Evaluation of IGS Reprocessed Precise Ephemeris Applying the Analysis of the Japanese Domestic GPS Network Data

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Abstract

The IGS reprocessed GPS precise ephemeris (repro1) is evaluated applying the Japanese dense GPS network data for the period from 869 to 1041 GPS weeks (September 1996 to December 1999; 173 weeks). We compare the weekly repeatability of the site coordinates of the Japanese network sites applying the reprocessed orbit with that applying the original IGS final orbit. For the case of the orbit-fixed analysis, the repeatability with the reprocessed orbit is better than that with the original orbit in the E-W and U-D components, although not significant compared with the standard error. On the other hand, for the case of the orbit-estimated analysis, the station coordinate repeatabilities are almost the same. Then we examine the systematic biases of the station coordinates between the reprocessed and the IGS final orbits, and we find that the coordinates applying the original final orbit deviate in north, east, and upward compared with those applying the reprocessed orbit although the difference is not significant compared with the uncertainties of site coordinate solutions. Finally we examine the systematic discontinuity of the station coordinates between the periods of the different reference frames applied in the IGS final orbit, and find that the jump between ITRF94 and ITRF97 is far larger than that between ITRF96 and ITRF97, although the most jumps are not significant compared with the one sigma uncertainties.

Key words : Global Positioning System, IGS reprocessed precise ephemeris, Japanese GPS network

1. Introduction

The IGS (International GNSS Service) has re-calculated the GPS precise ephemeris (repro1 reprocessed ephemeris) for the period from GPS weeks 749 to 1409 (May 1994 to January 2007) (Gendt and Ferland, 2010). The conditions of the analysis are almost same as those that were applied for the period after 1410 week. For the reference frame, ITRF2005 is adopted (Altamimi *et al.*, 2007), together with the igs05 absolute phase center variation (PCV) models for both satellite and receiver antennas. Nine analysis centers analyzed the tracking data using 2009 state-of-the-art analysis software. By contrast, in the original IGS final orbit estimation, there were fewer analysis centers for the early periods, and the reference frame changes over time as the ITRF was updated. Moreover there was a significant discontinuity at week 1400 when the analysis centers switched to the absolute PCV models from a model that used a constant (but block-dependent) phase center offset for the satellite antennas from a relative PCV model for the ground antennas that assumed zero correction for the commonly used choke ring antennas (Dow *et al.*, 2009). For example, during the period June 1996 to February 1998, the IGS adopted the ITRF94 reference frame and seven analysis centers analyzed the tracking data using late-1990s the state-of-the-art software. For this period the satellite position sigmas indicated in the table in the summary file are much reduced for the reprocessed orbit compared with the original IGS final orbit, for instance 887 GPS week (January 5 – 11, 1997) from 20 – 40 mm sigmas of the final orbit to less than 15 mm sigmas of the reprocessed orbit.

In this study we evaluate the IGS reprocessed ephemeris using a subset of the Japanese dense GPS network data for the period from September 1996 to December 1999 (from 869 to 1041 GPS week; 173 weeks), comparing the estimated weekly station coordinates using the reprocessed orbits with those of the original IGS final orbits. We first obtained the

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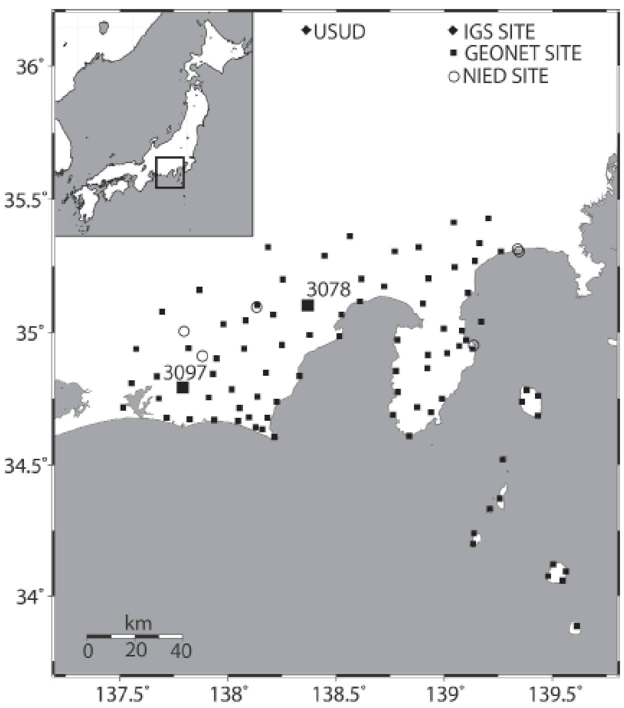

Fig. 1 GEONET and NIED analyzing sites in Tokai area, Central Japan, with USUD IGS site.

