

# Chapter 9

## Improving Efficiency of Data Analysis for Huge GNSS Network

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**Abstract** The development of GNSS system and its applications is accompanied by the fast development of the ground tracking networks. The expansion of tracking network could contribute to the improvement of precision of satellite orbits, clocks, ERPs and so on. However, the increase of number of tracking stations causes non-linear gain of computing time, especially in the case of data processing based on the Zero-difference (ZD) strategy. Parameter elimination is one of the most used methods to fasten ZD data processing, nevertheless it involves matrix transformation and inversion at each epoch and the computing time is still very long in case of huge network and Multi-GNSS combined solutions. The first part of the paper presents the current status of ZD data processing in case of huge networks and Multi-GNSS data processing. Using 110 GPS/GLONASS stations from the IGS network, we perform classical IGR-like data processing with different data sampling ranging from 5, 6, 7..... till 15 min. Estimated parameters including orbits, clocks, ZTDs, coordinates, ERPs etc. Comparison of the products using different sampling data shows: precision of orbit and clock somehow linearly increases with sampling rate changing from 5 to 15 min, and ERP precision is not influenced by the change of sampling rate. To analyze the impacts of products based on different data sampling on positioning applications, we perform PPP for 22 globally distributed IGS stations using 4 weeks' data and kinematic precise orbit determination for GRACE satellites. Results show that the coordinates/orbits precision is at the same level: precision of PPP coordinate is of 2.3, 3.8, 8.8 mm in NEU directions using products based on

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5 min sampling data, and of 2.5, 4.3, 8.6 mm in case of using 15 min sampling data.

**Keywords** GNSS · SHA · Analysis center · Precise orbit determination · Efficiency

## 9.1 Introduction

GNSS (Global Navigation Satellite System) tracking network expands with the developing/upgrading of GNSS stations. Currently, there are about 380 GNSS tracking stations within IGS (International GNSS Service) global network, including about 150 GPS/GLONASS stations [1]. Additionally, there are many other regional GNSS networks, e.g. the CMONOC (Crustal Movement Observation Network of China) consisting of 260 reference stations and more than 2,000 campaign stations [2]. With more stations adding to the network and contributing to data analysis, GNSS products like orbits, clocks and Earth Rotation Parameter (ERPs) etc. could be improved. The combined GPS/GLONASS data analysis may improve the accuracy of reference frame and other station-dependent parameters as well. However, including more stations and satellites into data analysis results in more parameters to be estimated and more computation time. Taking the current daily data analysis using GPS/GLONASS constellation with 32 GPS satellites and 24 GLONASS satellite as example, Table 9.1 summarize the number of parameters for GPS only and GPS/GLONASS combined daily data analysis. In Table 9.1, we assume there are 2 ambiguity parameters for each station/satellite pair and 1 ISB (inter system bias) parameter for each station/GLONASS satellite pair. Additionally there are 12 ZTD parameters for each station, 15 orbit parameters for each satellite, 3 coordinates for each station and 6 ERP parameters. The epoch-wise clock parameters are eliminated during data analysis. From Table 9.1, we clearly see that the dramatic non-linear increase of parameter numbers with the growth of number of tracking stations. Consequently, this may cause problems in data analysis using huge GNSS networks.

Currently, there are two strategies to handle this problem: the first is to use the double-difference observations to remove clock parameters and reduce number of ambiguities [3]; and the second is applied in Zero-difference solutions, it

**Table 9.1** Growth of the number of parameters versus the increase in the number of stations tracking GPS and GPS + GLONASS (G + G) constellation

Number of stations	Ambiguity		Others		ISB (G + G)	Total number of parameter	
	GPS	G + G	GPS	G + G		GPS	G + G
50	3,200	5,600	1,236	1,686	1,200	4,436	8,486
100	6,400	11,200	1,986	2,436	2,400	8,386	16,036
150	9,600	16,800	2,736	3,186	3,600	12,336	23,586
200	2,800	22,400	3,486	3,936	4,800	16,286	31,136

eliminates epoch-wise parameters and non-active parameters at each epoch [4]. Using the double-difference strategy, clock parameters no longer exist by definition and thus special procedure is needed to recovery them, which makes the procedure of data analysis more complicated [5]. On the other hand, using the parameter elimination strategy in Zero-difference solution cannot really solve the problem when the number of stations and satellites increases to more than 200. Taking the routine daily IGR analysis at Shanghai Astronomical Observatory for example, GPS-only Zero-difference analysis needs 2 min for one iteration using around 100 stations and it takes around 20 min to finish the entire solution. While in case of GPS-only analysis using 300 stations, it takes more than 40 min for one iteration and the entire daily analysis takes more than 10 h on the same computer. As for the combined GPS/GLONASS data analysis, it needs 10 min for one iteration, which is almost 5 times of the GPS-only solution. Based on this analysis, the computation time is extremely long for the combined GPS/GLONASS solution using more than 200 stations. The reason that Zero-difference solution is time-consuming is because parameter elimination has to be carried out at each epoch, which actually involves a lot of matrix inversion and multiplication between big matrixes. The matrix dimension at each epoch is at the same level as we stated in Table 9.1.

