Producing Coordinate Time Series for Iraq's CORS Site for Detection Geophysical Phenomena

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ABSTRACT

Global Navigation Satellite Systems (GNSS) have become an integral part of wide range of applications. One of these applications of GNSS is implementation of the cellular phone to locate the position of users and this technology has been employed in social media applications. Moreover, GNSS have been effectively employed in transportation, GIS, mobile satellite communications, and etc. On the other hand, the geomatics sciences use the GNSS for many practical and scientific applications such as surveying and mapping and monitoring, etc.

In this study, the GNSS raw data of ISER CORS, which is located in the North of Iraq, are processed and analyzed to build up coordinate time series for the purpose of detection the Arabian tectonic plate motion over seven years and a half. Such coordinates time series have been produced very efficiently using GNSS Precise Point Positioning (PPP). The daily PPP results were processed, analyzed, and presented as coordinate time series using GPS Interactive Time Series Analysis. Furthermore, MATLAB (V.2013a) is used in this study to computerize GITSA with Graphic User Interface (GUI).

The objective of this study was to investigate both of the homogeneity and consistency of the Iraq CORSs GNSS raw data for detection any geophysical changes over long period of time. Additionally, this study aims to employ free online PPP services, such as CSRS_PPP software, for processing GNSS raw data for generation GNSS coordinate time series.

The coordinate time series of ISER station showed a +20.9 mm per year, +27.2 mm per year, and -11.3 mm per year in the East, North, and up-down components, respectively. These findings showed a remarkable similarity with those obtained by long-term monitoring of Earth's crust deformation and movement based on global studies and this highlights the importance of using GNSS for monitoring the movement of tectonic plate motion based on CORS and online GNSS data processing services over long period of time.

Key words: tectonic plates motion, CTS, PPP, GITSA, CORS, CSRS.

أنتاج المتسلسلات الزمنية للموقع الأرضي لمحطة ال CORS في العراق للكشف عن الظواهر الجيوفيزيائية

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الخلاصة

اصبحت انظمة الملاحة جزء لايتجزء من العديد من التطبيقات الجيودسية الواسعة والمختلفة، وأحد هذه التطبيقات استخدام الهاتف المحمول لتحديد موقع المستخدم لتوظيف المعلومات الموقعيه في الكثير من الاستخدامات كوسائل التواصل الاجتماعية و كذلك تحديد مواقع وسائل النقلال المختلفة مثل السيارات والطائرات والسفن. ومن ناحية اخرى يستخدم علم هندسة الجيوماتكس الانظمة الملاحية في العديد من التطبيقات العملية والعلمية كأنتاج الخرائط. في هذا البحث تمت معالجة الارصادات المأخوذة من محطة (ISER) الواقعة في شمال العراق والتي تعتبر من محطات ال(CORS) باستخدام اسلوب تعيين الموقع النقطي الدقيق وعلى مدى ست سنوات ونصف لبناء متسلسلات زمنية لحساب مقدار الحركة في الصفيحة التكتونية العربية، وقد انتجت هذه المتسلسلات الزمنية بكفاءة عالية باستخدام برنامج تحليل المتسلسلات الزمنية التفاعلي (GITSA)، ايضا تم

استخدام برنامج (MATLAB V.2013a) من اجل حوسبة برنامج (GITSA) مع واجهة المستخدم الرسومية (GUI). اظهرت المتسلسلات الزمنية لمحطة (ISER) حركة مقدارها (20.9+ ملم/سنة) باتجاه الشرق، (27.2+ ملم/سنة) باتجاه الشمال، و (11.3- ملم/سنة) باتجاه المركبة الرئسية. حيث اظهرت هذه النتائج تشابهاً كبيراً مع نتائج الدراسات الجيولوجية وهذا يوضح اهمية استخدام الانظمة الملاحية لمراقبة حركة الصفائح التكتونية على مدار فترات زمنية.

الكلمات الرئيسية: حركة الصفائح التكتونية، المتسلسلات الزمنية للمواقع، تعيين الموقع النقطي، المحطات المرجعية المستمرة.