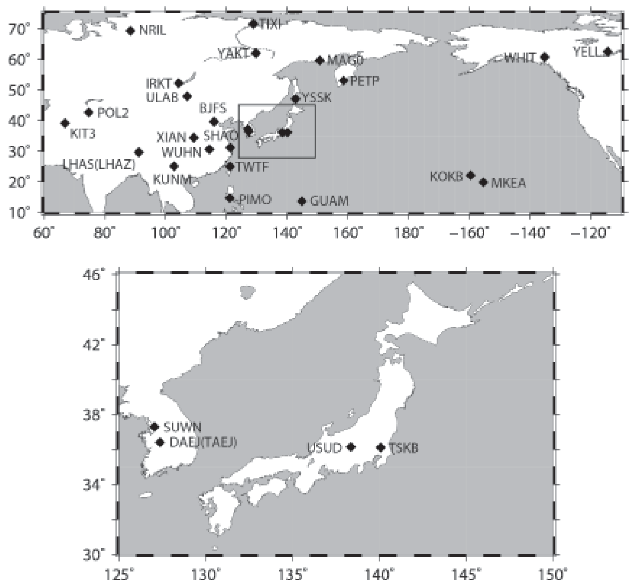

Fig. 2 IGS fiducial sites used in the analysis.

coordinates at the end of time series and the velocity at the Japanese sites, then evaluate the repeatability (rms scatter) of the coordinates, and evaluate systematic biases. Finally we estimate the discontinuities of the coordinates at epochs for which the reference frame changed.

2. Data and Analysis

Since our primary scientific interest has been the Tokai area of central Japan (**Fig. 1**), we use for our evaluation of the 95 GEONET (Miyazaki *et al.*, 1998) and five NIED (Shimada, 1997) stations in this region. However, in order to avoid contamination of our orbit studies by the seismo-volcanic event of July to September 2000 (Nishimura *et al.*, 2001) and the slow earthquake event from mid-2000 to mid-2005 (Miyazaki *et al.*, 2006), we limit the span of our study to the 173-week period from September 1996 to the end of 1999.

We processed the data using the GAMIT/GLOBK 10.4 software (Herring *et al.*, 2010), and estimated site coordinates, phase ambiguities, hourly tropospheric delays, and tropospheric gradients every four hours for each site. We examine two types of analysis, one in which the orbits are fixed and one in which they are allowed to adjust. In the latter case, however, we first apply constraints at the level of ten parts per billion (~2 m in position) to resolve the phase ambiguities, then relax these constrains for the final estimation. In the estimating coordinates of the Tokai network and optionally the orbital parameters, we define the terrestrial reference frame by minimizing the adjustments of the coordinates of ~20 IGS station in and around eastern Asia (**Fig. 2**) to their values in ITRF 2005 (Altamimi *et al.* 2007). We adopt igs05 PCV models for IGS and NIED network receivers and satellite antennas, and the absolute PCV model determined by Geospatial Information Authority of Japan (Shimada, 2012; Hatanaka *et al.*, 2001a, 2001b) for the GEONET sites because the network a unique antenna radome not included in the igs05 models. For the solution longer than one week we estimate the velocities of stations in addition but some exception exists mentioned below.

In **Fig. 3** we show an example time series of the baseline between sites 3097 and 3078 in the Tokai network (**Fig. 1** shows the location of the sites) applying the reprocessed and the original final orbits with and without orbit estimation for both orbits. In some periods the time series show annual variations especially in the U-D component, although there does not seem any significant jump in any solution. In general for the most of the stations in the Tokai network the trend is linear with few significant jumps. Some time series exhibit significant annual variation that is not spatially coherent, suggesting that its causes are either local ground motion or temperature sensitivity of the antennas or monuments.