Parameter eliminate is performed at each epoch, therefore the computation time depends on the total number of epochs. Reducing the number of processing epochs could in genera reduce computation time. However, decrease of observations could result in the decrease of precision of estimated parameters. This impact could be marginable for daily constant parameters, e.g. orbit, coordinates, ERPs and ISB etc. For other parameters like clocks and ZTDs this impact could be noticeable. In order to find the optimal setting of Zero-difference data analysis to improve efficiency and to keep the highest precision, we analysis the impacts on processing time and product precision by changing data sampling. Four week data of around 110 stations from the IGS global network is used in this paper. Data analyses are performed under different scenarios with different data sampling.

## 9.2 Data and Analysis Settings

Data analysis is based on the iGPOS (integrated Geodetic Platform of SHAO) system, which is the platform of the GNSS data analysis center SHAO (SHA) [6, 7]. iGPOS is based on the traditional least-square estimator. It implements Zero-difference strategy, its correction models follow IERS and IGS conventions [8]. Routine parameters include: orbits (15 parameters for each satellite), coordinates (3 parameters for each station), ERP (6 parameters for each day), clocks (epoch-wise parameter for each satellite and station), ZTD (1 parameter each hour for each station) and ambiguities. After the generation of all parameters, we densify the GNSS clocks from original sampling (normally 5 min) to 30 s [9]. Comparisons between the products of SHA and IGS analysis centers show: GPS orbit precision



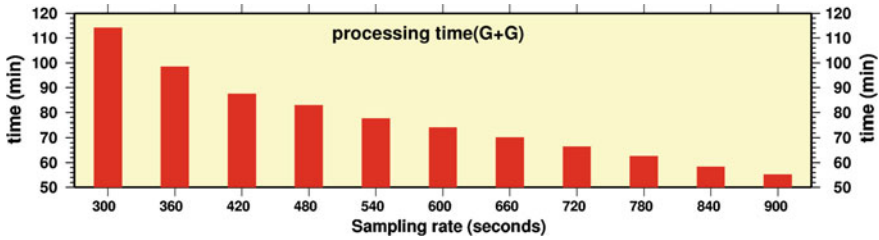


Fig. 9.2 Mean processing time using data of different sampling of GPS + GLONASS combined solution

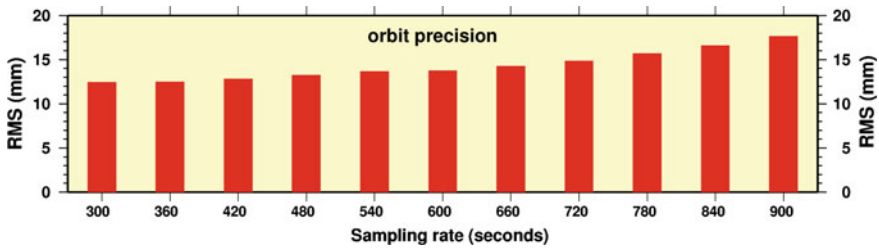


Fig. 9.3 Mean precision of orbits using data of different sampling, comparing to the IGS final orbits

15 min, which is decrease by more than 30 %. All the tests show that the efficiency of data analysis could be greatly improved by changing data sampling.

### 9.3.2 Impacts on Product Precision

Besides efficiency, product precision is another important issue for GNSS data analysis centers. Currently GNSS orbits/clocks and other products from IGS analysis centers are the most accurate products providing to world-wide users. Product precision should not be sacrificed while improving efficiency.

#### 9.3.2.1 Orbits

Figure 9.3 shows the comparisons between IGS orbits and the derived GPS orbits under different data sampling. The RMS values range from 13 to 18 mm, which, in general, is in the range of the current IGS orbit precision. And it could be explained that there are enough tracking stations to ensure that satellites are simultaneously tracked by many stations at each sampling epoch. And the accurate orbit dynamic models ensure the overall orbit precision. Also, we notice that orbit precision is better than 14 mm when sampling is smaller than 10 min, and it gradually degrades when the sampling is bigger than 10 min. Based on the results

