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An Optimum Strategy for Producing Precise GPS Satellite Orbits using Double-Differenced Observations

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ABSTRACT

Both the double-differenced and zero-differenced GNSS positioning strategies have been widely used by the geodesists for different geodetic applications which are demanded for reliable and precise positions. A closer inspection of the requirements of these two GNSS positioning techniques, the zero-differenced positioning, which is known as Precise Point Positioning (PPP), has gained a special importance due to three main reasons. Firstly, the effective applications of PPP for geodetic purposes and precise applications depend entirely on the availability of the precise satellite products which consist of precise satellite orbital elements, precise satellite clock corrections, and Earth orientation parameters. Secondly, the PPP processing strategy has been employed by the International GNSS Service (IGS) and IGS analysis centers to evaluate their products in terms of homogeneity and precision over a long period of time. Thirdly, the precise positions, which are determined using PPP technique, and are referenced directly to the geodetic reference frame of the satellite orbital parameters. Thus, the definition of the geodetic datum of the site coordinates using different strategies plays an enormous role in the process of generation satellite orbital parameters which have to be compatible with the corresponding satellite clock corrections and the Earth orientation parameters. This study focuses on producing uninterrupted series of satellite orbit and clock products using different criteria and assesses these products using PPP. The double-difference processing technique was used to achieve the goal of this study by Bernese GPS software version 5.0. Twenty-two globally distributed IGS stations were selected to run PPP based on the generated products and then compare the results with corresponding PPP results which were created based on the IGS rapid products. The comparison pointed to a significant improvement in the generated precise products which have considerably increased the precision of positions. What is more, this study stated that there is an observable agreement between the horizontal positions accuracies which are generated using different techniques for modeling the reference frame.

Key Words: GPS, Orbit, Clock, BSW, EOP.

الاسلوب الامثل لانتاج مدارات الاقمار الاصطناعية للنظام الملاحي العالمي باستخدام الارصادات التفاضلية

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الخلاصة

لقد استخدمت الارصادات التفاضلية والصفرية لتعيين المواقع الارضية باستخدام الانظمة الملاحية العالمية من قبل علماء الجيوديسيا لمختلف التطبيقات الجيودسية، حيث تتطلب هذه التطبيقات مواقع جيودسية ذات موثوقية عالية. وبتسليط الضوء

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على طرق تعيين المواقع المختلفة هذه نجد ان تعيين المواقع عن طريق الارصادات الصفرية والمسمى باسلوب تعيين الموقع النقطي الدقيق له اهمية كبيرة نتيجتاً لثلاثة اسباب. اولاً: التطبيقات الفعالة لتعيين الموقع النقطي الدقيق للاغراض الجيودسية يعتمد كليا على توفر العناصر المدارية الدقيقة للاقمار الاصطناعية كذلك عناصر تصحيح ساعات القياس وعناصر التدوير الارضي. ثانياً: لقد استخدم اسلوب تعيين الموقع النقطي من قبل مراكز تحليل البيانات التابع الى IGS لغرض تقييم مقدار دقة التجانس للعناصر المدارية وتصحيح ساعات القياس. ثالثا: تعيين المواقع الدقيقة بأستخدام اسلوب الرصد النقطي يُسنِد هذه المواقع الى المرجع العالمي المستخدم في تحديد مدارات الاقمار الاصطناعية. ولهذا السبب ان عملية تعيين المرجع العالمي لمدارات الاقمار الاصطناعية اصبح من المواضيع المهمة والتي لها دور كبير في توجية ستراتيجيات تعيين العناصر المدارية للاقمار الاصطناعية. هذه الدراسة تسلط الضوء على انتاج سلسلة من العناصر المدارية وعناصر تصحيح ساعات القياس باستخدام معايير مختلفة وتقيم النتائج عن طريق استخدام تعيين الموقع النقطي الدقيق.لانجاز هذا العمل تم تعيين الموقع النقطي الدقيق عن طريق برنامج Bernese GPS software حيث تمت معالجة الارصادات المأخوذذة من 22 محطة ارضية IGS باستخدام البيانات المدارية المنتجة في هذا البحث ومن ثم تمت مقارنة النتائج مع نظيرتها والتي أُنتجت بالاعتماد على بيانات IGS السريعة. اضهرت النتائج تحسن كبير وملحوظ بالاضافة الى وجود توافق كبير بدقة المواقع الافقية المنتجة في هذا البحث و بمعايير مختلفة.

الكلمات الرئيسية: GPS، مدار، الساعة، BSW, EOP.

1. INTRODUCTION

The contribution of precise point positioning using GNSS has been significantly witnessed in several geodetic applications, such as monitoring the deformation in the Earth's crust, shifts in the Earth's tectonic plates, and realization of the International Terrestrial Reference System (ITRS). However, these applications are necessary to precisely position time series for a number of permanent GNSS receivers, which are working continuously to providing uninterrupted observations over the whole period of monitoring, for detection any unusual change, jump, and shift. In this research, the abbreviation "PTS" will be used to refer to position time series. On the other hand, these PTSs have been produced powerfully using double difference GNSS observations (dual-frequency carrier observations) "DD" and Precise Point Positioning "PPP". Nevertheless, the successful processing of these two GNSS positioning techniques depends on the availability of accurate, reliable, and homogeneous satellite orbital information (ORB), satellite clock correction estimates (CLK), and Earth Orientation Parameters (EOP). The DD processing technique determines the precise position of a mobile receiver based on observations from reference station which has a well-known position, **Hofmann-Wellenhof, et al., 2008**.