3. Results

3.1 Station coordinates repeatability

Table 1 shows the coordinate repeatability of the Tokai network sites for the solution in which orbit parameters are not estimated. The coordinates at the end of time series and the velocity of network sites are obtained applying GLOBK. The scatter of the coordinate is obtained by the difference of the observed coordinates and those from the calculation using the coordinates and velocity obtain by GLOBK. The

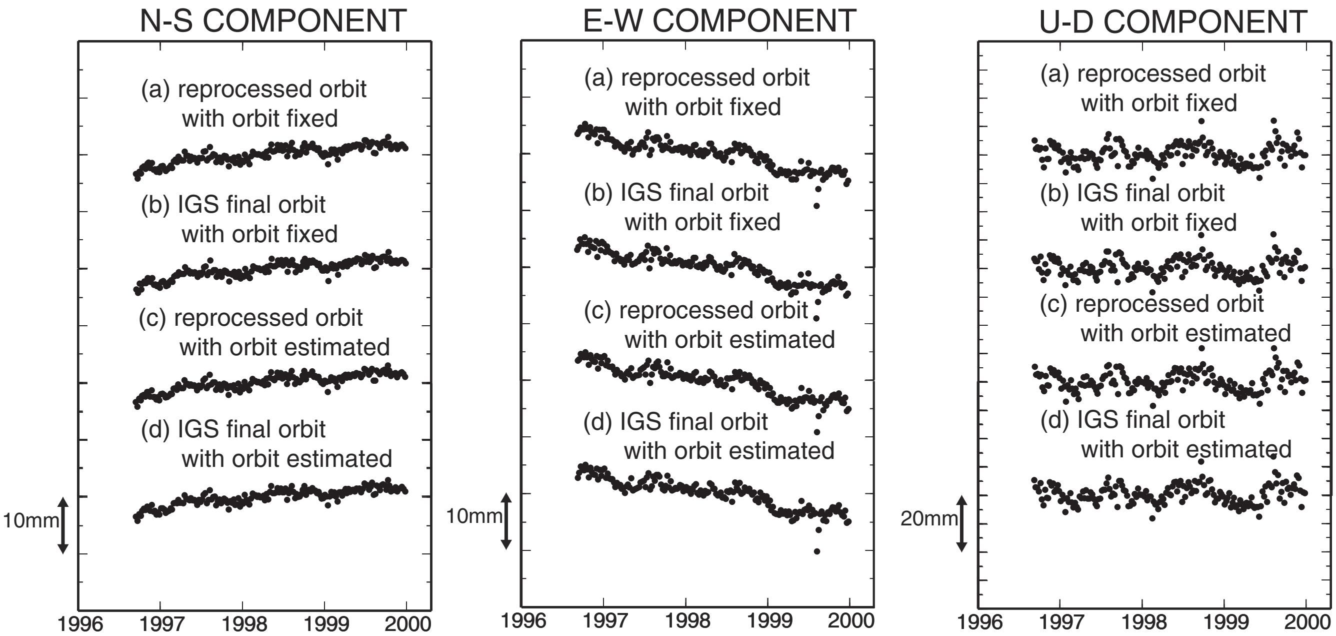

Fig. 3 Time series of the baseline between 3097 and 3078 sites in the Tokai network. (a) Applying the reprocessed orbit with orbit parameter not estimated. (b) Applying the original final orbit with orbit parameter not estimated. (c) Applying the reprocess orbit with orbit parameter estimated. (d) Applying the original final orbit with orbit parameter estimated.

repeatability of the reprocessed orbit is better than that of the original IGS final orbit in all three components, especially E-W and U-D components. The noise increase (quadratic difference of the rms values) is 0.6 mm in N-S, 1.5 mm in E-W, and 3.1 mm in U-D. When the orbits are allowed to adjust (**Table 2**) there is virtually no differences between the original and reprocessed orbits, because the orbit relaxation reduces the deviation of the original final orbits.

3.2 Systematic biases of the station coordinates

To examine the systematic biases of the station coordinates between the reprocessed and the original final orbits, we first estimated the linear velocities of each site using the reprocessing orbit fixed solutions. We then adopted these velocities and estimated the average station coordinates over the data span for both the orbit-fixed and orbit-free cases (**Table 3**). The average differences for the network are about 0.5 mm for the orbit-fixed solutions and 0.1 mm for the orbit-free solutions, for the both horizontal and vertical coordinates. For the orbit-fixed solutions, the coordinates applying the IGS final orbit deviate north, east and upward compared with those applying the reprocessed orbit, although the one-sigma uncertainties of each station solution distribute from 0.1 mm to 0.4 mm for the horizontal components, and from 0.4 mm to 0.9 mm for the vertical component for both the reprocessed and the original final orbits, thus the difference is not significant compared with the uncertainties of the site coordinate solutions.

