

## Impact of GPS Data Processing Strategies on Result Accuracy and Reliability Analysis (Post-print)

**Authors:** Deng Biao, Guo Ruocheng, Li Xiaoming, Wang Jing, Deng Yuechuan

**Date:** 2020-09-03T00:00:00+00:00

### Abstract

The accuracy of high-precision GPS data processing results is often constrained by data types and processing strategies such as ocean tide models, satellite orbit constraint mode settings, and precise ephemeris products. This paper conducts relevant experiments considering the aforementioned influencing factors, and proposes a method of increasing the number of baseline solution sessions for combined adjustment based on error theory to improve baseline solution accuracy. Experimental results indicate that incorporating ocean tide models in data processing yields better accuracy than not using such models; the FES2004 model achieves the optimal overall internal and external consistency accuracy, while the NAO99b model demonstrates superior external consistency accuracy in coastal regions, with other ocean tide models being essentially comparable. The loose orbit mode exhibits better internal consistency accuracy than the fixed orbit mode, but its external consistency accuracy is slightly inferior to that of the fixed orbit mode. Different precise orbit products have relatively minor influence on the final solution results. The method of increasing the number of baseline solution sessions for combined adjustment demonstrates significant effectiveness in improving the accuracy of data processing results, and shows good convergence characteristics under several precise ephemerides.

### Full Text

#### Preamble

#### The Influence of GPS Data Processing Strategy on the Accuracy of Results and Reliability Analysis

Deng Biao<sup>1</sup>, Guo Ruocheng<sup>2</sup>, Li Xiaoming<sup>1</sup>, Wang Jing<sup>1</sup>, Deng Yuechuan<sup>1</sup>  
(1. School of Geographic Information and Tourism, Chuzhou University, Chuzhou 239000, China;

2. Wuhan Seismic Metrological Verification & Surveying Engineering Institute Co., Ltd., Wuhan 430000, China)

## Abstract

The accuracy of high-precision GPS data processing results is often constrained by data types and processing strategies such as ocean tide models, satellite orbit constraint mode settings, and precise ephemeris products. This paper conducts relevant experiments considering these influencing factors and proposes a method based on error theory to improve baseline solution accuracy by increasing the number of baseline solution iterations and performing combined adjustment. Experimental results demonstrate that incorporating ocean tide models in data processing yields better accuracy than solutions without tide models. The FES2004 model achieves the best overall internal and external coincidence accuracy, while the NAO99b model exhibits superior external coincidence accuracy in coastal regions; other tide models produce essentially equivalent results. The relaxed orbit mode demonstrates better internal coincidence precision than the fixed orbit mode, though its external coincidence precision is slightly inferior. Different precise orbit products have minimal impact on final solution results. The proposed method of increasing baseline solution iterations and performing combined adjustment significantly improves data processing accuracy and demonstrates good convergence across several precise ephemeris products.

**Keywords:** ocean tide model; orbital mode; ephemeris products; number of baseline solutions

## 0 Introduction

With increasing accuracy requirements for GPS data processing in fields such as precision engineering surveying, geodynamics, and meteorology, numerous researchers and engineering technicians have conducted extensive studies on static positioning data processing methods. Reference [1] investigated baseline solution accuracy based on rapid ephemeris, concluding that accuracy varies between fixed and relaxed orbital modes for baselines of different lengths. Reference [2] examined the influence of meteorological data participation in GPS data processing on baseline solution accuracy and precipitation estimates. Reference [3] experimentally studied the relationship between GAMIT solution results for small-area GPS networks and IGS station selection. Reference [4] discussed partitioning schemes for crustal deformation network stations. Reference [5] investigated the impact of different tropospheric delay parameter estimation intervals on baseline solutions of varying lengths using GAMIT software. These studies indicate that different parameter settings affect solution accuracy to some degree [6], making research on different data processing strategies important for high-precision GPS positioning.