In terms of consuming processing time and avoiding of the baseline processing complications, PPP algorithm, which deals with undifferenced carrier phase together with pseudo-range observations of stand-alone GNSS geodetic receiver, was established and developed **Kouba and Héroux, 2001**. PPP is the most accurate and effective positioning technique where the positional accuracy of PPP relies entirely on the accuracy of the precise orbital information and the satellite and receiver clocks corrections. PPP technique has been run for more than two decades today by different multi-GNSS data processing software, such as GIPSY-OASIS, **Zumberge, et al., 1997** and Bernese GPS software BSW, **Dach, 2007**. Currently, PPP represents an alternative to DD and can deliver centimeters to millimeters accuracy using precise satellite orbital information, satellite clock corrections, and Earth orientation parameters throughout processing and modeling of systematic errors, **Kouba and Héroux, 2001**. In summary, PPP has become an alternate to DD due to a reason that PPP provides reliable positions with absolute accuracy, very simple and effective in terms of processing strategy and time-consuming. On the other hand, the efficiency of PPP relies on the availability of ORB which has to be consistent with both of CLK and EOP, **Kouba and Héroux, 2001**.

Currently, the International GNSS Service ''IGS' is the central source of ORB, CLK, and EOP products. Since June 1992, high-quality GPS/GNSS observations raw data and continuous IGS products have been delivered to the GNSS communities for supporting different scientific and multidisciplinary applications. IGS has made massive effort to meet the requirements of different users throughout producing different IGS products; these are Final products (IGS), Rapid products (IGR), and Ultra-rapid products (IGU). The essential variations between these three categories are the accuracy, updates, and latency **Ray, 2017**. One of the main functions of the IGS and the IGS Analysis Centres (ACs) is to improve their three categories of products. For example, at the end of 2006, the IGS agreed to adopt the absolute antenna phase center models instead of relative antenna phase center models for both satellite and receiver antennas and Global Mapping Function (GMF) for computation the tropospheric delay **Gendt, 2006**. However, such developments have an advantage in limited term applications, for example, GPS meteorology. Additionally, the IGS and ACs are continuously updating their GPS/GNSS data processing software by adopting the latest mapping function and realization of the International Terrestrial Reference System (ITRS). Moreover, the remarkable increase in the size of the permanent IGS station has positively enhanced the quality of the IGS products **Ray and Griffiths, 2011 and BEUTLERL, et al., 2003.** Consequently, many researchers have addressed that the precision of positions may be negatively affected owing to a lack in modeling the atmospheric effects, considering different processing models, using different ITRS realizations. Therefore, massive efforts have been made by the IGS ACs to reprocess all the IGS raw observation data which have been recorded and archived since the official establishment of IGS in 1994 to generate consistent and homogeneous ORB, CLK, and EOP.

This study aims to evaluate the efficiency of the modified BSW5.2 orbit determination software (ORBDET) for GPS/GNSS orbit development. Many examinations were carried out by the author on using different criteria of ORBDET process control file. The main points which were investigated in this study are: Firstly, BSW primarily defines the initial station coordinates to run parameter estimation programs GPSEST and ADDNEQ2, **Dach, et al., 2007**. The ADDNEQ2 program is a software tool that accumulates the normal equations using a particular binary format. This study proposed a technique of fixing the station coordinates using the station coordinates and velocity estimates which are defined by the reference frame used in the processing. The second aim of this study is to investigate the optimum strategy for defining the geodetic datum for generation ORB estimates which have to be compatible with generated CLK and EOP for optimum PPP solution.

2. THE IGS GPS AND GLONASS ORBIT GENERATION

The subject of modeling the GPS and GLONASS precise orbit estimates is characterized as an essential theme in GNSS theory. This superiority arises due to the importance of knowing precise and reliable satellite positions for measuring the signal traveling time from the satellite to the receiver, **Xu, 2003**.

On the 1st of January 1994, the International GNSS Service (IGS) became officially operational and many ACs and institutions are being participated in various aspects of this action, such as tracking the GPS and GLONAAS satellite, archiving the GNSS raw observation data, analyzing the GNSS raw data, and assessing their final results. On the other hand, the IGS is combining the analysis centers' products to yield IGS, IGR, and IGU products for supporting different requirements of the IGS users’ community. It is worth to mention here that before the establishment of the IGS, the availability of precise orbit estimates represented the main limitation in geodetic applications. Regarding the routine orbit combinations by IGS, **Beutler, et al., 2003**, examined two techniques for orbit combination; the first technique comprises of a weighted averaging process of the Earth-fixed satellite positions as produced by the individual ACs, where the second technique depends on the individual IGS orbit files as pseudo-observations in an orbit determination process. They found a notable agreement at the level of 5 cm. Moreover, **Beutler, et al., 2003**, processed a set of continental baselines in two different regions using two different processing software to evaluate the quality of the combined orbits. Both types of combined orbits gave similar baseline repeatability of a few ppb (parts per billion) in both regions which compared favorably to the best individual orbits in the region.

Steigenberger, et al., 2006, addressed the initial GPS reprocessing project (GPS-PDR) to reprocess the GPS raw observations data of more than two hundred IGS stations using BSW 5.0 over the period from January 1994 to the end of 2005. This effort was carried out by Technische Universität Dresden (TUD), GeoForschungs-Zentrum (GFZ) Potsdam, and Technische Universität München (TUM). Their preliminary results were built on employing a mapping function that based on numerical weather model, 2^{nd} and 3^{rd} order of ionospheric corrections, and absolute antenna phase center corrections for receivers and satellites. Their results indicated noticeable enhancements in both of the homogeneity and quality of the parameter estimates. **Steigenberger, et al., 2009,** evaluated the **Steigenberger, et al., 2006** reprocessing effort and precision, and reliability of the satellite orbital parameters of GPS-PDR scheme. **Steigenberger, et al., 2009** pointed out the significant improvement in orbital parameter estimates by a factor of two particularly on the first years and they attributed this remarkable improvement to the noteworthy growth in the number of IGS stations over the period from 1994 to 2005 and using advanced algorithms for modeling the atmospheric effects.

