ABSOLUTE SITE VELOCITY ESTIMATION USING THE GPS PRECISE POINT POSITIONING TECHNIQUE

*Jhih-Jia Chen [a] and Ming Yang [*b]*

[a] *Department of Geomatics, National Cheng Kung University, Tainan 70101, Taiwan*
Tel: +886-6-2370876 ext. 832 /
email address: p66981102@mail.ncku.edu.tw

[b]*Department of Geomatics, National Cheng Kung University, Tainan 70101, Taiwan*
Tel: +886-6-2757575 ext. 63820 /
email address: myang@mail.ncku.edu.tw

KEY WORDS: Precise Point Positioning; Site Velocity Estimation; International Terrestrial Reference Frame

ABSTRACT: Global Positioning System (GPS) have been widely used in various applications that require high-precision positioning results, such as geodetic control networks and site velocity estimation. Traditionally, site velocities have been determined using relative GPS positioning due to its higher accuracy than that of point positioning. However, the obtained velocity results are thus relative in nature. In recent years, the precise point positioning (PPP) technique, which uses International GNSS Services (IGS) products -- precise satellite ephemerides and clocks -- to directly estimate site positions in the International Terrestrial Reference Frame (ITRF), has become a promising tool for absolute site velocity estimation. Nevertheless, the PPP-derived site positions have been reported to be partially biased as a result of the fact that the above IGS products are based on the loosely constrained IGS analysis centre (AC) solutions. Therefore, it is an interesting issue to examine the accuracy of PPP-derived site velocities. In this research, we computed a set of PPP-derived velocity solutions for 33 evenly distributed IGS global tracking stations from 5/11/2006 to 31/12/2010, and compared them with their respective quantities defined in the ITRF. During the ITRF2005 period (since 5/11/2006), the velocity differences in the east, north, and up directions were -0.23±0.75, -0.35±0.44, 0.83±1.69 mm/yr, respectively; and after Helmert transformation, they were -0.01±0.52, -0.02±0.38, 0.00±1.68 mm/yr respectively. Only the vertical component was notably improved by the transformation. This indicates that the quality of IGS products improves with time, so the biases that existed in the PPP solutions are gradually diminished. It is concluded that under the current ITRF2005, one can reliably use the PPP technique to obtain highly accurate absolute horizontal site velocities, on the level of sub-mm/yr.

1. INTRODUCTION

Since the 1980's, GPS has provided an ideal technique for supporting site velocity estimation, either for regional or global applications, because of the low equipment costs and high precision (Parkinson, 1996).

Normally, relative positioning is used for this kind of application. But the obtained velocity results are thus relative in nature. However, we also want to obtain the absolute site velocity. The International Association of Geodesy (IAG) proposed that the highly accurate geodetic, geodynamic or oceanographic analysis should either use the ITRF directly or carefully tie their own systems to it (Louis, 1992).

If we want to obtain the site velocity under ITRF by using relative positioning, we need to add some additional processes. First, few nearby IGS tracking stations in the regional network computing should be added. Second, combining with the IGS weekly SINEX (Software Independent Exchange Format) results include coordinates and full variance-covariance matrix of IGS global tracking stations. Finally, we can acquire the station coordinates and velocities solution under ITRF (Brockmann, 1997).

On the other hand, precise point positioning (PPP), using undifferenced GPS observables, has become a promising tool for investigating many geophysical processes at the millimeter level in recent years (Teferle et al., 2007). Furthermore, PPP provides a means to obtain site positions directly in the reference frame of the applied GPS products.

However, satellite and station dependent biases are not canceled by differencing, and PPP at the several-millimeter level is strongly dependent on the quality of IGS products (Teferle et al., 2007). Ray also points out that IGS final products are based on the loosely constrained IGS AC solutions, and that the PPP position estimates contain centimeter-level motions of the geocentre. Because the scale factor are IGS AC averaged, it is also different than

ITRF (Ray et al., 2004). Such deviations must not be neglected. Suitable methods of correcting this can be achieved by using weekly IGS geocentre estimates or by computing a global Helmert transformation (Altamimi et al., 2002). Therefore, the accuracy of PPP-derived site velocities without transformation will be an interesting issue to examine. On the other hand, IGS uses ITRF2005 as its reference frame since 5/11/2006, and its update reference frame as ITRF2008 since 17/4/2011. Compared to ITRF2000 and ITRF2005, the station distribution has become more reasonable, and the precision of site coordinates and velocities has also improved greatly (Altamimi et al., 2007). Therefore, we want to examine the accuracy of PPP-derived site velocities during the ITRF2005 period.

