Performance Analysis and Conversion Parameter Evaluation of WGS84/ITRF Ephemeris Framework Implemented by NGA and IGS

Qinghua Zhang[1, 2, 3, 4] , Fengjuan Rong[4, *] and Zhengsheng Chen[2]
[1] *Beijing Key Laboratory of Urban Spatial Information Engineering, Beijing, 100038, China;*
[2] *State Key Laboratory of Geo-information Engineering, Xi'an, 710054, China.*
[3]*College of Mechanical Engineering, Nanjing University of Science and Technology, Nanjing, Jiangsu 210094, China*
[4]*Army Engineering University of PLA, Nanjing, Jiangsu 210007, China*
Email: lengyu880412@163.com.

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Abstract: The WGS84 coordinate system of GPS is dominated by the United States. At present, the ephemeris framework of WGS84 is mainly established and maintained by NGA with precise ephemeris. However, the IGS precise ephemeris usually adopted by navigation users is an ephemeris framework of ITRF. This paper mainly evaluates the differences and transformation parameters between WGS84/ITRF. In the example of this article, the WGS84/ITRF transformation parameter sequence is used daily from 2001 to the present. By analysing the seven conversion parameters, it is found that only in a few days there are still wild values. After eliminating field values, the three translation parameters are not more than 10cm, three rotation parameters are no more than 0.1mas, and the scale parameters are not more than 0.1ppb.The characteristics of conversion parameters in WGS84/ITRF can provide important reference for the GNSS users in the precision positioning and orbit determination.

1 INTRODUCTION

In the field of satellite navigation, spatial datum and time datum are the important foundation for the establishment of navigation system. At present the four satellite navigation system with different spatial datum, the GPS by WGS84 (World Geodetic System 84), GLONASS by PZ-90, BDS by CGCS2000, Galileo by GTRF, and IGS by ITRF (International Terrestrial Reference Frame) framework. The definitions of these five spatial datum traced to ITRS are basically the same, but there are some differences in the implementation (Janssen, 2009; Kotsakis, 2009; Zhang et al. 2015). In practice, the coordinate framework is a form of implementation of the coordinate system, including the two forms of the T (Territorial) framework and the E framework. Among them, the T frame is represented by a series of core coordinates and speed field locks of a series of GNSS ground tracking stations, and the E framework is represented by the satellite ephemeris. The use of the practical application of the navigation satellite ephemeris reference frame (E frame), the precise ephemeris or (Jiao, 2003) broadcast ephemeris. As the GPS system has accumulated a large amount of data during the long run, the differences in the WGS84/ITRF E framework will be evaluated and analyzed in this paper.

GPS uses the WGS84 coordinate system, the United States Department of Defense Agency NGA to define and implement the specific realization method including T framework and the E framework in two forms, the E framework is the precise ephemeris provided by the implementation (SP3) broadcast ephemeris to achieve control and GPS system. However, the precise ephemeris provided by IGS (International GNSS Service) (SP3 format) is used by users in PPP (Precise Point Positioning) or post differential positioning, which is an implementation of the ITRF E framework. This article will analyze and evaluate the Helmert conversion parameters for the WGS84 E framework implemented by NGA and the ITRF E framework implemented by IGS. At present, there have been many research achievements on the GNSS

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coordinate transformation method in the world. The layout of GLONASS completed a total of 24 constellations at the end of 1995 and began to run, the German FAF Munich University Institute of Geodesy and navigation in Germany and several other research institutes in 1996 conducted a full range of GPS/GLONASS stations in Europe, and the conversion parameters of PZ-90 and WGS-84 are estimated (Rossbceh, 1996; Misra, 1996). In 1997, in order to determine the WGS84/PZ-90 coordinate transformation parameters applicable to the Russian region, the 29th Research Institute of the Russian Ministry of Defense selected eight observation stations in Russia for GPS/GLONASS joint survey (Bazlov, 1999; Bazlov, 2002). In 1998, the International Association of Geodesy (IAG) took the lead in implementing the global GLONASS joint test, namely IGEX-98 (International GLONASS Experiment), and obtained worldwide conversion parameters (Boucher and Alta, 2001). Nevertheless, the existing research results are based on the T framework to estimate the conversion parameters. In this article, the differences and transformation parameters between ITRF's E framework (IGS precise ephemeris expression) and WGS84's E framework (NGA precise ephemeris expression) are deeply studied.