1. INTRODUCTION

Over the past three decades, different navigation positioning systems have been developed by scientific communities due to the urgent needs for precise positioning systems which could work under a wide range of conditions. Thus, the GNSS, which in turn is an abbreviation for Global Navigation Satellite System, has been established and developed. The GNSS has developed noticeably and its applications have been employed in several fields in our daily activities, such as positioning, transportation, and telecommunication. What is more, GNSS has an effective role in different professional fields in geodesy, environmental monitoring, meteorology, mapping **Gleason and Gebre-Egziabher, 2009**.

In General, GNSS employs different navigation satellites to provide independent geospatial positions and enables everybody on this world to have the capacity to acquire information on their locations with near-perfect accuracy and pass on this information to others. Until recently, the GNSS consists of three global operational navigation satellite systems, these are United States NAVSTAR Global Positioning System (GPS), the Russian GLONASS, and the European Union's Galileo. More recently, GNSS has become an integral part of different applications. One of these applications of the navigation systems is the use of the mobile phone to locate the position of mobile owner for many applications of social media. Moreover, the navigation systems can be employed in transportation systems such as, cars, planes and, ships. On the other hand, there is wide range of applications which are specialized in geomatics science such as, mapping, networking, monitoring, etc..., **Noll, et al., 2008**.

The uninterrupted deviations in the geometry of geodetic control networks due to the Earth's deformation, is a major area of interest within the field of physical geodesy. Accordingly, research on the Earth's deformation have been carried out based on employing different space geodetic systems for measuring annual and semi-annual velocity estimates over particular periods. Such of these space navigation systems are Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), Global Positioning system (GPS), and Doppler Orbitography and Radiopostioning Integrated by Satellite (DORIS). Over the past three decades, different studies have approved the capability of using GNSS for supporting multidisciplinary applications, particularly the scientific applications which necessitates high level of positional accuracy over long period of time. Such of these applications are the long term monitoring of huge structure and tectonic plate motion, **Larson, et al., 1997**.

Bock, et al., 1993, processed around seventy days of Permanent GPS Geodetic Array (PGGA) data to prove the possibility of employing GPS data for investigation the seismic deformation before and after the seismic activities. **Bock, et al., 1993** results pointed to that there was no pre-seismic movements, robustly constant co-seismic movements at most PGGA positions. What is more, further studies were carried out for measuring the vertical crustal displacements based on estimation vertical velocities of control GPS (CGPS) stations. For example, **Wahr, et al., 2001,** analyzed the carrier-phase observations from two CGPS (Kellyville and Kulusuk) to estimate the up-down crustal signal of the Greenland ice sheet. The **Wahr, et al., 2001,** has received considerable critical attention owning to two reasons. Firstly, they implemented GIPSY OASIS

II V.5.0 for Precise Point Positioning processing technique with precise orbital information and satellite clock corrections produced by Jet Propulsion Laboratory (JPL). Furthermore, the most interesting finding of **Wahr, et al., 2001**, study was that the up-down velocity estimates which were generated based on CGPS observations, were compared with those estimates from absolute gravity measurements. **Deitrich, et al., 2005**, used Bernese GPS Software V5.0 with double-difference positioning technique to analyze GPS raw observation data for ten CGPS over the period from 1995 to 2002, which are distributed in the west part of Greenland, to investigate the crustal deformation in the up-down direction. Their finding should the importance of using homogenous and consistent satellite orbital information, satellite clock corrections, and Earth Orientation Parameters (EOP) for producing precise coordinate times series. **Wahr, et al., 2001**, study were expanded by **Khan, et al., 2008**, where they included additionally 3 CGPSs and analyzed further 7 years of CGPS observations at Kellyville and Kulusuk.
Rudenko, et al., 2013, analyzed GPS data for 403 CGPS which are distributed globally over the period from 1998 to 2007 to produce precise weekly solution. 266 CGPS of 403 CGPS were employed for producing height time series to calculate vertical velocity estimates which were compared later with corresponding estimates from tide gauge stations and additional GPS solutions. **Rudenko, et al., 2013**, study points to the noticeable agreement of about 1 millimeter per year between their solution and other solutions which were produced by Universit´e de La Rochelle. Finally, **Rudenko, et al., 2013,** emphasized on successful application of estimation the vertical displacement for tide gauges sites using GPS coordinate time series to enhance the vertical crust motion in tide gauge measurements of sea level variations.
For more details about the contribution of the coordinate time series generated by GNSS solutions for estimation vertical and horizontal of land movements, the reader is referred to **Alhamadani, 2014** research which addresses the main global and regional studies of the earth's deformation as one of the main and essential applications in geodesy. What is more, **Alhamadani, 2014** highlighted and discussed the role of continuous GNSS measurements for modeling plate motions in both of global and regional scales and modeling Glacial Isostatic Adjustment. The successful application of the GNSS for detection any displacement in stations positions is to process consistent and homogeneous GNSS raw data which consist of carrier-phase and code range observations and produced by Continuously Operating Reference Station (CORS). The CORSs have been significantly utilized in support of three dimensional positioning, meteorology, and geophysical applications around the world.