For the orbit-estimated solutions, the coordinate difference is far smaller than that of the orbit-fixed solutions. For this case also the coordinates applying the IGS final orbit deviate north, east, and upward compared with those applying the reprocessed orbit, although the one-sigma uncertainties of each station solution distribute from 0.1 to 0.4 mm for the horizontal components, and from 0.4 mm to 0.9 mm for

Table 1 The repeatability of weekly data of the Tokai network sites during the period from September 1996 to the end of 1999 when orbit parameter not estimated. The uncertainties are the standard deviation.

N-S component	E-W component	U-D component
Reprocessed ephemeris		
2.0 ± 0.6 mm	2.6 ± 0.7 mm	6.6 ± 1.4 mm
IGS final ephemeris		
2.1 ± 0.6 mm	3.0 ± 0.6 mm	7.4 ± 1.2 mm

Table 2 The repeatability of the weekly data of the Tokai network sites during the period from September 1996 to the end of 1999 when orbit parameter estimated. The uncertainties are the standard deviation.

N-S component	E-W component	U-D component
Reprocessed ephemeris		
2.7 ± 0.5 mm	3.5 ± 0.5 mm	8.7 ± 0.9 mm
IGS final ephemeris		
2.7 ± 0.5 mm	3.5 ± 0.5 mm	8.6 ± 0.9 mm

Table 3 The average of the coordinate difference between the solutions applying the IGS final orbit and the reprocessed orbit for 86 Tokai network sites during the period from September 1996 to the end of 1999. The uncertainties are the standard deviation.

N-S component	E-W component	U-D component
(IGS final orbit) – (reprocessed orbit) when orbit parameter not estimated		
0.42 ± 0.01 mm	0.52 ± 0.01 mm	0.53 ± 0.09 mm
(IGS final orbit) – (reprocessed orbit) when orbit parameter estimated		
0.103 ± 0.001 mm	0.033 ± 0.001 mm	0.099 ± 0.009 mm

the vertical component for both the reprocessed and the original final orbits, thus the difference is also not significant compared with the uncertainties of site coordinate solutions.

3.3 Discontinuity between the different reference frames in IGS final orbit

Applying the estimated velocities of the Tokai network sites in chapter 3.2, we estimated the coordinates for each of the periods for which the original IGS final orbits were computed using different reference frames: ITRF94 GPS weeks 0869-0946, ITRF96 weeks 0947-1020, ITRF97 weeks 1021-1041 (**Table 4**).

In general the systematic jump between ITRF94 and ITRF97 is far larger than that between ITRF96 and ITRF97, although the every discontinuity is not significant compared with the one sigma uncertainties except the jump in the U-D component between ITRF94 and ITRF97.

Table 4 The average of the coordinate difference between the solutions applying the IGS final orbit and the reprocessed orbit for 80 Tokai network sites for the period of ITRF94, ITRF96, and ITRF97 reference frames applied for IGS final orbit. The uncertainties are the standard deviation.

N-S component	E-W component	U-D component
ITRF94 - ITRF97		
(IGS final orbit) - (reprocessed orbit) when orbit parameter not estimated		
0.20 ± 0.20 mm	-0.40 ± 0.26 mm	-4.06 ± 0.60 mm
(IGS final orbit) - (reprocessed orbit) when orbit parameter estimated		
0.03 ± 0.24 mm	-0.07 ± 0.26 mm	-0.26 ± 0.68 mm
ITRF96 – ITRF97		
(IGS final orbit) - (reprocessed orbit) when orbit parameter not estimated		
0.07 ± 0.24 mm	-0.30 ± 0.34 mm	-0.42 ± 0.68 mm
(IGS final orbit) - (reprocessed orbit) when orbit parameter estimated		
-0.09 ± 0.24 mm	0.07 ± 0.36 mm	-0.06 ± 0.79 mm