In terms of dealing with the orbit errors, **Dach, et al., 2007** discussed the effect of unmodelled orbit errors on the estimated station coordinates. They stated that there is a correlation between the error Δx in a component of the baseline length and the orbital error. **Dach, et al., 2009** highlighted the used technique for the generation of the ORB, CLK, and EOP products at the Centre for Orbit Determination in Europe (CODE) using BSW5.0, and this included the advantage of involving GLONASS in the CODE products. Additionally, **Dach, et al., 2007** study presented the CODE strategy for GNSS orbit generation process and the importance of the using IGS network that is distributed globally over the whole world. **Griffiths and Ray, 2009** assessed the precision the IGS Final orbit estimates using three approaches: the IGS accuracy codes, weighted root mean square for residual estimates of long-arc analysis; and in the third approach they calculated the differences in the geocentric satellite positions at the central period between consecutive sets of daily IGS Final orbit files. For all the GPS satellite, they found the IGS accuracy codes nearly constant (0.5 cm to 1 cm), but the Weighted Root Mean Square (WRMS) long-arc values are overstated, especially during eclipse seasons.

3. IGS REANALYSING PROJECTS

The IGS and IGS ACs have been carrying out reprocessing campaigns on a periodic base. The ACs reanalyze the full IGS (GPS and GLONASS) raw observation data, which have been recorded and archived since 1994 to the present time, using the most advanced models and processing software. The first reprocessing campaign was started in 2010, where ten ACs participated to reanalyze all the GPS observation raw data since 1994 to the end of 2007, **Gendt and Ferland, 2010** and **Ray, 2017**. The second reprocessing campaign was carried out in 2013, where all the IGS ACs contributed in this campaign and reanalyzed the complete history of GPS and GLONASS raw data. The second reprocessing was achieved based on the latest mapping function for modeling the tropospheric delay, modeling the second order and third order ionospheric terms, most recent methodologies. Finally, the second reprocessing campaign results were provided later to the International Earth Rotation Reference System Service (IERS) for the realization of International Terrestrial Reference Frame 2008 (ITRF2008), for more information, "https://www.iers.org". In contrast, the third reprocessing campaign, which is the latest effort, has contributed to producing ITRF2014, **Ray, 2017**.

4. THE PREPARATION FOR ORBIT PRODUCTS GENERATIONS

At this time, twelve independent IGS ACs are contributing their orbit products to the IGS Analysis Centre Coordinator (ACC), where the latter depends on the weighted linear combination to generate the official IGS combined products (IGS, IGR, and IGU). GNSS satellite orbit improvement is one of the fundamental functions of BSW5.0, through the process of the orbit models which are implemented in program orbit generation (ORBGEN). To achieve the aims of this research, it is important to illustrate the main aspects that have to be considered in the GPS satellite orbit improvement, **Dach, et al., 2007**.

1. The process of precise orbit generation has to be started from raw observation data of a dense globally well-distributed network for a consistent estimation of orbit parameters. Using regional network will improve subset of orbit parameters. Moreover, the broadcast navigation message or precise orbit file can be used as a priori orbit estimates if no better sources are available, **Dach, et al., 2007**.
2. Double-difference carrier phase and code observations are processed to resolve the ambiguity which positively impacts the quality of the estimated orbits. Furthermore, to avoid baseline processing problem, the processed global network has to be split up into a number of regional clusters, each regional cluster gives sub-solution, **Dach, et al., 2009**.
3. Preparation of standard orbital parameter (STD) and the radiation pressure parameters (PRP) for use within BSW5.2. These preparations require a set of Earth orientation parameters (EOP) values for transformation the satellite positions from the inertial (celestial) reference frame to the Earth-fixed Earth-centre reference frame. In the inertial (celestial) reference frame, the satellite orbits can be fitted to parameterized models for the dynamical motions. Thus, the Earth orientation parameters have to cover the whole period of processing for generation reliable orbital information in a standard format. Concerning the radiation pressure parameters, the radiation pressure file contains the derivatives of the satellite positions with respect to the initial conditions and the dynamical parameters, however, it is only required for orbit improvement, **Dach, et al., 2007**.

5. INTERNAL ORBIT ACCURACY ESTIMATES

In the process of satellite orbital parameters generation, the IGS internal orbit accuracy estimates are considered in this study to detect and exclude the satellites with unhealthy status, these IGS initial orbit accuracy estimates are:

1. IGS accuracy code: the estimates of the IGS orbit quality are provided throughout the IGS precise orbit products (header of the orbit file). These estimates are called the IGS accuracy codes. IGS accuracy codes are being calculated on daily basis based on the WRMS for the differences between the IGS ACs orbit products and the average orbits after applying a 7-parameter Helemrt transformation, **Griffiths and Ray, 2009**.

2. Long-arc WRMS residuals: other indications for the accuracy of the IGS orbit products are being provided by the IGS ACs. These indications called Long-arc WRMS residual estimates. Additionally, the IGS, that produce the IGS final orbits in 7-day batches, also computes the “long-arc” WRMS residual estimates for each satellite orbit using a dynamical fit of the orbital parameters over one week **Beutler, et al., 1995**.

6. USING BSW5.0 FOR SATELLITE ORBIT IMPROVEMENT

In this study, BSW5.0 was used for precise orbital parameter improvement. BSW5.0 relies on the DD phase and code observation processing using process control file (RNX2SNX). The latter has been modified and the new edition is denoted in this research by "ORBDET.PCF". ORBDET.PCF deals with cluster processing and starts from the RINEX observation data of selected regional network. In general, BSW5.0 initiates the processing campaign from either precise orbit products or broadcast ephemerides and generates the orbital information within the normal equation (NEQ) for producing a global one-day solution. In order to combine the NEQs from cluster processing stage, a simple process control file is formed in this study, is named as "ORBDET_C.PCF", for combination and generating the final NEQ information and global orbital elements. These generated orbital elements may be used later in the program ORBGEN to create a new standard orbit file with the orbital parameters estimated in ADDNEQ2.

