Tectonic Motion Monitoring of Antarctica Using GPS Measurements

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Abstract

With its low installation cost and high accuracy, GPS has become an essential method in the field for tectonic motion let alone location decision. In this study, data obtained from IGS stations between 2004 and 2012 analyzed using precise point positioning. Monitoring of tectonic motion demonstrates that the Antarctic continent behaves as a rigid plate. The speed vector for each station decided based on the GPS data processing result showed that Antarctica rotates around the Mawson and its rotation speed was calculated as about 0.001" per year on an X-Y plane. The processed GPS results were compared with other models for verification and suggested the Tectonic Motion of Antarctica precisely. It is expected that the tectonic motion of Antarctica can be used as the basic data on various scientific purposes.

Keywords: *Monitoring, GPS, Precise Point Positioning, Tectonic Motion, Antarctica*

1. Introduction

Antarctica plays a vital role in the functioning of the global climate system. It should be little surprise then that Antarctica is an important place for science - the pursuit of knowledge about the physical and natural world. It is also the coldest - the average annual temperature at the South Pole is -49° C. The continent is almost completely covered by ice with an average thickness of over 2,000 meters. This is the storehouse for 70 percent of the world's fresh water. In winter the formation of sea ice more than doubles the size of Antarctica. This seasonal change has a profound influence on atmospheric and water temperatures and global weather patterns [1]. As GPS ensures low installation cost and high accuracy for decision of the location, it has been recommended as an ideal method for a study of positioning [2-4]. Studies on tectonic motion using GPS are being conducted on all around the earth such as Eastern Asian region including Japan, China and Siberia, Middle European region, and Caribbean and North American region [5-7]. As information on the tectonic motion by means of all kinds of geophysical methods and GPS piles up recently, a number of studies which try to explain stress distribution which determines crustal displacement and characteristics of ground movement have been introduced [8].

This study monitored tectonic motion of Antarctica by GPS data processing. For the study, the GPS data were collected for 8 years and 6 months in the 7 IGS (International GNSS

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Service) CORS (Continuously Operating Reference Stations) in Antarctica. The data were processed in the methods of PPP (Precise Point Positioning) per week using Bernese GPS Software 5.0 (BSW5.0 afterwards). Tectonic motion of Antarctica was calculated based on position change of CORS. The tectonic motion of the whole Antarctica was analyzed using velocity vector determined by processed GPS data and evaluated by comparing with the plate motion models.

2. Data Acquisition and Processing

The RINEX data were collected at intervals of 1 day 30 seconds for the 7 CORS including Casey (CAS1), Davis (DAV1), Mawson (MAW1), Ross Island (MCM4), O'Higgins (OHI2), East Ongle Island (SYOG), and Vesleskarvet (VESL), which were registered in IGS. GPS data was obtained on a weekly basis for 8 years and 6 months from July 2004 to December 2012 from Crustal Dynamics Data Information System (CDDIS) of NASA (National Aeronautics and Space Administration) of USA [9].

The deviations occurring during sensing by GPS due to physical movement of the earth must be removed using a proper model and this type of correction includes pole movement, atmospheric load, and ocean tidal loading [10]. BSV5.0 eliminated these correction factors by using precise orbiting and all kinds of models provided by NASA JPL (NASA Jet Propulsion Laboratory), AIUB (Astronomical Institut Universität Bern). In this study, the GPS data from the 7 CORS were processed in the methods of PPP using BSV 5.0 BPE (Bernese Processing Engine). Tropospheric delay was modeled using the Saastamoinen model and Niell Mapping Function. For prevent multi-path with over 10° of mask angle was used for processing by editing PCF file. Precise Ephemeris of JPL were used to remove signal delay and to collect satellite position information respectively and estimates of the coordinates of the stations calculated on a daily basis with ambiguity fixing, the absolute phase antenna center variations (PCVs) for receivers.

3. Monitoring of Tectonic Motion

In this Study, data of GPS CORS were processed in order to monitoring the Antarctic plate motion. Due to most of the Antarctica being covered with a thick ice sheet, bedrock outcrops can only be found at coastal areas and at a small number of mountain outcrops, where these IGS CORS are located. We analyzed data from 7 IGS CORS to obtain coordinate solutions for 8.5 years from 2004 to 2012.

To calculate the velocity of tectonic motion, GPS data was processed using PPP method by BPE, and its result was adjusted based on July 7th, 2004 (DOY 2004.189) fixed on the ITRF2000 coordinate system because the newer realization of the International Reference Frame (ITRF2005) was not available yet at the epoch of 2004 and considering that ITRF2000 used as input data time series and daily EOP (Earth Orientation Parameters). Figure 1 coordinate time series of north and east component of CORS by PPP. The vertical axis of the graph is the fluctuation amount of coordinate value on the data processed from July 7th, 2004 while horizontal axis indicates observed time.