This research aims to figure out the Arabian tectonic plate motion using one of the CORSs which are located in Iraq. Furthermore, the processing of the raw GNSS data will be carried out using Precise Point Positioning (PPP) technique for producing coordinate time series over particular period of time. The PPP processing technique is carried out in this research using Canadian Spatial Reference System (CSRS) - PPP tool that provide a service for generation of positions of raw GNSS data with higher level of accuracy. Finally, the time series of station coordinates based on CSRS-PPP will be produced in this research using GPS Interactive Time Series Analysis (GITSA) **Goudarzi, M.A, et al., 2013** and **Goudarzi, 2015**.

Consequently, this research assesses the continuity, homogeneity, and precision of the GNSS observations of one CORS in Iraq and this will remarkably show any jump, shift, and any discontinuity in the raw data over the period of time. Based on what has been reviewed above, there are two questions that need to be answered:

1. Are the coordinate time series of CORS which are generated using PPP based in International GNSS Service (IGS) precise orbital information, Earth orientation

parameters, and satellite clock corrections, accurate, consistent, and homogenous over the complete period of time?

2. Are the precision, consistency, and homogeneity of the coordinate time series of Iraqi CORS, generated based on PPP sufficient to provide accurate and reasonable clarification for detecting different geophysical phenomena in Iraq over a period of time?

2. CASE STUDY AREA

Currently, the CORSs represent the main source of continuous raw GNSS observation data. At this time, there are two thousand and six hundred and sixty one CORSs which are distributed globally around the world, six of the CORSs are located in Iraq and distributed from the north to the south of the country. For more information, the reader is referred to https://www.ngs.noaa.gov/. These six CORSs were officially established by the National Geodetic Survey (NGS) and then independently owned and operated. These six CORSs are ISER, ISSD, ISBA, ISKU, ISNA, ISBS as shown in **Fig. 1**. The first two letters (IS) stand for Iraq Surveying while the last two letters stand for the province name, i.e. ER is Erbil, SD is Salah Adin, BA is Baghdad, KU is Kut, NA is Najaf, and finally BS is Basra.

To achieve the goals of this research, the carrier-phase observations from CORS-ISER were processed using Natural Resources Canada (NRCan), Canadian Spatial Reference System - Precise Point Positioning (CSRS-PPP). In this study, the ISER is selected due to the reason that ISER has approximately continuous GNSS raw data in comparison with other five stations over the period from the mid of 2009 to the end of 2016. **Fig. 2** shows the data availability for these six Iraqi CORSs, the horizontal axis presents the time for eight years from 2008 to 2016, where the vertical axis presents the six CORS stations, for example ISER station is being operated from 7th of July 2009 till the present time.

3. SINGLE POINT POSITIONING TECHNIQUE

One of the essential requirements for successful application of GNSS for distinguishing geohazards and anomalies is the availability of precise geodetic positions which have high absolute positional accuracy. These geodetic positions have been produced efficiently through PPP via synchronously computing the receiver clock correction estimates. Generally, PPP represents the practical application of the zero-difference processing technique. However, the successful implementation necessitates precise satellite orbital information which is compatible with precise clock correction estimates and Earth Orientation Parameters (EOP) **Zumberge, et al., 1997**.