The most significant aspects of ORBDET process control file are:

1. ORBDET rejects the GPS raw observations with significant gaps or unexpected residuals.
2. In the cluster processing stage, the satellite problem files (CRX) are used to exclude bad satellites from the tabular orbitalparameters.
3. Station with observations less than 75% are excluded from the processing. In addition, code observations less the elevation cut-off angle of 10^o are excluded.
4. The minimum number of observations, which are required to create the single-difference observations (baselines) from zero-difference phase observations, is 600 observations. Moreover, maximum baseline length to be formed is 6000 km.
5. For baselines up to 2000 km length, the ambiguity is fixed using quasi-ionosphere-free (QIF) approach, **Mervart, 1995**.
6. Regarding the definition of the geodetic datum of the network, three strategies for datum definition, which are supported by ADDNEQ2, were proposed and investigated in this study, these are:
   i. Free network solution:
   This solution is derived without applying any geodetic reference datum. Consequently, the geodetic datum of the output solution will be defined by the geodetic datum of the satellite orbital parameters which are fixed for producing the global solution. In other words, the free network geometry is formed from the GPS and GLONASS raw observation data and not influenced by geodetic reference datum coordinates.
   ii. Minimum constrain solution:
   The datum definition of the network in this solution is defined using network conditions, where no-net translation, no-net rotation, or no-net scale conditions may be imposed in this solution. As a result, the geodetic datum of the output solution will be defined and affected by the used geodetic reference datum.
   iii. Reference coordinates constrained:

This solution constrains coordinates of a certain set of reference stations to their positions for defining the geodetic datum.

For more details, see **Dach, et al., 2007.**

7. ORBITAL ESTIMATION FOR ONE-ARC SOLUTION:

The orbital estimation for one-arc solution includes the following elements:

1. Up to 6 orbital (Keplerian) elements (Semi-major axis, eccentricity, inclination, ascending node, perigee, and argument of latitude).
2. Up to 6 radiation pressure parameters (dynamical parameters) for each arc, which are: the direct solar radiation pressure; so-called 'y-bias' in the direction of the satellite's solar panel axis; an acceleration perpendicular to the directions of direct solar radiation pressure and the satellite's solar panel axis.
3. Periodic terms of the direct solar radiation pressure, the y-bias in the direction of the satellite's solar panel axis, and the acceleration perpendicular to the directions of previous terms. These terms are represented by once per revolution harmonic functions of the argument of latitude for the satellite.

8. TEST CAMPAIGNS AND RESULTS

To assess the efficiency of the modified BSW5.0 ORBDET and ORBDET_C process control files for GPS orbit improvement, many investigations have been carried out in this study using different criteria and options within these two process control files. Two points were investigated in this study to address the optimum solution, these are:

A. First Investigation:

The estimation program GPSEST and normal equation program ADDNEQ2, which are used in this study, read the prior coordinates of all stations. A global network was selected (147 stations) and split it up into four regional clusters, which are Australia and Antarctica and New Zealand cluster, Europe cluster, Canada and North America cluster, and South America cluster, and the fifth cluster comprises redundant baselines.

For generation orbit products, the station's selection was carried out in this study based on the length of the observation period, global distribution, and contribution to existing International terrestrial reference frame. The a-priori coordinates should be known within a few centimetres accuracy; otherwise, GPSEST runs additional iteration throughout introducing the output coordinate estimates from the previous iteration as new a-priori values. What is more, this study dealt with two strategies for defining the reference geodetic datum. The first strategy, the coordinates of 147 stations were improved via GPSEST software run (several iterations) and then submitted the final output estimates to run ADDNEQ2 software for combining five final cluster solutions. Regarding the second strategy, the coordinates of 147 stations were fixed to the used ITRF2005 in all the GPSEST and ADDNEQ2 runs. Both situations were investigated by carrying out two campaigns, over 6 weeks, and then the output orbit parameter estimates (in standard format) were compared with those corresponding the IGR products. It is worth to mention here that the results which were obtained from fixing ITRF2005 as a-priori values for all iterations of GPSEST run are better than using the improved coordinate estimates.

B. Second Investigation:

The second investigation in this study was carried out on the subject of orbit generation process, where three campaigns were run over five months (1442-1464). The processing was stated from the RINEX observation data for these 147 stations and IGR orbit products together with the corresponding Earth rotation parameter (ERP) as a priori information. These three campaigns are:

1. **IGR2C** constrains coordinates of a selected set of reference stations (IGS05.FIX, ftp://ftp.unibe.ch/aiub/BSWUSER50/STA/) to their a priori coordinates for defining the geodetic datum, the strength of the constraint sets to 10 cm in east, north, and up components.
2. **IGR28** defines the geodetic datum of the site coordinates using no-net translation, no-net rotation, and no-net scale conditions.
3. **IGR29C** defines the geodetic datum of the site coordinates using no-net rotation only, **Steigenberger, et al., 2006**.

The generated GPS orbit files in Bernese format (standard format) are used then with the IGR pole information to generate clock products by modified BSW5.0 clock determination process control file (CLKDET). **Fig. 1** describes the processing procedure that is proposed in this study to produce ORB, CLK, and EOP and evaluate the homogeneity as well as the consistency of these estimates using PPP.

9. GENERATION PPP SOLUTIONS

Regarding the PPP campaigns, a network of 22 globally distributed IGS stations was selected for PPP campaigns, see **Fig. 2**. **Table 1** lists station four digits site name for 22 selected IGS stations, country name, geographic coordinates, receiver clock type, and satellite system, for more details regarding the full IGS network, the reader is referred to **Ray, 2017** (http://www.igs.org/network). The PPP process control file was run four times in this study to generate PPP daily solutions for four types of ORB, CLK, and EOP estimates. The first three PPP solutions were accomplished based on the ORB, CLK, and EOP estimates which were produced by IGR2C, IGR28, IGR29C campaigns, as in the previous section. These three PPP solutions are named IGR2C_PPP, IGR28_PPP, IGR29C_PPP. The fourth PPP solution was carried out using the essential IGR ORB, CLK, and EOB products and named as IGR solution. The latter IGR solution was done to evaluate the three solutions IGR2C_PPP, IGR28_PPP, IGR29C_PPP. Finally, the daily position of four PPP campaigns was presented as coordinate time series using Coordinate Time Series Analysis (CTSAna), **WESSEL and SMITH, 1998**.

