Robustness Assessment of Regional GNSS Geodetic Networks for Precise Applications

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ABSTRACT

Over the past few decades, the surveying fieldworks were usually carried out based on classical positioning methods for establishing horizontal and vertical geodetic networks. However, these conventional positioning techniques have many drawbacks such as time-consuming, too costly, and require massive effort. Thus, the Global Navigation Satellite System (GNSS) has been invented to fulfill the quickness, increase the accuracy, and overcome all the difficulties inherent in almost every surveying fieldwork. This research assesses the accuracy of local geodetic networks using different Global Navigation Satellite System (GNSS) techniques, such as Static, Precise Point Positioning, Post Processing Kinematic, Session method, and finally Real Time Kinematic for different surveying applications. To achieve this assessment, GNSS observations were executed to highlight the characteristics for each GNSS observation technique. Furthermore, the level of accuracy which is gained from each positioning technique is enormously investigated to figure out the amount of allowable error and the suitability for different geodetic applications. In relative positioning, at least two receivers (or more) are required for timing and positioning while the Precise Point Positioning necessitates single receiver. Some of geodetic applications require about positions with centimeter level of accuracy or less. The robust geodetic networks provide accurate positions which in turn serve different earth science applications.

Key words: GNSS, Precise Point Positioning, Geodetic Network, DGPS, ITRF, IGS, CORS

تقييم متانة الشبكات الجيوديسية (GNSS) للتطبيقات الدقيقة

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الخلاصــــــــــــة

خلال العقود الاخيرة، كانت اعمال المسح الحقلي تنجز بالطرق التقليدية لانشاء الشبكات الجيوديسية الافقية والراسية. ألا أن اساليب مسح المواقع التقليدية هذا تتسم بالكثير من السلبيات كأستهلاكها للوقت وحاجتها الى جهد كبير لانجاز العمل الحقلي والحسابي بألاضافة الى الكلفة العالية. ولهذا السبب تم التوجه الى استخدام انظمة التوابع الملاحية العالمية لتعيين المواقع الافقية والرئسية والتي تتسم بزيادة الدقة والتغلب على اغلب الصعوبات المرافقة لاعمال المسح الحقلي. يهدف هذا البحث الى تقييم دقة الشبكات الجيودسية الصغيرة (المحلية) والناتجة من استخدام تقنيات رصد ملاحية مختلفة كالرصد المستمر والرصد النقطي الدقيق والرصد المتحرك والرصد باستخدام عدد من المستلمات المتزامنة. لانجاز هذا التقييم تمت عملية رصد عدد من المواقع حيث تمت عملية تحليل ارصادات GNSS احصائيا لتسليط الضوء على الخصائص لكل من طرق الرصد المستخدمة. بالاضافة الى ذلك فان هذا البحث قيّم مستوى الدقه المتوقع لكل اسلوب رصد لتعين مقدار الخطأ المتوقع والمسموح به في الاحداثيات الافقية والرئسية. فيما يخص اسلوب الرصد التناسبي، فان هذا الاسلوب يتطلّب على الاقل استخدام مستلمات ملاحية عدد 2 لتعين كلا من الموقع والوقت

بشكل دقيق، في حين ان اسلوب الرصد النقطي الدقيق يعمل بمستلم ملاحي واحد ولكن يحتاج الى فترة رصد طويلة. من هذا نجد ان التطبيقات الجيدسية تحتاج الى مستويات مختلفة من الدقة قد تصل الى حدود السنتمترات او اقل من ذلك ولهذا السبب يجب التركيز على دراسة متانة الشبكات الجيودسية لتأسيس مواقع دقيقة لمحطات السيطرة والتي بدورها تخدم التطبيقات العلمية الدقيقة.

الكلمات الرئيسية: متانة الشبكات الجيوديسية، المواقع الجيودسية، الرصد الملاحي

1. INTRODUCTION

In the field of surveying engineering, various definitions of Land Surveying are found. However, the term of Land of Surveying, generally, is defined as a science and technique of precisely observing the distances and angles between stations on the surface of the Earth. Recently, the Global Navigation Satellite System (GNSS) has been widely used by land surveyors since three decades. Consequently, the GNSS is vastly employed for the purpose of determining the positions, velocities, and time. Consequently, the GNSS, in general, has been considered as the main source for the different applications such as agriculture, mapping, public safety, military, monitoring, surveying and geographical information system (GIS), **Bakuła, 2013; Wielgosz et al., 2013; Baryła et al., 2014;Krzan and Przestrzelski , 2016.**

In various field survey actions, there is always desperate need to involve different measurement techniques e.g. GNSS and Total Station. As a result it is important to evaluate the level of accuracy that can be accessible using each positioning technique and gain full understanding the methodology behind each technique. In GNSS relative positioning technique, at least one or more reference (base) stations are needed to determine the unknown positioning, whereas the Precise Point Positioning (PPP) just needs one receiver without base station **Ebner and Featherstone, 2008**, **Abdallahand and Schwieger, 2014.** Some of applications required meter level or centimeter level positioning and this depends on the required accuracy, **Hofmann-Wellenhof et al., 2008.** This research focuses on achieving many goals using GPS and GLONASS. These goals include studying the accuracies of Iraqi CORS stations and assessment different GNSS positioning methods in comparison with Total Station solution.