When studying GPS data processing, the aforementioned literature primarily uses the root mean square (RMS) of baseline results as an accuracy evalua-

tion metric. While this indicator can reflect baseline accuracy to a certain extent, baseline RMS represents an internal precision metric. RMS correlates with result quality—when result quality is poor, RMS tends to be large, though the converse is not necessarily true. Given that most previous studies have not analyzed or have inadequately analyzed the external reliability of data processing, this paper considers both internal and external precision in GPS data processing. We investigate the influence of ocean tide models, orbit mode settings, and ephemeris products on baseline solution accuracy, employing baseline RMS values and coordinate component deviations as accuracy assessment indicators. Building upon these experiments and based on error theory, we propose a method involving multiple iterations of baseline solution for the same observation data followed by combined adjustment of the multiple baseline solutions, designing dedicated experiments to verify the effectiveness of this method in improving GPS data processing quality.

## 1 Data Processing Strategy and Accuracy Analysis

This study utilizes data from seven globally distributed IGS (International GPS Service) tracking stations: ULAB, CHAN, GMSD, TWTF, KUMN, BJFS, and SHAO. The station distribution is shown in [Figure 1: see original paper].

The computational data consist of single-day observations from January 1, 2013. Baseline solutions were performed using the high-precision GPS data processing software GAMIT 10.71, followed by adjustment calculations based on qualified indicators. Since IGS station coordinates exhibit extremely high precision (the IGS website indicates the above stations have accuracies within 2 mm), they can be considered true values [7]. Adjustment results were directly compared with published IGS station results, with accuracy evaluated in conjunction with baseline solution RMS. To prevent adverse effects on solution results due to the known point network configuration, subsequent experiments consistently selected CHAN, TWTF, GMSD, ULAB, and KUMN as known points, with BJFS and SHAO as unknown points for comparative verification.

[Figure 1: see original paper] Location Map of IGS stations

### 1.1 Influence of Ocean Tide Models on Solution Results

Oceanic tidal loading caused by gravitational forces from celestial bodies such as the sun and moon induces periodic crustal deformation that can reach decimeter-level in the vertical direction in coastal areas [8] and affects horizontal components to varying degrees [9]. Currently, more than ten major global ocean tide models exist internationally. This study selected the FES2004, NAO99b, CSR4.0, and GOT00 models for experimentation. The coverage, resolution, and acquisition methods of these ocean tide models are summarized in [10-13].

Global Ocean Tide Loading Models

Model	Coverage	Resolution (°)	Method	Data Acquisition
FES2004	Global	0.125° × 0.125°	Blending Assimilation	ERS1/2   NAO99b   Global   0.5° × 0.5°   Representative assimilation   Tide gauge station + hydrodynamic model   CSR4.0   66°S–66°N   0.5° × 0.5°   Response and empirical method   GOT00   Global   0.5° × 0.5°

To analyze the influence of ocean tide models on solution results, five experimental schemes were designed: (1) no ocean tide model correction; (2) FES2004 model correction; (3) NAO99b model correction; (4) CSR4 model correction; (5) GOT00 model correction. Experimental parameters included: satellite cutoff elevation angle of 15°, known site constraints of 0.050 m, unknown point constraints of 50 m, observable choice set to LC\_{HELP}, and fixed orbit mode (BASELINE). All GAMIT software parameter settings were identical except for the ocean tide model configuration. Results are listed in . To visually demonstrate model impacts, coordinate component deviations for BJFS and SHAO stations are plotted in [Figure 2: see original paper] and [Figure 3: see original paper], respectively.

#### Baseline Calculation and Results Statistics (mm)

As shown in , the FES2004 model yields the lowest baseline RMS values, followed by NAO99b, with other models performing slightly better than the no-model solution. Results demonstrate that incorporating ocean tide models produces superior internal coincidence precision for the entire network baseline solution compared to solutions without ocean models.

Figures 2 and 3 reveal that after incorporating ocean tide models, BJFS station shows improved deviations in X, Y, and Z components compared to the no-model solution. For SHAO station, Y-direction accuracy improves significantly, X-direction accuracy improves to some extent, while Z-direction deviation increases slightly. The FES2004 model provides optimal accuracy improvement for all components at BJFS station, while its improvement for SHAO station is inferior to NAO99b but comparable to other models. The NAO99b model achieves the best accuracy improvement for SHAO station but performs poorly for BJFS station. This primarily occurs because BJFS is located inland with minimal ocean tide influence, whereas SHAO is near the East China Sea and significantly affected by ocean tides. Additionally, ocean tide models are constructed from observational data over specific periods and inherently contain errors, and daily ocean tides are variable, introducing errors when calculating specific day-of-year values from models.