The CTS analysis addressed the WRMS estimates for each station for four PPP solutions which are shown in **Fig. 3**, and **Fig. 4** which shows the CTS for station WTZR in Germany. These WRMS estimates, which are yielded by CTSAna, are computed for the variations between the generated positions by PPP solution and the parallel positions on the fit model are computed for each IGS station in north-, East-, and height- components. **Table 2** contains the mean and RMS values for the WRMS values for 22 IGS stations over five months. Two significant points can be concluded by **Table 2** and **Fig. 3**, firstly, there are slight differences between IGR28, IGR2C, and IGR29C WRMSs. Secondly, the generated orbit products and clock correction products give PPP results better than the IGR result. **Fig. 5** displays four histograms which illustrate the distribution of the WRMS estimates in millimeters for campaigns IGR2C_PPP, IGR28_PPP, IGR29C_PPP, and IGR. Regarding the north component, the IGR2C, IGR28, and IGR29C (improved) PPP solutions showed a high level of similarity where more than 86% of stations have WRMS values of less than 2 mm whereas less than 14% of stations gave WRMS values which range between 2.0 mm and 2.3. On the contrary, the WRMS estimates for the north component of IGR PPP solution are less than 2.0 mm for 60% of IGS stations and 2.1 mm to 2.7mm for 60% of the IGS stations.

Correspondingly, the WRMS values for the east component of IGR2C, IGR28, and IGR29C (improved) PPP solutions point to a high level of consistency where slightly more than 30% are ranged from 1.5 mm to less than 2.0 mm, and around 70% of stations gave WRMS within the range from 2.1 mm to less than 3.8 mm. In contrast, the WRMS estimates for the east component of IGR PPP solution are less than 2.0 mm for just 9% of IGS stations and greater than 2.5 mm for 91% of the IGS stations. Concerning the height component, the WRMS estimates of the IGR2C_PPP height component for one-third IGS stations range from 3.0 mm to 4.0 mm, and the one-third IGS stations changes from 4.0 mm to 5.0 mm, and the last one-third ranges from 5.0 mm to 6.0 mm. As far as the WRMS estimates of both IGR28C_PPP and IGR29C_PPP height components, these tow solution gave similar results where 36% of IGS stations have WRMS range from 3.0 mm to slightly less than 4.0 mm, and from 4.0 mm to 6.0 mm for 64% of IGS stations. In comparison with the IGR height component, the WRMS values for all the IGS stations are ranged from 4.0 mm to more than 6.0 mm.

10. CONCLUSIONS

This study has given an account of and the reasons for the widespread use of sophisticated GPS and GLONASS processing software for producing own precise satellite orbital information, satellite clock corrections, and Earth orientation parameters for optimum use in double-difference processing or precise point positioning. Many studies have stated the importance of using accurate and consistency products for successful application of PPP. Consequently, the recent developments in GPS and GLONASS data processing strategies have heightened the need for reanalyzing all the archived IGS data since 1994 using developed mapping function, modeling the second and third ionospheric refraction terms, and considering the latest geodetic reference datum. Because of this, this study has addressed the capability of using Bernese GPS software for reanalyzing the GPS raw observation data over a particular period of time. The finding of this study can be highlighted throughout the following points:

1. A preliminary strategy for GPS satellite orbit improvement using global double-difference network solution has been implemented and tested in this study. The experimental work in this study addressed the importance to process the regional network individually, and then combine the cluster solution into one–day global solution.
2. Approximately 147 GPS raw observations data have then been processed starting from IGS Rapid ORB, CLK, and EOP products for estimation satellite orbital estimates in BSW5.0 format.
3. Regarding the definition of the geodetic datum, three strategies have been involved in this study for estimation GPS satellite orbit products.
4. The same global network in point (2) has then been used with own satellite orbit products (three cases) and EOP from IGR for zero-difference processing to generate GPS satellite and receiver clock corrections using In-house modified BSW5.0–CLKDET process control file.
5. The estimated orbit product in point (2), satellite and receiver clock in point (4) and the EOP from IGR have been used in BSW5.0-PPP processing strategy for 22 stations to evaluate the consistency of generation precise ORB, CLK, and EOP products over five months by the author. Moreover, the IGS Rapid products have been used in BSW5.0-PPP processing for the same network.

6. The PPP results (three cases) and IGR PPP result have been presented as CTSs.
7. The three PPP solutions, which were carried out based on in-house generated products, have shown significant improvement in comparison with the PPP solution based on IGR products.
8. Regarding the comparison between the three improved PPP solutions, there is no noticeable difference (less than 0.01 mm) in the north-, East-, and height- components. However, there is a noticeable difference between these three PPP solutions and IGR PPP solution.
9. The WRMS estimates in the north components for PPP solutions identified that the IGR2C_PPP, IGR28_PPP, and IGR29C_PPP north components have been enhanced by 77%, 73%, and 55%, respectively, in comparison with the IGR north component. Moreover, the east components for both of IGR2C_PPP and IGR28_PPP solutions have an identical percentage of improvement, which equals to 55%, in comparison with IGR east component. However, the east component for IGR29C_PPP solution has been improved by 45% in comparison with IGR east component. Finally, the WRMS estimates in the height components for PPP solutions showed that the IGR2C_PPP, IGR28_PPP, and IGR29C_PPP height components have been improved by 45%, 55%, and 41%, correspondingly, in comparison with the IGR height component.
10. In general, the in-house generated precise products have remarkably increased the precision of the three-dimensional positions. On closer examination, an obvious agreement was seen between the horizontal positions of IGR2C_PPP and IGR28_PPP. What is more, one of the more significant findings to emerge from this study is that using no-net translation, no-net rotation, and no-net scale conditions for the definition of the geodetic datum of the coordinates is the optimal strategy for generation homogenous and consistence ORB, CLK, and EOP products for PPP applications.