As far as the Double-Difference (DD) relative positioning technique is concerned, it has been widely used by the GNSS users due to the reason that in the DD, simultaneous GNSS observations made at a couple of geodetic receivers to a couple of satellites are differenced to abolish some major biases such as the satellite clock and receiver clock biases and possibly diminish part of the atmospheric biases. The efficiency of DD depends on the baseline length between the receivers, GNSS data processing, and the length of period of observation. Nonetheless, these major biases can be modeled and corrected for short baselines of less than 20 km, **Blewitt, 1997**. Consequently, the positional accuracy of unknown stations depends on the accuracy of reference station, and thus, this accuracy is known as a relative accuracy, whereas the positional accuracy of the PPP depends entirely on the accuracy of the satellite position and the satellite clock corrections, **Linette, 2004**.

It is worth to mention here that most of studies of investigation the Earth's deformations based on GNSS positioning have been carried out using DD processing technique to obtain a high level of precision for three dimensional velocity estimates. However, other investigations have shown that absolute three dimensional velocity estimates of stations can be efficiently produced using PPP processing technique. Accordingly, in this research the PPP processing technique is used instead of DD, and this will yield the coordinates of the unknown station in the Earth-fixed Earth-center reference frame.

4. RESEARCH METHODOLOGY

This research was carried out by dealing with three main themes. Firstly, selection the optimum CORS in Iraq based on the data availability. Secondly, using GNSS processing software based on online service. Thirdly, presentation the changes in the three dimensional coordinate using coordinate time series analysis. Thus, the methodology of this research h is summarized as follow:

1. Download the raw GNSS observation data for a CORS-ISER via National Geodetic Survey (NGS) (https://www.ngs.noaa.gov/, (accessed October 11, 2017).
2. Post-processing the GNSS observation data using Natural Resources Canada (NRCan), Canadian Spatial Reference System - Precise Point Positioning (CSRS-PPP) for GNSS raw data post-processing.
3. Using the GPS Interactive Time Series Analysis (GITSA) by computerize it with Graphic User Interface (GUI) in MATLAB (V.2013a) to create coordinate time series.
4. Finding the velocities of the tectonic plate motions by numerical and statistical computations. **Fig. 3** shows the structure of the research methodology.

5. COORDINATE TIME SERIES ANALYSIS – GPS INTERACTIVE TIME SERIES ANALYSIS

Time series analysis is an important part of Geodesy and Geodynamics studies, particularly when continuous GNSS observations are utilized to explore very low rate of deformations. GITSA is precise and robust tools for processing and analyzing coordinate time series, **Goudarzi, et al., 2013**. GITSA software has been developed at the Center for Research in Geomatics (CRG), Laval University. Additionally, GITSA can be employed for investigating different time series in the field of Earth sciences, when the purpose of analysis is to distinguish the temporal behavior of individual of several time dependent variables within the time series. For example, The study of long-term record of mountain uplift, sea level fluctuations, millennium-scale variations in the atmosphere-ocean system and so on.

GITSA performs number of functions which range from time series data file import and transformation to wavelet spectral analysis. Additionally, GITSA comes with some utilities such as a GPS date converter that enables users to convert different date formats which are used in GNSS applications. In summary, all the coordinate time series analysis programing software can be utilized for:

1- Visual interpretation, for instance recurrence plots, spectrogram, and wavelet power spectrum.
2- Operations of time series processing, such as filtering and frequency responses of filters.
3- Statistical analysis, i.e. cross-spectral and auto-spectral analysis, evolutionary power spectrum, and wavelet power spectrum**, Goudarzi, 2015.**

Furthermore, GITSA includes ten math and statistical calculation approaches to make sure the highest level of accuracy and confidentiality in coordinate time series, these approaches are:

1. Jump detection and removal.
2. Outlier detection and removal.
3. Data interpolation.
4. Trend analysis.
5. Residual analysis.
6. Regression analysis.
7. Evolutionary power spectrum.
8. Amplitude spectral analysis.
9. Auto-spectral analysis.
10. Spectral analysis.