Considering both baseline RMS and coordinate deviation metrics, among the aforementioned schemes, the FES2004 ocean tide model correction achieves the best internal and external coincidence. Furthermore, its high model resolution theoretically yields higher interpolation accuracy than other models for general point measurements. Therefore, the FES2004 model should be prioritized when

using ocean tide models for solution calculations.

## 1.2 Influence of Orbit Mode Settings

Three baseline solution modes are commonly used. To analyze long-baseline solution modes and result reliability, experiments were conducted using fixed and relaxed orbit modes. Experimental parameters remained consistent with previous sections, with only the orbit mode changed between fixed and relaxed configurations using software default constraints. For brevity, only the previously validated FES2004 model was used as the ocean tide model parameter, with all other settings identical. Baseline solution and network adjustment statistics are presented in . To visually compare the influence of the two orbit mode settings on solution results, [Figure 4: see original paper] and [Figure 5: see original paper] illustrate coordinate component deviations for BJFS and SHAO stations relative to published IGS coordinates.

### Baseline Calculation and Outcome Statistics (mm)

As shown in , the relaxed orbit mode produces smaller baseline RMS values than the fixed mode, and the maximum relative error of the weakest baseline in the network is superior in the relaxed mode, indicating higher internal coincidence precision. This occurs primarily because the relaxed orbit mode simultaneously solves for ephemeris errors as unknown parameters, effectively performing an error adjustment on baselines before network adjustment, thus demonstrating good internal coincidence precision. Conversely, the fixed orbit mode essentially ignores ephemeris errors. Although its baseline RMS values are slightly inferior to the relaxed solution, its coordinate deviations from published IGS coordinates are smaller, indicating higher external coincidence precision, particularly in the Z direction where the fixed solution shows clear advantages. In the relaxed solution, although satellite orbit errors are incorporated into the overall solution to achieve higher internal coincidence precision, error distribution may transfer orbit errors to baselines, resulting in good overall consistency between baseline and satellite errors. However, actual calculations may not yield optimal baseline reliability, particularly evident in Z-direction deviations, leading to overall poorer reliability compared to the fixed orbit mode.

## 1.3 Influence of Ephemeris Products on Result Accuracy

Ephemeris products are known to significantly affect baseline solutions, particularly for long baselines where broadcast ephemeris cannot meet requirements and precise ephemeris must be employed. Currently, IGS provides final precise ephemeris products (IGS), rapid precise ephemeris (IGR), and ultra-rapid precise ephemeris (IGU). Differences in accuracy, latency, update rate, and sampling interval among these products are summarized in [14-15].

### Precision Satellite Ephemeris Products of IGS

Satellite Ephemerides	Accuracy (cm)	Latency	Updates	Sample Interval (min)
IGS	12-18 days	Every Thurs-day	-	15
IGR	17-41 hours	At 17 UTC daily	-	15
IGU	3-9 hours	At 03, 09, 15, 21 UTC	4 times daily	15

To analyze the influence of different precise ephemeris products on result accuracy, experiments were conducted using IGS, IGR, and IGU products to solve for IGS station coordinates in space rectangular coordinates. All parameters remained identical except for the ephemeris product employed. compares the results.

#### Comparison of the Results by Different IGS Ephemeris Products

As shown in , coordinate results for IGS stations using different precise ephemeris products are all at the millimeter level. Three-dimensional coordinate component deviations fluctuate within 7 mm for IGU products and within 8 mm for IGR and IGS products, with IGU showing slightly larger deviations in the Z direction. These results indicate essentially equivalent performance among the three ephemeris products, consistent with their published accuracy specifications. Under identical observation periods and data processing conditions, various precise ephemeris products produce substantially equivalent solution accuracy. Under certain conditions, ultra-rapid or rapid ephemeris can substitute for final precise ephemeris to achieve essentially equivalent accuracy.