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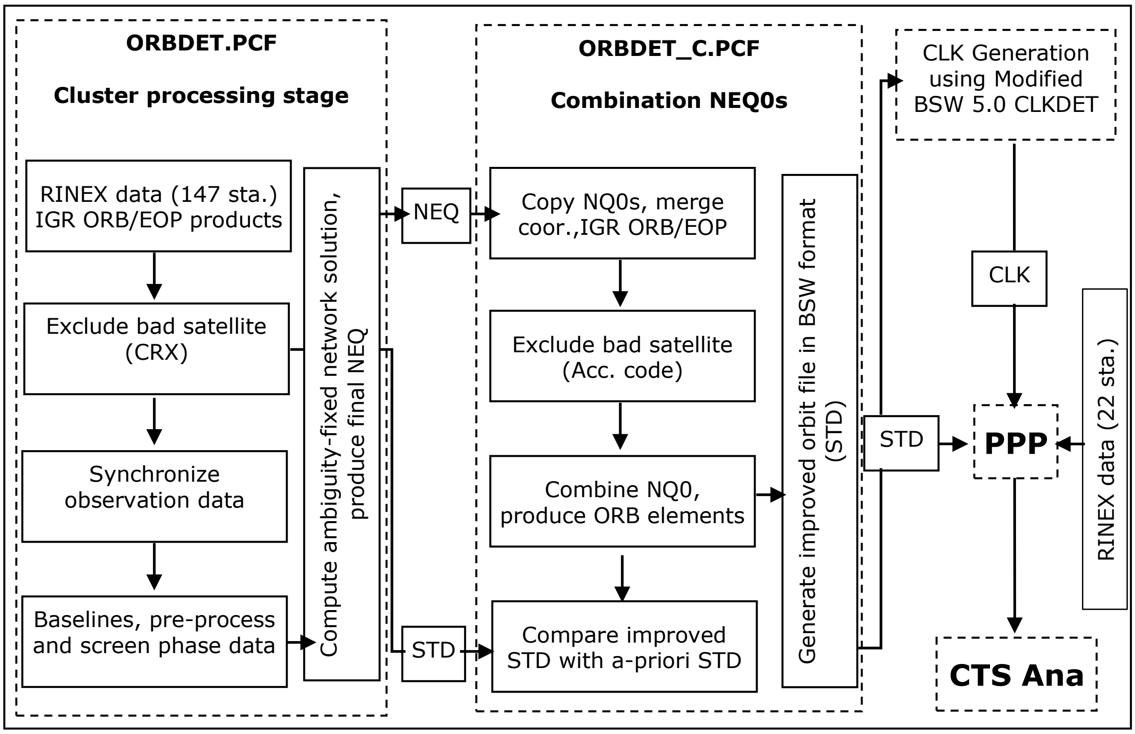

Figure 1. The modified BSW5.0 ORBDET, ORBDET, and CLKDET processing strategy.

Figure 2. Globally Distributed IGS stations.

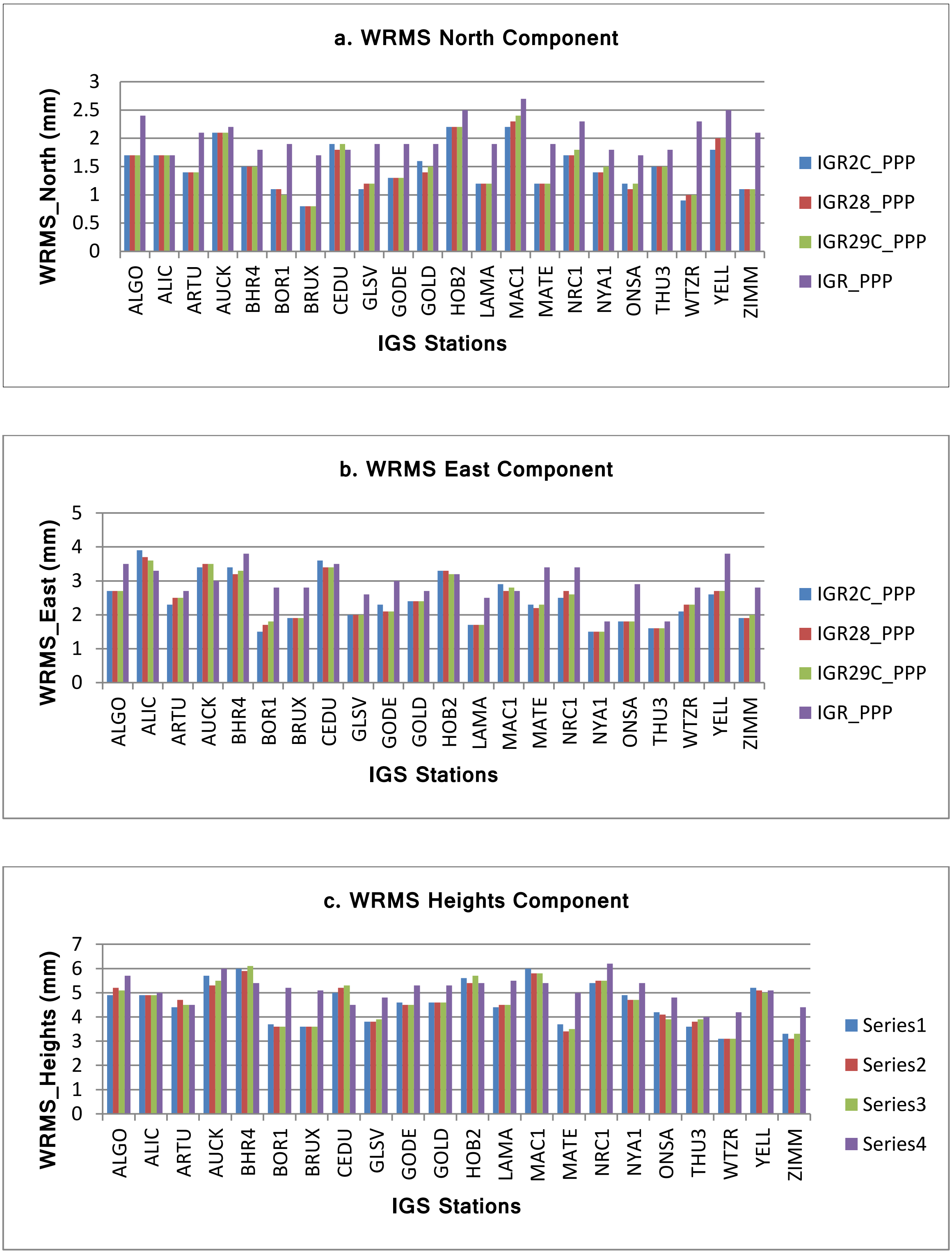

Figure 3. WRMS Estimates in Millimetres for PPP solutions (North, East, and Height Components) for a Globally Distributed Network in the Whole World.