6. THE RESULTS AND DISCUSSION

The present study was designed to discuss a number of significant themes in the field of using space positioning techniques for geophysical applications. The first theme in this study focuses on employing one of the CORSs in Iraq for the purpose of detection the tectonic plate motion over the period from June 2009 till to December 2016. This theme necessitates investigating the GNSS data availability of 6 CORSs, which are distributed in Iraq, over the whole period of time which is mentioned before. The ISER CORS has the highest data availability and consequently its GNSS raw data, which was generated and archived in via NOAA's National Geodetic Survey over the whole period, was downloaded for further data processing. The second theme in this research deals with the ability of producing coordinate time series for CORSs in Iraq based on precise point positioning technique. The successful achievement of this theme depends entirely on:

1. using sophisticated software for processing the GNSS raw observation data on daily basis, and
2. using software for analyzing the output coordinates of selected CORS over the whole period of time and presenting the changes in the position components as a time series.

Without a doubt the process of producing precise, continuous and homogenous coordinate time series for ISER represents the most significant achievement and challenge in this research due to different reasons: the positional accuracy of PPP is massively affected by the quality of precise orbital information, satellite clock correction, and the EOP which are used for carrying out PPP processing. What is more and important, the compatibility between these precise products plays an enormous role in output PPP results. Thus, using CSRS online service for processing ISER data over six years and a half leads to a lack in the precision of PPP results as a result of inconsistency in used precise products. Consequently, any discontinuity, contradictory, and unexpected change in the coordinate time series are possibly due to:

1. changing in the used precise product sources, i.e IGS final products, IGS rapid products, or any analysis center own products,
2. changing in the used reference frame that is used for generation the IGS precise products,
3. changing in the station hardware, geodetic antenna and/or receiver, and finally
4. changing in the receiver firmware update.

In general, the findings in this research are presented as a numerical results based on statistical calculations and graphical results which are showed as coordinate time series based on GPS Interactive Time Series Analysis (GITSA) software. The difference in the coordinates are calculated annually between last day and first day of the year in East, North and Up components over the period from the mid of 2009 to the end of 2015. These annual differences are illustrated in **Table 1** and **Fig. 4**. As it is shown in **Table 1** and **Fig. 4** that the maximum changes in East and Up components is appeared in 2012, while the maximum change in the North component happens in 2011. Overall, **Table 1** and **Fig. 4** show a clear displacement in station position in the direction North East and subsidence in the vertical position. **Table 2** shows the ISER movement in the horizontal direction for every year and the total mean of the horizontal direction for the whole period. **Table 3** demonstrations the annual velocity in millimeters per year from July 2009 to 2015 and the total mean velocity for E, N, and U components. In general, **Table 3** indicates to:

1- 2009/2 has the largest velocity in the Up/Down component, and minimum velocity in the East component.
2- 2010 has the smallest velocity in the Down component.
3- 2011 has the smallest velocity in the North component.
4- 2012 has the largest velocity in the East component.
5- 2013 has the largest velocity in the North component.

The graphical results which are the coordinate time series visualized in three figures, **Fig. 5** is to visualize the difference in the North direction, **Fig. 6** is to visualize the difference in the East direction, while **Fig. 7** is to visualize the difference in the Up direction.

For every figures there is two rectangular axis, the horizontal axis represents the time in years while the vertical axis represents the coordinate. The dots represent the station coordinate while the line on the does represents the stander deviation of the observation. The gabs between the dots caused by a zero value of the stander deviation at particular day.

The coordinate time series and the numerical and statistical analysis of ISER station showed a velocity (+20.9 mm/year) in the East component, (+27.2 mm/year) in North direction, and (-11.3 mm/year) in Up component. These findings showed a remarkable similarity with those obtained from the geological studies and this highlights the importance of using GNSS for monitoring the movement of tectonic plate motion over a particular period of time.