2 THE DEFINITION OF WGS84 AND ITRF

WGS84 (World Geodetic System 84), also known as the 1984 World Geodetic Coordinate System, was established back in the 1960s. At that time, the National Imagery and Mapping Agency (NIMA) was commissioned by the U.S. Department of Defence (DoD) to establish the Global Geodetic Coordinate System, including WGS60, WGS66, and WGS72. WGS84 is refined and enhanced by NIMA and produces WGS84 (G730) and WGS84 (G873). After that, WGS84 (G1150) and WGS84 (G1674) were introduced in 2002 and 2012 respectively.

The WGS 84 T frame is the ground reference station coordinate and velocity field in Figure 1, and its E Frame is implemented with a sophisticated ephemeris provided by the NGA.

ITRF is the International Geo-Reference Frame, which is the realization of ITRS (International Terrestrial Reference System). With the development of observational techniques such as GPS, VLBI(Very Long Baseline Interferometry), SLR(Satellite Laser Range) and DORIS(Doppler Orbitography and Radio positioning Integrated by Satellite), and the need for a series of earth science research at the time, the IERS Center is responsible for establishing ITRF. It is an integrated, global, highprecision geocentric reference frame. ITRF is implemented by globally distributed observatories, which are usually equipped with observational and solution equipment's such as VLBI, SLR, GPS and DORIS.And since 1988, there were a total of 15 Version of the framework, namely ITRF0, ITRF88, ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005 and ITRF2008.

The ITRF TFramework is realized with the ground reference station coordinates and velocity fields in Figure 2 in significantly greater numbers and types than the WGS84. In this paper, the ITRF EFramework is implemented with the final ephemeris provided by IGS.

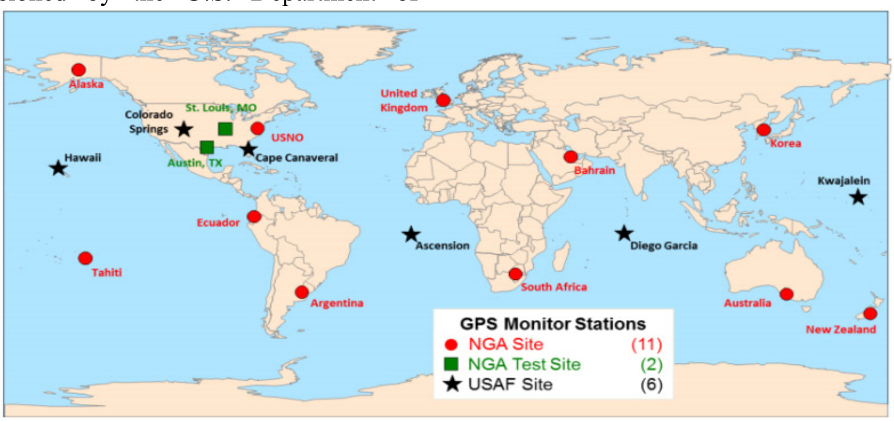

Figure 1: WGS 84 (G1762) Reference Frame Stations (http://earth-info.nga.mil/GandG/wgs84)

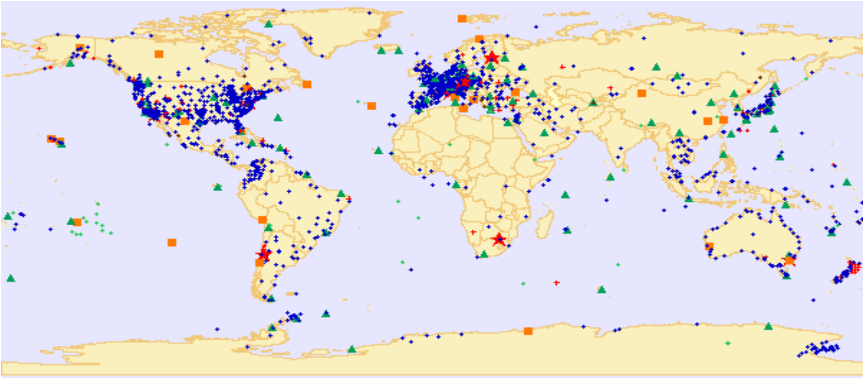

Figure 2: ITRF (2008) Reference Frame Stations (http://www.iers.org/IERS/EN/DataProducts/ITRF/itrf).