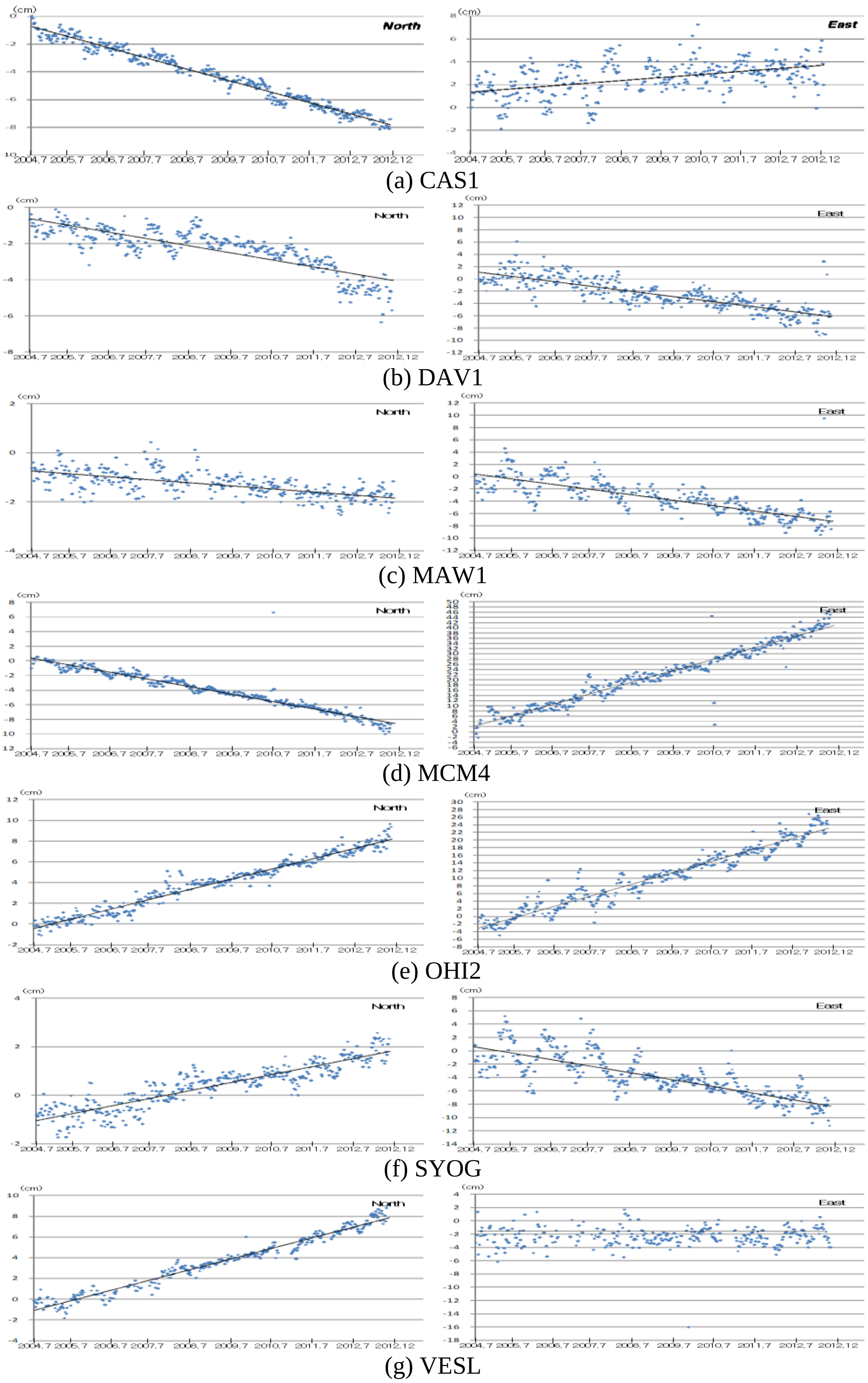

Figure 1. Coordinate Time Series of CORS

Normal Equation Solution, for calculate of tectonic motion velocity, created after PPP processing was processed using ADDNEQ2 module in the method of Free Network Solution for the entire study period. In this study, the 4 tectonic motion models were compared with PPP result. Table 1 shows velocity of IGS CORS.