In the literature on GNSS observations, the relative importance of the accuracy that can be gained from different GNSS positioning techniques has been subjected to considerable discussion. Furthermore, studying the mechanism of GNSS observation methods (field work) together with the procedures of GNSS raw data processing are important for evaluation the level of accuracy and how to mitigate all possible errors involved in the satellites-related errors, receiver-related errors, and signal-related errors.

When using Differential GPS (DGPS) positioning technique, millimeter level accuracy can significantly be obtained due to the reason that some errors can relatively vanished by both of between receiver's difference and between satellites difference. The accuracy of the height component is relatively lower than the accuracy of the horizontal components due to the reason that there is no observations of satellites appear below the horizon. Furthermore, the accuracy of the northern component is slightly better than the eastern component because of the designing of motion of satellites and satellite orbits, **GPS, 2016.**

Generally, double-differences corresponding to between receives difference and between satellites difference are noticeably reduce satellite clock and orbit errors, localized atmospheric errors, and receiver clock errors. Furthermore, triple-differences correspond to between receives difference, between satellites difference, and between time difference is considerably eliminates the effect of integer ambiguities, **Hofmann-Wellenhof et al., 2008.**

The GNSS receivers have their point position referenced for the geodetic world system 1984 (WGS84). The reference system of WGS84 is used for Continuously Operating Reference Station (CORS) stations network. A link for the another reference such as International Terrestrial Reference Frame (ITRF) is created for the CORS network besides that the difference between the WGS84 reference frame system and the ITRF is a few centimetres only. The ITRF reference frame is a realization of an International Terrestrial Reference System (ITRS), which are Cartesian coordinates of Earth centred earth fixed and they are computed at different epochs, **ESA, 2016**. The potential of error sources include the sources of conventional error that frequently required to be handled with PPP, for example the satellite orbit and clock errors, troposphere delays error and ionospheric delay error, **Bidikar et al., 2014**. It is important to mention here that most of these error sources can considerably be mitigated to some extent through modeling processes. The ionospheric delay effect can be reduced throughout constructing the ionosphere-free observation combinations while the receiver clock offset and tropospheric delay effect could estimate as unknown parameters, **Gérard and Luzum, 2010**.

Table .1 highlights the small changes in the coordinates per year for six Continuously Operating Reference Stations (CORS) in Iraq which were established by National Geodetic Survey "http://www.ngs.noaa.gov/". These six CORS stations are ISBA in Baghdad, ISBS in Basra, ISER in Erbil, ISNA in Najaf, ISSD in Tikrit, and finally ISKU in Kut. The changing estimates in both of Cartesian and East, North, and Up coordinates were estimated using the velocity estimates of International Terrestrial Reference Frame 2000 (ITRF00) and IGS08. These velocity estimates are referred in the **Table .1** as VX, VY, VZ for the Cartesian coordinates X, Y, Z) and VN, VE and UP for the North, East, Up coordinate system, **NGS, 2016**.

2. CASE STUDY AND DATASET

This research was carried out based on two case studies. The first case study was the University of Baghdad, Al-Jadirya Campus, where eleven control stations were established as shown in **Fig .1**. The selection of locations of these ten control stations was accomplished under two conditions, the first condition is avoiding any obstructions and reflective surfaces, and the second condition is to keep the visibility between adjacent control stations which is one of the most important conditions for performing he field survey works by TS.

The second case study was local GNSS observation data which were taken from six sites, these are Al-Basra city, Al-Mosul city, Wasit city, Al-Najaf city, Babylon city, and Baghdad city. The raw GNSS data from these six sites were processed based on Iraqi CORS stations and some selected IGS (International GNSS Services) stations which are located outside Iraq. The positions of these six selected sites were computed based on DGPS processing solution using two schemes. The first scheme is to correct the raw GNSS data based on Iraq CORS stations and the second scheme is to correct the raw GNSS data based on the IGS stations which are located outside of Iraq. The comparison between two solutions (schemes) was employed for evaluation the characteristics of Iraqi CORS stations in comparison with the IGS stations.

3. METHODOLOGY

Although extensive studies have been carried out to address the accuracy of GNSS solutions, no single study exists which gives clear evidence about the level of accuracy that can be reached out from GNSS solutions, particularly the differential GNSS solutions. However, most of research and studies which have been performed in the subjects of using GNSS for geodetic applications, discussed intensively the precision of GNSS solutions based on number of factors, e.g. error sources, data processing, length of observation, baseline length, etc…

The assessment of accuracy for different GNSS techniques is explained in this research such as studying of characteristics of Iraqi CORS stations and explaining different observation techniques of GNSS based on (DGPS) and Total Station measurements.

First Case Study:

Regarding field works, a network of twelve stations were established in the University of Baghdad, Al-Jadirya campus and observed using different GNSS positioning techniques and Total Station, see **Fig. 1**. The Topcon GPS GR5 and Total Station (GTS751) were employed in this research. In this research, the term TS will be used in its broadest sense to refer to Total station solution. Topcon tools software was also used for processing the GNSS raw data from DGPS. Additionally, AutoCAD civil 3D (2016) was used to adjust the traverse observation data taken by GTS751. In this research, the robustness of the geodetic networks which are established by GNSS observations was carried out based on five GNSS positioning techniques, these are Static GNSS survey, Post-Processing Kinematic Survey (PPK), Real-Time Kinematic Survey (RTK), Precise Point Positioning Survey (PPP), and finally Session Survey. The precise positions from the land surveying by TS were considered as a reference solution to evaluate the GNSS positioning accuracy in term of geometry of Travers shape (baseline lengths, baseline bearings, and areas).