2. METHODOLOGY AND DATA SET

We have assessed PPP using IGS final products: IGS precise satellite ephemerides (15 minutes) and clocks (5 minutes) for computing a set of PPP-derived velocity solutions for 33 evenly distributed IGS global tracking stations from 5/11/2006 to 31/12/2010. The software used for the processing of the GPS data is PANDA (Position And Navigation Data Analysis) of Wuhan University. The basic observable was ionosphere free, and there was an elevation mask of 10°. This research used data from a total of 33 evenly distributed IGS global tracking stations. Figure 1 shows their locations.

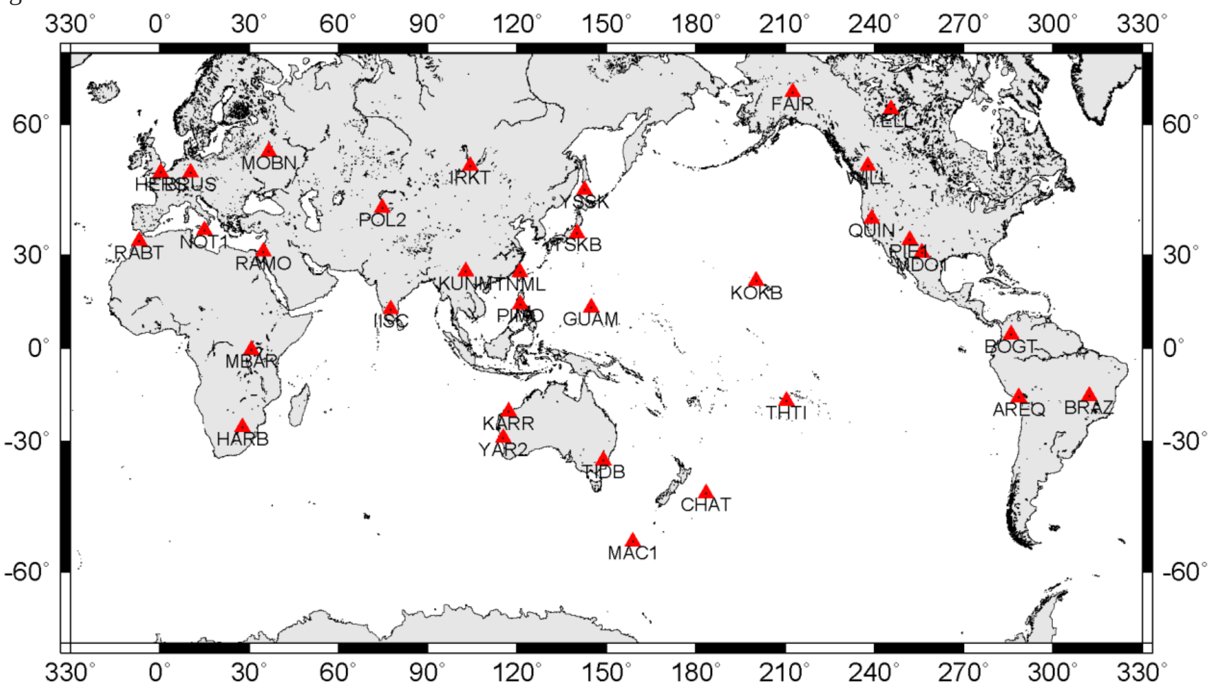

Figure 1, Location of the IGS stations

Data was collected over a period of almost 4 years. The initial observations were made on 5/11/2006, and the final observation on 31/12/2010.

