IZMIR KATIP CELEBI UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

LOCAL GEOID MODELLING IN THE IZMIR METROPOLITAN AREA USING VARIOUS GLOBAL GEOPOTENTIAL MODELS AND DIFFERENT INTERPOLATION TECHNIQUES

M.Sc. THESIS

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İZMİR METROPOLİTAN ALANDA ÇEŞİTLİ JEOPOTANSİYEL MODELLER VE ENTERPOLASYON TEKNİKLERİ KULLANARAK LOKAL JEOİT MODELLEME

YÜKSEK LİSANS TEZİ

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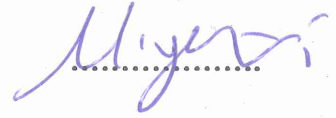**Tez Danışmanı: Doç. Dr. Mevlüt YETKİN**

HAZİRAN 2019

Semih SAATÇI, an M.Sc. student of IKCU Graduate School Of Natural And Applied Sciences, successfully defended the thesis entitled "LOCAL GEOID MODELLING IN THE IZMIR METROPOLITAN AREA USING VARIOUS GLOBAL GEOPOTENTIAL MODELS AND DIFFERENT INTERPOLATION TECHNIQUES ", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

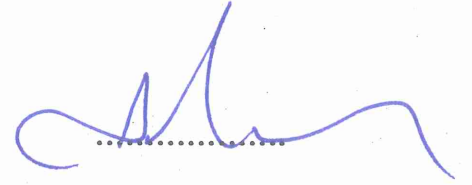**Thesis Advisor :**

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To my growing family;

FOREWORD

First and foremost, I would like to thank my advisor,and my family.

I would like to express my sincere gratitude to my dear wife, my colleagues for their help throughout the course of my study, and my precious consultant Mr. Assoc. Prof. Dr. Mevlüt YETKİN.

June 2019   Semih SAATÇI

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ABBREVIATIONS

GPS   **:** Global Positioning System
GNSS   **:** Global Navigation Satellite System
ICGEM   **:** International Centre For Global Earth Models
BÖHHBÜY **:** Code of Production of Large Scale Map and Map Information
                 (in Turkish)
WGS84   **:** World Geodetic System 1984
3D   **:** Three Dimension
CHAMP   **:** CHAllenging Minisatellite Payload
GRACE   **:** Gravity Recovery And Climate Experiment
GOCE   **:** Gravity field and steady-state Ocean Circulation Explorer
A   **:** Altimeter Data Set
G   **:** Gravimetric Data Set
S   **:** Satellite Data Set

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LOCAL GEOID MODELLING IN THE IZMIR METROPOLITAN AREA USING VARIOUS GLOBAL GEOPOTENTIAL MODELS AND DIFFERENT INTERPOLATION TECHNIQUES

ABSTRACT

Generally, height is the numerical value of the line between two points in space on the vertical plane. This numerical value becomes dependent on many dynamics when it comes to the Earth. Heights have many types about physical, geopotential and mass characteristics of the Earth. These heights are used in geodetic measurements and all related scientific and technical studies. Definition of height mathematically must be considered with all factors that affected. As a result, the data must be cleared from the variables effects.

Leveling is a technical way to reach height information used in practice. Leveling accuracy depends on the accuracy of the points used. Satellite positioning systems have become an easy-to-reach alternative for horizontal and vertical positioning. Compared with local measurements, this method saves time, work and it has become preferable method with easy control. There is a systematic difference between the height systems global positioning systems and leveling method. This difference can be modeled. This difference model must be harmonious with earth surface at every point. Produced high accuracy model provide ease and speed in studies. In this study, geodetic undulations are summarized with used difference models and usage patterns. The difference between height systems at each point can be defined of the geoid model. Various mathematical models have been developed to calculate the difference at desired point. This technique is called interpolation. Each mathematical model can give different results depending on the size and characteristics of the study area. The most appropriate technique can be decided by various trust tests.

İZMİR METROPOLİTAN ALANDA ÇEŞİTLİ JEOPOTANSİYEL MODELLER VE ENTERPOLASYON TEKNİKLERİ KULLANARAK LOKAL JEOİT MODELLEME

ÖZET

Yükseklik genel anlamda; uzay boşluğundaki iki nokta arasındaki normalin düşey düzlemdeki sayısal değeri olarak tanımlanabilir. Bu sayısal değer yerküre söz konusu olduğunda bir çok dinamiğe bağlı hale gelir. Yerkürenin fiziksel, jeopotansiyel, kütlesel özellikleri dikkate alındığında bir çok yükseklik çeşidi ortaya çıkar. Bu yükseklikler jeodezik ölçüm ve buna bağlı olan her türlü bilimsel ve teknik çalışmada kullanılmaktadır. Matematiksel olarak tanımlanamayan, maddesel olarak düzgün dağılım göstermeyen yerküre üzerinde yükseklik tanımlaması yapabilmek için etki eden bütün faktörleri dikkate almak gerekir. Sonuç olarak elde edilen verilerin anlamlı olabilmesi için kullanma amacına bağlı değişkenlerin etkilerinden arındırılmış olması gereklidir.

Pratikte kullanılan yükseklik bilgisine ulaşmak için nivelman ölçüsü gereklidir. Doğruluğu test edilmiş düşey yer kontrol noktalarına bağlı bir nivelman ölçümünün kontrolü, yine o noktalardan yapılacak kontrol ölçümü ile sağlanabilir.

Uydu konumlama sistemleri yatay ve düşey konum belirleme çalışmalarında pratik, kolay kontrol sağlayan, kolay ulaşılır bir alternatif haline gelmiştir. Yersel ölçümlerle karşılaştırıldığında zaman ve emek tasarrufu sağlarken, aynı zamanda kolay kontrol edilebilmesi ile de vazgeçilmez bir yöntem haline gelmiştir.

İşte bu küresel konumlama sistemleri ile elde edilen yükseklik sistemleri ile nivelman yöntemi ile elde edilen yükseklik sistemleri arasında sistemsel bir farklılık bulunmaktadır. Nivelman yöntemi ile elde edilen yükseklik sistemini küresel konumlama sisteminden elde edebilmek için aradaki farkın modellenmesi gerekir. İhtiyaç duyulan modellerin yerkürenin fiziksel kondisyonuna göre çeşitlendirilmesi gerekir. Yüksek doğruluk sağlamak için ihtiyaca uygun üretilen modelle kısa sürede ihtiyaca cevap vererek çalışmalarda büyük kolaylık sağlar. Jeoit ondülasyonu olarak adlandırılan bu fark modellerinin hangi koşullarda üretildiği, hangi değişkenlere bağlı olduğu ve nasıl kullanıldığı bu çalışmada özetlenmiştir.

Üretilen jeoit modelinin kapsadığı alanın her bir noktasında yükseklik sistemleri arasındaki fark tanımlanabilir. İstenen noktadaki farkın hesaplanması için çeşitli matematiksel modeller geliştirilmiştir. Bu tekniğe enterpolasyon adı verilir. Her bir matematiksel model çalışma alanının büyüklüğüne, özelliklerine göre farklı sonuçlar verebilir. Çeşitli güven testlerine tabi tutularak kabul edilen sonuçlar arasındaki farktan o çalışma alanına ait en uygun tekniğe karar verilebilir.

1. INTRODUCTION

Height in general terms; can be defined as the numerical value of the normal in the vertical plane between the two points in the space. This numerical value becomes dependent on many dynamics when it comes to earth. Many types of height about earth cause of physical, geopotential and mass characteristics of earth. These heights are used in geodetic measurement and all related scientific and technical studies. All factors should eveluate for define height on the mathematically unidentifieable earth. The result data should be cleared from all the variables effects.

Leveling measure required to reach the height information used in practice. Control of the leveling measurement depends on repeating the measurement from the same points. Satellite positioning systems have become an easy-to-reach, practical,easy-to-control alternative to horizontal and vertical positioning. It has become an preferable method compared to local measurements with saves time, effort and easy control.

There is a systematic difference between the heights obtained by global positioning systems and leveling method. To obtain the leveling height system from the global positioning system, the difference must be modeled. The models needed should be selected according to the physical condition of the earth. Models are produced with high accuracy and provides great convenience in studies. This study summarizes the geoid undulations which under these conditions are produced.

There is a previous study in our area. In 2009 they used CHAMP and GRACE techniques and compare results with TG03 National Turkey Geoid. Readers want to see another perspective can review this study. [1]

Height difference can be defined at each point of the area covered by the produced geoid model. Various mathematical models have been developed to calculate the difference at the desired point. This technique is called interpolation. Each mathematical model can give different results depending on the size and characteristics of the study area. The most appropriate technique of the study area can be decided with various confidence tests.

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1.1. Literature Review

In this section, some resources are examined related to the subject of study. The following resources can be reviewed for more information. The resources utilized in this study shown in references section at last.

- For more information about comparison of global geopotential Models From the CHAMP and GRACE missions for regional geoid modeling in Turkey article, can read Erol B., Sideris M.G., Çelik R.N. (2009) [1].
- Abbak R.A. (2017) give detailed information about height systems [2].
- More information on global geopotential models can be obtained from the ICGEM website [3].
- GNSS/Leveling technique disscussed in detail Yılmaz, M., Turgut, B., Güllü, M., Yılmaz, I. (2016). And Younis G. (2017) [4].
- Reader can obtain information about recent global geopotential models for strip area to see and besides recent global geopotential models topic detailed researched in Doganalp S. (2016) [5].
- Latest gravimetric satellite missions detailed researched in Ustun A. (2002) [6].
- Detailed information about CHAMP project, can see website [7].
- Learn about GRACE satellite mission, visit website [8].
- GOCE satellite mission detailed information in website [9].
- There are compare EGM96 geopotential model and TG99 Turkey Geoid and interpolation techniques are discussed in detail in Turgut, B., İnal C., Yiğit C.Ö. (2002) [10].
- To get detailed information about interpolation technique for local geoid determination, reader can see Teke K., Yalçınkaya M. (2016) [11].
- Local geoid determination with GPS technique discuss detailed in Erol B., Çelik R.N. (2004) [12].
- Compare EGM96 Geopotential model, Turkey Geoid(TG99) and GNSS/Leveling technique in Turgut, B., İnal C., & Yiğit C.Ö. (2002) [13].
- For more information about interpolation techniques in Yiğit, C.Ö., (2003) [14].
- Readers can take information about physical geodesy in Üstün, A., (2006) [15].
- Geoid determination techniques discuss in Arslan, E., Yılmaz M. (2005) [16].

- There is a experimental application about leveling with GNSS surveys in Kartal, A., (2001) [17].
- There is another experimental application about geoid determination with GNSS/Leveling and Kriging technique Akçın, H., (2002) [18].
- Orthometric height determination from ellipsoidal heights using geoid discuss in Akiz, E., Yerci M. (2009) [19].
- There is a review recent GOCE global geopotential model in Avşar, N.B., Erol B., Kutoğlu Ş.H. (2015) [20].
- Evaluation of global geopotential models with Gps-Leveling data in Tepeköylü, S., Üstün A., (2008) [21].
- Comparison Of Local Geoid Height Surfaces at Karaaslan, Ö., Kayıkçı E.T., & Aşık Y. (2016) [22].
- Determination of local geoid with geometric method in Zhan-Ji Y., Ö., Yong-qi C. (1999) [23].
- Evaluation Of Global Geopotential Models research article in India can read at Goyal R., Dikshit O., & Balasubramania N. (1999) [24].
- There are Evaluation of recent combined global geopotential models in Brazil in Nicacio E., Dalazoana R., S.R.C. de Freitas (2018) [25].
- There is another GOCE geopotential model work in Godah W., Krynski J. (2013) [26].
- Detailed information geoid determination by GPS/Leveling Method in the Republic of Tatarstan in Komarov R.V., Kascheev R.A., Zagretdinov R.V. (2007) [27].
- Validation of recent geopotential models in Tierra Del Fuego in Gomez M.E., Perdomo R., Cogliano D.D. (2017) [28].
- On the selection of optimal global geopotential model for geoid modeling: A case study in Pakistan. The discuss found in Sadiq M., Ahmad Z. (2009) [29].
- Polynomial interpolation methods in development of local geoid model in Das R.K., Samanta S. (2018) [30].
- Precise Local Geoid Determination to Make GPS Technique More Effective in Practical Applications of Geodesy in Erol B., Çelik R.N. (2018) [31].

- The Influence of Regularization Methods on the Accuracy of Modern Global Geopotential Models in Kanushin V.F., Ganagina I.G., Goldobin D.N., Kosarev N.S., Kosareva A.M. (2015) [32].

- Towards the Selection of an Optimal Global Geopotential Model for the Computation of the Long-Wavelength Contribution: A Case Study of Ghana in Yakubu C.I., Ferreira V.G., Asante C.Y. (2017) [33].

- Reader can see use of GNSS measurements instead of leveling in mining in Akçın, H., Şekertekin A.İ. (2014) [34].

- Elaborate info about Integration of GNSS/Leveling data with global geoptential models to define the height reference system of Palestine in Younis G. (2017) [35].

- Reader if want to know more information about "Importance of Precise Local Geoid Models in Engineering Measurements" can see Erol B., & Çelik R.N. (2005). [36].

2. HEIGHT CONCEPT

Most required height systems in engineering studies are orthometric heights. Orthometric heights are usually determined by leveling, which is directly dependent on the physical condition of the working environment. There are many height systems in defining the physical earth. There are height differences in order to express mathematically between surfaces. These height systems show the distance of physical surface, geoid and ellipsoid surfaces to each other. There are many elevation systems used in geodesy [2]. These systems can be classified as;

- Geopotential Numbers
- Orthometric Height
- Elipsoidal Height
- Normal Height
- Dynamic Height

In this section, these height systems used in the study will be explained. Height systems see in Figure 2.1.
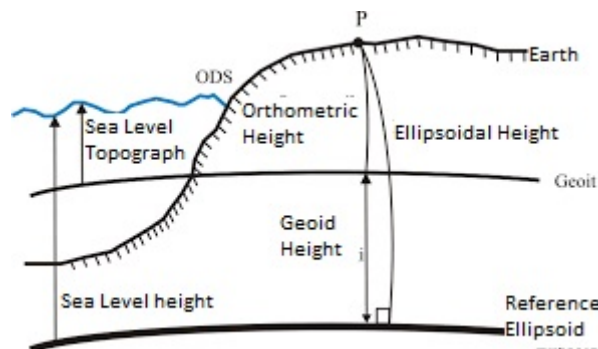
Figure 2.1 : Height Systems [2].

Gravity-dependent heights are preferred as well as geometry-related heights in engineering applications. In determining the heights, consideration the effect of the gravitational potential and geometric position of the points to each other. Particularly

when the fluid dynamics and motion vectors are examined, the relation with gravity field will be seen clearly. Therefore, heights are also used in gravity area especially in sewage, tunnel, highway, railway and oil pipeline projects [2].

2.1. Geopotential Numbers

The difference between the gravitational potential (Wp) of the nivo surface passing through a given point and the gravitational potential of the geoid (W0) is called the geopotential height or geopotential number of that point. A physical force, such as dynamic height, is a magnitude dependent on the gravitational potential. Therefore, it is frequently used in some engineering projects. Mathematical equations;

$$C_P = W_0 + W_P = \int_0^P dW = \int_0^P g dH \qquad (2.1)$$

showns as. The unit of C_p is kGal x meter has no geometrical meanings and defined a physical size. This value is also a reference value for other height systems [3].
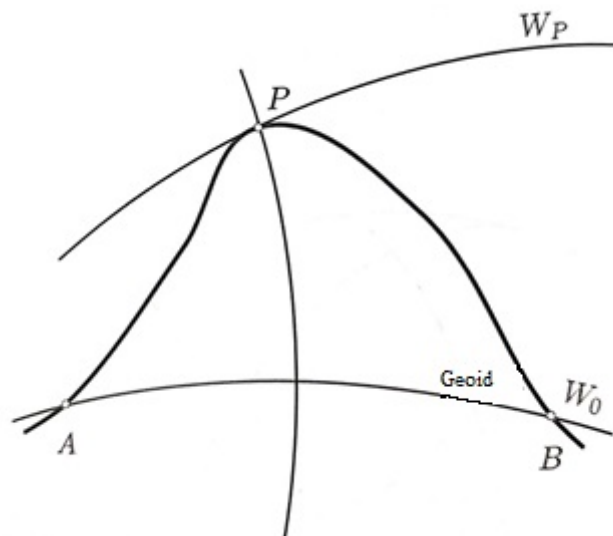
Figure 2.2 : Geopotential Heights [2].