Fig. 2 addresses the baseline length differences in millimeters between TS solution and five GNSS solutions. **Fig. 3** illustrated the different in baseline bearing in seconds between TS solution and five GNSS solutions. In both of **Fig. 2** and **Fig. 3,** the dark blue color stands for the difference between TS solution and PPK solution, the red color is the difference between TS solution and PPP solution, the green color corresponds to the difference between TS solution and RTK solution, the magenta color represents the difference between TS solution and Session solution, and finally, the light blue color stands for the difference between TS solution and Static solution. **Fig. 4** shows the differences between Travers areas in meter square between TS solution and five GNSS solutions. Finally, the differences in the point positions for each station between the TS solution and each of the five GNSS solutions are presented as vectors as shown in **Fig. 5**.

Second Case Study:

Regarding the assessment of Iraqi CORS stations, the raw data from six CORS stations were downloaded in RINEX format by the IGS website and processed using online services such as Online Positioning User Service (OPUS). The computed positions of these six stations were compared with the results from International GNSS Service (IGS08) solution and International Terrestrial References Frame (ITRF00) solution over the period from 2008 to 2015. **Fig. 6** shows the differences in Easting, Northing, and Up components for these six CORS stations between OPUS solution (as own solution) and IGS08 solution and ITRF00 solution. What is more, **Fig. 7** demonstrates the differences in X-, Y-, and Z-coordinates for six CORS stations between OPUS solution (as own solution) and IGS08 solution and ITRF00 solution.

4. RESULTS , DISCUSSION AND CONCLUSIONS

The Iraqi Geospatial Reference System (IGRS) could be considered as a combines of network for Global Positioning System (GPS), CORS and a High Accuracy Reference Network (HARN) for application of surveying control points.

There are clear differences among the results when using the NGS Online Positioning User Service (OPUS) and the other results depending on the velocity of CORS stations in Iraq.

The results of coordinates that acquired from the different sources such as online services (OPUS) or the velocities of IGS08 solution and ITRF00 solution are listed **table.1**.

In this research, the precise applications for accurate positioning were introduced. In general, two main themes were applied. The first part includes the analysis of Iraqi CORS stations and study the changing depending on characteristics such as velocities based on IGS information in addition to the accuracy of positioning using Iraqi CORS stations and that located outside. The second part includes the comparison between the results of observations from DGPS solutions and these which were obtained from using total station. These different techniques such as STATIC, PPK, PPP, SESSION, RTK and total station were applied in this research. Online services were used for processing the data for all DGPS raw data. In this research, two stations were taken with DGPS as static techniques which were observed more than eight hours for two control points which related with the baseline and other deferent technique had different times depending on the method of techniques. From the experimental results obtained data in this research the following conclusions had been made:

1. Under the conditions of visible satellites, when the number of visible satellites was greater than 6, PDOP value did not exceed 2.66.
2. There is a clear difference in the accuracy when using Iraqi CORS stations as compared with another CORS stations located outside Iraq, such as Bahrain, Iran, Israel and others. These irregular differences may reach to 4.5 cm.

3. Over the period of 2009-2015 in Iraq, there is an increasing in easting and northing components around (3.5cm), while ellipsoid height has irregular differences.
4. This study showed that the differences in positions between those based on OPUS processing software and those based either IGS08 or ITRF00 are smalls.
5. When Point Positioning technique could achieve centimeter positioning accuracy level and it has the ability to solve the satellite Orbit and clock error.
6. The reference datum of GNSS is WGS84, where heights are referred to a theoretical "mathematical" ellipsoid, not to real-life terrain or geopotential surface. Hence, in order to reference GNSS derived heights to terrain, the geoid–ellipsoid separation must be known to be used in the equation of $h = H + N$.
7. The difference in X-coordinates when using OPUS and both of IGS08&ITRF00 reach to 2.30 cm and 2.50 cm, correspondingly.
8. The difference in Y-coordinates when using OPUS and both of IGS08&ITRF00 reach to 0.76 cm and 2.96 cm, correspondingly.
9. The difference in Z-coordinates when using OPUS and both of IGS08&ITRF00 reach to 17.20 cm and 17.99 cm, correspondingly.
10. The difference of Easting coordinates when using OPUS and both of (IGS08&ITRF00) reach to 17.40 cm and difference of northing coordinates reach to 20.40 cm for each of them and for EL.H coordinates reach to 0.90 cm.
11. The difference of PPK and RTK techniques comparing with classical surveying (Total Station) is in millimeter level, but for Stand-alone is in centimeter level.
12. Regarding the length of baseline, the difference between PPK technique and Total Station technique reaches to (1.90 mm) and RMSE of (1.20 mm) for all baselines.
13. Regarding the length of baseline, the difference between RTK technique and Total Station technique reaches to (3.20 mm) and RMSE of (1.50 mm) for all baselines.
14. Regarding the length of baseline, the difference between session technique and Total Station technique reaches to (2.10 mm) and RMSE of (1.30 mm) for all baselines.
15. Regarding the length of baseline, the difference between Static technique and Total Station technique reaches to (4.34 mm) and RMSE of (3.20 mm) for all baselines.
16. Regarding the length of baseline, the difference between PPP technique and Total Station technique reaches to (11.2mm) and RMSE of (4.2 mm) for all baselines.

5. RECOMMENDATION

Future work will be focused on improving the GPS orthometric heights using another local Geoid Model (if it possible) and more developer than the last version of Global Geoid Model which had used in this research (EGM 2008) and Study the accuracy when using another collection of Satellite System such as European satellites and china satellites in the surveying applications in Iraq.