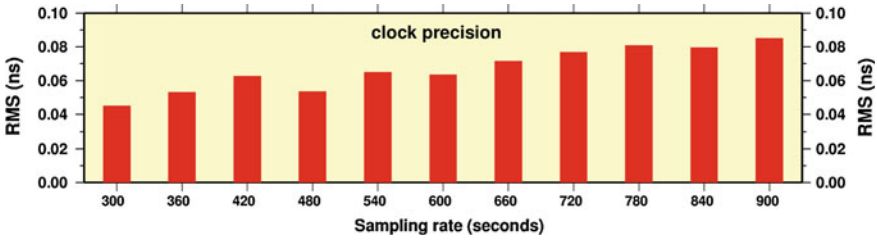


Fig. 9.4 Mean precision of satellite clocks using data of different sampling, comparing to the IGS final clocks

of orbit comparison, we could reduce the data sampling to 10 min. By doing this, the precision remains unaffected while computation time is largely reduced.

### 9.3.2.2 Satellite Clocks

Figure 9.4 shows the comparisons between IGS satellite clocks and the derived GPS clocks under different data sampling. The RMS values range from 0.04 to 0.08 ns, which, in general, is in the range of the current IGS clock precision. As clocks have to be estimated at each epoch, the errors introduced by changing data sampling could be absorbed by epoch-wise clocks. We notice that clock precision is better than 0.06 ns when sampling is smaller than 10 min, and it gradually degrades when the sampling is bigger than 10 min. Results based on data sampling of 15 min have the worst precision of 0.085 ns (~2.6 cm). Based on the results of clock comparison, we could reduce the data sampling to 10 min. By doing this, the precision remains almost unaffected while computation time is largely reduced.

### 9.3.2.3 Earth Rotation Parameters

ERP parameters are defined as daily constants therefore the impact from difference data sampling should be marginal. Figure 9.5 shows the comparisons between IGS

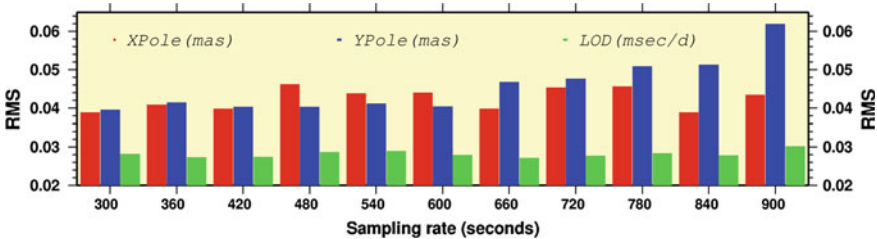


Fig. 9.5 Precision of pole parameters using data of different sampling, comparing to the IGS final ERP parameters

ERPs and the derived ERPs under different data sampling. The RMS values range from 0.04 to 0.08 mas for pole parameters and are around 0.025 ms per day for LOD parameter. We notice that ERP precision is better than 0.04 mas when sampling is smaller than 10 min, and it gradually degrades when the sampling is bigger than 10 min. Meanwhile, LOD parameters are almost unaffected by the difference of data sampling.

### 9.3.2.4 Reference Frame

Reference frame is defined by satellite orbits and station coordinates. To reflect the impact on reference frame using different data sampling, we make Helmert transformation between estimated orbits and IGS final orbits to derive Helmert parameters [11]. Results show: the change of mean scale parameter is small than 0.01 ppb, change of mean translation parameters are less than 0.4 mm. The daily variation of these parameters shows random property with values much smaller than its precision. Figure 9.6 shows the mean rotation parameters for each sampling scenario. We notice that the rotation parameters changes randomly in the range smaller than 0.02 mas for the direction of Y and Z, while the mean rotation parameter in X-axis becomes gradually bigger along with the increase of data sampling. One possible explanation is related to the tracking network. As there are fewer stations along the longitude of  $\pm 90$  (Y-axis), the coordinates/orbits along the Y-axis could be more affected by number of observations. According to the mapping function, larger values are required in X-axis in order to introduce such impact.

## 9.4 Impacts on User Applications

To further assess the influence of data sampling, we apply the products derived from different scenario (named 5 min-Prod, 6 min-Prod, ..., 15 min-Prod) in static and kinematic PPP (Precise Point Positioning). For the static PPP, data of 22 IGS

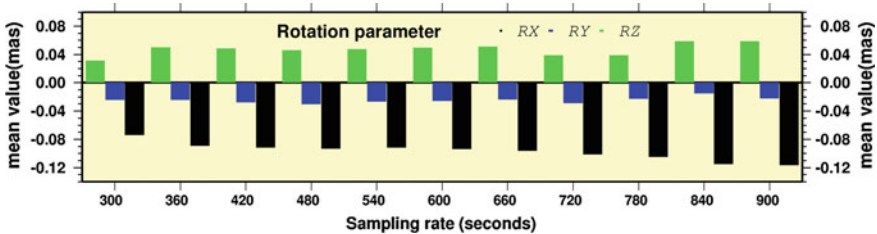


Fig. 9.6 Mean rotation parameters of Helmert transformation between GPS orbits under different data sampling and the IGS final orbits

stations, which are not used in product generation step, spanning the whole 4 weeks are used; and data of GRACE satellites spanning from Doy (Day of year) 94–100, 2010 are used in kinematic PPP.