3 HELMERT COORDINATE TRANSFORMATION MODEL AND ESTIMATION OF E - FRAME CONVERSION PARAMETERS

3.1 Helmert Coordinate Transformation Model

The seven-parameter Helmert Transformation, also known as the Bursa-Wolf model (Závoti, 2012), contains seven parameters, of which three are translation parameters; three are rotation parameters and onescale parameters (Figure 3). In the figure below, for two different spatial Cartesian coordinate frames (in this paper, the WGS84 E frame implemented by NGA and the ITRF E frame implemented by IGS). Seven parameters contain three translation parameters, three rotation parameters and one scale parameter.

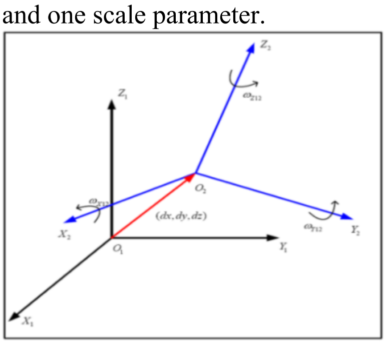

Figure 3: Seven parameters Helmert transform of two coordinates.

It can be expressed as

$$\begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} = \begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} + \begin{bmatrix} dm & \omega_z & -\omega_y \\ -\omega_z & dm & \omega_x \\ \omega_y & -\omega_x & dm \end{bmatrix} \begin{bmatrix} X_2 \\ Y_2 \\ Z_2 \end{bmatrix} \quad (1)$$

In the ideal case, the classical least-squares method is used, that is, under the least squares criterion, where is the inverse of the coordinate covariance matrix (i.e., the weight matrix) of each point. The conversion parameters between the two coordinate bases are as follows (classical least squares solution):

$$\check{\beta} = (A^T PA)^{-1} A^T PL \quad (2)$$

3.2 E Framework Conversion Parameter Estimation

Framework conversion parameters usually include the ground common point method and ephemeris method. The ground point method is the most common method for solving the different coordinate reference transformation parameters. Its principle is to select some GNSS ground observation stations (the best global distribution), and the precise point positioning method is used to estimate the coordinate values of the stations in different GNSS coordinate data, and further obtain the transformation parameters. The essence of the ephemeris method is the same as that of the terrestrial common point method, except that the position of the satellite is regarded as a common point. The principle of the ephemeris is to estimate the transformation parameters by estimating the values of the satellites in different GNSS coordinate frames.

If the precision ephemeris is used to estimate the datum conversion parameters, a set of parameters can be estimated by the precision of a day. The interval between precise ephemeris is 15 minutes, and there are 96 groups of parameters every day. The least square method is used to deal with the superfluous observation data and finally get a set of estimation parameters. Using the ephemeris method we can calculate a set of conversion parameters every day. Its flow is as follows (Figure 4):

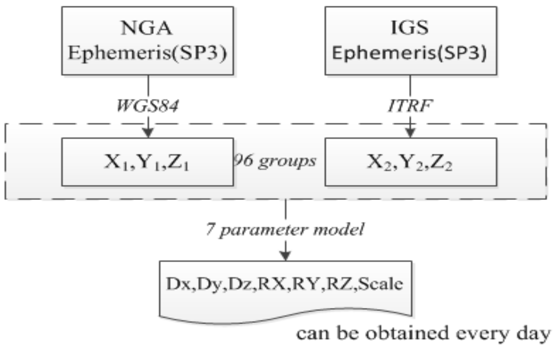

Figure 4: Flowchart of conversion parameters estimation using ephemeris.

4 CALCULATING RESULTS

From the Helmert transformation model in Section 3, the transform seven parameters of the WGS84 / ITRF E frame can be obtained by using GPS final precision ephemeris (* .sp3) provided by NGA and IGS. In this study, the author selected a total of 6005 transform parameters (one set per day) from 2001 to 2017. This study not only analyzed the time series of seven conversion parameters, but also calculated the average daily transform parameters. Based on this, the impact of the WGS84 / ITRF E framework implemented by NGA and IGS Precise Ephemeris on user positioning is analysed. The detailed results are as follows.

The evolution of the three translational parameters is analysed in Figure 5. From the analysis of the graph, it can be found that after the first day of 2012, the translation parameters decreased significantly in the direction of X and Y. On the 344th day of 2010, the translation parameters appeared abnormal in X and Y directions. In Z direction, the translation parameters had 5 abnormal jumps. For the same result of each year, see Figure 6, we can find that in recent years the values of the three translation parameters become smaller and smaller, and closer to zero.