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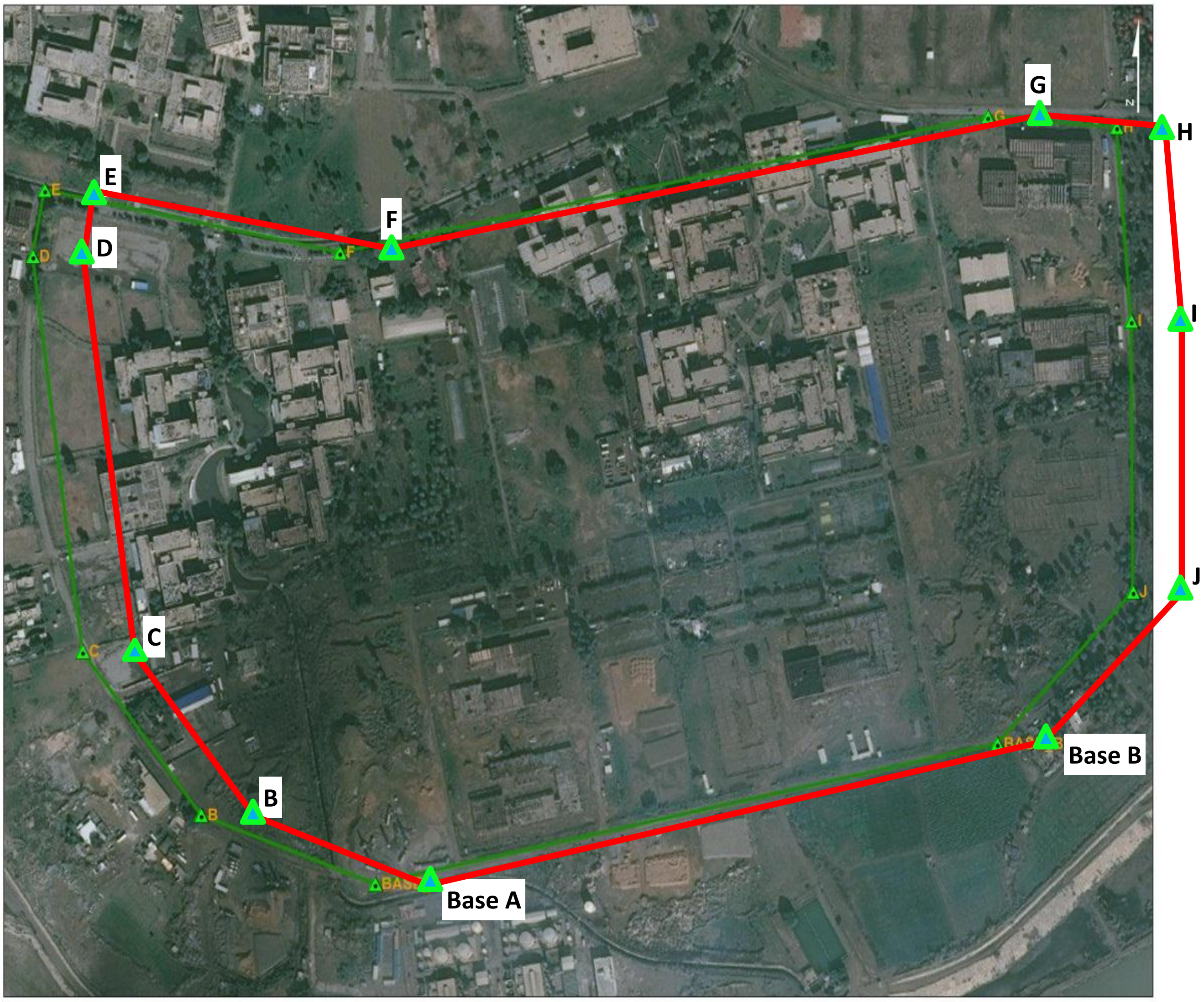

Figure 1. Area of Study, University of Baghdad, Aljadirya Campus.