Considering that not all the stations always move linearly, the PPP-derived velocity solutions were not compared with the velocities that ITRF announced. We obtained site coordinates at each epoch in the same interval from IGS weekly SINEX (Software Independent Exchange Format) results, and estimated their velocity under ITRF in the same interval. We analyzed these results by two parts. First, we compare the velocity difference under the local geodetic coordinate system. Second, we used Helmert transformation to analyze the significance for each parameter, and analyzed its improvement when using Helmert transformation to remove the biases between the PPP results and ITRF.

2.1 Site velocity estimation

Geodetic coordinates of points on the surface of tectonic plates change with time due to plate motion, and thus become dependent on the epoch in which the coordinates were obtained. If these elements (direction and magnitude) are known, it is possible to determine the change of the point coordinates as a function of time (Brockmann, 1997):

$$y(t_i)=a+bt_i \tag{1}$$

Where t_i for i=1…N are the daily solution epochs in units of years, the first two terms are the site position, a, and linear rate, *b*, respectively.

2.2 Helmert transformation

We can compare two coordinate sets after estimating up to seven transformation parameters of a Helmert transformation (three translations, three rotations, and a scaling factor):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + \begin{bmatrix} D & \omega_z & -\omega_y \\ -\omega_z & D & \omega_x \\ \omega_y & -\omega_x & D \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{2}$$

Where T_x, T_y, T_z are the translation parameters, D is the scale parameter, ω_x, ω_y, ω_z are the rotation parameters. (X, Y, Z), (x, y, z) are the coordinate vectors from these two coordinate systems.
And we can also compare two velocity sets ($\dot{X}, \dot{Y}, \dot{Z}$)、($\dot{x}, \dot{y}, \dot{z}$) in different coordinate systems after estimating up to seven transformation parameters of a Helmert transformation:

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \\ \dot{Z} \end{bmatrix} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} + \begin{bmatrix} \dot{T}_x \\ \dot{T}_y \\ \dot{T}_z \end{bmatrix} + \begin{bmatrix} \dot{D} & \dot{\omega}_z & -\dot{\omega}_y \\ -\dot{\omega}_z & \dot{D} & \dot{\omega}_x \\ \dot{\omega}_y & -\dot{\omega}_x & \dot{D} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{3}$$

Where $\dot{T}_x$, $\dot{T}_y$, $\dot{T}_z$ are the rate of translation parameters, $\dot{D}$ is the rate of scale parameter, $\dot{\omega}_x$, $\dot{\omega}_y$, and $\dot{\omega}_z$ are the rates of rotation parameters.

3. RESULTS

Figure 2 illustrates the horizontal velocity field in the local geodetic system components (N, E) obtained from the final PPP solution, compared with the IGS SINEX result. It shows good agreement between these solutions.