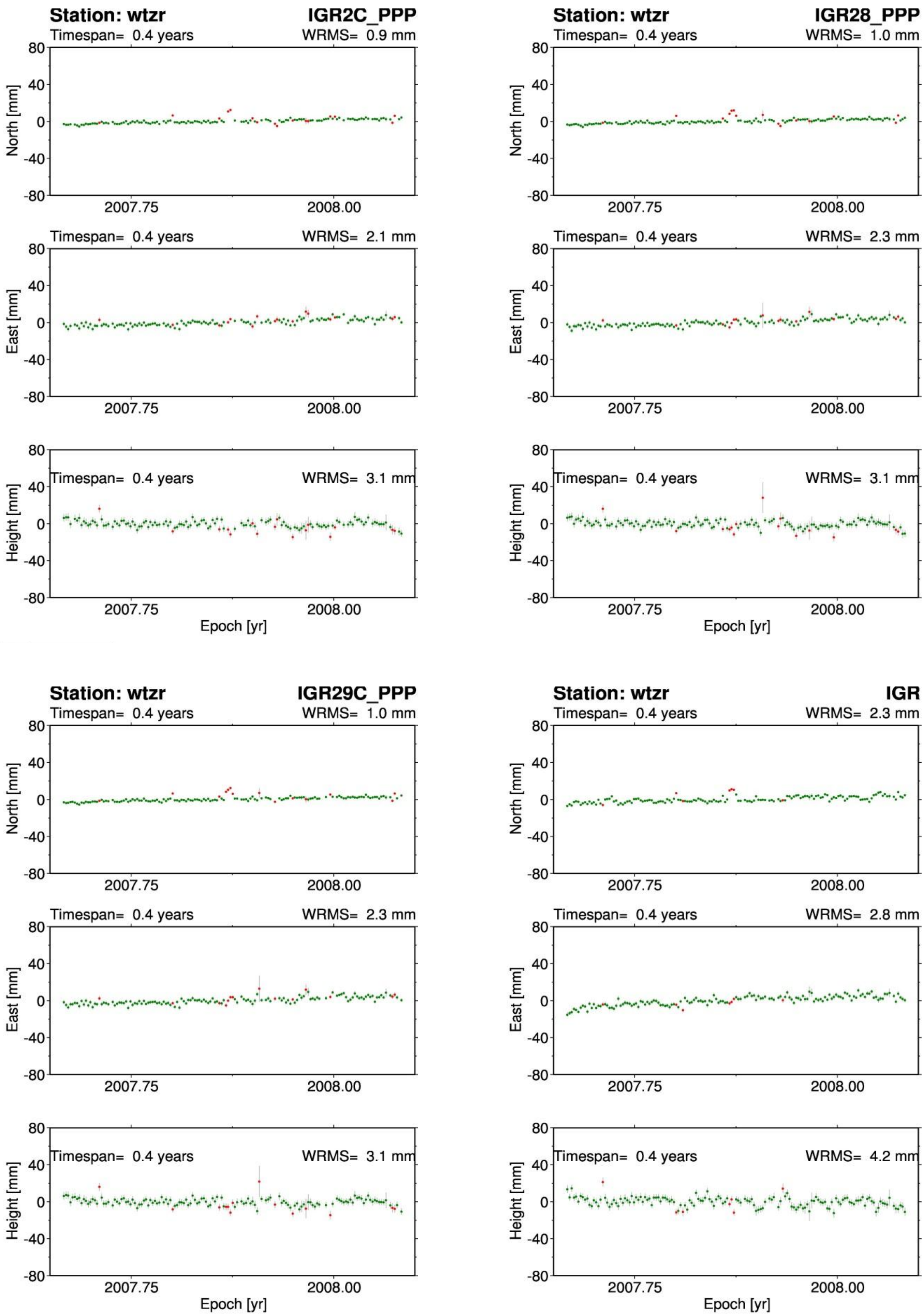

Figure 4. CTSAna Plots For WTZR**.**

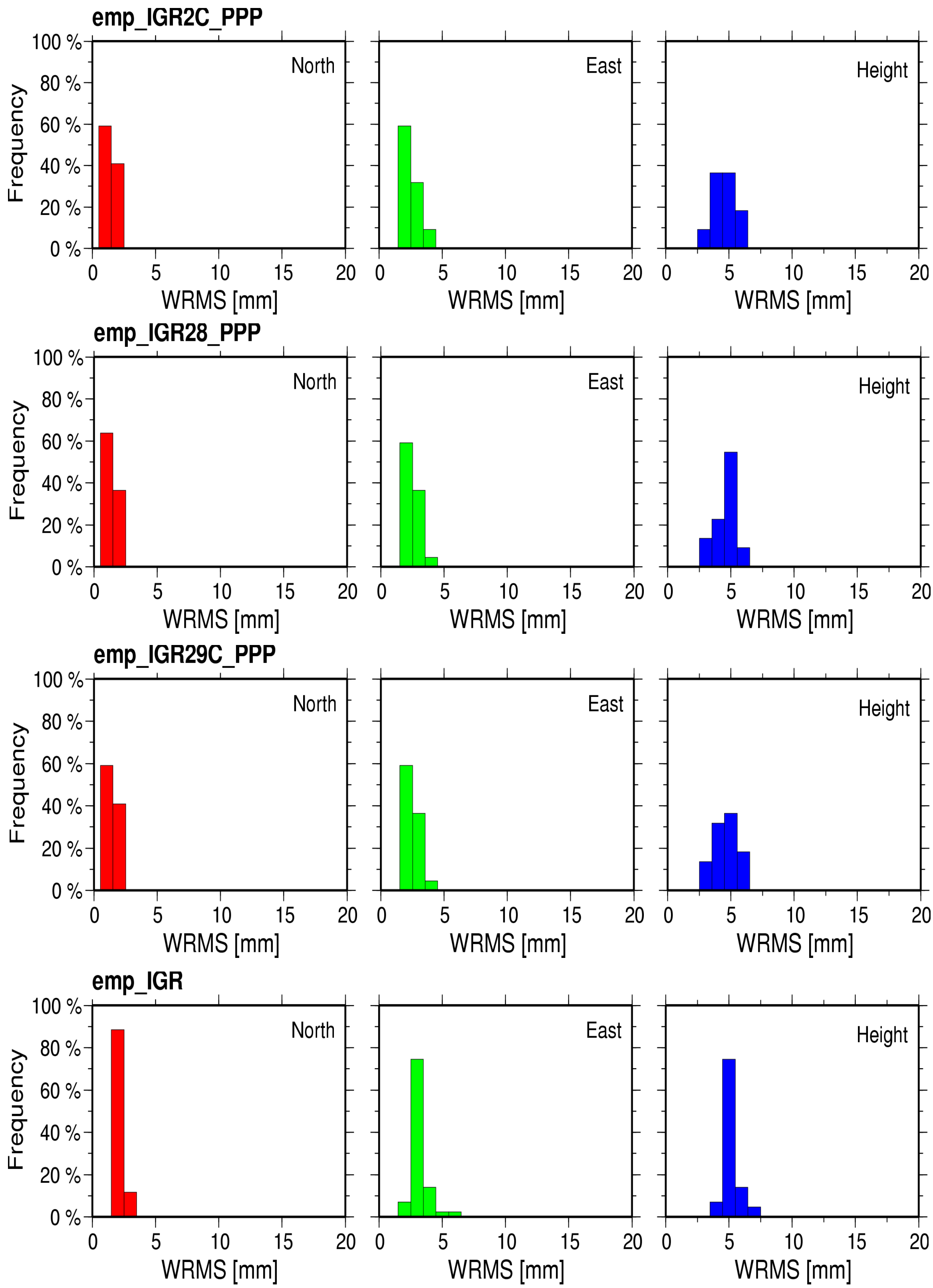

Figure 5. Weighted Root Mean Square Error Histograms.

Table 1. List of Selected Twenty Two IGS Stations for PPP Solutions.

Site	Country	Latitude	Longitude	Clock	Sat. System
ALGO	Canada	45.958611	-78.071389	EXTERNAL H-MASER	GPS+GLO+GAL
ALIC	Australia	-23.67	133.885278	INTERNAL	GPS+GLO+GAL+BDS+QZSS
ARTU	Russian	56.429722	58.560278	INTERNAL	GPS
AUCK	New Zealand	-36.602778	174.834167	INTERNAL	GPS+GLO+GAL+BDS+QZSS
BHR4	Bahrain	26.208889	50.608056	EXTERNAL CESIUM /RCVR2	GPS
BOR1	Poland	52.276944	17.073333	EXTERNAL H-MASER	GPS+GLO+GAL+BDS+QZSS+SBAS
BRUX	Belgium	50.798056	4.358333	EXTERNAL CH1-75A MASER	GPS+GLO+GAL+BDS
CEDU	Australia	-31.866667	133.809722	EXTERNAL H-MASER	GPS+GLO+GAL+BDS+QZSS+IRNSS
GLSV	Ukraine	50.364167	30.496667	INTERNAL	GPS+GLO
GODE	United States	39.021667	-76.826667	EXTERNAL H-MASER	GPS
GOLD	United States	35.425	-116.889167	INTERNAL	GPS+GLO
