayhan, 1992)**

- Turkey Doppler Geoid – 1993 **(Ayhan and Kılıçoğlu, 1993)**

- Turkey Geoid – 1999A (TG-99A) **(Ayhan et al., 2002; Kılıçoğlu, 2002)**

- Turkey Geoid – 2003 (TG 03) **(Kılıçoğlu et al., 2004)**

- Turkey Geoid – 2007 (TG-07) **(Yıldız et al., 2006)**

- Turkey Hybrid Geoid (THG 09) **(Kılıçoğlu et al., 2011)**

- Turkey Geoid – 2013 (TG-13) **(Yıldız et al., 2013)**

The first gravimetric geoid in Turkey is Turkey Geoid 1991 (TG-91). Its accuracy is 1.5-2.1 ppm over 45 km distance. Gravity measurements in 62.250-point, 450 m *450 m Digital Terrain Model, Earth geopotential model (tailored GPM2) and 32 GPS/levelling point were used for computation. It is computed by using Least Squares Collocation method. The following model is Updated Turkey Geoid (TG-99A). TG99-A is computed by using existing gravimetric geoid TG-91 and 197 GPS/Levelling points. The mean and standard deviation of the residuals between computed and observed geoid heights at 197 reference GPS/levelling benchmarks used in the computation of TG99A are 1.4 cm and 9.1 cm, respectively. Then, the TG99A model was validated at 122 independent GPS/levelling test points and the statistics of the residuals revealed the mean and standard deviation of the differences of –0.1 cm and 14.5 cm, respectively. Thus, the reported internal and external accuracy measures of TG99A are 10 cm and 15 cm, respectively. **(Ayhan et al., 2002)**. After TG99A-computed works on determination, the study started a more accurate local geoid model. For this reason, the TG 03 model was computed. TG03 has been available since 2003 as an updated version of TG99A that was provided by the General Command of Mapping. According to the information in an official report by TNGC (2003), heterogeneous data (gravity, topography and geoid heights) were used by Least Squares Collocation (LSC) in a Remove Restore procedure. EGM96 was employed as the reference model of the Earth's geopotential. The data used consisted of the surface gravity anomalies, gravity anomalies derived from ERS1, ERS2 and TOPEX/POSEIDON altimetry data, GPS/levelling geoid heights, and topographic heights. Surface gravity data are in modified Potsdam Datum, and the free air anomalies were computed in GRS80 **(TNGC, 2003; Kılıçoğlu et al., 2004**.) None of the TG03, the TG07, TG09 and TG13 geoid models could achieve an accuracy better than 8.6 cm in terms of standard deviations of geoid height residuals at the test points. Standards for determination and use of local GPS/levelling surfaces as parametric models for transformation of the GPS ellipsoidal heights into the regional vertical datum are determined by the Large-scale Maps and Spatial Data Production Regulation **(LSMSDPR 2005).** The Istanbul GPS/leveling local geoid (height transformation model) was determined in 2005 and it provides an order polynomial model and 4.1 cm external accuracy in height transformation **(Erol, Erol and Işık, 2017).** The 4.1 cm accuracy can be associated with the data quality and the data distribution. As indicated by the results of the latest geoid models in Turkey, the accuracy cannot meet the demand. The gravity data and the methods used in the computation are effective in the accuracy of the geoid model. Today, new technologies in absolute and airborne gravimetry and the launch of satellite gravity missions have enhanced geoid modelling capabilities, which enables an alternative definition of the height reference surface referring to a precise geoid model. More importantly, the current and upcoming international satellite gravity missions, combined with theoretical progress in geoid modelling, contribute significantly to improvement of the accuracy of the regional geoid models for their adoption as a new datum **(Erol, Erol and Işık, 2017).** So, the height System Modernization Project is still in progress based on all of this information**.** The purpose is to have accurate terrestrial gravity data and have a 1-2 cm-accuracy geoid model after the modernization project.

CONCLUSION

This study has summarized the historical perspective of Turkish vertical control approaches, their current situation and developments. The problems in levelling-based vertical control approach have led Turkish researchers to find an alternative approach to vertical control. From this point of view, geoid-based vertical datum approach is under consideration as an alternative way. The maximum accuracy of the regional geoid models achieved in Turkey is 8.8 cm, but the accuracy should be at least 5 cm according to the Large-scale Map and Map Production Regulation. Datum inconsistencies and quality of the terrestrial gravity data are effective on the rough accuracy of the computed geoid models. A modernization project is still in progress to achieve a 1-2 cm accuracy regional geoid model and to re-define the vertical datum of Turkey based on this model. The Modernization Project also aims to recover the gravity infrastructure of the country. The method used in the computation of the geoid model and the quality of the satellite-based data are efficient in obtaining the required accuracy. Until reaching the aimed accuracy (1-2 cm accuracy regional geoid model), the local GPS/levelling surface models will be used as geodetic infrastructure in Turkey.

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