6. CONCLUSIONS

The purpose of the current study was to investigate the effectiveness of employing CORS in Iraq for detection the Arabian tectonic plate motion and any geohazard. Additionally, this study examined the GNSS data availability of six Iraqi CORSs and it has showed that the ISER CORS has the highest GNSS observation data in comparison with other five CORSs over 7.5 years. What is more, free online GPS post-processing services CSRS-PPP is used in this study for processing daily GNSS raw observation data over long period. This processing strategy was carried manually in this study and this represents a vast challenge as it necessities a massive effort for processing huge observation data on daily bases. The analysis of observation data undertaken here has extended our knowledge of the degree of consistency, and precision of satellite orbital information, satellite clock correction, and EOP products which were considered by CSRS-PPP for producing smooth, homogenous, continuous, and reliable position time series. However, the coordinate time series for the East offset of ISER station indicates to a recognizable outlier in the mid of 2011 which is a most likely cause of unpredictable random bias in the carrier phase observables that affects only the East component. On the other hand, the coordinate time series for the ISER station point to identifiable jumps in 2015 in the North, East, up-down components. The most probable reason for these jumps is inconsistency in the products that affect the horizontal and vertical positions, **Goudarzi, 2015**. Generally, the position time series of ISER CORS showed similar trend, fluctuations and periodic signal over the whole period of processing.

7. REFERENCES

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Figure 1. Iraqi CORSs Map.

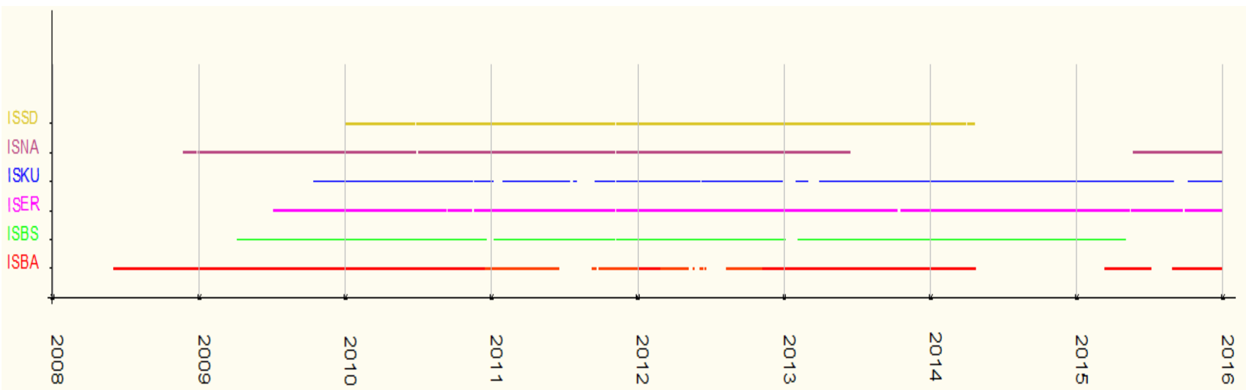

Figure 2. Iraqi CORS Data Availability.

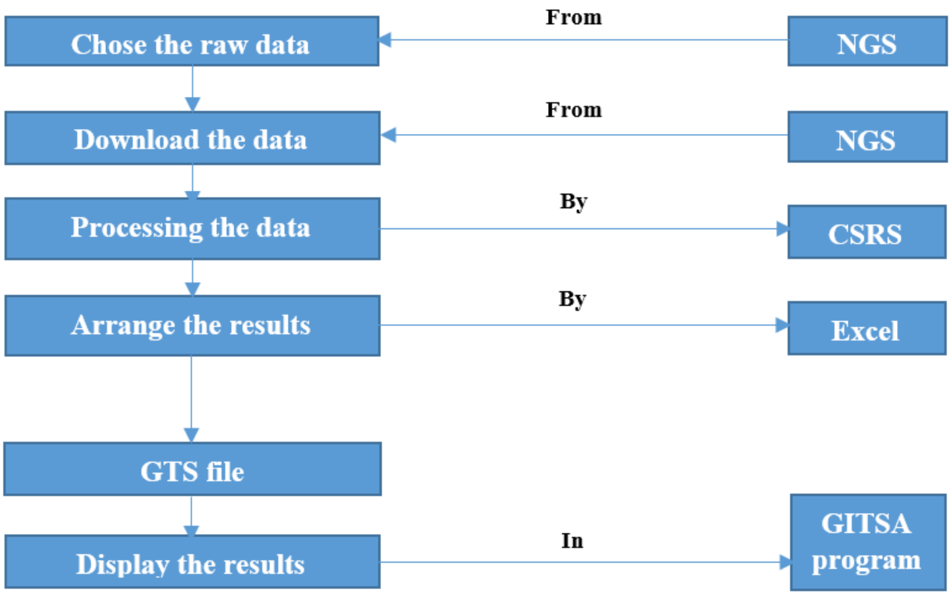

Figure 3. Structure of Research Methodology.

