Determination of Astro-Geodetic Vertical Deflections using Digital Zenith Camera System in Istanbul, Turkey

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Key words: Digital Zenith cameras, Astro-Geodetic Geoid, Vertical Deflections

SUMMARY

In this study we introduce the first observations of a Digital Zenith Camera System (DZCS) used in Istanbul, Turkey. In the scope of this study we discuss the astro-geodetic observations performed on a test station using a CCD camera, Schmidt-Cassegrain type telescope with 14 inches aperture, two inclinometers, and a dual frequency geodetic GPS receiver which is used for time measurements and ellipsoidal coordinates of the station with a computer control unit for data capturing and system control. The observations performed with the equipment stated above are based in Bogazici University (BOUN) Kandilli Observatory and Earthquake Research Institute (KOERI), and Istanbul Technical University. The results of the first test observations show the limits of the system designed and they help us to plan future studies. We performed the test observations using a larger aperture telescope and astronomic CCD camera in TÜBİTAK National Observatory (TUG) in order to compare the performance of different type of instruments for astro-geodetic observations. This article presents the preliminary research we conducted in 2011, which guides us to develop a new DZCS for our current astro-geodetic studies that is supported by The Scientific and Technological Research Council of Turkey.

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1. INTRODUCTION

There are several recent investigations on gravity field of the earth and its change as a function of time in Geodesy and Geophysics. Earth sciences and space researches are also interested in gravity studies. Geoid, which approximately has an equal potential to the potential of mean sea level, is the main datum for height systems and is used in coordinate transformation, reduction of measurements, density investigations and similar scientific studies. Current studies focus on the determination of a cm-geoid, which has also has a significant role to make a more beneficial use of GNNS systems. Astro-geodetic technique is one of the oldest fundamental technique used for geoid determination. Restrictions in direction measurements with analog instruments, and time measurements decreased the usage of this method. The determination of vertical deflections using traditional optical-mechanical direction measuring systems and time recording devices has an accuracy of ±1".

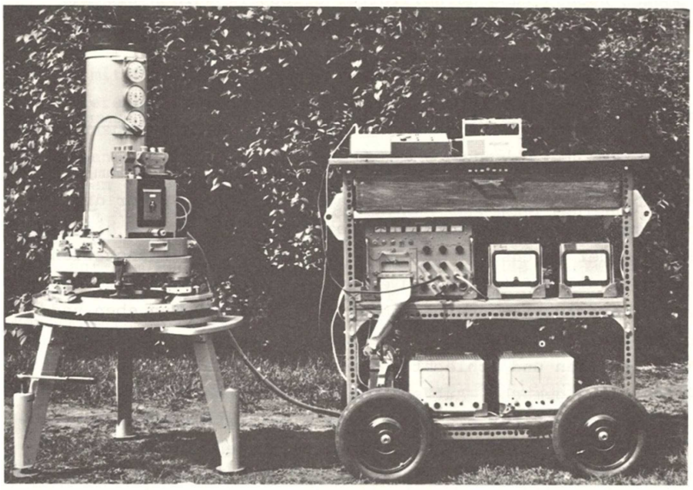

Figure 1. Transportable Zenith Cameras of IfE Hannover, TZK1 (Gessler, 1975)

Beginning from 1970s the first transportable photographic zenith camera was designed and used in Hannover, Germany (Gessler, 1975). Its aim was to determine astro-geodetic vertical deflections especially in mountainous areas. First zenith cameras are equipped with analog sensors on photographic plates and use classical time determination techniques such as chronographs. The analog system was very successful yet it was very hard to handle the data captured and processed. However, photographic zenith camera was used for many astro-geodetic studies between 1974 and 1984 in Europe. After the invention of charged coupled devices (CCDs) revolutionary developments appeared in the study area of Astronomy, and particularly in Astrometry. Therewith, analog zenith camera systems were also redesigned and equipped with CCD cameras, GPS devices, and precise tiltmeters. Institute of Geodesy at Hannover, and ETH Zurich announce high precision digital zenith camera systems beginning from the 2000s. These DZCSs have announced vertical deflection data at about 900 new stations in Europe since 2003 in order to determine local and regional geoids at mm and cm level (Hirt et al., 2010). The success of these pioneer studies and the necessity of determining high precise astro-geodetic data motivated other studies at Poland (Kudrys, 2009), and Serbia (Ogrizovic, 2009) as well as our study in Istanbul.