2.2. Orthometric Heights

The orthometric height can be defined its general sense as the distance of a point on the physical earth in to the plumb curve on geoid surface. The topographic structure of the physical earth and the depth of the equipotential surface lead to changes in

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orthometric heights. Physical earth is a completely complex structure with varying height such as mountains, seas, lakes, hills, plains. This concept is related to geopotential rather than geometric. Since all the engineering projects produced on earth, the height type required will be the orthometric height. The orthometric height should be sufficient to provide the required precision of the engineering structures to be produced. Position and height information of the structures in the three dimensional plane must be correct. Also all working area must be correct orthometric heights. Analysis of a new building in the sun's rays, the height of the rehabilitation wall along the stream in the stream improvement work, the extent to which the gsm base station can serve a new area, is related to the correctness of the orthometric height values. Therefore, the structure produced should have the right height values not only in itself but also between structures that would be problematic, such as other buildings, retaining walls, peaks, stream beds [2]. Orthometric heights shown in Figure 2.3 below.
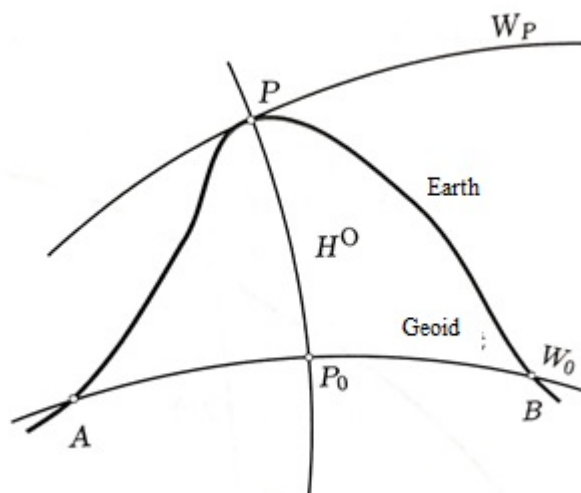
Figure 2.3 : Orthometric Heights [2].

2.3. Ellipsoidal Heights

Since the shape of the earth is geoid, it is not possible to make calculations on this non-geometric shape and to express this surface mathematically. Mathematical definition is to express the world on another geometric figure. This figure is one of the main issues of geodesy and has been a subject of great concern since ancient times. We use globe or ellipsoid for earth shape. Plane, cone, cylinder and other geometric shapes like these used to express the earth in the plane. After that, the ellipsoid was used as a reference instead of other geometric shapes. All data needed on an ellipsoidal surface that passes through a desired part of the physical earth can be defined. The topographical conditions of the physical earth are very complex. Therefore unavoidable there will be differences between the surface of this reference ellipsoid surface and the physical surface of the earth. Ellipsoidal height; it can be defined as the vertical distance of a point on the physical earth to the reference ellipsoid passing through that point. The general method used to describe the world mathematically is to define a reference ellipsoid. WGS84 reference ellipsoid used in global positioning systems is a common example. Reference ellipsoid height (h) takes the physical center of the earth to the origin point. This height is directly dependent on the parameters of the preferred ellipsoid and is independent of the gravitational potential of the earth [2]. Ellipsoidal heights shown in Figure 2.4 below.
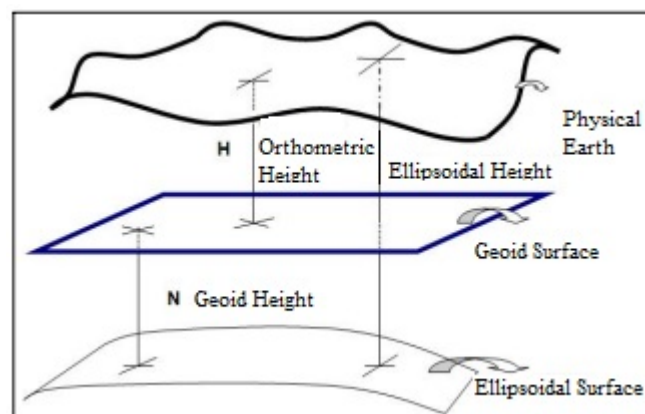
Figure 2.4 : Ellipsoidal Heights [2].

2.4. Normal Heights

The normal height is by definition the length of the normal between a point on the earth and the quasigeoite passing through that point [2] . The equality of this height is as follows;

$$H^N = \frac{C_P}{\bar{\gamma}}$$

(2.2)

Here we need to know the normal gravity so we can find the normal height. Normal gravity;

$$\bar{\gamma} = \gamma_0 \left[1 - (1 + f + m - 2f\sin^2\varphi) \frac{H^N}{a} + \frac{H^{N^2}}{a^2} \right]$$

(2.3)

calculable with. γ_0 is normal gravity on elipsoidal surface, f is stickiness, m is dimensionless size and a is the large radius of nivo ellipsoid. As the normal gravity is used in the calculations, the normal height creates a slightly different surface from the geoid. This surface is called quasi-geoid. There is a difference between geoid and quasi-geoid like difference between height anomaly and geoid height. The mathematical expression of this;

$$H^N = h - C$$

(2.4)

as. The ellipsoidal height is shown "h". This difference is observed in our country between 0 and 1.20m [2]. Normal heights shown in Figure 2.5 below.
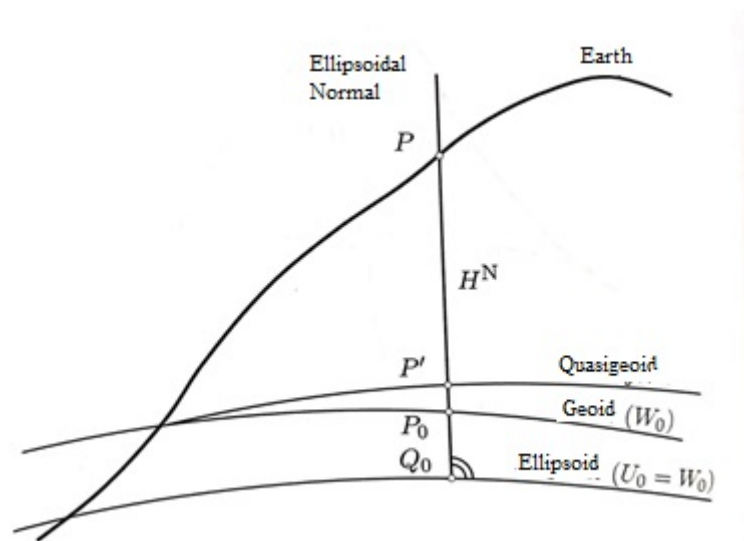
Figure 2.5 : Normal Heights [2].

2.5. Dynamic Heights

Dynamic heights are obtained by dividing the geopotential value at a point by a fixed-selected gravity value. For example, the normal gravity value should be selected on the ellipsoid surface of 45 degree latitude. Dynamic height is;

$$H^D = \frac{C_P}{\gamma_0^{45^0}}$$

(2.5)

shown as. $\gamma_0^{45^0} = 980.6199203$ gal for GRS80 ellipsoid. The geopotential and dynamic heights have same characteristics because the starting surface is not certainly. This is the biggest obstacle to using these values in practice. In order to convert the leveling heights to a dynamic height, you need to apply the dynamic correction term[2]. This process steps showns as;

$$\Delta H_{AB}^D = H_B^D - H_A^D = \frac{1}{\gamma_0}(C_A - C_B)$$

(2.6)

$$= \frac{1}{\gamma_0}\int_A^B g\,dH$$

$$= \frac{1}{\gamma_0}\int_A^B (g + \gamma_0 - \gamma_0)\,dH$$

$$= \frac{1}{\gamma_0}\int_A^B \gamma_0\,dH + \frac{1}{\gamma_0}\int_A^B (g - \gamma_0)\,dH$$

$$= \int_A^B dH + \int_A^B \left(\frac{g - \gamma_0}{\gamma_0}\right)dH$$

$$= \Delta H_{AB} + \sum_A^B \left(\frac{g - \gamma_0}{\gamma_0}\right)\Delta H$$

3. GEOID

Geoids are used to describe the earth in scientific studies. Geoid is the equipotential surface of the earth. In other words, the physical structure of the earth can be expressed in geoids, which is an equilibrium surface, because it is so complex and uneven that it cannot be expressed mathematically. According to Archimedes' theory, it is defined as the equipotential surface formed by the stagnant ocean surface under the land. This is also considered the true form of the earth. It is necessary to evaluate the geoid in conjunction with a reference ellipsoid. There are a number of methods used to describe the geoid surface. The most common of these are;

- Gravity Field Model
- Astrogeodetic Method
- Global Geopotential Model
- GNSS / Leveling Method

can be listed as. In terms of the area covered by the defined geoid surface, local and global geoid should be considered in two groups.

3.1. Global And Local Geoids

Global geoid models are created with the help of gravitational data collected from all over the world. They are often generated with a large number of data collected in multinational studies from stations around the world. The data of the satellite technology contribute to the definition of global geoids.

Local geoids are directly related to the physical properties of the study area as they are subject to a particular field of study. Local geoids are preferred than global geoids because they provide more reliable results for using in scientific studies and for reflecting height differences more strongly. One of the frequently used methods

related to this subject is Stokes' boundary value problem. This problem is based on the principle of creating a gravimetric mathematical model and making it physically computable. Accordingly, a potential can be calculated by taking advantage of the gravity anomalies given for each point on the geoid surface. But the physical structure of the earth must be mathematically eliminated cause of the surface is only on the geoid. The disturbing potential T value is expressed by Stokes integral as follows;

$$T = \frac{R}{4\pi} \iint_{\sigma} \Delta g S(\psi) d\sigma \tag{3.1}$$

R is the average radius of the earth, σ is surface of the earth, $S(\psi)$ is Stokes function and expressed as;

$$S(\psi) = \frac{1}{sin\left(\psi/2\right)} - 6sin\frac{\psi}{2} + 1 - 5cos\psi - 3cos\psi ln\left(sin\frac{\psi}{2} + sin^2\frac{\psi}{2}\right) \tag{3.2}$$

$$sin^2\frac{\psi}{2} = sin^2\frac{\varphi_P - \varphi}{2} + sin^2\frac{\lambda_P - \lambda}{2} cos\varphi_P cos\varphi$$

3.2. Local Geoid Determination

3.2.1. Determination of geoid with the GNSS / Leveling technique

Before using satellite techniques in engineering measurements, techniques were used in geoid determination studies such as astrogeodetic method, gravimetric method, potential coefficients method. The satellite data has become indispensable in geoid determination studies because is easily accessible by developing satellite-based positioning systems [3].

Leveling measurements can be achieved by applying the required height. Leveling needs precision work and levelling process that takes a long time. In order to prevent this, reliable geoids need to be converted to orthometric heights from satellite measurements. Orthometric heights are values generated based on the National Vertical Control Network. Ellipsoidal heights are the height from the reference

ellipsoid. The GNSS / Leveling method is used to convert the difference, which is a combined system, between these two elements accurately and reliably.

Mathematical geoid model of the earth can make with orthometric heights by leveling methods and satellite measurements at same points. The results are ready for use in the interpolation process to give the undulation value of any point within the workspace after being tested with various trust tests [4].

3.3. Global Geopotential Models

In order to mathematically express the Earth, it must be modeled as a reference ellipsoid. The surface of the geoid and the surface of the ellipsoid are separate from each other due to their shape. Some of the physical values resulting from the difference are the key issues in solving our engineering problems. Geodetic undulation value between orthometric heights and ellipsoidal height values allows us to calculate the differences between these surfaces. Prior to satellite-based measurements, geoid undulations were performed by techniques such as astro-geodetic observations, gravimetric measurements. These techniques are both sensitive and long-lasting and cannot be effective controls for their results. With the development of satellite technology, the elipsoidal heights can be measured in seconds, and its control and accuracy have been made in a very short time and frequently [5].

Therefore, satellite based geodetic determination technique has become much more preferable than the others. Global geopotential models are systems that define the gravitational potential at every point on a global scale by calculating the gravitational acceleration for the entire globe. This technique is based on the principle of superficial surface formation by accepting the center of the ground as a zero point. This provides visual evidence that the geoid is a non-geometric, shapeless form in the global sense. Global geopotential models covering the entire globe have been produced by the above mentioned methods such as astrogeodetic observations, gravimetric measurements, calculation of gravitational potential constants. In the formation of global geopotential models, artificial satellites with low altitude and close to the polar circle are used. These satellites consistently and precisely collect data from their orbits with the accelerometer, GPS module, etc. This collected position and gravitational acceleration data constitute a geopotential model of the

earth by forming a mathematical model. This method produces faster and more efficient results than other methods. Many successful satellite missions have been used in this method. In the next section will be given more information about these satellite missions. The program of the German Institute of Earth Sciences (ICGEM) provides detailed information on these successful global geopotential models. In addition, it is possible to make many calculations for a certain area or geographic coordinate of certain points such as gravitational potential, gravity anomaly, sea surfaces of in the world in a short time. In this study, EGM96, XGM2016, CHAMP, EIGEN, GRACE and GOCE satellite models and GEM, GRIM models were used to calculate the models. ICGEM web page shown in Figure 3.1 below. (http://icgem.gfz-potsdam.de/calcgrid)
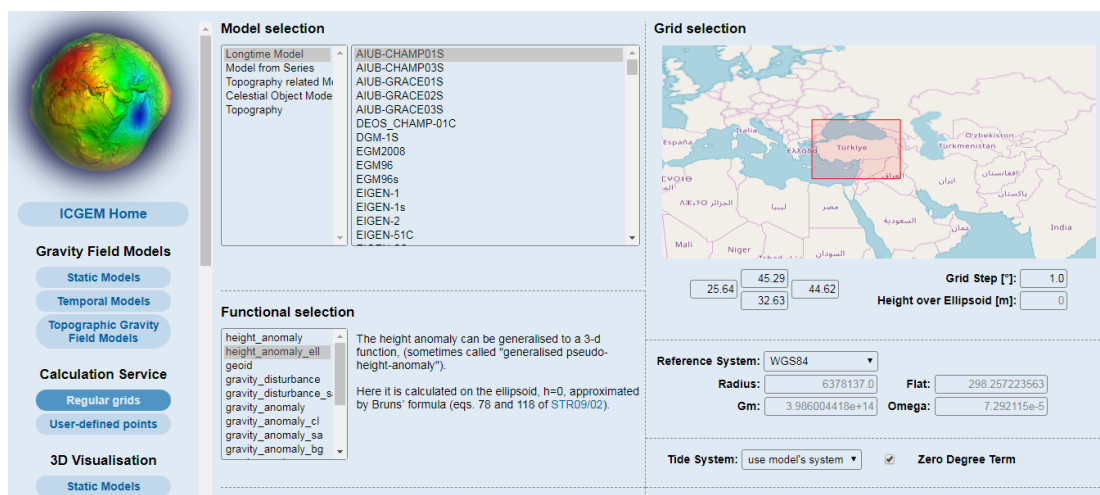
Figure 3.1 : ICGEM Calculations Screen http://icgem.gfz-potsdam.de/calcgrid.

The results of the project data obtained from ICGEM system will be shown in the application part of this study.