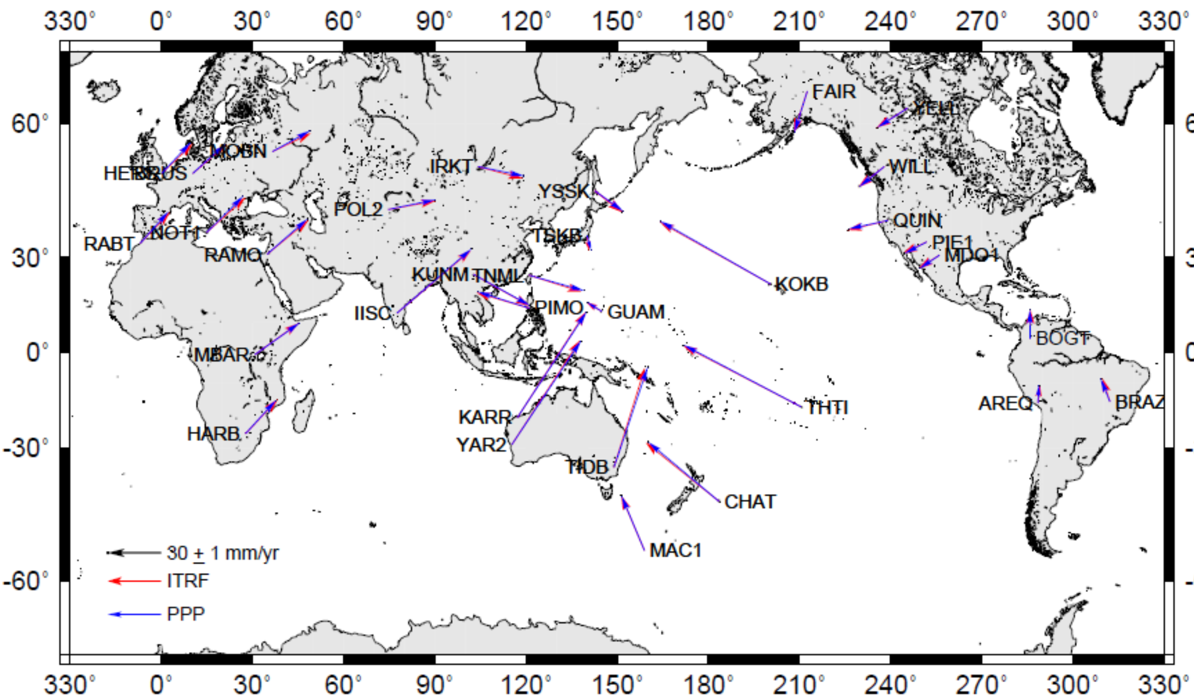

Fig 2, velocity field in the local geodetic system components (N, E) obtained from the final PPP solution and ITRF

Fig 3 shows the horizontal differences of velocity (SINEX-PPP) during the ITRF2005 period. However, there were existing systematic differences at Asia and Europe. Nevertheless, this kind of systematic difference is not obvious in the global view. And the amount of velocity differences is below 1mm/yr.

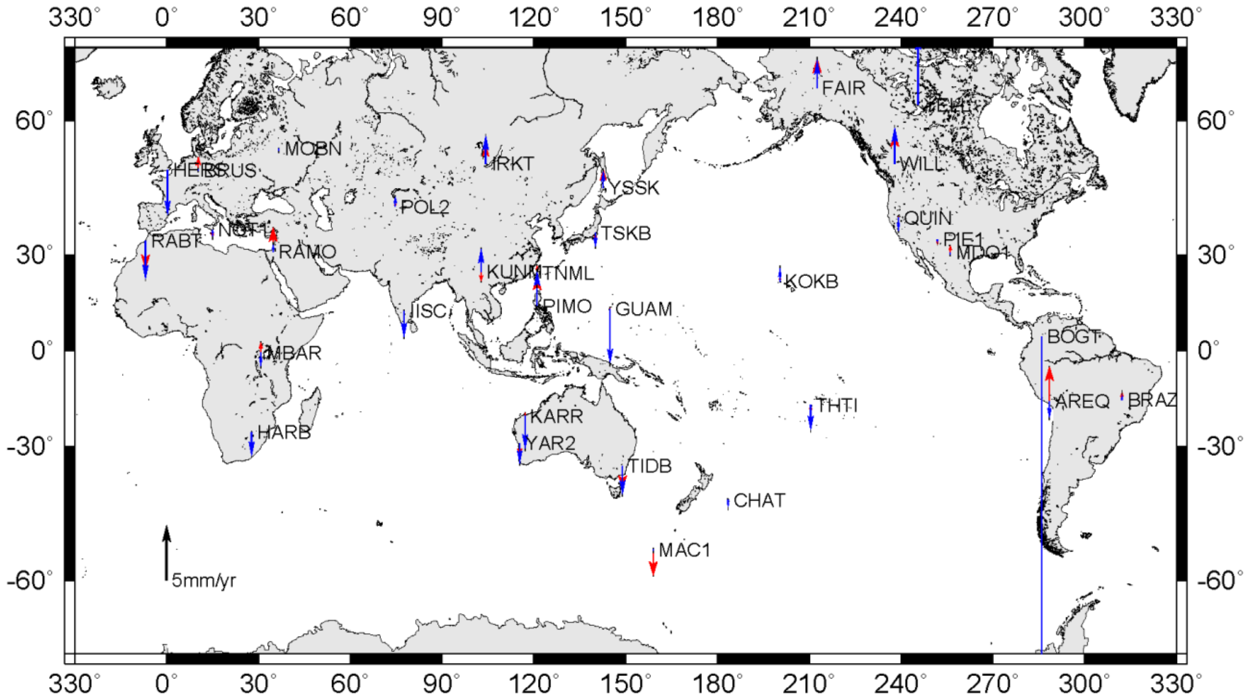

Fig 3, Difference between the velocities of the PPP solution and ITRF at the horizontal components