### 9.4.1 Static PPP

Station used including: ALGO, AMC2, BRAZ, DRAO, GUAM, GUAO, HOB2, IISC, ISPA, KARR, KELY, KOKB, KUNM, MAS1, MDVJ, OHI2, RAMO, SCH2, SYOG, TIXI, TSKB, WUHN, YELL. BERNESE 5.0 [12] software is used for static PPP. In the first step, daily coordinates are firstly estimated with data sampling set to 30 s. Coordinate repeatability is derived for each station in weekly combination. As we use 4 weeks data, there are 4 repeatability values for each station, and mean values are used for comparison. Figure 9.7 shows the mean repeatability of all stations using different products, which shows that the impacts on the static PPP coordinates is less than 2 mm in horizontal and less than 6 mm in vertical directions.

### 9.4.2 Kinematic Orbits of Low Earth Orbiters

Kinematic coordinates are most sensitive to the errors in orbits/clocks and other input products. To reflect the impact of different products on kinematic PPP, data of GRACE-A and GRACE-B satellites are processed using the in-house developed LEO orbit determination software [13]. The kinematic orbits are compared to the precise PSO orbits from JPL for precision assessment. Figure 9.8 shows the RMS for results using products under different scenario. The precision in 3D changes from 8 to 10 cm. Considering the accuracy of kinematic PPP, we could conclude that the kinematic PPP is marginally affected by the data sampling in products generation. Comparing the GRACE-A kinematic orbit on Doy 98 based on 5 min-Prod and 15 min-Prod, results show: the mean coordinate difference is of (0.1, 0.2, 0.5) cm and RMS is of (3.4, 3.6, 3.6) cm in the R, T, N directions, respectively.

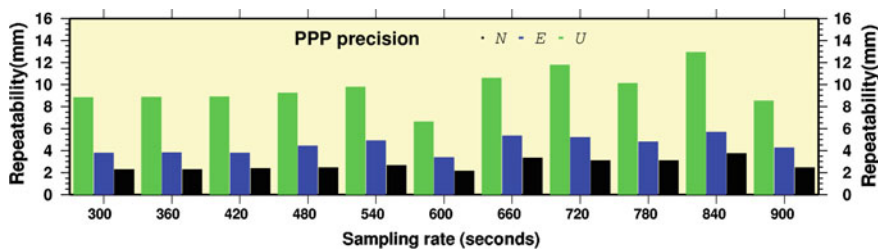


Fig. 9.7 Median coordinates precision of static PPP of 22 stations, using different GPS orbits/clocks from different scenario



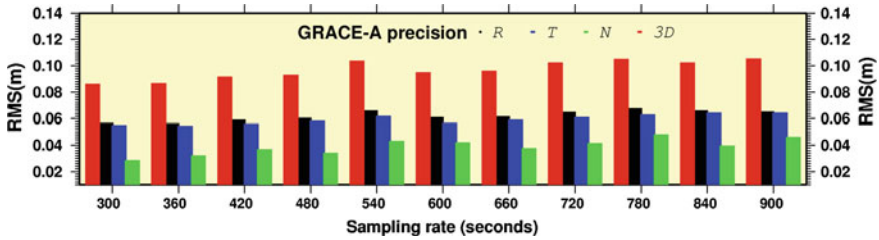


Fig. 9.8 Kinematic orbit precision of GRACE-A, using different GPS orbits/clocks from different scenario

### 9.5 Conclusions

Data analysis using Zero-difference strategy is widely used, because it could estimate most satellite and station related parameters. However, its computation efficiency has become a bottleneck with the development of the observing network and inclusion of multi-GNSS systems. We discuss the impacts of changing data sampling on product precision and user application. Using the GNSS data analysis platform of SHAO, big amount of data from the 110 IGS globally distributed stations are analyzed. Results show:(1) Computation time linearly decreases with the data sampling change from 5 to 15 min; and this trend is more obvious when processing more stations and satellites; Computation efficiency could be improved by more than 50 % by changing data sampling from 5 to 15 min; (2) The change of data sampling has not too much impact on the derived orbits, clocks, ERPs and reference frame; And the impact could be ignored when data sampling is between 5 and 10 min; (3) PPP using products based on different data sampling shows the user kinematic and static positioning are almost not influenced by the input products.

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