2. GEOID DETERMINATION STUDIES IN TURKEY

The geoid determination studies started in the late 1970s in Turkey (Ayan, 1976; Ayhan, 1993; TNUGG, 2003; TNUGG, 2011, Erol and Erol, 2012) and modernization of national geodetic infrastructure, including the vertical datum definition, became a necessity after the increasing use of GNSS techniques in the 1990s.

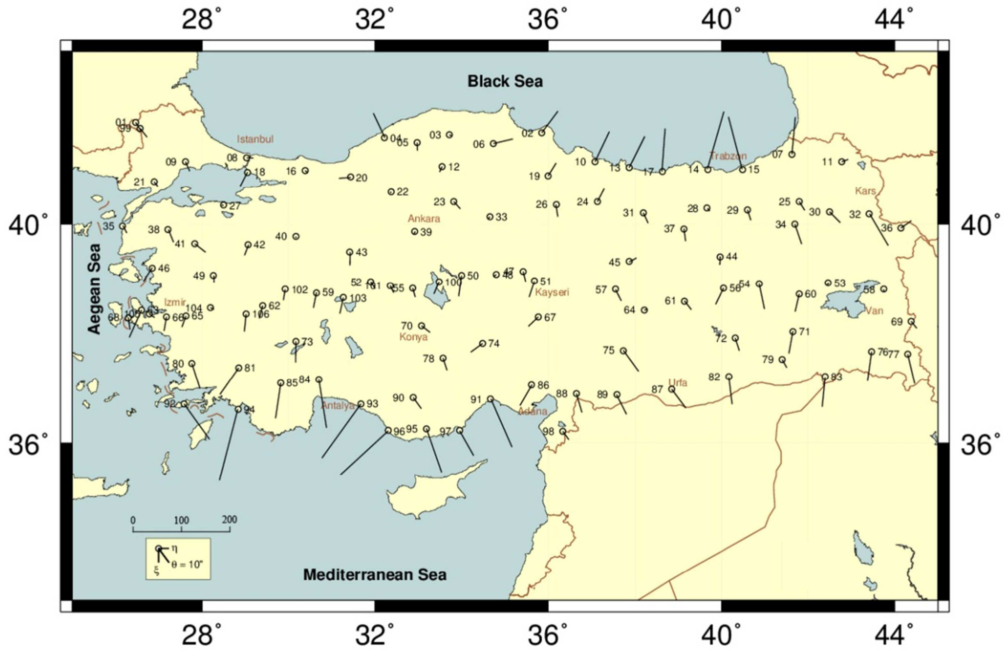

Figure 2. Astro-geodetic vertical deflections from Ayan, 1976

Turkish regional geoid models have been developed by employing a reference earth gravitational model, surface gravity observations and digital terrain models. The recent gravimetric models for Turkish territory were computed depending on OSU91 (TG-91) and EGM96 (TG-03) earth gravitational models. After various new data sets became available including the release of the EGM08, the availability of new surface gravity observations and high resolution digital terrain model, advanced satellite altimetry-derived gravity over the sea (DNSC08) and a larger number of GPS/leveling stations, a new geoid model for Turkey (TG-

09) was computed by Turkish General Command of Mapping. Afterwards, GPS/leveling geoid heights were combined with gravimetric geoid model in order to obtain a hybrid geoid model (THG-09) to be used in GPS positioning applications (Figure 3). The accuracy of THG-09 tested with GPS/leveling data which were not used in the combination stated above and finally the external accuracy reported was ± 8.38 cm by TNUGG (2011).