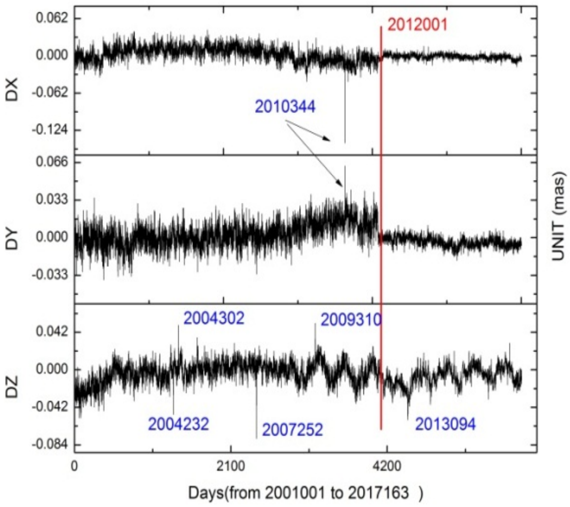

Figure 5: Time series of DX, DY and DZ.

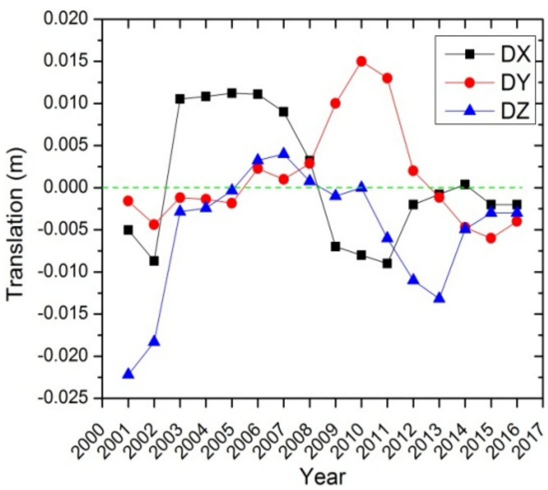

Figure 6: Annual mean statistics of DX, DY and DZ.

In Figure 7, the evolution of three rotation parameters is depicted. The unit of rotation angle is mas. From the following analysis, it can be found that after the first day of 2012, the three rotation parameters changed a lot. On the twentieth day of 2002, the rotation parameters of Y appeared abnormal jump. On the ninety-ninth day of 2002, the rotation parameters also had 1 abnormal value. From the analysis of the annual average in Figure 8, it is found that in recent years, the three rotation parameters all jerk up and down near zero, and there is no obvious trend deviation.

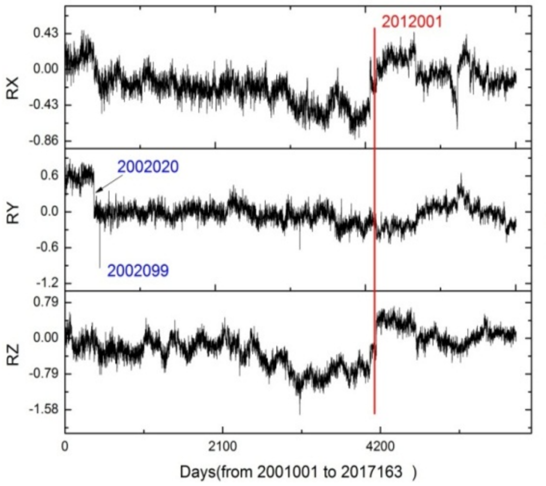

Figure 7: Time series of RX, RY and RZ.

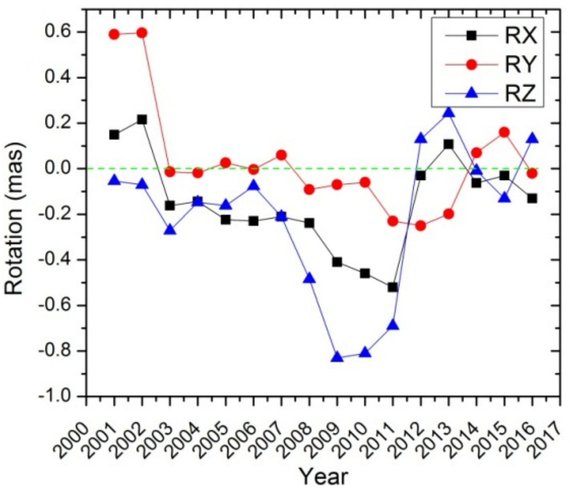

Figure 8: Annual mean statistics of RX, RY and RZ.