#### 1.4 Baseline Solution Iterations and Their Influence

GPS baseline solutions are affected by multiple factors, including both software model errors and human interference during processing, such as adjusting satellite cutoff elevation angles, removing erroneous satellites, or modifying satellite sampling intervals based on baseline residuals. This means the baseline solution process contains both systematic and random errors. To improve measurement accuracy and reliability, multiple field observation sessions could be employed, but this substantially increases field workload and costs. As is well known, observation accuracy can be improved through multiple measurement iterations under certain observation conditions. Based on this theory, this paper proposes a method of multi-iteration baseline solution and combined adjustment for observation data—performing multiple baseline solutions on observation data and conducting combined adjustment of the multiple baseline results.

To verify the influence of baseline solution iterations, this experiment was designed with six iterations. Each iteration independently solved baselines and performed combined adjustment with previous iterations. Before the experiment, TEQC software was used for data preprocessing. Experimental parameters included the FES2004 ocean tide model and fixed orbit mode, with other parameters consistent with previous sections. During the experiment, partial satellites, time periods, and satellite cutoff elevation angles were adjusted according to residual plots. After each baseline solution iteration met quality requirements, deviations between combined adjustment coordinates and published IGS coordinates are listed in . To visually compare relationships between iteration counts, [Figure 6: see original paper] and [Figure 7: see original paper] illustrate the relationship between coordinate deviations and iteration counts for BJFS and SHAO stations.

#### Comparison of the Results of Different Baseline Processing Times (mm)

As shown in , coordinate deviations for both BJFS and SHAO stations decrease significantly with increasing baseline solution iterations. Figures 6 and 7 indicate that after four iterations, accuracy improvement becomes less pronounced with additional iterations. This demonstrates that while increasing iteration counts improves point accuracy, the improvement becomes insignificant beyond a certain threshold, consistent with the law of random error propagation wherein increasing measurement iterations improves accuracy, but with diminishing returns.

To further analyze the effectiveness of multi-iteration baseline combined adjustment, three different precise ephemeris products were independently solved six times using the method described above. Except for the ephemeris products, all other parameter settings remained identical. To eliminate human interference, only satellite elevation angles were varied across iterations: 15°, 16°, 17°, 18°, 19°, and 20°. This approach facilitates verification of multi-iteration baseline combined adjustment reliability. For brevity, results are presented as relationship plots between iteration counts and deviations from published IGS coordinates for BJFS and SHAO stations, shown in [Figure 8: see original paper] through [Figure 13: see original paper].

As illustrated in Figures 8 through 13, using any of the three precise ephemeris products, BJFS station accuracy improves significantly with increasing baseline solution iterations, with deviations in X, Y, and Z components all decreasing and demonstrating good convergence. SHAO station components show both convergence and divergence phenomena with increasing iterations, though overall convergence is observed. These results indicate that increasing baseline solution iterations for combined adjustment can improve result accuracy and reliability, while also suggesting that adjusting only satellite cutoff elevation angles is not optimal. In practice, methods such as analyzing baseline residual plots, adjusting satellite cutoff elevation angles, modifying satellite sampling intervals, and filtering periods with poor geometric dilution of precision should be combined to further enhance multi-iteration baseline combined adjustment effectiveness.

## 2 Conclusions

Based on experiments analyzing the influence of ocean tide models on baseline and coordinate results, this paper investigated the effects of orbit modes and different precise ephemeris products on result accuracy, validating the internal and external reliability of relaxed and fixed orbit solution modes. Building upon this foundation, a method of multi-iteration baseline solution and combined adjustment was proposed. Through experimental analysis of different ocean tide models, orbit mode settings, ephemeris products, and multi-iteration baseline solutions, the following conclusions are drawn:

- 1) Using ocean tide models yields superior accuracy metrics for baselines and coordinate deviations compared to solutions without tide models. The FES2004 ocean tide model achieves the best overall internal and external coincidence accuracy. Its higher resolution compared to other models can better reduce interpolation errors; therefore, it should be prioritized when using ocean tide models for calculations.
- 2) The relaxed orbit mode produces solutions with higher internal coincidence precision but poorer external reliability in the space rectangular coordinate system compared to the fixed orbit mode. This occurs because solving for ephemeris errors as unknown parameters tends to adjust related errors into baselines, resulting in high internal coincidence precision but relatively poor external coincidence precision. For general engineering applications, the fixed orbit solution mode is recommended for baseline solutions.
- 3) Final, rapid, and ultra-rapid ephemeris products produce essentially equivalent solution accuracy, consistent with their published accuracy specifications. This indicates that rapid or ultra-rapid ephemeris can substitute for final precise ephemeris under certain conditions to achieve essentially equivalent accuracy.
- 4) For the same observation dataset, the proposed method of reasonably increasing baseline solution iterations and performing combined adjustment produces higher accuracy than single-iteration baseline calculations. This demonstrates that increasing baseline solution iterations for combined adjustment can effectively improve data solution accuracy and reliability, warranting promotion and further verification in GPS data processing.

## References

- [1] Gao Wang, Gao Chengfa, Pan Shuguo, et al. Research on high-precision baseline solution with GAMIT based on rapid ephemeris[J]. Science of Surveying and Mapping, 2015, 40(2): 22-25, 38.
- [2] Li Xingguang, Zheng Nanshan. Discussion on the influence of parameter settings on high-precision GPS data solution[J]. Science of Surveying and Mapping, 2015, 40(1): 33-37, 51.

- [3] Wu Xijuan, Gao Junqiang, Huang Yan. Relationship between GAMIT solution results for small-area GPS networks and IGS station selection[J]. Journal of Nanjing University of Technology (Natural Science Edition), 2010, 32(4): 96-99.
- [4] Wan Jun, Cheng Yingyan, Dang Yamin, et al. Partitioning scheme for high-precision solution of crustal deformation network stations[J]. Science of Surveying and Mapping, 2016, 41(4): 1-4.
- [5] Huang Zudeng, Mei Lianhui. Research on tropospheric parameter estimation in high-precision GPS data processing[J]. Journal of Geomatics, 2013, 38(5): 12-15.
- [6] Cao Yanfeng, Chen Baoxian, Chen Xiuwan, et al. Model for improving MODIS atmospheric precipitable water retrieval accuracy based on GPS data[J]. Remote Sensing Information, 2014(12).
- [7] Zhang Guangru, Bi Jinzhong. Influence of different data processing strategies on PPP convergence accuracy[J]. Science of Surveying and Mapping, 2018, 3(43).
- [8] Cao Bingqiang, Cheng Yingyan, Xu Changhui. Influence of ocean tide models on continuous tracking reference station data solution—A case study of Fujian Province[J]. Science of Surveying and Mapping, 2015, 40(12): 108-111.
- [9] Urschl C, Dach R, Hugentobler U, et al. Validating Ocean Tide Loading Models Using GPS[J]. J Geod, 2005, 78(10): 616-625.
- [10] Matsumoto K, Takanezawa T, Ooe M. Ocean Tide Models Developed by Assimilating Topex/Poseidon Altimeter Data into Hydrodynamical Model: A Global Model and a Regional Model around Japan[J]. J Oceanogr, 2000, 56(5): 567-581.
- [11] Lyard F, Lefevre F, Letellier T, et al. Modelling the Global Ocean Tides: Insights from FES2004[J]. Ocean Dynamics, 2006, 56(5-6): 394-415.
- [12] Wang Yihang, Fang Guohong, Wei Zexun, et al. Accuracy assessment of global ocean tide models based on satellite altimetry[J]. ADVANCES IN EARTH SCIENCE, 2010, 25(4): 353-359.
- [13] Sun Jialong, Guo Jinyun, Guo Shuyan, Liu Xin. Accuracy analysis of CSR4.0 and NAO.99b models in Chinese waters based on tide gauge data, 2013, 28(5): 2787-2795.
- [14] Liu Pan, Liu Zhimin, Zhang Mingmin, Guo Jin. Influence of different IGS ephemeris products on ground-based GPS water vapor retrieval[J]. Science of Surveying and Mapping, 2018, 12(43): 17-22.
- [15] <http://www.igs.org/products/data>

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv – Machine translation. Verify with original.*