The latest geopotential models on the ICGEM site can be listed as follows and can see also different geoid models on Figure 3.2 to Figure 3.7;

2018

o   Tongji-Grace02k; 1. July 2018
o   SGG-UGM-1; 19. April 2018
o   GOSG01S; 19. April 2018
o   RFM_Moon_2520; 14. February 2018
o   IGG_RL01; 24. January 2018

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2017

- o   IGGT_R1; 1. December 2017
- o   IfE_GOCE05s; 22. November 2017
- o   GO_CONS_GCF_2_SPW_R5; 28 August 2017
- o   Dv_MoonTopo_2180; 8 August 2017
- o   GAO2012; 27 July 2017
- o   XGM2016; 22 May 2017
- o   NULP-02s; 8. May 2017
- o   Tongji-Grace02s; May 2017

2016

- o   ITU_GRACE16; Octob0er 2016
- o   ITU_GGC16; 17. June 2016
- o   EIGEN-6S4; 11. May 2016
- o   GOCO05c; 10. May 2016
- o   GrazLGM300c; 9. May 2016
- o   Tongji-GRACE02; 11. April 2016
- o   GGM05C; 9. February 2016

2015

- o   REQ_TOPO_2015; 7. December 2015
- o   AIUB-GRL200A/B; 1. September 2015
- o   Tongji-GRACE02; 23. July 2015
- o   GGM05G; 9. June 2015
- o   GOCO05s; 31. March 2015
- o   GO_CONS_GCF_2_SPW_R4; 7. January 2015

2014

- o   EIGEN-6C4; 2. December 2014
- o   ITSG-Grace2014s; 28. November 2014
- o   GO_CONS_GCF_2_TIM_R5; 21. July 2014
- o   GOGRA04S and JYY_GOCE04S; 15. July 2014
- o   RWI_TOPO_2012, RWI_ISOS_2012, RWI_TOIS_2012; 3. April 2014
- o   EIGEN-6S2; 20. March 2014
- o   dV_ELL_RET2012; 27. February 2014

o   GGM05S; 29. January 2014

o   EIGEN-6C3stat; 17. January 2014

Figure 3.2 : XGM2016 http://icgem.gfz-potsdam.de/vis3d/celestial.
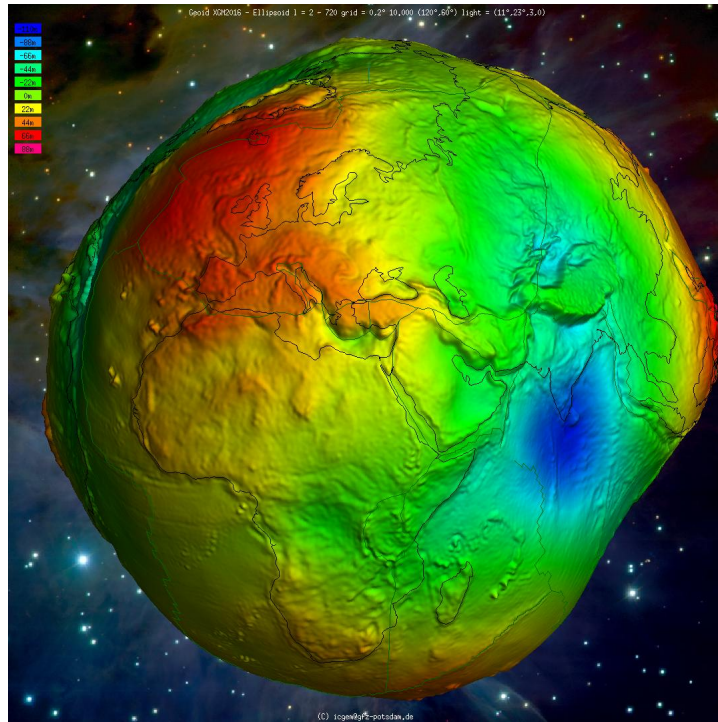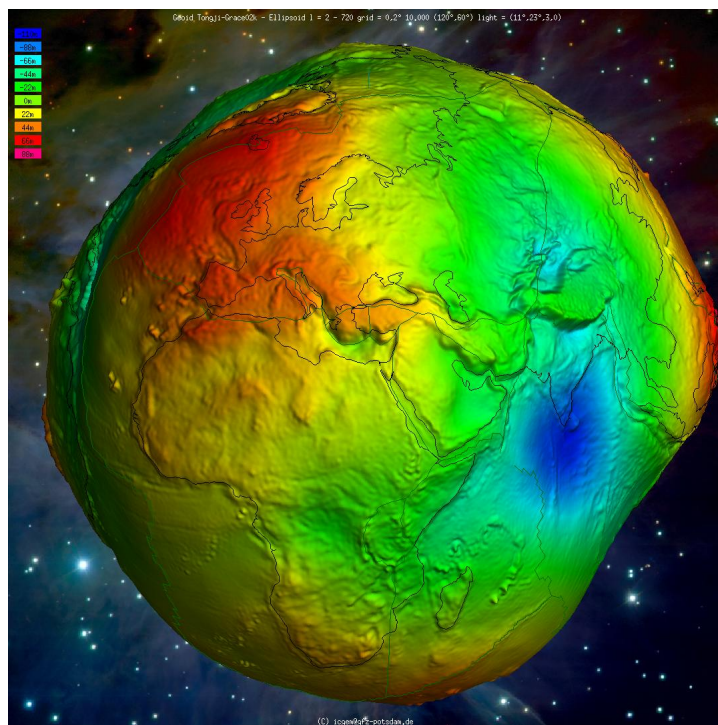
Figure 3.3 : Tongji GRACE02k http://icgem.gfz-potsdam.de/vis3d/celestial.

Figure 3.4 : Gosg 01s http://icgem.gfz-potsdam.de/vis3d/celestial.

Figure 3.5 : iggt-r1 http://icgem.gfz-potsdam.de/vis3d/celestial.

Figure 3.6 : EIGEN 1s http://icgem.gfz-potsdam.de/vis3d/celestial.

Figure 3.7 : Ggm 02s http://icgem.gfz-potsdam.de/vis3d/celestial.
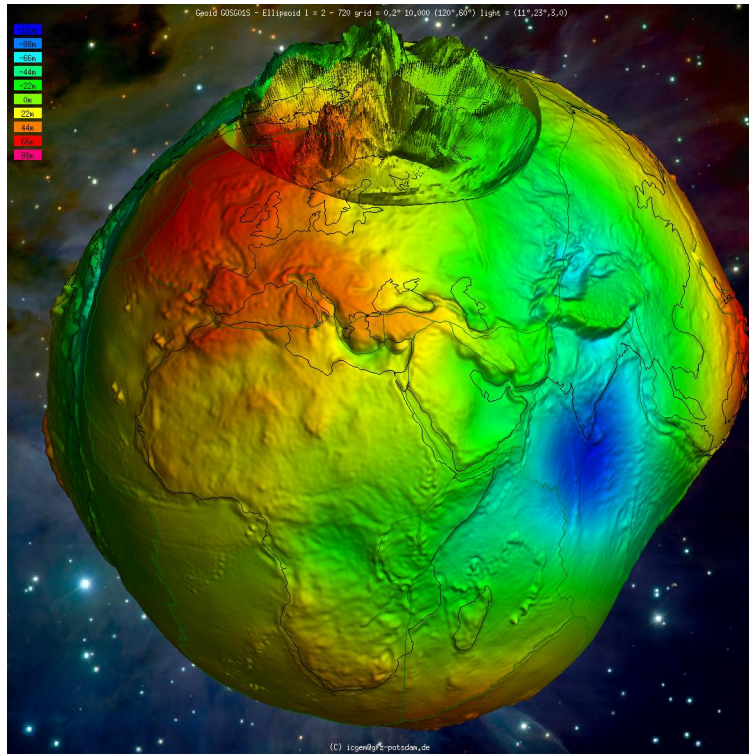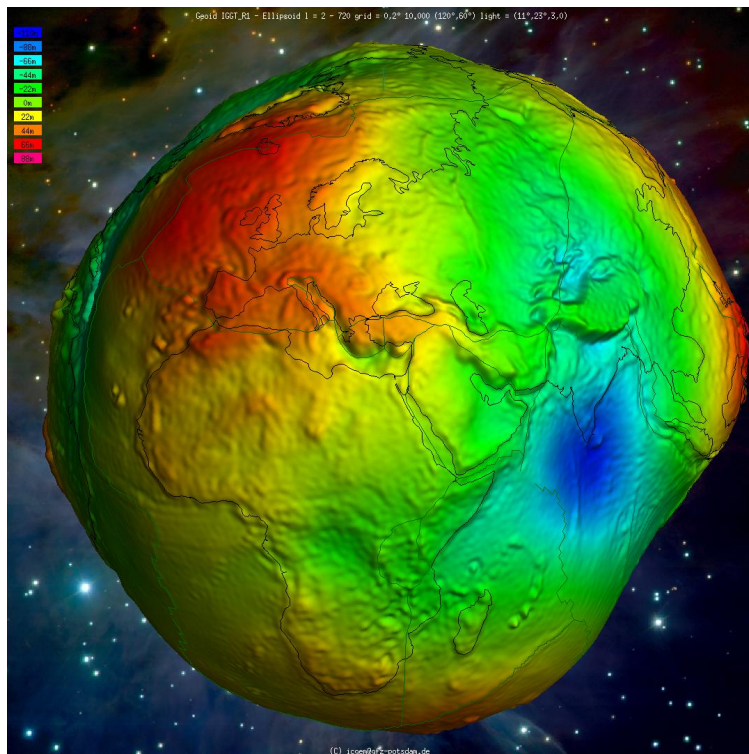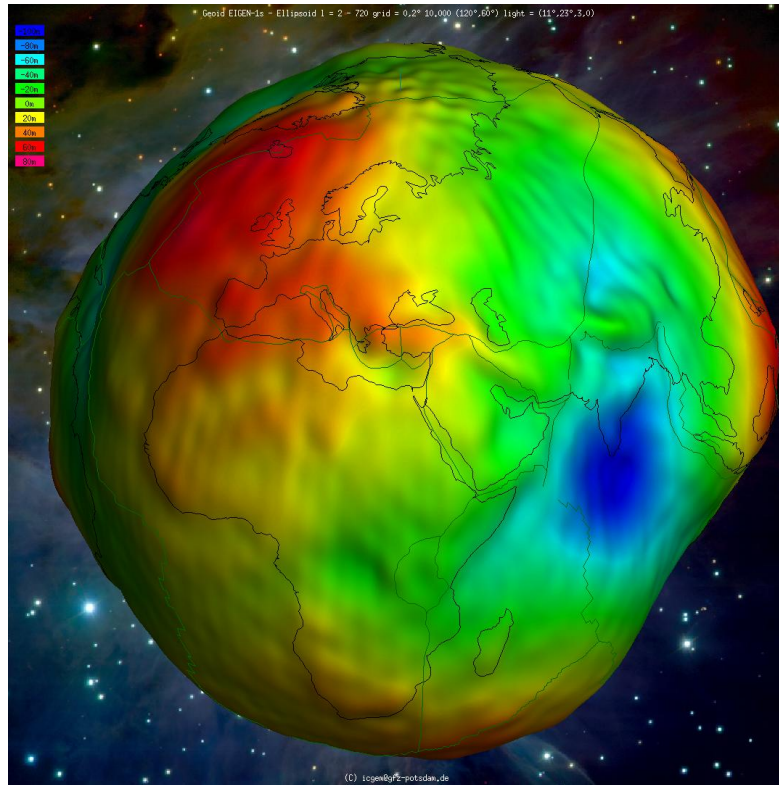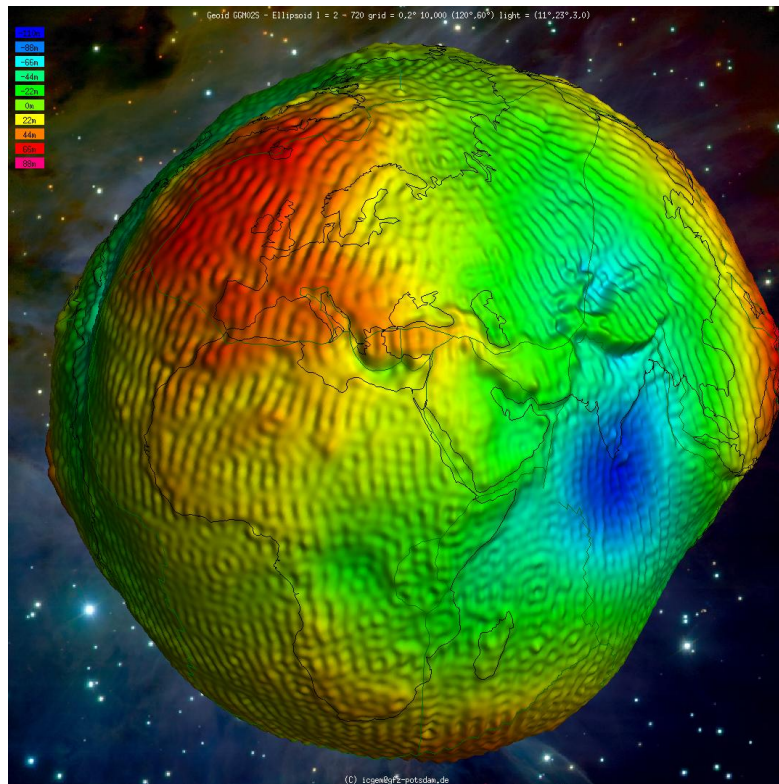
3.3.1. Gravimetric satellite missions

At the end of the long preparation period in the early 2000s, artificial satellites were used to determine the gravity area of the earth. The common characteristics of these satellites is that they have an orbit near the polar circle and they have an altitude that we can call a nearby ground satellite. The geoid identifications have become more accurate, faster and controllable with the data collected from the satellite orbits that they follow during the working periods. Many of geoids produced from the same satellite mission using all or part of the long data collection sets.

There are satellite missions that have completed the mission and have produced several successful geoit models. Besides, there are satellite mission studies which aim more accurate models with more sensitive data. These satellite missions are managed by multidisciplinary work teams not only by the data for calculating the gravitational potential of the globe, but also by geological data, collecting data that observe climatic changes [6].

3.3.1.1.   CHAMP

Champ was established by the German Institute of Earth Sciences (GFZ) for earth sciences and atmospheric research in October 1994. The project was launched from Russia on 15 July 2000 as a result of many years of preparatory work. The satellite mission, which has been designed for 5 years, ended 10 years, 2 months and 4 days after the burning of the atmosphere in the world. CHAMP project partners shown in Figure 3.8 below.
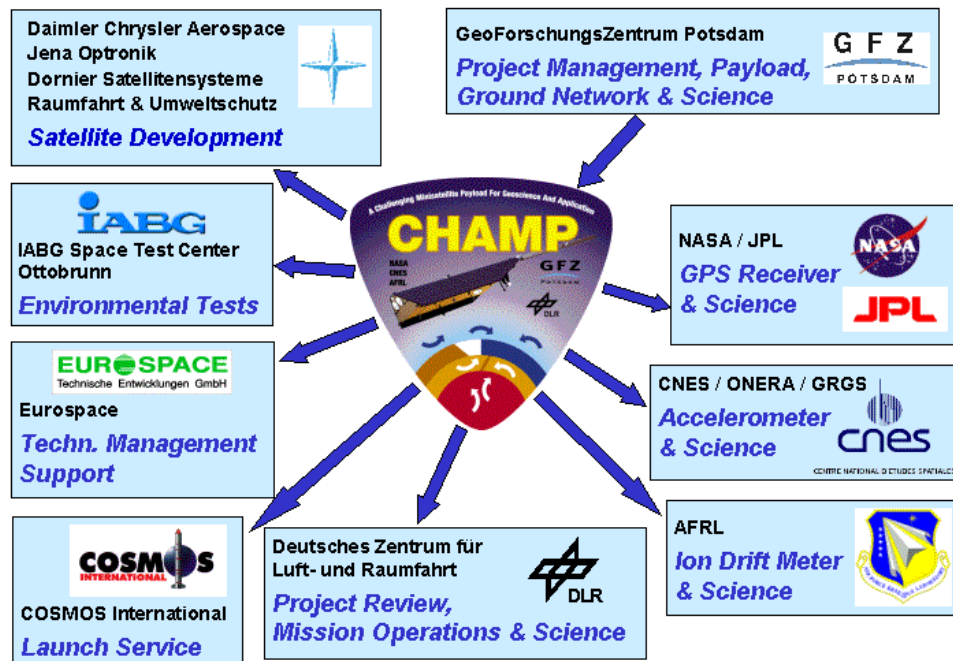
Figure 3.8 : Application Partners of the CHAMP Project https://www.gfz-potsdam.de/champ/projekt-partner/.