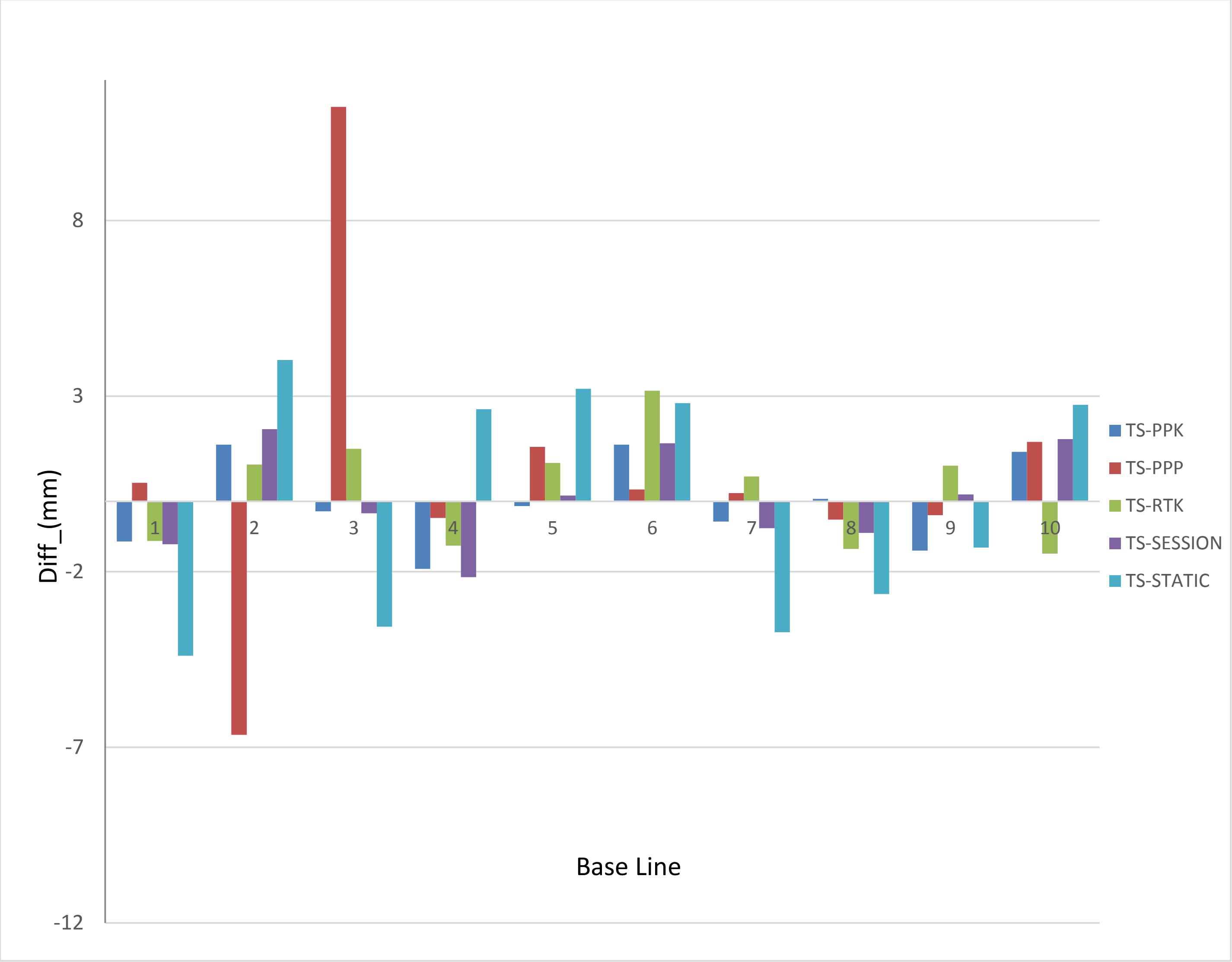

Figure 2. The difference in Baseline length in millimeter between different GNSS observation techniques and total station technique.

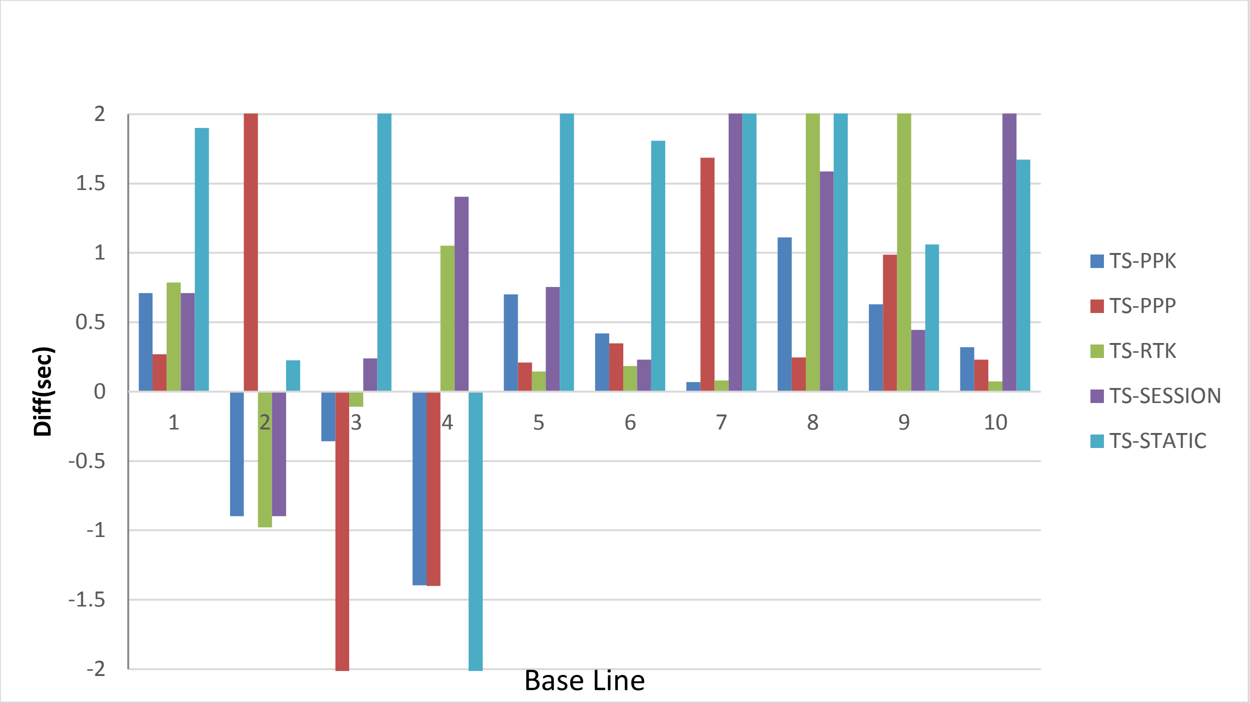

Figure 3. The difference in Baseline bearing in second between different GNSS observation techniques and total station technique.