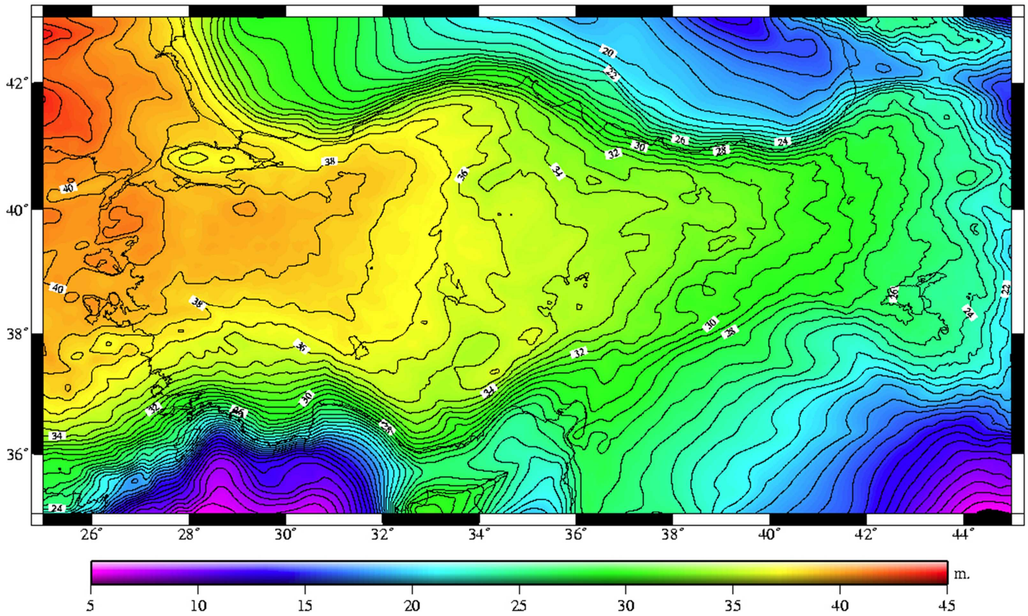

Figure 3. Turkish Geoid Model (TG-09).

3. VALIDATION OF CURRENT MODELS WITH ASTRO-GEODETIC DATA

The observations used in computation of the global models should be homogenously scattered to the entire earth which is not possible given the circumstances of this fact. Therefore quantities computed from global geopotential models including geoid undulation are directly depending on the quality and distribution of gravity data and signal power of satellite missions. Moreover, computed large differences between reported various models indicates necessity of validation processes before using them for geodetic and geophysical purposes (Erol and Erol, 2012). From this point of view there are some studies (Roland and Denker, 2003) that evaluated the fitting of some of the global models to the gravity field in Europe using external data (GPS/leveling and gravity anomalies); and also some others (Amos and Featherstone, 2003) used astro-geodetic vertical deflections on the Earth surface in the external data for validating the EGMs in Australia.

The computation methods of geoid models (Featherstone, 2001, Hirt and Seeber, 2007; Erol et al., 2009), that GNSS and orthometric heights can be used to estimate the position of the geoid at discrete points provides a practical solution to the geoid problem in relatively small areas. However, local geoid models with high precision can be applied only in a limited area, so they are not suitable for extrapolation. These local solutions do not contribute to a unified vertical datum definition in a country. In Turkey, geoid modeling studies for modernization of geodetic infrastructure is still an ongoing investigation. Modernization of vertical datum needs to be stated with all the components of observation and computation techniques including astro-geodetic methods. Current geoid models in Turkey need to be validated using astro-geodetic vertical deflections which represent independent observables for comparison with gravity field models. Recently, DZCS vertical deflection data showed that geometric-astronomical leveling used as a method to validate GNSS-based height determination studies (Hirt et al, 2011). Moreover, during the last decade DZCS was successfully used for the validation of gravimetric quasigeoid models in Germany (Hirt 2007, 2008). Especially in the mountainous areas astro-geodetic method of vertical deflections determination is more effective than the gravimetric method and requires less data points compared with gravimetric geoids (Gerstbach, 1996).

4. OBSERVATION METHOD AND INSTRUMENTATION

Astromical coordinates *(Φ,Λ)* define positions of the observation points on the earth surface, and equatorial coordinates describes the positions of the stars in celestial sphere. Astronomic coordinates and equatorial coordinates can be linked with Greenwich Apparent Sidereal Time *(GAST)* for a star located at zenith (Figure 4).

$$\Phi = \delta,\ \Lambda = \alpha - GAST \tag{1}$$

However, a star usually cannot be observed at zenith and that's why zenithal direction has to be interpolated using the reference stars imaged near zenith with a CCD camera. The stars on the zenithal star field have to be identified using appropriate star catalogs.