Figure 4 illustrates the vertical velocity field in the local geodetic system components (U) obtained from the final PPP solution, compared with the SINEX result. The PPP solution of stations AREQ, GUAM and KARR are notably different to the SINEX results.

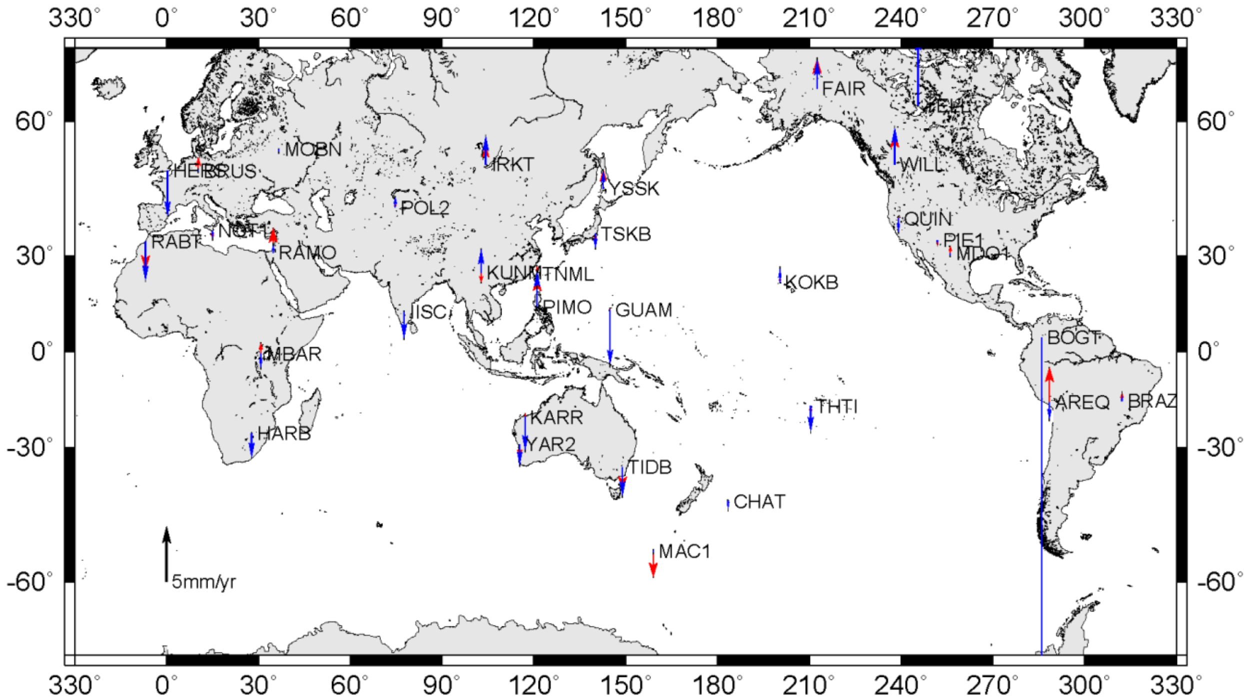

Fig 4, velocity field in the local geodetic system components (U) obtained from the final PPP solution and ITRF

Fig 5 shows the differences of velocity (SINEX-PPP) at the height direction during the ITRF2005 period. The difference of velocity is larger than the horizontal component.