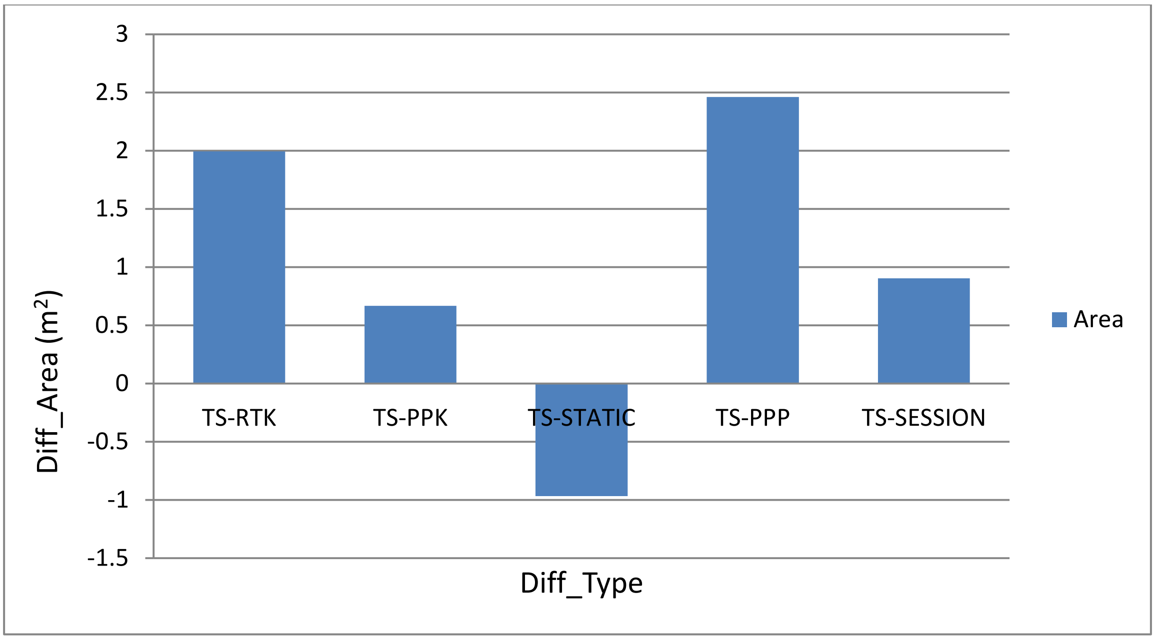

Figure 4. The difference in areas in square meter between different GNSS observation techniques and total station technique.