CHAMP is a multi-national project and a partnership of many large corporations and companies. Satellite has made various geological and atmospheric observations with technical equipment like magnetometer, accelerometer, star sensor, GPS receiver, laser reflector, ion deviation meter. The satellite with a very low orbit height of 454 km has a 87 degree orbit angle [7]. Geoid shape produced CHAMP shown in Figure 3.9 below.
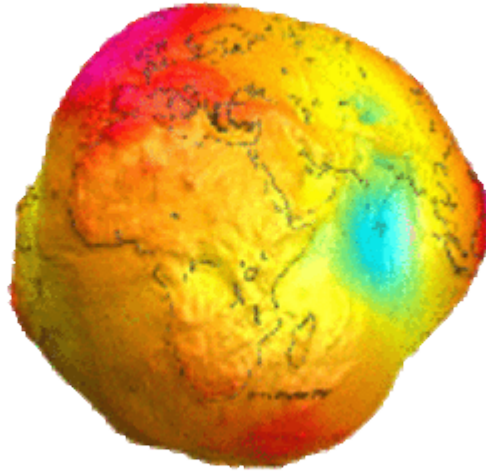
Figure 3.9 : Geoid Generated From CHAMP Satellite Data https://www.gfz-potsdam.de/champ/wissenschaftliche-ergebnisse/.

The gravitational patterns generated by the data collected by the satellite mission during the operation are called EIGEN. Some models can be listed as follows;

- EIGEN-CHAMP03S : Gravity model produced from 33-month CHAMP data,
- EIGEN-3P : Model produced from 3-year CHAMP data,
- EIGEN − 2 : Model produced from 6-month CHAMP data,
- EIGEN − 1S : Model produced with all CHAMP data.

3.3.1.2. GRACE

It is the satellite mission that started its work in March 2002. This is a multinational and multidisciplinary project too that carries out studies on oceanography, hydrology and other earth sciences as well as gravitational potential. The project was carried out in collaboration with several major organizations, such as the German Institute of Earth Sciences (GFZ), the American Aerospace and Aeronautics Agency (NASA). Gravity anomalies produces GRACE project shown in Figure 3.10 below.
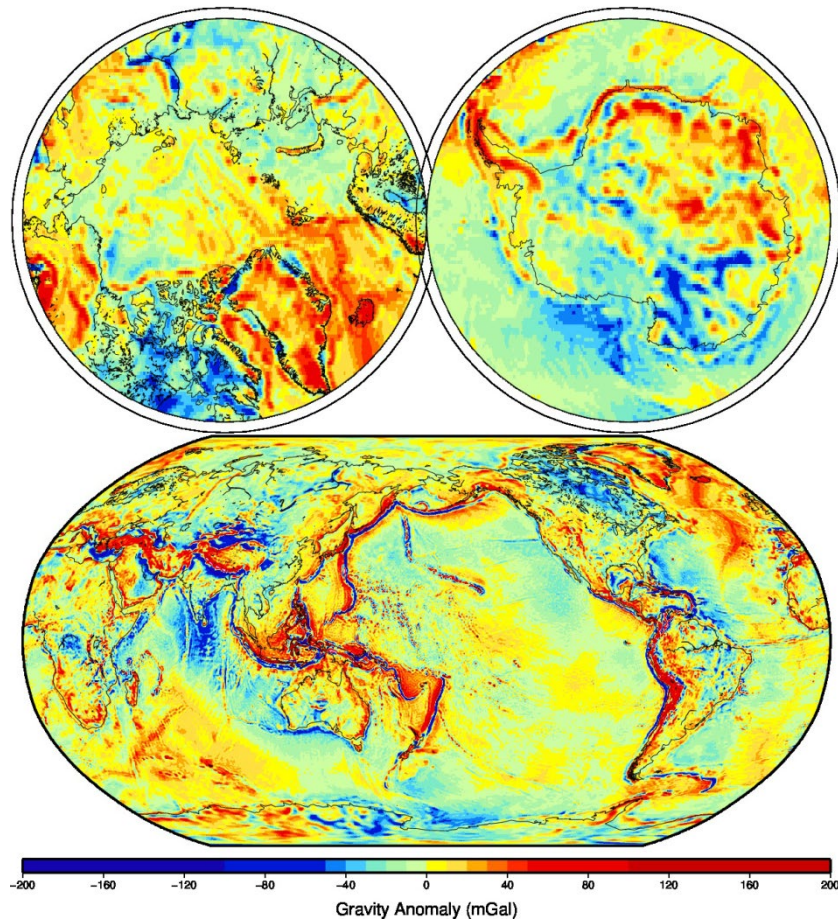
Figure 3.10 : GRACE Gravity Anomalies 2006
http://www2.csr.utexas.edu/grace/gallery/gravity/.

GRACE has a 5-year working life, like the CHAMP project. During this study, the working principle of the GRACE satellite is to collect data sets for 30 day periods and use them in global model produces. The reason for this is that the gravitational fields of the points on the physical earth constantly change temporarily and spatially. GRACE satellite;

- Vehicle Start-Up System
- Satellite System
- Scientific coordination System
- Mission Operation System
- Scientific Data System

it consists of components [8]. Geoid model produced GRACE shown Figure 3.11 below.
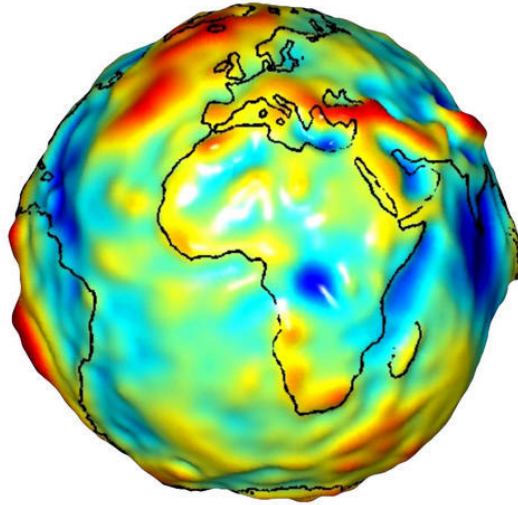
Figure 3.11 : The Geoid Model of the GRACE Satellite; Africa and Europe
http://www2.csr.utexas.edu/grace/gallery/gravity/.

3.3.1.3.   GOCE

This is the satellite mission launched by the European Space Agency (ESA) when March 17, 2009. It is the most advanced gravity detection satellite because, developed from the experience gained from other satellite missions. In addition to monitoring the gravitational potential, it has also been used in sea level surveys, oceanography and geophysics. His duty term ended with the end of his fuel as planned on 21 October 2013, and three weeks later, on 11 November 2013, he broke into the earth's atmosphere and burned to death.

The mission control center of GOCE is located in the European Space Operation Center (ESOC) in Darmstadt, Germany. The data download center is located in Kiruna and Svalbard stations in Norway and processing and archiving missions are carried out at ESA's International Observation Center (ESRIN) in Italy [9].

Some of the tasks of the GOCE satellite are as follows;

- To determine gravity field anomalies in 1mGal precision,
- To determine the geoid in of 1-2 cm. precision,

- These targets are obtain than better 100 km.resolution.

The Geoid Model Produced by GOCE shown Figure 3.12 below.
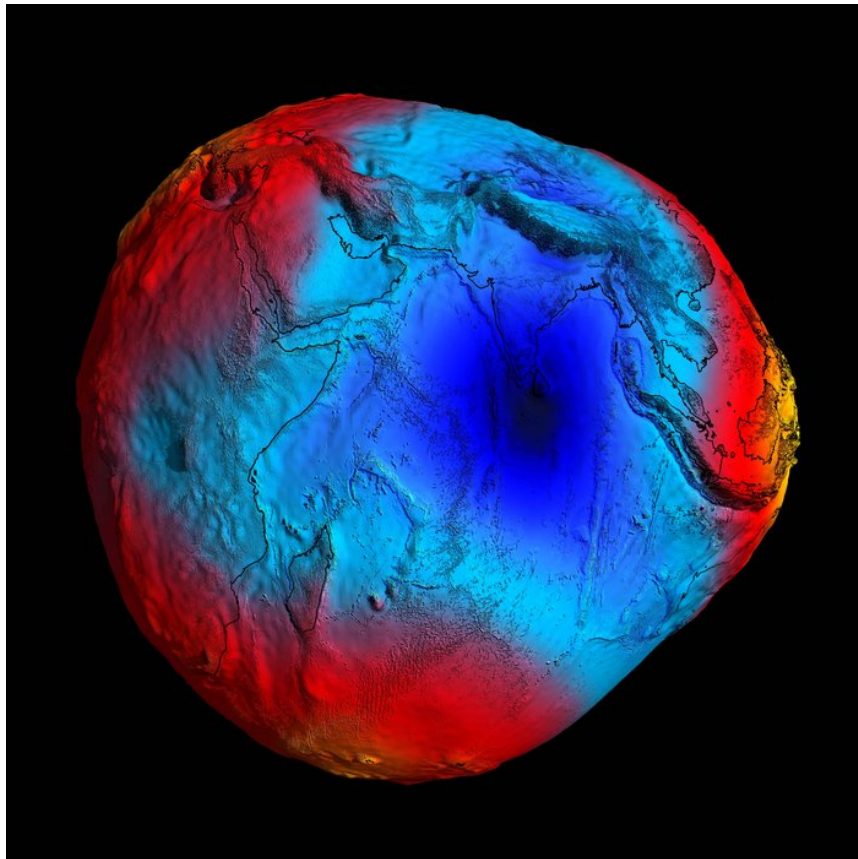
Figure 3.12 : The Geoid Model Produced by GOCE in 2011
https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/goce/news.

The GOCE satellite is fixed at the lowest possible satellite altitude of 250km to detect the strongest gravitational field signal. In 2012, it continued its duty by lowering to 235 km for save fuel. GOCE project has formed the core team of consortium consisting of 41 companies spread across 13 European countries. This industrial core team has shared tasks as follows;

- Satellite Contractor - Thales Alenia Space (Italy)
- Platform Contractor - EADS Astrium GmbH (Germany)
- Gradyometer - Thales Alenia Space (France)
- Accelerometer and System Support - ONERA (France)

4. INTERPOLATION TECHNIQUES

Interpolation techniques; these are the mathematical expressions used to find the desired numerical value for each point within the boundaries of the study area. The geodetic model derived from the main points is tested by various enterpole methods at the test points. In this way most appropriate interpolation method for that region is found.

This study aims to find the most suitable model of the working area used in practice. The aim of the course is to provide many practical examples by utilizing the new geoid determination and interpolation calculation systems such as computer technology. The mobile application will provide the data with the precision needed by the end user in the workspace. Therefore, interpolation techniques used in this section will be summarized [10].

4.1. Interpolation with Radial Based Functions (Multiquadratic, Natural Cubic Spline, Thin Plate Spline)

4.1.1. Multiquadratic interpolation

The aim of this interpolation technique is to express all points in the study area in a single mathematical function. General multiquadratic surface expression;

$$\Delta N = \sum_{i=1}^{m} c_i [Q(x, y, x_i, y_i)]$$

(4.1)

showns as. There c_i is unknown coefficients calculated from the known ΔNi residual heights of the base points, Q(x,y,x$_i$,y$_i$) is kernel function [11].

4.1.2. Natural cubic spline interpolation

This model, which is a type of interpolation with polynomials, is applied using the cubic surface mathematical models. Changes in the variable number and unknown degree of the polynomial vary depending on the physical conditions in the study area [11].

4.1.3. Thin plate spline interpolation

The most important feature of this function is the softening of the angles at the breaking points of the lines while the surface is formed. This provide smoother surface. Because of this feature, it is also used frequently in different disciplines [11]. The mathematical expression is;

$$I[f(x,y)] = \iint_{R^2} \left(f_{xx}^2 + 2f_{xy}^2 + f_{yy}^2 \right) dx dy \tag{4.2}$$

The interested reader can read Inal (2002) for more information.

4.2. Interpolation with Polynomials

In this method, the study area is generally defined by two-variable high-grade polynomials. General orthogonal polynomial expression is;

$$N(X,Y) = \sum_{\substack{k=0 \\ i=0}}^{n} \sum_{j=k-i}^{k} a_{ij} x^i y^j \tag{4.3}$$

shown as. Here is a_{ij}: polynomial coefficients, n; polynomial degree, x,y; plane coordinates. n=1 equation the surface becomes linear, n=2 equation the surface becomes quadratic, n=3 equation the surface becomes cubic. Quadratic surface;

$$N(x,y) = a_0 + a_1 y + a_2 x + a_3 x^2 + a_4 xy + a_5 y^2 \tag{4.4}$$

equality is expressed with a polynomial of 6 unknowns. Cubic surface;

$$N(x, y) = a_0 + a_1y + a_2x + a_3x^2 + a_4xy + a_5y^2 + a_6x^3 + a_7x^2y \quad (4.5)$$
$$+ a_8xy^2 + a_9y^3$$

it is expressed with a polynomial of 10 unknowns with this equality. Non-orthogonal general polynomial expression;

$$N(X, Y) = \sum_{i=0}^{n} \sum_{j=0}^{n} a_{ij}x^iy^i \quad (4.6)$$

showns as. n=1 equation the surface becomes bi-linear, n=2 equation the surface becomes bi-quadratic, n=3 equation the surface becomes bi-cubic. Bi-quadratic surface is

$$N(x, y) = a_0 + a_1y + a_2x + a_3x^2 + a_4xy + a_5y^2 + a_6x^2y + a_7y^2x \quad (4.7)$$
$$+ a_8x^2y^2$$

It is expressed with a polynomial of 9 unknowns with this equality. Bi-cubic surface;

$$N(x, y) = a_0 + a_1y + a_2x + a_3xy + a_4y^2 + a_5xy^2 + a_6x^2 + a_7x^2y \quad (4.8)$$
$$+ a_8x^2y^2 + a_9y^3 + a_{10}xy^3 + a_{11}x^2y^3 + a_{12}x^3 + a_{13}x^3y$$
$$+ a_{14}x^3y^2 + a_{15}x^3y^3$$

It is expressed with a polynomial of 16 unknowns with this equality [11].

4.3. Interpolation with Weighted Average Method

Considering that there are n points in the study area, geoitic undulation in other points;

$$P_i = \frac{1}{D^k} \quad (4.9)$$

to be;

$$N = \frac{\sum_{i=0}^{n} N_iP_i}{\sum_{i=0}^{n} Pi} \quad (4.10)$$

calculates with this equations. Here is D_i ; Length between the point which determinate geoid undulations and the i base point, k ; is the integer. As the k value grows, new points geoid undulation is affected more than the the neighboring points. This converts the solution to the nearest neighboring interpolation method [11].

4.4. Interpolation with Kriging Method

This is a linear interpolation model found by a South African mining engineer D.G. Krige. The purpose of development is to determine the mineral deposits more accurately. The basic principle is to estimate the optimum value from the data of the closest base points to the point where the data is to be produced [10].

5. APPLICATION

5.1. Aim and Scope

The selected area is the region covering the İzmir Metropolitan Area. The height information is needed for land management, infrastructure and engineering works such as construction and road projects in the city. This should be done accurately, quickly and reliably from advanced technological tools like satellite-based positioning systems. In addition to this practical objective, the main objective of the project is to determine the most appropriate geoid model and interpolation method for Izmir Metropolitan Area by applying the methods described above. One of the aims of this study is to produce a self-updating program with new systems produced from gravimetric satellite missions.