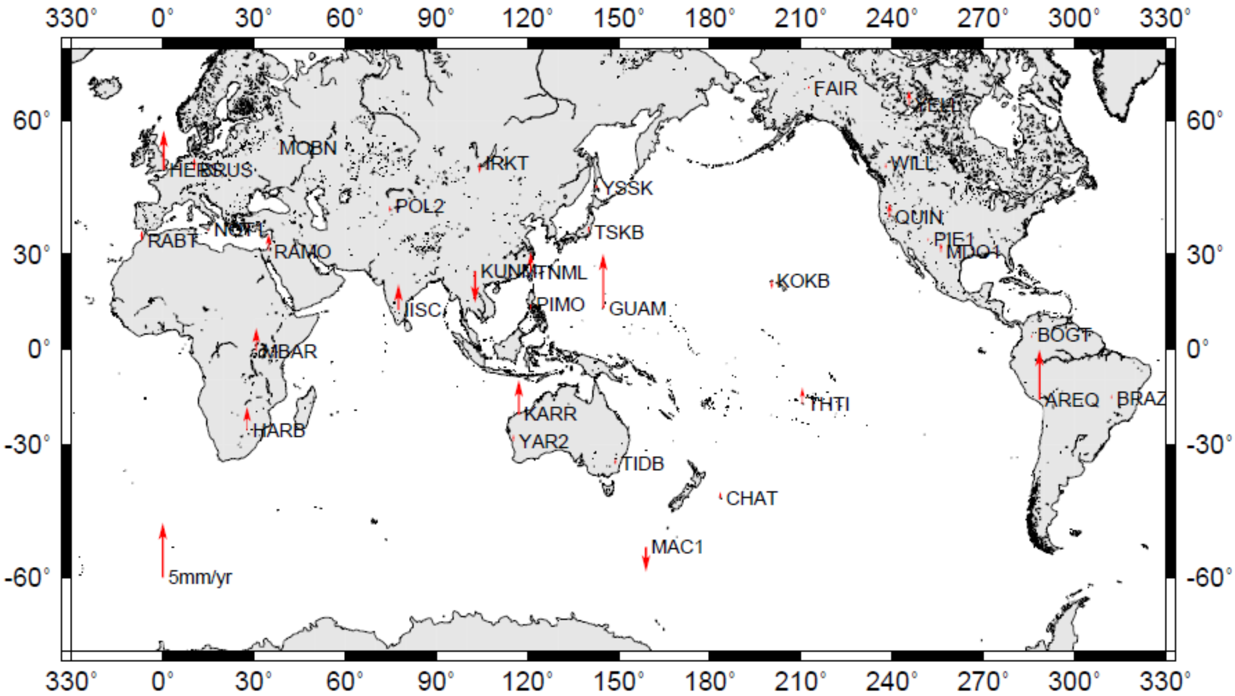

Fig 5, Difference between the velocities of the PPP solution and ITRF at the vertical components

We obtain the transformation parameters to analyze the significance for each parameter by formulation 3. Table 1 presents the transformation parameters during the ITRF2005 period. Only the rate of scale parameter is significant, and it is consistent that the differences of velocity at the vertical components are larger than the horizontal components.

Tab 1, The transformation parameters

	ITRF2005 period
$\dot{T}_x$	0.376±0.198mm/yr
$\dot{T}_y$	0.459±0.198mm/yr
$\dot{T}_z$	-0.380±0.194mm/yr
$\dot{D}$	0.142±0.030ppb/yr
$\dot{\omega}_z$	0.000001±0.000008"/yr
$\dot{\omega}_y$	0.000002±0.000008"/yr
$\dot{\omega}_z$	0.000006±0.000008"/yr

Table 2 presents the difference of velocity in the local geodetic system components (E, N, U). During the ITRF2005 period, the velocity differences in the east, north, and up directions were -0.23±0.75, -0.35±0.79, and 0.83±1.69 mm/yr, respectively. The RMS is smaller than 1mm/yr at the horizontal components, and the RMS is 1.88mm/yr at the vertical component. After performing the 7-parameter Helmert transformation to absorb the systematic biases between the PPP results and the ITRF, the differences for the east, north, and up directions were reduced to -0.01±0.52, -0.02±0.38, 0.00±1.68 mm/yr, respectively. However, only the vertical component is notably improved by the transformation. This demonstrates that we can obtain highly accurate absolute horizontal site velocities, on the level of sub-mm/yr.