HOB2	Australia	-42.804444	147.438611	EXTERNAL H-MASER	GPS+GLO+GAL+BDS+QZSS+IRNSS
LAMA	Poland	53.892222	20.669722	INTERNAL	GPS+GLO
MAC1	Australia	-54.499444	158.935556	INTERNAL	GPS+GLO+GAL+BDS+QZSS+IRNSS
MATE	Italy	40.648889	16.704444	EXTERNAL H_MASER	GPS+GLO+GAL+BDS+SBAS
NRC1	Canada	45.454167	-75.623611	EXTERNAL H-MASER	GPS+GLO+GAL
NYA1	Norway	78.929444	11.865278	EXTERNAL H-MASER	GPS+GLO
ONSA	Sweden	57.395278	11.925278	EXTERNAL H-MASER	GPS+GLO
THU3	Greenland	76.536944	-68.825	EXTERNAL RUBIDIUM	GPS
WTZR	Germany	49.144167	12.878889	EXTERNAL H-MASER EFOS 18	GPS+GLO+GAL+BDS+SBAS
YELL	Canada	62.480833	-114.480556	EXTERNAL MASER	GPS+GLO+GAL
ZIMM	Switzerland	46.876944	7.465	INTERNAL	GPS

Table 2. The Mean and RMS Values for the WRMS Estimates for Four PPP solutions.

	IGR			**IGR28**			**IGR2C**			**IGR29C**		
	North (mm)	East (mm)	Up (mm)	North (mm)	East (mm)	Up (mm)	North	East	Up	North	East	Up
Mean	2.036	2.945	5.100	1.486	2.431	4.536	1.481	2.436	4.572	1.509	2.440	4.568
RMS	2.056	2.990	5.128	1.539	2.517	4.613	1.532	2.534	4.651	1.565	2.521	4.647