5.2. Method and Material

This study was carried out with 19 base points and 30 test points in the study area covering 200 km^2 part of Izmir city center. The orthometric heights of the base points and test points were calculated by leveling measurement as described in BÖHHBÜY, and ellipsoidal heights were determined by GNSS measurements. Using the GNSS / Leveling method, geoid undulations are calculated from the difference between the orthometric heights and the ellipsoidal heights. The distribution of points for the study area is shown in Figure 5.1.
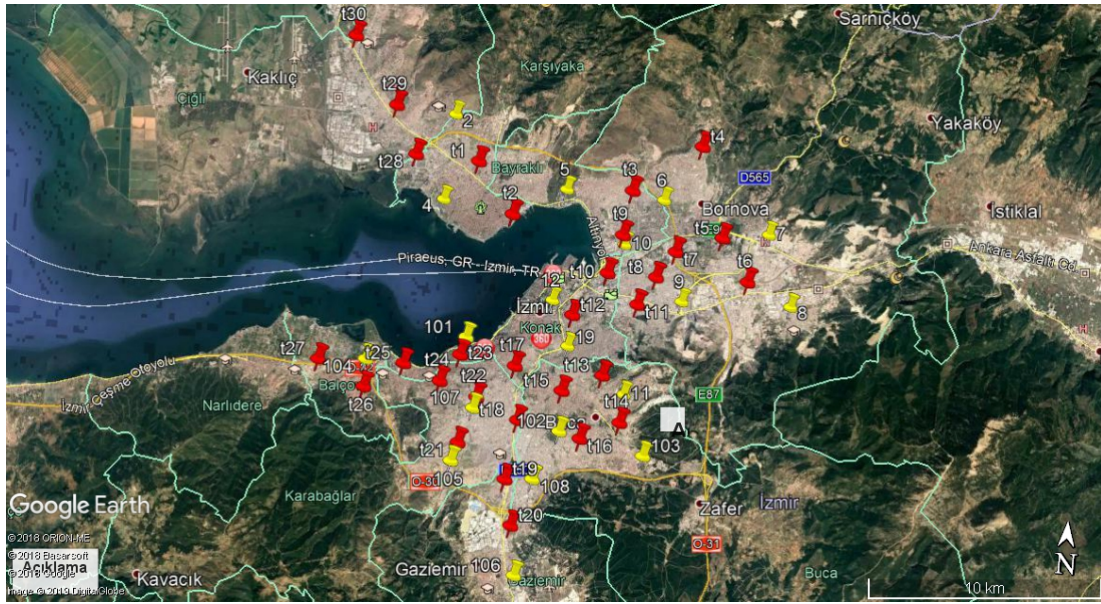
Figure 5.1 : Locations of Base and Test Points.

Various interpolation techniques have been tested. Surfer13 program was used in these calculations. Before entering the needed data into the program, an Excel file that includes the easting, northing and geoid undulation values of the numbered base points has been created. Figure 5.2 shows the created Excel file.

Figure 5.2 : Surfer Data File Excel Format.

Then, opening the Surfer 13 program and entering the Data section from the Grid tab, the Excel file prepared for base points has been loaded to the program, shown in Figure 5.3.
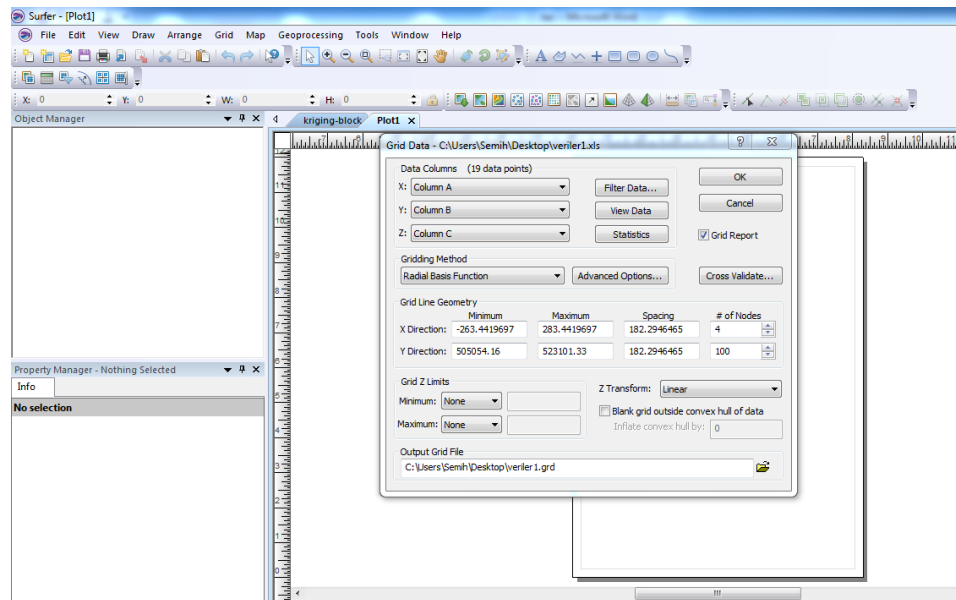
Figure 5.3 : Surfer13 Grid Selection Screen.

Grid method is selected from the incoming grid selection screen window to be applied to the project. For this project Kriging-point, Kriging-block, Radial Base-Multiquadratic, Radial Base - Thin Plate, Radial Base - Natural Cubic Spline, Local Polynomal, Natural Neighbor, Nearest Neighbor methods were used. After selecting the method, the program has been executed and the Grid Data Report has been created, shown in Figure 5.4.
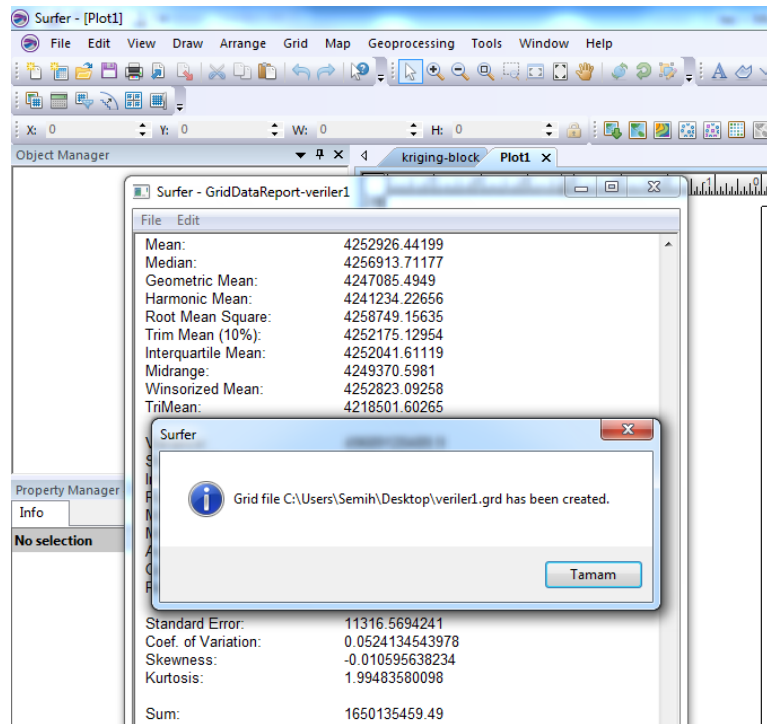
Figure 5.4 : Surfer13 Data Report Screenshot.

In this report, the number of base points, easting and northing coordinate values, median, variance, standard deviation, and more information are available.

Then, the calculation step is proceeded for the geoid undulation values. To do so, the Grid tab is clicked. Firstly, we will be asked to save the grid file. Once the grid file has been selected, the data file in Excel format must be prepared for the test points, including the point number, easting value, northing value, and height information, like base points. The Residuals command will ask us for the file that contains the information of the test points. After uploading this file to the program, a window will appear to confirm the columns of the information shown in Figure 5.5 below.
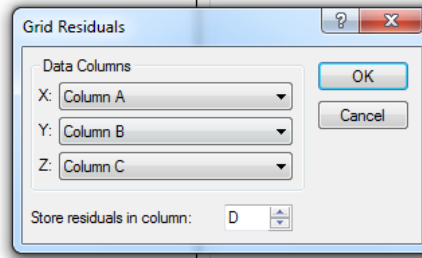
Figure 5.5 : Surfer13 Column Selection Window.

Here the X coordinate, Y coordinate and Z coordinate containing the column and finally the desired data to be written to the column is selected and press OK. Z height values calculated with the grid selected for the test points on the incoming information screen are created as printed on the selected column shown in Figure 5.6.

Figure 5.6 : Surfer13 Test Points Result Screen.

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5.3. Numerical Data

The Gauss Kruger coordinates (X and Y), orthometric heights(H), ellipsoidal heights(h) and the geoid undulation(N) of the points in the study area shown in table 5.1 below.

Table 5.1 : Numerical Data.

Point	Y	X	Orthometric Height(H)	Ellipsoidal Height(h)	Undulation (N)
2	508019.79	4262166.33	85.41	123.84	38.43
4	507810.35	4258527.77	1.24	39.26	38.02
5	513068.19	4259408.69	2.56	41.03	38.47
6	517279.17	4259315.49	16.33	54.68	38.35
7	521906.16	4258230.99	55.05	94.07	39.02
8	523101.33	4255235.83	59.78	98.16	38.38
9	518412.97	4255048.14	26.50	64.75	38.25
10	515748.35	4257276.88	2.75	40.67	37.92
11	516263.37	4250877.94	174.89	213.36	38.47
12	512863.26	4254628.63	7.69	45.14	37.45
19	513689.83	4252724.24	68.93	107.21	38.28
102	513640.23	4249031.07	70.41	108.63	38.22
103	517327.22	4248285.64	165.30	203.61	38.31
108	512670.29	4246873.41	98.49	136.58	38.09
101	509290.88	4252668.17	12.27	50.32	38.05
107	509854.67	4249686.07	150.97	188.98	38.01
105	509103.32	4247355.66	126.92	165.56	38.64
106	512239.56	4242705.56	133.50	171.53	38.03
104	505054.16	4251358.79	23.02	61.61	38.59
T1	509165.74	4260231.49	17.45	55.80	38.35
T2	510817.97	4258098.24	1.83	39.90	38.07
T3	515887.83	4259554.73	10.22	48.74	38.52
T4	518694.27	4261665.11	290.89	329.74	38.85
T5	519923.31	4257873.76	33.32	71.84	38.52
T6	521165.95	4256085.41	40.73	79.20	38.47
T7	517967.56	4257107.43	15.49	53.77	38.28
T8	517219.70	4255953.22	11.72	49.79	38.07
T9	515637.89	4257624.07	2.78	40.71	37.93
T10	515117.46	4255950.55	4.96	42.89	37.93
T11	516513.39	4254708.15	17.80	55.96	38.16
T12	513764.58	4254020.41	16.07	53.96	37.89
T13	515275.52	4251562.72	155.59	194.15	38.56
T14	516197.39	4249612.17	114.90	152.92	38.02

Table 5.1 (Continuation) : Numerical Data.				
T15	513597.35	4250751.93	77.01	115.37	38.36
T16	514554.61	4248774.07	85.42	123.68	38.26
T17	511495.56	4251629.03	92.02	130.16	38.14
T18	511800.39	4249327.47	63.85	102.03	38.18
T19	511490.95	4246763.95	96.40	134.59	38.19
T20	511915.75	4244816.68	122.01	160.23	38.22
T21	509350.88	4248153.39	108.93	147.32	38.39
T22	509962.95	4250161.96	136.10	174.03	37.93
T23	509101.59	4251902.59	91.80	129.89	38.09
T24	508326.00	4250700.14	78.20	116.46	38.26
T25	506694.36	4251319.91	11.98	50.37	38.39
T26	505077.87	4250181.27	64.60	103.44	38.84
T27	503019.80	4251183.49	31.70	70.13	38.43
T28	506438.81	4260291.11	4.88	43.13	38.25
T29	505430.52	4262318.22	10.77	49.15	38.38
T30	503412.42	4265129.78	9.73	48.26	38.53

The orthometric heights of the test points from the ellipsoidal heights of geoids, which are formed by the abovementioned methods, are calculated by several interpolation methods. The results are shown in the tables in the appendix. The comparisons among used methods have been indicated in Table 5.2, 5.3, and 5.4.

Table 5.2 : Comparison Table Kriging, Radial Base And Nearest Neighbor Methods.

	Kriging (Point)	Kriging (Block)	Radial (Multi-quadratic)	Radial (Natural Cubic Spline)	Radial (Thin Plate)	Nearest Neighbor
Max. Value	38.69	38.69	38.77	39.16	38.98	39.02
Min. Value	37.84	37.84	37.77	37.74	37.75	37.60
Difference	0.85	0.85	1.00	1.42	1.23	1.42

Table 5.3 : Comparison Table Global XGM2016, Tongji Grace02k, SGG-UGM1, EIGEN 6S4 Methods.

	Global XGM2016 WGS84	Global Tongji Grace02k WGS84	Global Tongji Grace02k GRS80	Global SGG-UGM1 WGS84	Global SGG-UGM1 GRS80	Global EIGEN 6S4 WGS84
Data	A, G, S(GOCO05s)	S(GRACE)	S(GRACE)	EGM2008, S(GOCE)	EGM2008, S(GOCE)	S(Goce), S(Grace), S(Lageos)

Table 5.3 (Continuation) : Comparison Table Global XGM2016, Tongji Grace02k, SGG-UGM1, EIGEN 6S4 Methods.						
Max. Value	39.01	38.61	37.68	39.00	38.06	38.99
Min. Value	38.82	38.27	37.34	38.70	37.77	38.68
Difference	0.19	0.34	0.34	0.30	0.39	0.31

Table 5.4 : Comparison Table EIGEN 6S4, Ulux CHAMP2013s, EGM2008, GOSG01s Methods.

	Global EIGEN 6S4 GRS80	Global Ulux-CHAMP2013s WGS84	Global Ulux-CHAMP2013s GRS80	Global EGM2008 WGS84	Global EGM2008 GRS80	Global GOSG01s WGS84
Data	S(Goce), S(Grace), S(Lageos)	S(Champ)	S(Champ)	A, G, S(Grace)	A, G, S(Grace)	S(GOCE)
Max. Value	38.06	38.80	37.87	39.12	38.18	39.20
Min. Value	37.75	38.46	37.53	38.83	37.90	38.86
Difference	0.31	0.34	0.30	0.29	0.28	0.34

As seen, there are differences between models produced with global geopotantial systems and models produced locally. While global systems show a harmonious gap, the difference between local systems is higher. This is because the global systems are close to each other with reference measurements based on the altimeter, gravimetric measurement and satellite measurements. It is seen that the reference system used in global methods is different in different cases such as WGS84 and GRS80. This difference ranges from around 1 m which cannot be considered as fixed. The chosen interpolation method in local also depends on the topographic and physical structure of the study area. For this reason, changes in different sizes can be observed between global and local models. There are 0.19-0.39 m differences between the global models used in this study. Differences between the local models used ranged from 0.85 to 1.42 m. With all this information, it is seen that Thin Plate Spline method is the most appropriate value for study area. This method is preferred to give the closest values to the true values of the test points. The test results of the Thin Plate Spline method are shared appendix chapter.

As can be easily seen from the data shared in the tables and reports above, the Thin Plate Spline method has clearly produced more favorable results than others. As the results of these techniques are directly related to the physical conditions of the study area, it is observed that different techniques are successful in different fields of study. The surface drawings of the data points of these data are shown in appendix. The 3D drawings created from these surfaces are also shown in appendix.

5.4. Comparison and Analysis

When all interpolation techniques are compared, it is seen that Thin Plate Spline function which is radial based function is the most suitable model for the study area. In addition, the results on the multi-quadratic and cubic surfaces are still close to the Thin Plate function and they are within the available limits. Test points 27,29 and 30 are excluded from the triangular pattern of the base points and no function can be estimated for these points.

5.5. Mobile Application Database

It is concluded that the Thin Plate Spline model produces the most suitable results in the results of many mathematical models used in İzmir Metropolitan Area. The reliability of the anchor points within this area will depend on the sensitivity of the ground control points and satellite-based positioning systems. These points can be used for the same precision work. The coordinate entered in the mobile application can be either a geographical or cartesian coordinate or an error message if it is outside the triangle areas.