In Figure 9, the scale parameter is plotted in units of ppb, and it can be found that there is no obvious trend change before and after 2012001. However, we can see from Figure 10 that the scale parameter shows a shrinking trend in the past three years. Throughout the daily scale parameters, a total of three numerical abnormalities occurred.

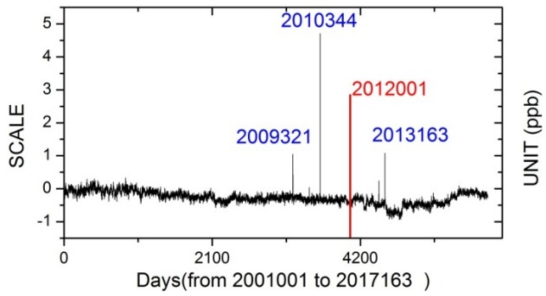

Figure 9: Time series of scale factor.

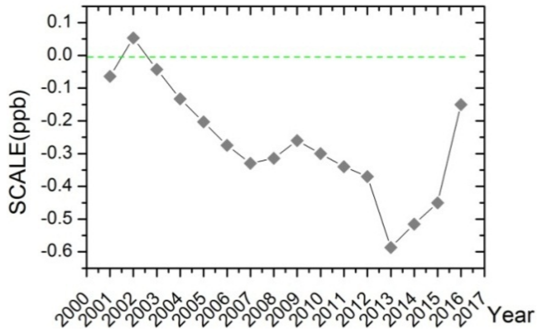

Figure 10: Annual mean statistics of scale factor.

The precise ephemeris of NGA and IGS are obtained by using different observation station data, precise orbit determination and time synchronization strategy, so there are certain differences between them. This difference can be unified by a set of conversion parameters. But if the user uses their precise ephemeris to determine the point position of the ground receiver, how much error can be caused? Figure 11 shows the user range error (URE) caused by the E framework difference of WGS84/ITRF. We can find from Figure 12 that user location error caused by the two frame difference at about 0.05m. In 2009-2012 years, the value of URE is relatively large, and the standard deviation is larger too. After 2012, the E framework difference between WGS84 and ITRF kept a stable and low level.

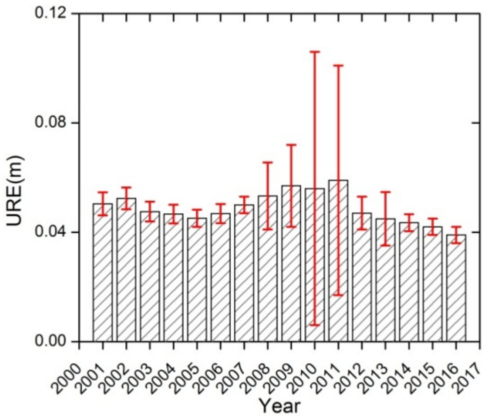

Figure 11: Annual mean values of URE.

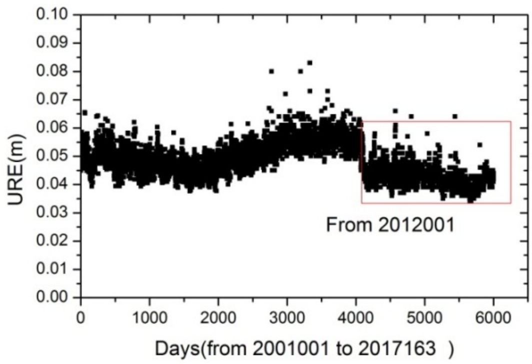

Figure 12: Time series of URE.

5 CONCLUSIONS

Over the past decade, WGS84 E framework (implemented by NGA ephemeris) and ITRF E framework (implemented by IGS final ephemeris) have been used to analyze time series, including three translational parameters, three rotation parameters and a scale parameter evolution. The analysis results show that the difference between WGS84 (NGA E framework) and ITRF (IGS E framework) is very small (the influence on user location is less than 5cm), and the difference is not constant. Therefore, when the user is in decimeter navigation scenes, systematic errors need not be considered. While precise positioning is carried out, such as plate motion, systematic errors need to be estimated .

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