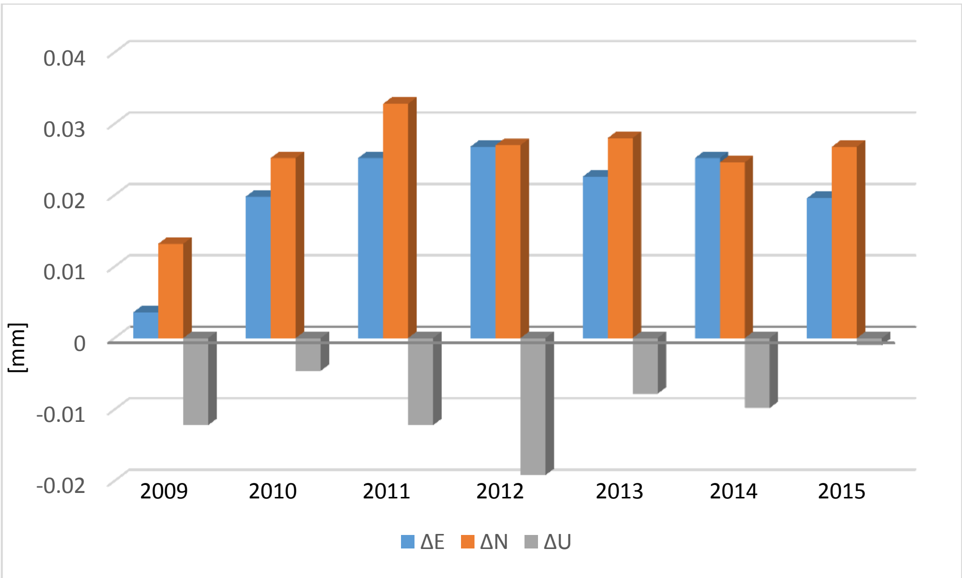

Figure 4. The Annual Changes In The Coordinates In Millimeters Unites.

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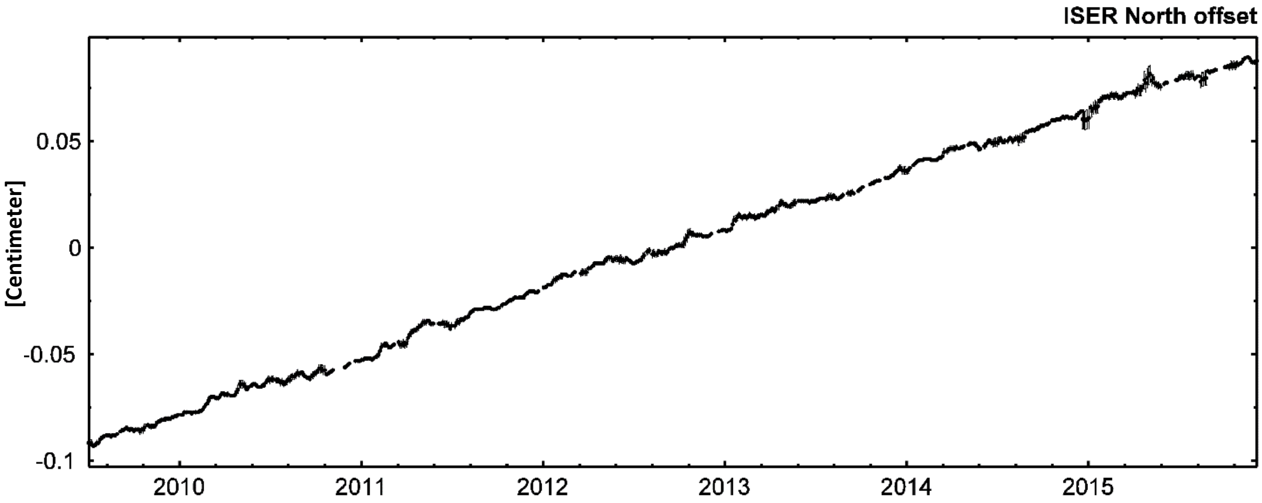

Figure 5. The coordinate time series for the North offset of ISER station.