For coordinate inquires in the working area boundaries, the program will run the loop according to the Thin Plate Spline mathematical model for the desired point. After that program provide geoid undulation value for the desired point. In the future, if the physical changes in the selected area, the data of the new baselines, and the ellipsoidal data are collected, the program will be updated and the user will produce up-to-date data.

6. RESULTS AND RECOMMENDATIONS

In our country, as in the rest of the world, the need for accurate and reliable measurement of the need for Surveying Engineering and related sectors is so needed. This situation obliges the sector to compete in itself, to make use of new technologies as much as possible, and to produce joint projects with other engineering disciplines and sciences.

One of the steps taken in this situation is the development of mathematical models which convert the height information obtained from the satellite-based measurements in the project into the heights used in the practice. With the help of this technology, orthometric height need to be used in all kinds of applications can be integrated with satellite based measurements. In a much shorter time, the position information in the horizontal plane can be reached by using the satellite-based measurement without the need for precise leveling. This is a valuable development for the sector in terms of saving workload, time and manpower. In our profession, researches should be done in the production of fast and easily controllable data with the convenience of technology. Work should be carried out to achieve better, qualified and useful information through studies in which not only the sector or the scientific discipline, but also the disciplinary and technical unity of various disciplines.

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APPENDIX

Numerical Data of Using Kriging and Radial Methods for Application

Table A1 : Kriging and Radial Methods

NN	Y	X	Kriging (Point)	Kriging (Block)	Radial-Multiquadratic	True Value
T1	509165.74	4260231.49	38.25	38.25	38.26	38.35
T2	510817.97	4258098.24	38.06	38.06	38.02	38.07
T3	515887.83	4259554.73	38.32	38.32	38.33	38.52
T4	518694.27	4261665.11	38.69	38.69	38.77	38.85
T5	519923.31	4257873.76	38.63	38.63	38.68	38.52
T6	521165.95	4256085.41	38.55	38.55	38.55	38.47
T7	517967.56	4257107.43	38.26	38.26	38.24	38.28
T8	517219.70	4255953.22	38.12	38.12	38.09	38.07
T9	515637.89	4257624.07	37.98	37.98	37.96	37.93
T10	515117.46	4255950.55	37.87	37.87	37.77	37.93
T11	516513.39	4254708.15	38.09	38.09	38.08	38.16
T12	513764.58	4254020.41	37.84	37.84	37.81	37.89
T13	515275.52	4251562.72	38.37	38.37	38.48	38.56
T14	516197.39	4249612.17	38.38	38.38	38.40	38.02
T15	513597.35	4250751.93	38.26	38.26	38.35	38.36
T16	514554.61	4248774.07	38.26	38.26	38.26	38.26
T17	511495.56	4251629.03	38.03	38.03	38.03	38.14
T18	511800.39	4249327.47	38.13	38.13	38.08	38.18
T19	511490.95	4246763.95	38.22	38.22	38.22	38.19
T20	511915.75	4244816.68	38.15	38.15	38.14	38.22
T21	509350.88	4248153.39	38.43	38.43	38.44	38.39
T22	509962.95	4250161.96	38.02	38.02	37.97	37.93
T23	509101.59	4251902.59	38.09	38.09	38.08	38.09
T24	508326.00	4250700.14	38.22	38.22	38.20	38.26
T25	506694.36	4251319.91	38.39	38.39	38.42	38.39
T26	505077.87	4250181.27	38.58	38.58	38.64	38.84
T27	503019.80	4251183.49				38.43
T28	506438.81	4260291.11	38.26	38.26	38.23	38.25
T29	505430.52	4262318.22				38.38
T30	503412.42	4265129.78				38.53

Numerical Data of Using Radial and Nearest Neighbor Methods for Application

Table A2 : Radial and Nearest Neighbor Methods

NN	Y	X	Radial-Natural Cubic Spline	Radial-Thin Plate	Nearest Neighbor	Measured Value
T1	509165.74	4260231.49	38.33	38.28	38.08	38.35
T2	510817.97	4258098.24	37.93	37.97	38.47	38.07
T3	515887.83	4259554.73	38.39	38.36	38.35	38.52
T4	518694.27	4261665.11	39.16	38.98	38.35	38.85
T5	519923.31	4257873.76	38.59	38.65	39.02	38.52
T6	521165.95	4256085.41	38.50	38.53	38.42	38.47
T7	517967.56	4257107.43	38.18	38.21	38.22	38.28
T8	517219.70	4255953.22	38.08	38.08	38.25	38.07
T9	515637.89	4257624.07	37.96	37.96	37.92	37.93
T10	515117.46	4255950.55	37.74	37.75	37.92	37.93
T11	516513.39	4254708.15	38.11	38.08	38.25	38.16
T12	513764.58	4254020.41	37.82	37.81	37.60	37.89
T13	515275.52	4251562.72	38.52	38.50	38.47	38.56
T14	516197.39	4249612.17	38.41	38.41	38.47	38.02
T15	513597.35	4250751.93	38.41	38.38	38.22	38.36
T16	514554.61	4248774.07	38.27	38.27	38.22	38.26
T17	511495.56	4251629.03	38.06	38.04	38.24	38.14
T18	511800.39	4249327.47	38.05	38.06	38.13	38.18
T19	511490.95	4246763.95	38.22	38.22	38.09	38.19
T20	511915.75	4244816.68	38.21	38.17	38.07	38.22
T21	509350.88	4248153.39	38.38	38.41	38.64	38.39
T22	509962.95	4250161.96	37.98	37.97	38.01	37.93
T23	509101.59	4251902.59	38.09	38.09	38.05	38.09
T24	508326.00	4250700.14	38.19	38.19	38.01	38.26
T25	506694.36	4251319.91	38.40	38.41	38.59	38.39
T26	505077.87	4250181.27	38.77	38.71	38.59	38.84
T27	503019.80	4251183.49				38.43
T28	506438.81	4260291.11	38.08	38.19	38.02	38.25
T29	505430.52	4262318.22				38.38
T30	503412.42	4265129.78				38.53

Numerical Data of Using Global XGM and Tongji Grace02k Methods for Application

Table A3 : Global XGM and Tongji Grace02k Methods

NN	Y	X	Global XGM 2016 WGS84	Global Tongji Grace02k WGS84	Global Tongji Grace02k GRS80	Measured Value
T1	509165.74	4260231.49	38.97	38.51	37.58	38.35
T2	510817.97	4258098.24	38.95	38.47	37.54	38.07
T3	515887.83	4259554.73	38.98	38.48	37.55	38.52
T4	518694.27	4261665.11	39.01	38.51	37.58	38.85
T5	519923.31	4257873.76	38.97	38.45	37.52	38.52
T6	521165.95	4256085.41	38.94	38.41	37.49	38.47
T7	517967.56	4257107.43	38.95	38.44	37.51	38.28
T8	517219.70	4255953.22	38.95	38.42	37.49	38.07
T9	515637.89	4257624.07	38.96	38.45	37.52	37.93
T10	515117.46	4255950.55	38.94	38.42	37.50	37.93
T11	516513.39	4254708.15	38.93	38.40	37.47	38.16
T12	513764.58	4254020.41	38.92	38.40	37.47	37.89
T13	515275.52	4251562.72	38.89	38.36	37.43	38.56
T14	516197.39	4249612.17	38.87	38.33	37.40	38.02
T15	513597.35	4250751.93	38.88	38.35	37.42	38.36
T16	514554.61	4248774.07	38.86	38.32	37.39	38.26
T17	511495.56	4251629.03	38.88	38.37	37.44	38.14
T18	511800.39	4249327.47	38.86	38.34	37.40	38.18
T19	511490.95	4246763.95	38.83	38.30	37.37	38.19
T20	511915.75	4244816.68	38.82	38.27	37.34	38.22
T21	509350.88	4248153.39	38.85	38.32	37.40	38.39
T22	509962.95	4250161.96	38.87	38.35	37.42	37.93
T23	509101.59	4251902.59	38.88	38.38	37.45	38.09
T24	508326.00	4250700.14	38.87	38.37	37.44	38.26
T25	506694.36	4251319.91	38.87	38.38	37.45	38.39
T26	505077.87	4250181.27	38.97	38.37	37.44	38.84
T27	503019.80	4251183.49	38.98	38.39	37.46	38.43
T28	506438.81	4260291.11	39.01	38.52	37.59	38.25
T29	505430.52	4262318.22	38.87	38.55	37.62	38.38
T30	503412.42	4265129.78	38.91	38.61	37.68	38.53

Numerical Data of Using Global SGG-UGM1 and EIGEN 6S4 Methods for Application

Table A4 : Global SGG-UGM1 and EIGEN 6S4 Methods

NN	Y	X	Global SGG-UGM1 WGS84	Global SGG-UGM1 GRS80	Global EIGEN 6S4 WGS84	Measured Value
T1	509165.74	4260231.49	38.87	37.94	38.89	38.35
T2	510817.97	4258098.24	38.81	37.88	38.85	38.07
T3	515887.83	4259554.73	38.89	37.96	38.81	38.52
T4	518694.27	4261665.11	39.00	38.06	38.80	38.85
T5	519923.31	4257873.76	38.88	37.95	38.76	38.52
T6	521165.95	4256085.41	38.86	37.93	38.73	38.47
T7	517967.56	4257107.43	38.83	37.90	38.77	38.28
T8	517219.70	4255953.22	38.79	37.86	38.76	38.07
T9	515637.89	4257624.07	38.82	37.89	38.80	37.93
T10	515117.46	4255950.55	38.77	37.83	38.78	37.93
T11	516513.39	4254708.15	38.75	37.83	38.76	38.16
T12	513764.58	4254020.41	38.72	37.79	38.78	37.89
T13	515275.52	4251562.72	38.71	37.78	38.74	38.56
T14	516197.39	4249612.17	38.71	37.78	38.70	38.02
T15	513597.35	4250751.93	38.70	37.77	38.74	38.36
T16	514554.61	4248774.07	38.70	37.77	38.71	38.26
T17	511495.56	4251629.03	38.71	37.78	38.77	38.14
T18	511800.39	4249327.47	38.72	37.78	38.74	38.18
T19	511490.95	4246763.95	38.73	37.80	38.71	38.19
T20	511915.75	4244816.68	38.73	37.79	38.68	38.22
T21	509350.88	4248153.39	38.78	37.84	38.75	38.39
T22	509962.95	4250161.96	38.74	37.81	38.77	37.93
T23	509101.59	4251902.59	38.75	37.81	38.80	38.09
T24	508326.00	4250700.14	38.78	37.85	38.79	38.26
T25	506694.36	4251319.91	38.81	37.88	38.82	38.39
T26	505077.87	4250181.27	38.87	37.94	38.82	38.84
T27	503019.80	4251183.49	38.90	37.96	38.85	38.43
T28	506438.81	4260291.11	38.85	37.92	38.92	38.25
T29	505430.52	4262318.22	38.88	37.95	38.95	38.38
T30	503412.42	4265129.78	38.90	37.96	38.99	38.53

Numerical Data of Using Global EIGEN 6S4 and ULux CHAMP2013s Methods for Application

Table A5 : Global EIGEN 6S4 and ULux CHAMP2013s Methods

NN	Y	X	Global EIGEN 6S4 GRS80	Global Ulux-CHAMP2013s WGS84	Global Ulux-CHAMP2013s GRS80	Measured Value
T1	509165.74	4260231.49	37.95	38.72	37.79	38.35
T2	510817.97	4258098.24	37.92	38.68	37.75	38.07
T3	515887.83	4259554.73	37.88	38.70	37.77	38.52
T4	518694.27	4261665.11	37.87	38.74	37.80	38.85
T5	519923.31	4257873.76	37.83	38.68	37.74	38.52
T6	521165.95	4256085.41	37.80	38.65	37.71	38.47
T7	517967.56	4257107.43	37.84	38.66	37.73	38.28
T8	517219.70	4255953.22	37.83	38.65	37.71	38.07
T9	515637.89	4257624.07	37.86	38.67	37.74	37.93
T10	515117.46	4255950.55	37.85	38.65	37.71	37.93
T11	516513.39	4254708.15	37.83	38.63	37.69	38.16
T12	513764.58	4254020.41	37.84	38.62	37.68	37.89
T13	515275.52	4251562.72	37.80	38.57	37.64	38.56
T14	516197.39	4249612.17	37.77	38.54	37.61	38.02
T15	513597.35	4250751.93	37.81	38.56	37.63	38.36
T16	514554.61	4248774.07	37.78	38.53	37.60	38.26
T17	511495.56	4251629.03	37.84	38.58	37.65	38.14
T18	511800.39	4249327.47	37.81	38.54	37.61	38.18
T19	511490.95	4246763.95	37.78	38.50	37.57	38.19
T20	511915.75	4244816.68	37.75	38.46	37.53	38.22
T21	509350.88	4248153.39	37.82	38.53	37.59	38.39
T22	509962.95	4250161.96	37.84	38.56	37.63	37.93
T23	509101.59	4251902.59	37.87	38.59	37.66	38.09
T24	508326.00	4250700.14	37.86	38.57	37.64	38.26
T25	506694.36	4251319.91	37.88	38.58	37.65	38.39
T26	505077.87	4250181.27	37.89	38.57	37.64	38.84
T27	503019.80	4251183.49	37.92	38.59	37.66	38.43
T28	506438.81	4260291.11	37.98	38.72	37.80	38.25
T29	505430.52	4262318.22	38.01	38.76	37.82	38.38
T30	503412.42	4265129.78	38.06	38.80	37.87	38.53

**Numerical Data of Using Global EGM2008 and GOSG01s Methods for
Application**

Table A6 : Global EGM2008 and GOSG01s Methods

NN	Y	X	Global EGM2008 WGS84	Global EGM2008 GRS80	Global GOSG01s WGS84	Measured Value
T1	509165.74	4260231.49	39.01	38.08	39.12	38.35
T2	510817.97	4258098.24	38.95	38.02	39.09	38.07
T3	515887.83	4259554.73	39.02	38.09	39.10	38.52
T4	518694.27	4261665.11	39.12	38.18	39.12	38.85
T5	519923.31	4257873.76	39.00	38.06	39.06	38.52
T6	521165.95	4256085.41	38.98	38.04	39.03	38.47
T7	517967.56	4257107.43	38.95	38.02	39.06	38.28
T8	517219.70	4255953.22	38.92	37.98	39.04	38.07
T9	515637.89	4257624.07	38.95	38.02	39.07	37.93
T10	515117.46	4255950.55	38.90	37.97	39.05	37.93
T11	516513.39	4254708.15	38.88	37.95	39.03	38.16
T12	513764.58	4254020.41	38.85	37.92	39.02	37.89
T13	515275.52	4251562.72	38.84	37.91	38.98	38.56
T14	516197.39	4249612.17	38.84	37.91	38.95	38.02
T15	513597.35	4250751.93	38.83	37.90	38.97	38.36
T16	514554.61	4248774.07	38.83	37.90	38.93	38.26
T17	511495.56	4251629.03	38.85	37.92	38.98	38.14
T18	511800.39	4249327.47	38.85	37.92	38.95	38.18
T19	511490.95	4246763.95	38.87	37.94	38.90	38.19
T20	511915.75	4244816.68	38.86	37.93	38.86	38.22
T21	509350.88	4248153.39	38.92	37.98	38.93	38.39
T22	509962.95	4250161.96	38.88	37.95	38.96	37.93
T23	509101.59	4251902.59	38.89	37.96	38.99	38.09
T24	508326.00	4250700.14	38.92	37.98	38.97	38.26
T25	506694.36	4251319.91	38.95	38.02	38.98	38.39
T26	505077.87	4250181.27	39.01	38.08	38.96	38.84
T27	503019.80	4251183.49	39.04	38.11	38.98	38.43
T28	506438.81	4260291.11	39.00	38.06	39.12	38.25
T29	505430.52	4262318.22	39.02	38.09	39.15	38.38
T30	503412.42	4265129.78	39.04	38.11	39.20	38.53

Gridding Report of Using Thin Plate Spline Methods of Application

Table A7 : Gridding Report

<div style="border:1px solid black">

Gridding Report

</div>

Wed May 15 14:51:12 2019
Elapsed time for gridding: 0.01 seconds

Data Source

Source Data File Name: C:\yl tez\veriler.xlsx (sheet 'dayanak')
X Column: A
Y Column: B
Z Column: C

Filtered Data Counts

Active Data: 19

Original Data: 19
Excluded Data: 0
Deleted Duplicates: 0
Retained Duplicates: 0
Artificial Data: 0
Superseded Data: 0

Exclusion Filtering

Exclusion Filter String: Not In Use

Duplicate Filtering

Duplicate Points to Keep: First
X Duplicate Tolerance: 0.0021
Y Duplicate Tolerance: 0.0023

No duplicate data were found.