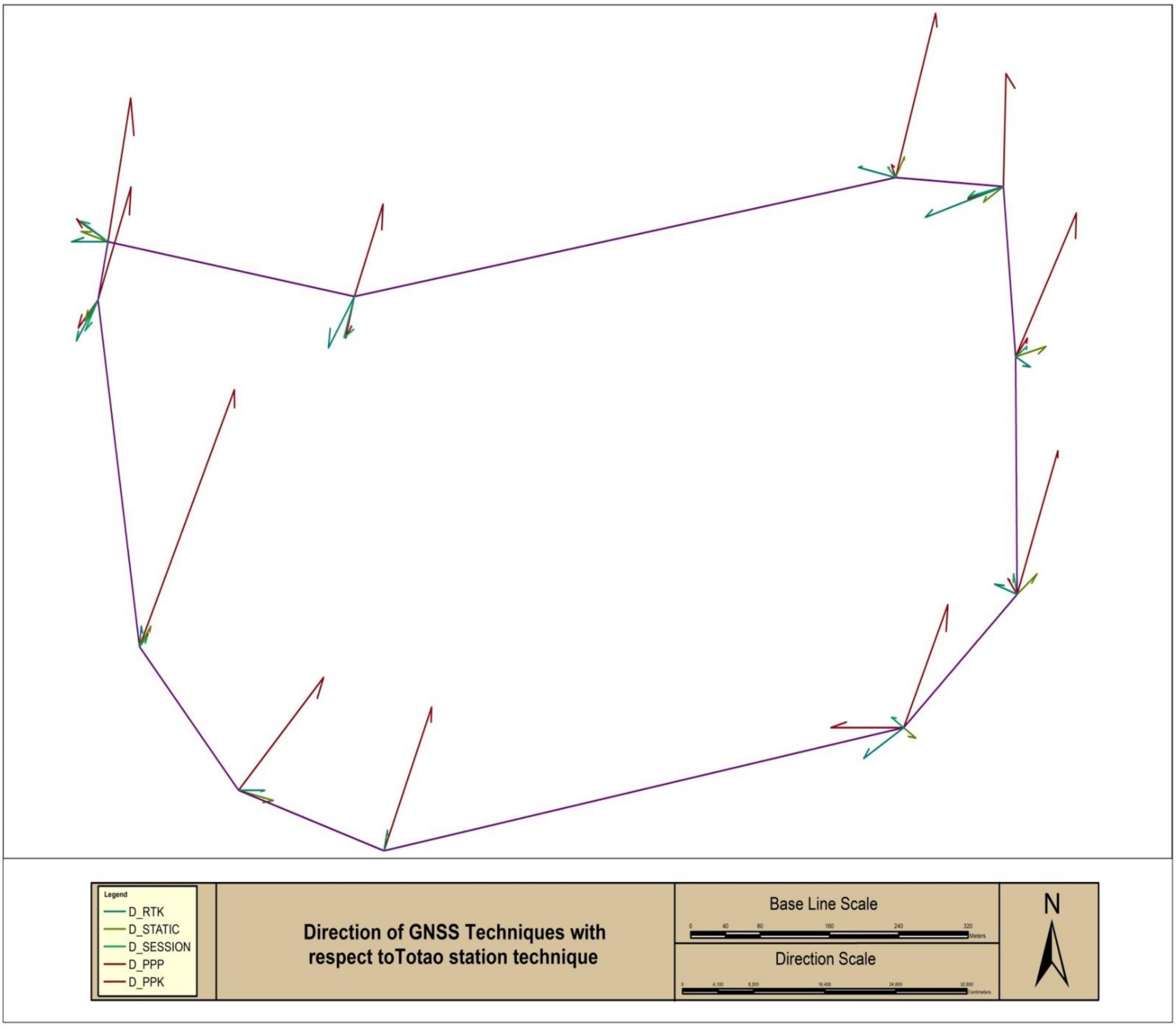

Figure 5. The Differences in Directions between TS Solution and Each of GNSS Solution.

Table 1. Characteristics of changing for coordinates per year depending on IGS information.

ISBA			ISBS			ISER		
Velocity(m/year)	IGS08	ITRF00	Velocity(m/year)	IGS08	ITRF00	Velocity(m/year)	IGS08	ITRF00
VX	-0.0298	-0.0271	VX	-0.0330	-0.0293	VX	-0.0299	-0.0262
VY	0.0058	0.0024	VY	0.0067	0.0034	VY	0.0035	0.0000
VZ	0.0224	0.0269	VZ	0.0294	0.0291	VZ	0.0262	0.0258
VN	0.0282	0.0322	VN	0.0341	0.0338	VN	0.0324	0.0319
VE	0.0250	0.0207	VE	0.0289	0.0240	VE	0.0233	0.0182
UP	-0.0021	0.0000	UP	0.0001	0.0000	UP	0.0001	0.0000
ISNA			ISSD			ISKU		
Velocity(m/year)	IGS08	ITRF00	Velocity(m/year)	IGS08	ITRF00	Velocity(m/year)	IGS08	ITRF00
VX	-0.0310	-0.0274	VX	-0.0301	-0.0265	VX	-0.0316	-0.0279
VY	0.0071	0.0036	VY	0.0051	0.0016	VY	0.0060	0.0025
VZ	0.0277	0.0273	VZ	0.0266	0.0262	VZ	0.0280	0.0277
VN	0.0326	0.0322	VN	0.0323	0.0318	VN	0.0331	0.0328
VE	0.0267	0.0217	VE	0.0245	0.0195	VE	0.0268	0.0217
UP	0.0001	0.0000	UP	0.0001	0.0000	UP	0.0001	0.0000

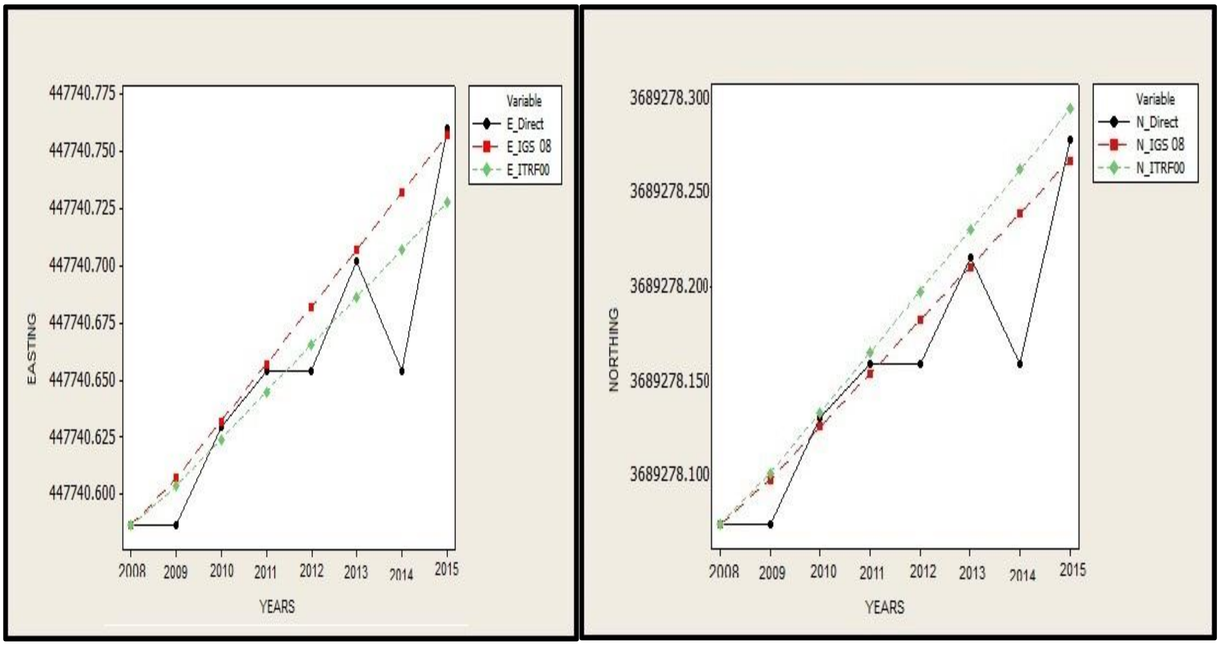

Figure6a. The difference of easting coordinates.