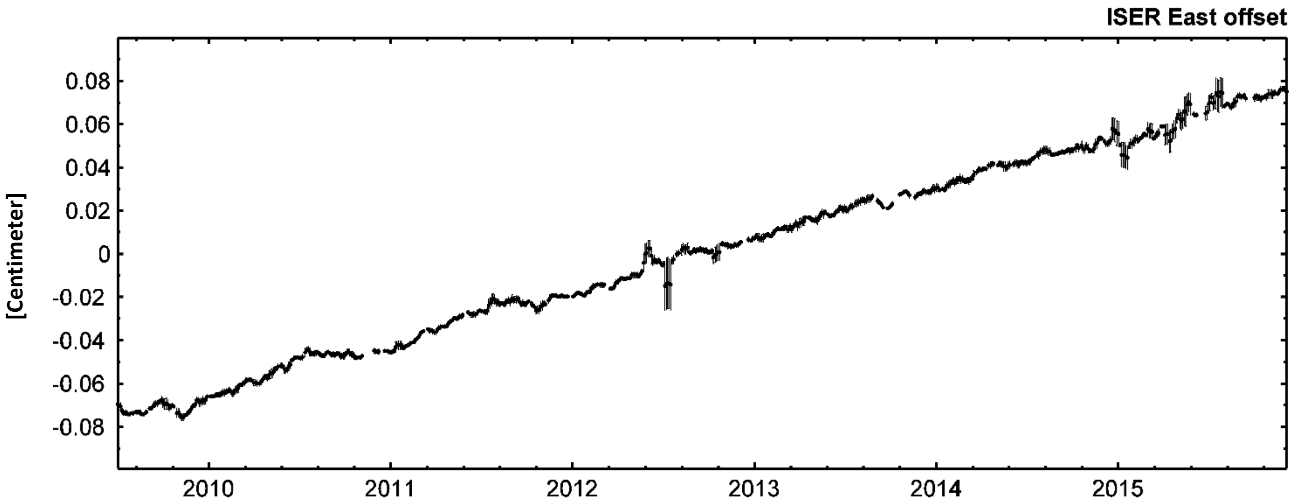

Figure 6. The coordinate time series for the East offset of ISER station.

Figure 7. The coordinate time series for the Up offset of ISER station.

Table 1. The Annual Changes In The Coordinates In Millimeters Unites.

	Mid of 2009	2010	2011	2012	2013	2014	2015
ΔE	03.6	19.8	25.2	26.8	22.6	25.2	19.6
ΔN	13.2	25.2	32.8	27.0	28.0	24.6	26.8
ΔU	-12.2	-04.6	-12.2	-19.2	-07.8	-09.8	-01.0

Table 2. The Horizontal Direction Per Year And The Total Mean Horizontal Direction.

Year	Horizontal Direction
Mid 2009	N 15^o 15' 18" E
2010	N 38^o 09' 26" E
2011	N 37^o 32' 05" E
2012	N 44^o 47' 13" E
2013	N 38^o 54' 31" E
2014	N 45^o 41' 25" E
2015	N 36^o 10' 47" E
Mean	N 38^o 17' 24" E

Table 3. The Velocity Estimates In mm/year For Every Year Over The Whole Period.

	East Dir.	North Dir.	Up/Down Dir.
2009	+7.2	+26.4	-24.4
2010	+19.8	+25.2	-4.6
2011	+25.2	+32.8	-12.2
2012	+26.7	+26.9	-19.1
2013	+22.6	+28.0	-7.8
2014	+25.2	+24.6	-9.8
2015	+19.6	+26.8	-1.0
Mean	+20.9	+27.2	-11.3