Breakline Filtering

Breakline Filtering: Not In Use

Z Data Transform

Transformation method: Linear (use Z values directly)

No untransformable data were found.

Data Counts

Active Data: 19

Univariate Statistics

_____
_____

	X	Y	Z
Count:	19	19	19
1%-tile:	505054.16	4242705.56	37.45
5%-tile:	505054.16	4242705.56	37.45
10%-tile:	507810.35	4246873.41	37.92
25%-tile:	509290.88	4249031.07	38.03
50%-tile:	513068.19	4252724.24	38.28
75%-tile:	516263.37	4257276.88	38.43
90%-tile:	518412.97	4259315.49	38.59
95%-tile:	521906.16	4259408.69	38.64
99%-tile:	521906.16	4259408.69	38.64
Minimum:	505054.16	4242705.56	37.45
Maximum:	523101.33	4262166.33	39.02
Mean:	513544.373684	4253231.85789	38.2621052632
Median:	513068.19	4252724.24	38.28
Geometric Mean:	513523.111611	4253228.86461	38.2607335497
Harmonic Mean:	513501.882626	4253225.87099	38.2593605938
Root Mean Square:	513565.668365	4253234.85083	38.2634757824
Trim Mean (10%):	N/A	N/A	N/A
Interquartile Mean:	512932.863	4252853.576	38.239
Midrange:	514077.745	4252435.945	38.235
Winsorized Mean:	513258.828421	4253296.26895	38.2615789474
TriMean:	512922.6575	4252939.1075	38.255
Variance:	23087090.6178	26873674.3203	0.110706432749
Standard Deviation:	4804.90276882	5183.98247685	0.332725762075
Interquartile Range:	6972.49	8245.81	0.4
Range:	18047.17	19460.77	1.57
Mean Difference:	5569.65309942	6074.57812866	0.369122807018
Median Abs. Deviation:	3777.31	4438.6	0.19
Average Abs. Deviation:	3708.54473684	4262.97052632	0.243157894737
Quartile Dispersion:	0.00679875296699 0.00523149359142	0.000969375908851	
Relative Mean Diff.:	0.0108455147886 0.00964721633791	0.00142822642443	
Standard Error:	1102.32029488 0.0763325248841	1189.2871443	
Coef. of Variation:	0.00935635363765 0.00869596065838	0.00121883373633	

Skewness:	0.248014722752	-0.134316436029	-0.119131571555
Kurtosis:	2.21030765367	1.97661690856	3.55841622898
Sum:	9757343.1	80811405.3	726.98
Sum Absolute:	9757343.1	80811405.3	726.98
Sum Squares:	5.01124421874e+012	3.43710127229e+014	27817.778
Mean Square:	263749695723	1.80900066963e+013	1464.09357895

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Inter-Variable Covariance

	X	Y	Z
X:	23087091	3833258.7	359.04292
Y:	3833258.7	26873674	259.96935
Z:	359.04292	259.96935	0.11070643

Inter-Variable Correlation

	X	Y	Z
X:	1.000	0.154	0.225
Y:	0.154	1.000	0.151
Z:	0.225	0.151	1.000

Inter-Variable Rank Correlation

	X	Y	Z
X:	1.000	0.153	0.163
Y:	0.153	1.000	0.144
Z:	0.163	0.144	1.000

Principal Component Analysis

	PC1	PC2	PC3
X:	0.849364865998	0.849364865998	-1.42837806726e-005
Y:	-0.527806142767	-0.527806142767	-7.63631803402e-006
Z:	8.10164589152e-006	8.10164589152e-006	-7.63631803402e-006
Lambda:	29255710.0674	20705054.8778	0.103592733803

Planar Regression: Z = AX+BY+C

Fitted Parameters

	A	B	C
Parameter Value:	1.42837806139e-005	7.63631801423e-006	-1.55228096118
Standard Error:	1.69482423719e-005	1.57088989137e-005	66.0365843313

Inter-Parameter Correlations

	A	B	C
A:	1.000	-0.154	0.024
B:	-0.154	1.000	-0.991
C:	0.024	-0.991	1.000

ANOVA Table

Source	df	Sum of Squares	Mean Square	F
Regression:	2	0.128046580528	0.0640232902642	
	0.549358910049			
Residual:	16	1.86466920895	0.116541825559	
Total:	18	1.99271578947		

Coefficient of Multiple Determination (R^2):   0.0642573221956

Nearest Neighbor Statistics

	Separation	|Delta Z|
1%-tile:	2076.03449803	0.04
5%-tile:	2076.03449803	0.04
10%-tile:	2076.03449803	0.06
25%-tile:	2448.53784749	0.16
50%-tile:	2802.10565691	0.43
75%-tile:	3424.59800585	0.63
90%-tile:	3644.5828276	0.64
95%-tile:	4190.04796576	0.83
99%-tile:	4190.04796576	0.83
Minimum:	2076.03449803	0.04
Maximum:	4434.4416044	0.83
Mean:	2988.42322364	0.42
Median:	2802.10565691	0.43
Geometric Mean:	2917.40903388	0.318123148032
Harmonic Mean:	2850.12863907	0.201079325981
Root Mean Square:	3061.62196639	0.486123224578
Trim Mean (10%):	N/A	N/A
Interquartile Mean:	2850.91972222	0.405
Midrange:	3255.23805121	0.435

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Winsorized Mean:	2918.14301759	0.401052631579
TriMean:	2869.33679179	0.4125
Variance:	467458.796014	0.0632444444444
Standard Deviation:	683.709584556	0.251484481518
Interquartile Range:	976.060158362	0.47
Range:	2358.40710637	0.79
Mean Difference:	788.358186601	0.293216374269
Median Abs. Deviation:	436.459808693	0.21
Average Abs. Deviation:	558.701566415	0.204736842105
Quartile Dispersion:	0.166190631842	0.594936708861
Relative Mean Diff.:	0.263804062411	0.69813422445
Standard Error:	156.853736095	0.0576944968845
Coef. of Variation:	0.228786063214	0.598772575043
Skewness:	0.502005864617	-0.0152285810976
Kurtosis:	2.13379219365	1.66560103043
Sum:	56780.0412493	7.98
Sum Absolute:	56780.0412493	7.98
Sum Squares:	178097052.237	4.49
Mean Square:	9373529.06511	0.236315789474

Complete Spatial Randomness

Lambda:	5.40984063561e-008
Clark and Evans:	1.3901585473
Skellam:	60.5370245848

Gridding Rules

Gridding Method:	Radial Basis Function
Basis Kernel Type:	Thin Plate Spline
Shape Factor (R^2):	1.5E+006
Anisotropy Ratio:	0.1
Anisotropy Angle:	0

Search Parameters

No Search (use all data):	true

Output Grid

Grid File Name:	C:\yl tez\veriler.grd
Grid Size:	100 rows x 93 columns
Total Nodes:	9300
Filled Nodes:	9300
Blanked Nodes:	0
Blank Value:	1.70141E+038

Grid Geometry

X Minimum:	505054.16
X Maximum:	523101.33
X Spacing:	196.16489130435
Y Minimum:	4242705.559

| | Y Maximum: | 4262166.33 |
| | Y Spacing: | 196.57344444444 |

Univariate Grid Statistics

	Z
Count:	9300
1%-tile:	36.8073542815
5%-tile:	37.1158689673
10%-tile:	37.4518121551
25%-tile:	37.9444502069
50%-tile:	38.225114617
75%-tile:	38.4872445562
90%-tile:	38.7816768343
95%-tile:	38.9761153524
99%-tile:	39.2736881279
Minimum:	36.7228071675
Maximum:	39.7869520422
Mean:	38.1807549146
Median:	38.2251187809
Geometric Mean:	38.1773047863
Harmonic Mean:	38.1738381424
Root Mean Square:	38.1841887223
Trim Mean (10%):	38.1953693096
Interquartile Mean:	38.2158784231
Midrange:	38.2548796049
Winsorized Mean:	38.1913723453
TriMean:	38.2204809993
Variance:	0.262250727121
Standard Deviation:	0.512104215097
Interquartile Range:	0.5427943493
Range:	3.0641448747
Mean Difference:	0.561063550003
Median Abs. Deviation:	0.272031757205
Average Abs. Deviation:	0.381975777348
Quartile Dispersion:	0.00710169192221
Relative Mean Diff.:	0.0146949307644
Standard Error:	0.00531027333724
Coef. of Variation:	0.0134126267603
Skewness:	-0.494984705685
Kurtosis:	3.59001648248
Sum:	355081.020706
Sum Absolute:	355081.020706
Sum Squares:	13559700.0959
Mean Square:	1458.03226838

2D Drawing of the working area Kriging (Point) Methods
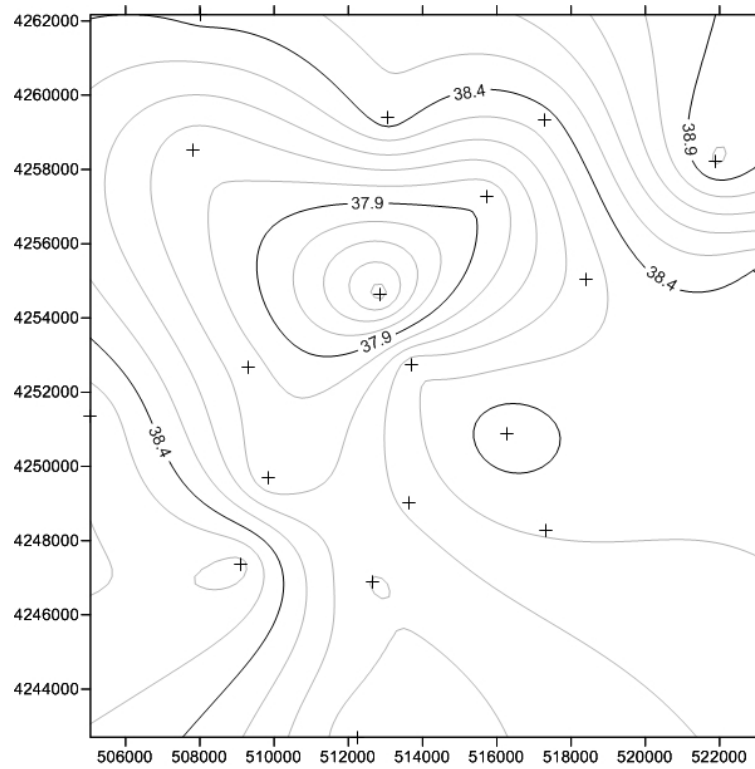
Figure A1 : Kriging (Point).
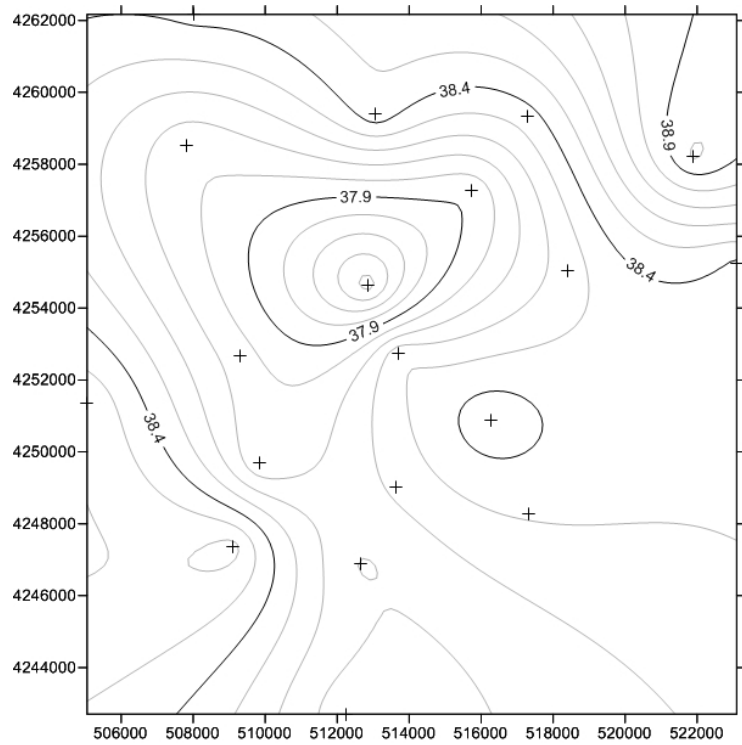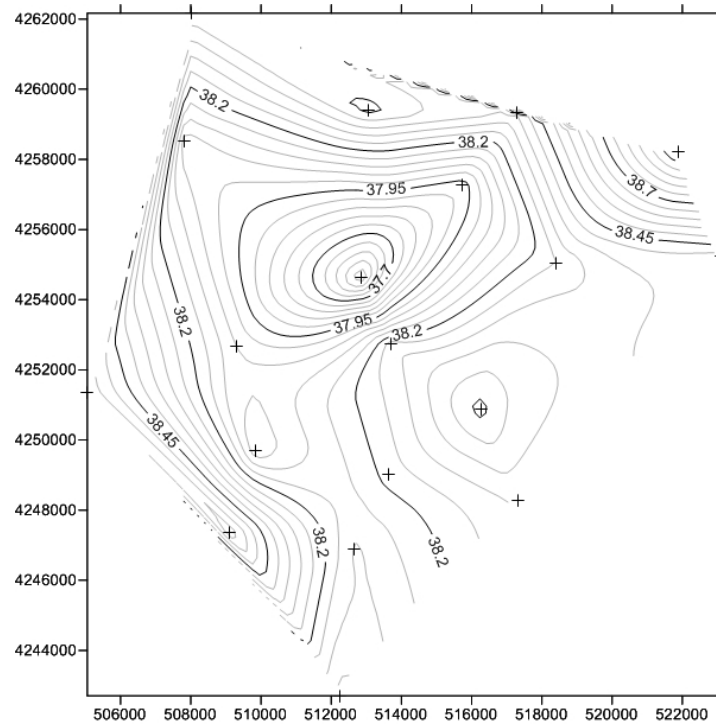
2D Drawing of the working area Kriging (Block) Methods
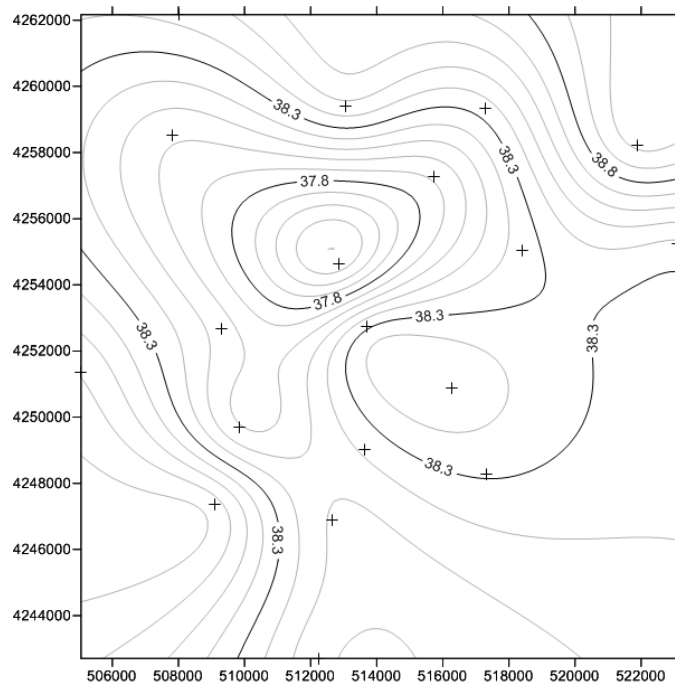

Figure A2 : Kriging (Block).