Tab 2, Difference of velocity during the ITRF2005 period

Original	mean (mm/yr)	STD (±mm/yr)	RMS (±mm/yr)	After Transformation	mean (mm/yr)	STD (±mm/yr)	RMS (±mm/yr)
dV_E	-0.23	0.75	0.79	dV_E	-0.01	0.52	0.52
dV_N	-0.35	0.44	0.56	dV_N	-0.02	0.38	0.38
dV_U	0.83	1.69	1.88	dV_U	0.00	1.68	1.68

4. CONCLUSIONS

We have assessed PPP using IGS final products for computing a set of PPP-derived velocity solutions for 33 evenly distributed IGS global tracking stations from 5/11/2006 to 31/12/2010, and compared them with their respective quantities defined in the ITRF. We can obtain such conclusions as the following:

During the ITRF2005 period, the velocity differences in the east, north, and up directions were -0.23±0.75, -0.35±0.44, 0.83±1.69 mm/yr, respectively. After Helmert transformation, the velocity differences in the east, north, and up directions were -0.01±0.52, -0.02±0.38, 0.00±1.68 mm/yr, respectively. Only the vertical component is notably improved by the transformation. The accuracy of PPP-derived site velocities was below 1mm/yr at horizontal before transformation.

Since the quality of IGS products improves with time, the biases that existed in the PPP solutions are gradually diminished. It is concluded that under the current ITRF2005, one can reliably use the PPP technique to obtain highly accurate absolute horizontal site velocities, on the level of sub-mm/yr.

5. REFERENCES

Altamimi, Z., Collilieux, X., Legrand, J., Garayt, B., and C. Boucher, 2007. ITRF2005: A New Release of the International Terrestrial Reference Frame Based on Time Series of Station Positions and Earth Orientation Parameters. Journal of Geophysical Research-Solid Earth, 112 (B9).

Blewitt, G., and D. Lavallee, 2002. Effect of Annual Signals on Geodetic Velocity. Journal of Geophysical Research-Solid Earth, 107 (B7).

Brockmann, E., 1997. Combination of Solutions for Geodetic and Geodynamic Applications of the Global Positioning System (GPS), Ph.D. dissertation, Astronomical Institute, University of Berne, Berne, Switzerland.

Jekeli, C., 2006. Geometric Reference Systems in Geodesy, Division of Geodesy and Geospatial Science. School of Earth Sciences, Ohio State University, U. S. A.

Kouba, J., and P. Heroux, 2001. Precise Point Positioning Using IGS Orbit and Clock Products. GPS Solutions, 5 (2), pp. 12-28.

Louis, M., 1992. IAG Resolutions Adopted at the XXth IUGG General Assembly in Vienna. Journal of Geodesy, 66 (2), pp. 132-133.

Nikolaidis, R., 2002. Observation of Geodetic and Seismic Deformation with the Global Positioning System, Ph.D. dissertation. University of California, San Diego, U. S. A.

Parkinson, B. W., and J. J. Spilker, 1996. Global Positioning System: Theory and Applications. American Institute of Aeronautics and Astronautics, Washington, DC, U. S. A.

Ray, J., Dong, D., and Z. Altamimi, 2004. IGS Reference Frames: Status and Future Improvements. GPS Solutions, 8 (4), pp. 251-266.

Schmid, R., Steigenberger, P., Gendt, G., Ge, M., and M. Rothacher, 2007. Generation of a Consistent Absolute Phase Center Correction Model for GPS Receiver and Satellite Antennas. Journal of Geodesy, 81 (12), pp. 781-798.

Teferle, F. N., Orliac, E. J., and R. M. Bingley, 2007. An Assessment of Bernese GPS Software Precise Point Positioning Using IGS Final Products for Global Site Velocities. GPS Solutions, 11 (3), pp. 205-213.

Zumberge, J. F., Heflin, M. B., Jefferson, D. C., Watkins, M. M., and F. H. Webb, 1997. Precise Point Positioning for the Efficient and Robust Analysis of GPS Data from Large Networks. Journal of Geophysical Research, 102 (B3), pp. 5005-5017.