Figure6b. The difference of northing coordinates.

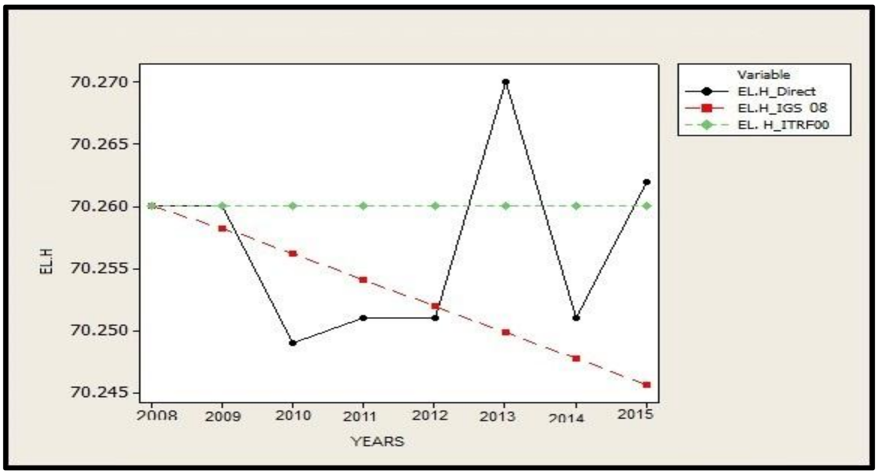

Figure6c. The difference of ellipsoid height coordinates.

Figure 6. The difference of easting, northing and ellipsoid height.

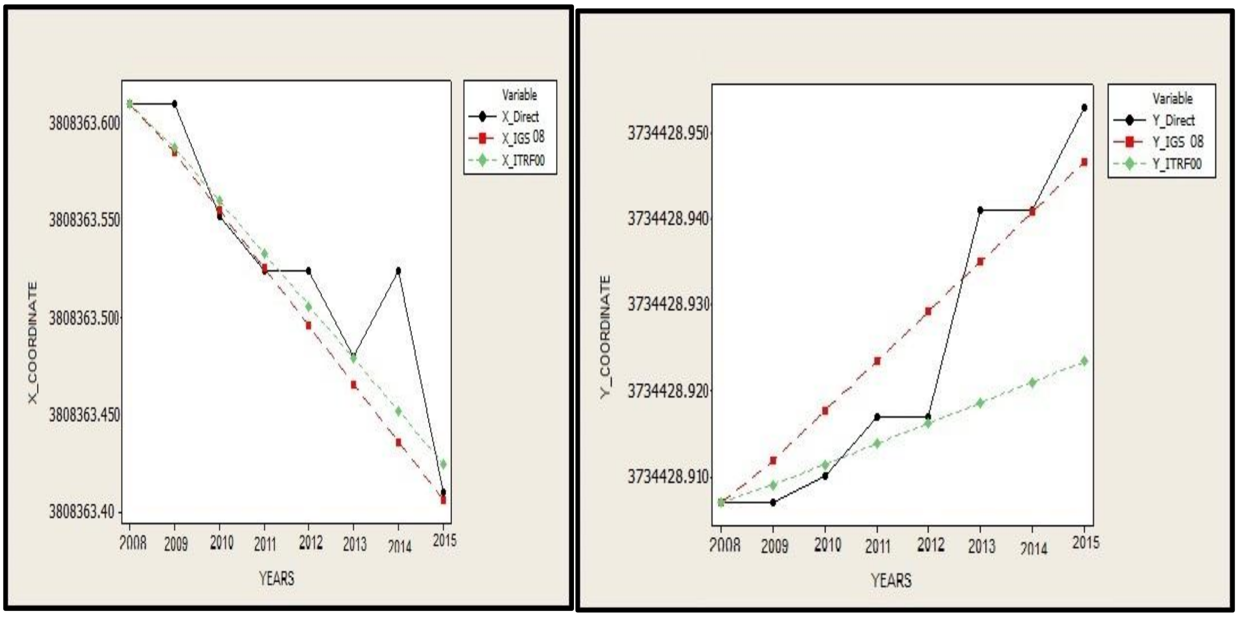

Figure7a. The difference of Cartesian coordinates for X.

Figure7b. The difference of Cartesian coordinates for Y.

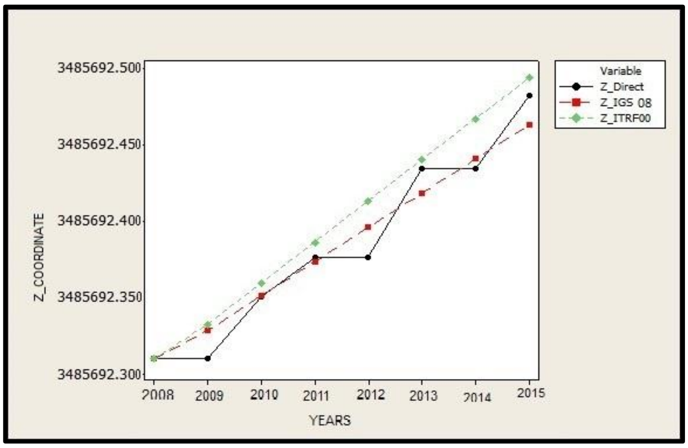

Figure7c. The difference of the difference of Cartesian coordinates for Z coordinates.

Figure 7. The difference of X, Y and Z.