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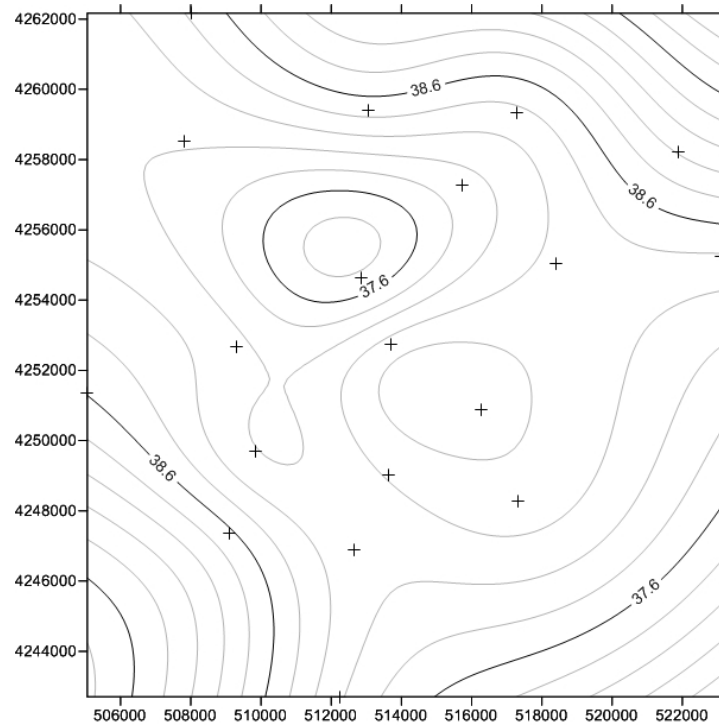**2D Drawing of the working area Nearest Neighbor Methods**

Figure A3 : Nearest Neighbor.

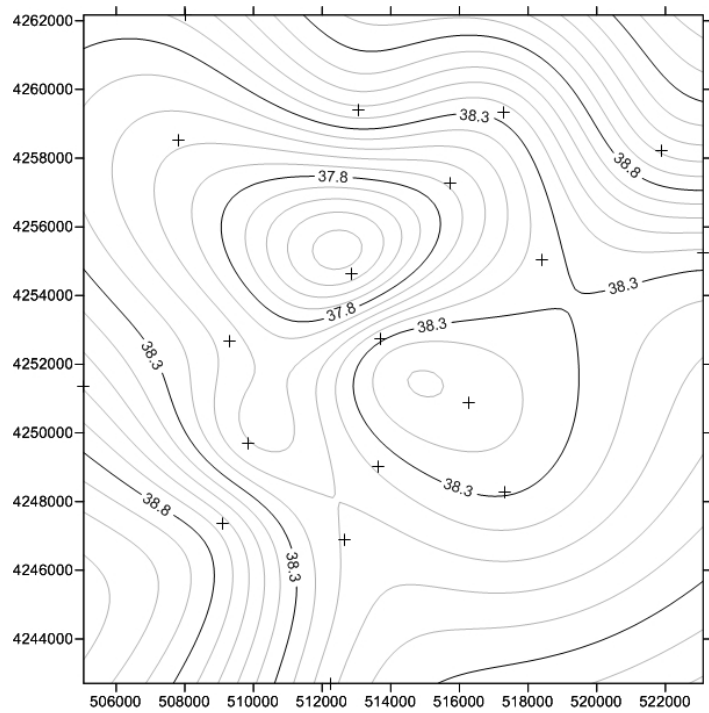**2D Drawing of the working area Radial Base (Multiquadratic) Methods**

Figure A4 : Radial Base (Multiquadratic).

2D Drawing of the working area Radial Base (Natural Cubic Spline) Methods

Figure A5 : Radial Base (Natural Cubic Spline).

2D Drawing of the working area Radial Base (Thin Plate Spline) Methods

Figure A6 : Radial Base (Thin Plate).

3D Drawing of the working area Kriging (Block) Methods
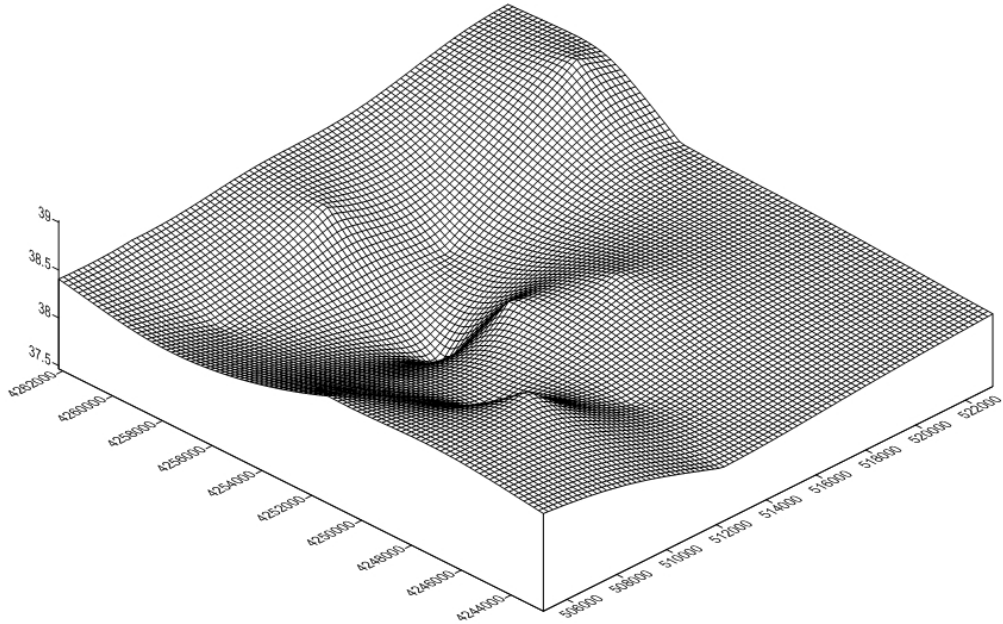
Figure A7 : Kriging (Block) 3D.

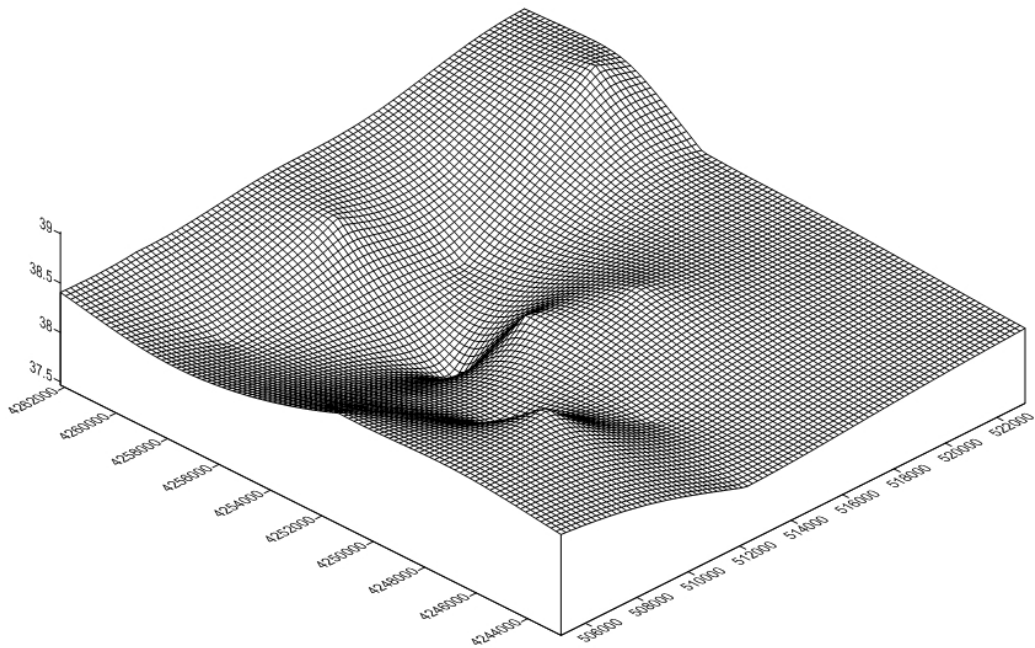**3D Drawing of the working area Kriging (Point) Methods**

Figure A8 : Kriging (Point) 3D.

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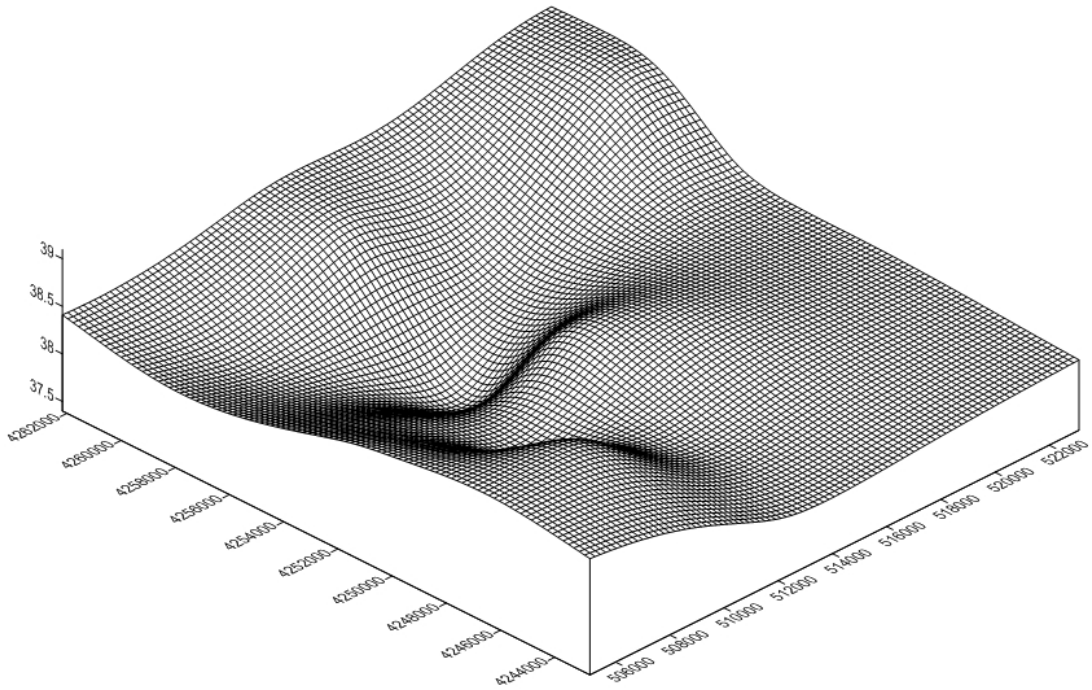**3D Drawing of the working area Radial Base (Multiquadratic) Methods**

Figure A9 : Raidal Base (Multiquadratic) 3D.

3D Drawing of the working area Radial Base (Natural Cubic Spline) Methods
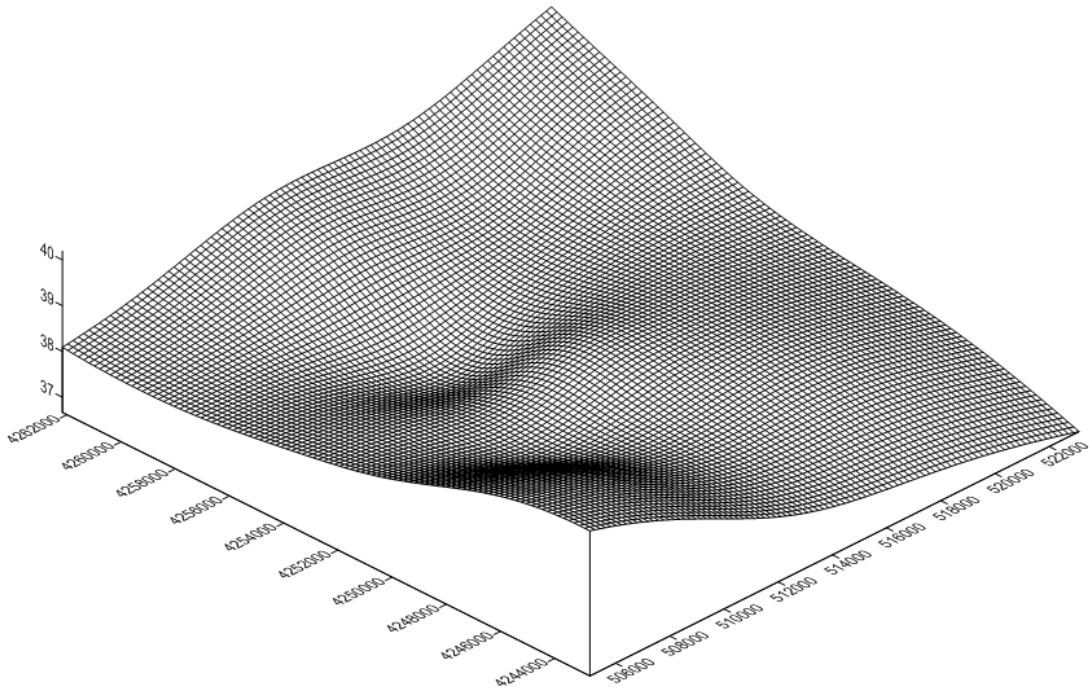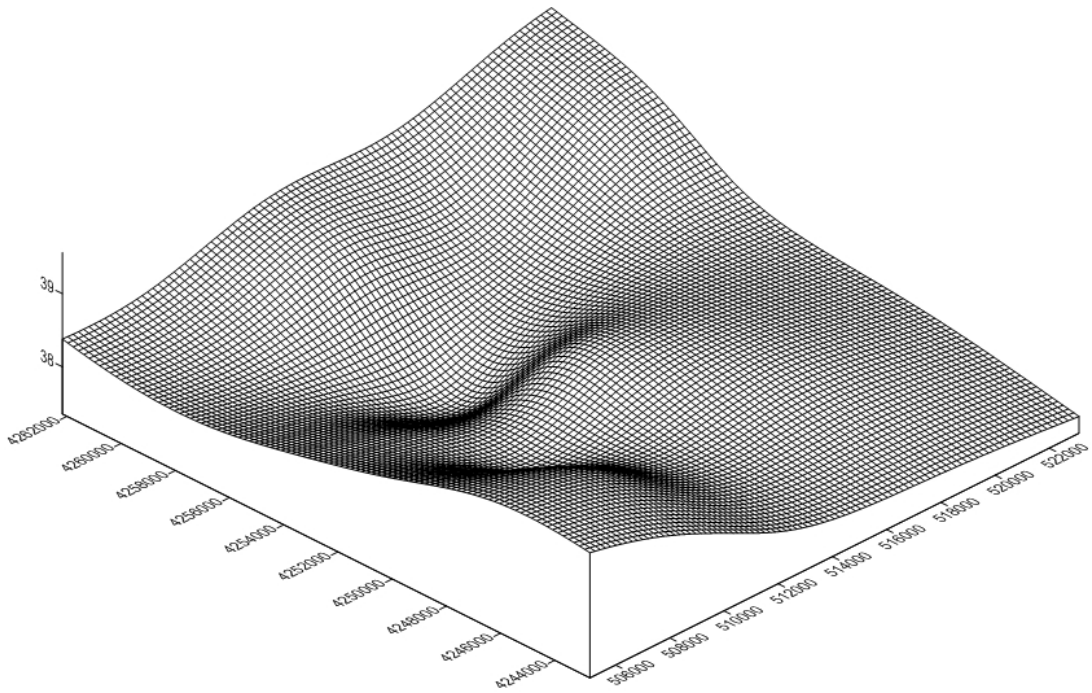

Figure A10 : Radial Base (Natural Cubic Spline) 3D.

3D Drawing of the working area Radial Base (Thin Plate Spline) Methods

Figure A11 : Radial Base (Thin Plate) 3D.

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To improve myself in my professional field, to follow scientific and technological developments, to contribute to the development of the profession.

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