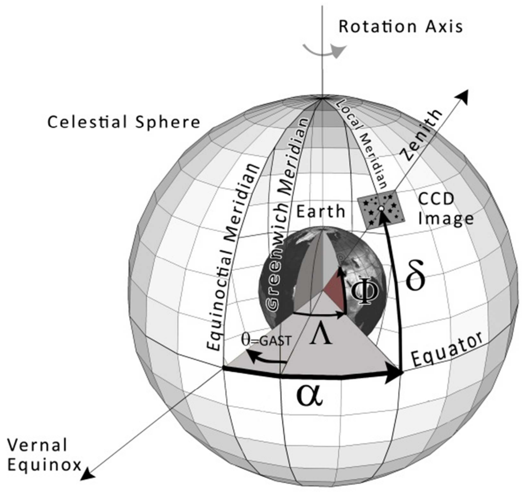

Figure 4. Basic principle of DZCS (Hirt, 2004)

Identification of stars for this study is made by using information from UCAC2 catalog for reference stars. UCAC2 which is the second USNO CCD Astrograph Catalog, contains positions and proper motions of more than 50 million celestial objects with an accuracy of 0.07 arcsec depending on the magnitude. Image coordinates of the stars *(x,y)* which are defined in image coordinate system cannot be linked directly with equatorial coordinates (α,δ). Tangential coordinates of stars have to be defined by projecting spherical equatorial coordinates (α,δ) onto a plane which is tangent to the celestial plane in a common point (α_0,δ_0). Therefore, the tangential coordinates can be obtained by,

$$\cot q = \cot \delta \cos(\alpha - \alpha_0)$$
$$\xi = \frac{\tan(\alpha - \alpha_0)\cos q}{\cos(q - \alpha_0)} \tag{2}$$
$$\eta = \tan(q - \delta_0)$$

Tangential coordinates are related to image coordinates through the projective transformation. At least four common stars in both systems have to be identified in order to estimate transformation parameters. In a case of having more than four common stars, transformation parameters are calculated using a least squares adjustment.

$$\xi = \frac{Ax + By + C}{Kx + Ly + 1}$$
$$\eta = \frac{Dx + Ey + F}{Kx + Ly + 1} \tag{3}$$

The position of the zenith is interpolated through an iterative process. The astronomical coordinates (Φ,Λ) can be calculated according to (1) using observation epoch *GAST*. Finally vertical deflections $(\xi,\ \eta)$ can be calculated using astronomical coordinates (Φ,Λ), and ellipsoidal coordinates (φ,λ) derived by GPS.

$$\xi = \Phi - \varphi \quad , \quad \eta = (\Lambda - \lambda)Cos\varphi \tag{4}$$

5. DZCS OF TURKEY

In the scope of this study, a Schmidt-Cassegrain type telescope with 14 inches aperture, two inclinometers, and a dual frequency geodetic GPS receiver with a computer control unit for data capturing and system control are used. The first test observations were performed at KOERI campus with the collaboration of Astronomy department at our institute (Table 1). We used the existent equipment such as a telescope, GPS receiver, inclinometers, and a low cost DSLR camera. Test observations firstly focused on capturing sufficient number of stars to be processed as well as vertical alignment of the system. Another step is to time-tag images considering the shutter delay of low-cost DSLR camera.

Further test observations are performed in Istanbul and Antalya using available instruments of astronomy departments. Initial observations were performed to acquire minimum number of stars for transformation between image and tangential coordinates. To achieve this goal we tested Canon 500D DSLR and Pictor 216xt CCD camera which are available in our institute. We used two dual-axis Leica Nivel20 inclinometers for orientation of the systems in vertical direction. However, we encountered some difficulties because of the noisy images and the integration of the inclinometers to the system at the beginning.