4. Discussion

Shimada (2012) compares the repeatability of the coordinate solutions of the Tokai network sites analyzing the absolute and the relative PCV models for the periods from September 1996 to the end of 1999, and from the beginning of 2005 to November 2006 using the IGS final orbit. In the latter period the coordinate solution applying the absolute PCV model shows the better repeatability than that applying the relative PCV model, although in the former period the both solutions show almost same repeatability. The author concludes that for the former period the regional reference frame has not yet precisely established in eastern Asia and the IGS final orbit is not accurate enough to clarify the superiority of the absolute PCV model comparing with the relative PCV models. This study proves the speculation of Shimada (2012) by evaluating the accuracy of the IGS final orbit compared with the reprocessed. The large station coordinate difference between ITRF94 and ITRF97 compared with that between ITRF96 and ITRF97 suggests that deficiencies in the ITRF94 affects the accuracy of the IGS final ephemeris.

On the other hand, the orbit-estimated solutions indicate less significant difference in the coordinate repeatability, the systematic biases, and the systematic discontinuity between the different reference frame, because the IGS final orbit has also improved applying the accurate ITRF 2005 coordinates and velocities of the fiducial network sites and the accurate absolute PCV model, thus the inaccuracy of the orbit becomes small compared with the orbit-fixed solution of the original orbit. The repeatability of the orbit-estimated solution is generally worse than the orbit-fixed solution because the network of the fiducial sites is not sufficiently global.

5. Conclusion

We evaluate the IGS repro1 reprocessed ephemeris applying the Japanese dense GPS network data for the period from September 1996 to December 1999 (from 869 to 1041 GPS week; 173 weeks). We compare the weekly repeatability of the analyzed site coordinates of the Tokai network, Central Japan, applying the reprocessed ephemeris and the original IGS final ephemeris. For the case of the orbit-fixed analysis, the repeatability of the reprocessed orbit is better than that of the original final orbit in E-W and U-D components, although not significant compared with the one-sigma uncertainties. In N-S component repeatability is almost same for the both orbits. On the other hand, for the case of the orbit-estimated solutions, the repeatability of both orbits is almost same.

We examine the systematic biases of the station coordinates of the Tokai sites and some biases seem between the IGS final and the reprocessed orbits, although the biases are not significant compared with the one-sigma uncertainties of the site coordinate solutions. The systematic biases with the orbit-estimated solutions are significant smaller than those with the solutions that orbit not estimated.

We also calculate the systematic discontinuity of the station coordinates between the different reference frames used in the IGS original final orbit. The jump between ITRF94 and ITRF97 is far larger than that between ITRF96 and ITRF97 for the orbit-fixed solution, although both jumps are not significant compared with the one-sigma uncertainties except the jump in U-D component between ITRF94 and ITRF97. This may show the inaccuracy of the IGS final orbit based on the ITRF94 reference frame in the region based on the inaccurate regional reference frame.

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日本国内の GPS 観測データ解析による IGS 再解析暦の評価

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要　旨

IGS (International GNSS Service) の再解析暦 (repro1) を，GPS 週 749 ～ 1041 (1996 年 9 月～ 1999 年 12 月）の期間の日本国内 GPS 観測網による観測データを用いて評価した．IGS 再解析暦を用いた解析による国内観測点の座標値解と IGS 最終暦を用いた解析による座標値解との週値再現性を比較した．軌道暦の補正値を推定しなかった場合，再解析暦による解の座標値再現性は，標準偏差と比較して有意とはいえないが，東西及び上下成分で最終暦より低減していた．一方，軌道暦の補正値を推定した場合は，両方の暦による再現性はほぼ同一であった．次に，再解析暦と最終暦による座標値解のあいだに系統誤差があるかどうかを調べたところ，最終暦による座標値解は再解析暦による座標値解より北方・東方及び上方に偏位していることがわかったが，これらの差は座標値解の標準誤差と比べて有意ではなかった．最後に，IGS 最終暦を計算したときに用いた基準座標系が異なる期間ごとの座標解の系統差を調べたところ，ITRF94 と ITRF97 とを用いた期間とのあいだには，ITRF96 と ITRF97 とを用いた期間とのあいだよりはるかに大きな系統差があったが，上下成分以外ではこの差は有意ではなかった．

キーワード：全地球測位システム，IGS 再解析暦，国内 GPS 観測網