Table 1. Equipment used for test observations

Component	Properties	Equipment
Optics	3556 mm f/10 4064 mm f/10	Meade 14” LX200GPS (I) Meade 16” LX200GPS (II)
CCD Camera	4.7 x 4.7 µm (pixel size) 13 x 13 µm	Canon EOS 500D (4768 x 3174) (I) Apogee Alta U47 (1024 x 1024) (II)
Inclinometer	Resolution:0.001 mrad	Leica Nivel20
Field of View	21 x 14 arcmin 11.4 x 11.4	System I System II

We also tested the system using Apogee Alta U47 CCD camera with 16-inches telescope that are based at TUG in Antalya (Figure 5). For each observation session different exposure times for images were also taken into consideration in order to determine the point shapes of captured stars. Exposure times shorter than 1 second gave circular shaped images to the stars whereas longer exposure times expose stars as trails.

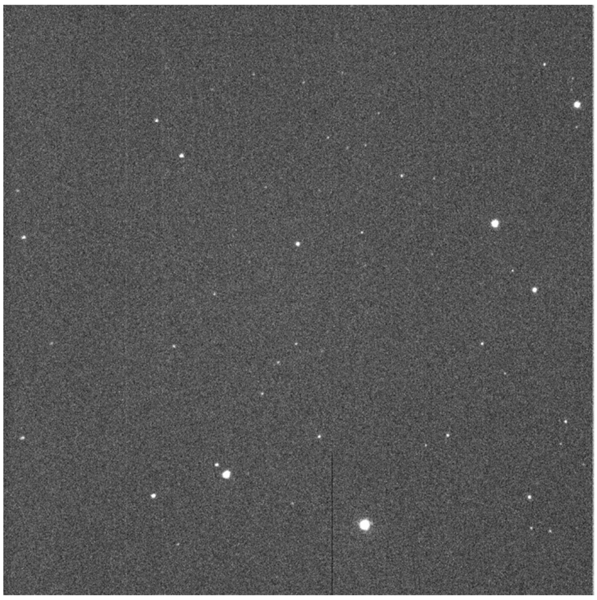

Figure 5. Zenithal Star field with 0.2 sec exposure time

As a result of test observations, all the CCD cameras we tested with two different telescopes were capable of capturing at least six stars (except Pictor 216xt). Besides, when compared to observations at Istanbul, the station at Antalya gave the maximum number of stars with 0.2 second exposure time.

6. FURTHER DISCUSSIONS AND FUTURE STUDIES

This study introduce pre-studies for Turkey's DZSC in order to determine astro-geodetic vertical deflections in Istanbul. The future studies are going to be performed at a specially designed observation station at KOERI campus in Istanbul. The systems will be installed on a substructure which will be equipped with an astronomical CCD camera, 8" Schmidt-Cassegrain type telescope, GPS receiver, inclination sensors and necessary software. Recently a new project is in progress for height modernization in Turkey which is aiming to achieve 1-cm Turkish geoid model. In this context, it is stated that the issues such as, new, consistent, and precise surface gravity observations, airborne gravity especially in remote areas, vertical velocity field and deformations in the leveling network, the establishment of more and stable GPS/leveling stations, topographic density model, digital terrain model are being investigated (TNUGG, 2011). From this point of view, we believe that our project on determination of astro-geodetic vertical deflections using DZCS contribute a lot to height modernization studies in Tukey. We are planning to obtain the first results this summer and then the system is going to be operated on some particular stations around Istanbul.

7. ACKNOWLEDGEMENTS

This project is supported by The Scientific and Technological Research Council of Turkey since January 2012 with the grant number 111Y125. The authors would like to thank all TUG members especially Dr. Tuncay Ozisik for his support to our project. We also would like to thank to KOERI Astronomy department for their collaboration and Leica Sistem INC. for their instrumental support to our test observations.

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BIOGRAPHICAL NOTES

Kerem Halicioglu is a PhD student in Istanbul Technical University, and PhDc since 2009. He is also working at Bogazici University Kandilli Observatory and Earthquake Research Institute, Geodesy Department. His PhD dissertation is about Determination of Vertical Deflections using CCD Zenith Cameras in Istanbul, Turkey. His other researches are on GPS processing and geodetic documentation studies at archeological sites.

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