Table 1. Velocity of IGS CORS

Station		Model	Velocity (mm/year)	
Name	ID		North (RMSE)	East (RMSE)
Casey	CAS1	this study	-9.40 ± 0.1	2.20 ± 0.2
		NNR-NUVEL-1A	-8.80	1.20
		ITRF2000	-9.60 ± 0.7	2.60 ± 0.2
		REVEL2000	-11.60 ± 0.7	3.70 ± 0.6
		CGPS2004	-9.90 ± 0.3	2.00 ± 0.3
Davis	DAV1	this study	-4.90 ± 0.1	-2.10 ± 0.1
		NNR-NUVEL-1A	-2.9	-2.3
		ITRF2000	-4.80 ± 0.2	-1.50 ± 0.3
		REVEL2000	-6.60 ± 0.7	-2.10 ± 0.7
		CGPS2004	-5.10 ± 0.3	-1.90 ± 0.3
Mawson	MAW1	this study	-3.00 ± 0.1	-2.10 ± 0.1
		NNR-NUVEL-1A	0.30	-2.10
		ITRF2000	-2.70 ± 0.3	-2.30 ± 0.2
		REVEL2000	-3.60 ± 0.7	-3.50 ± 0.7
		CGPS2004	-3.30 ± 0.5	-1.80 ± 0.6
McMurdo	MCM4	this study	-12.10 ± 0.1	10.70 ± 0.3
		NNR-NUVEL-1A	-11.80	7.60
		ITRF2000	-12.00 ± 0.2	9.70 ± 0.3
		REVEL2000	-12.20 ± 0.6	10.60 ± 0.7
		CGPS2004	-11.60 ± 0.3	8.70 ± 0.3
O'higgins	OHI2	this study	11.70 ± 0.1	15.20 ± 0.2
		NNR-NUVEL-1A	10.30	16.40
		ITRF2000	10.20 ± 0.2	14.4 ± 0.1
		REVEL2000	10.10 ± 0.9	14.7 ± 0.8
		CGPS2004	-	-
Syowa	SYOG	this study	1.30 ± 0.1	-2.10 ± 0.1
		NNR-NUVEL-1A	5.0	-1.80
		ITRF2000	1.30 ± 0.4	-3.60 ± 0.1
		REVEL2000	0.30 ± 1.0	-4.40 ± 1.2
		CGPS2004	2.50 ± 0.7	-3.7 ± 0.9
Vesleskarvet	VESL	this study	12.80 ± 0.2	-0.3 ± 0.2
		NNR-NUVEL-1A	11.10	3.0
		ITRF2000	11.10 ± 0.6	2.30 ± 0.9
		REVEL2000	8.20 ± 1.8	-4.70 ± 1.4
		CGPS2004	8.60 ± 0.7	-0.10 ± 0.7

The Velocities of latitude and longitude direction using PPP was calculated as 0.3~15.2 mm/year in accordance with the CORS and the standard deviation ranged ±0.1~±0.3 mm/year. Considering the calculated direction of tectonic motion, Antarctica showed the aspect of rotating to the same direction as the earth rotation centering on the outline of SYOG, MAW1 station. The speed of tectonic motion was as small as 1.30~4.90 mm/year for SYOG, MAW1, and DAV1 Station, while it was as big as 15.20 mm/year and 12.10 mm/year for OHI2 and MCM4 stations respectively, which are far away from the rotation pole.

4. Calculation of Rotation Pole

In this study, we calculated approximate rotation pole and rotation amount of Antarctica using movement speed of CORS by data processing result. Figure 2 shows mathematical model to calculate rotation center.

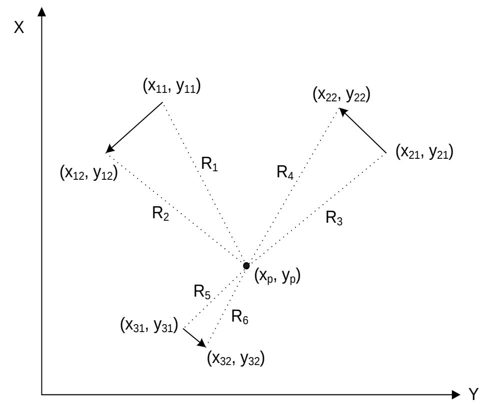

Figure 2. Mathematical Model

For calculation of rotation center of Antarctica, total 7 equations were made and determinants were composed for each station and their results are shown in Table 2.

Table 2. Rotation pole and rotation rate

X_p (m)	Y_p (m)	Rotation rate(″ /year)
1647163.145	2307646.302	0.001±0.0001

The rotation rate of Table 3 was averaged after calculating the range (R) and vector size from rotation center to each station by Eq. 1 method.

$$\tan^{-1}\left(\frac{\delta}{R}\right) = \theta \text{ radian}$$

(∵ Because δ is small compared to R $\delta = R\theta$ radian) (1)

The estimated Rotation pole position in geographic coordinates is projected onto the Southern Hemisphere. σmax and σmin mean semi-major, semi-minor axes of the 1 σ pole error ellipse, respectively. This study, NUVEL 1A, ITRF2000, CGPS 2004 and REVEL 2000 are summarized in Table 3 [11-14].

Table 3. Rotation pole and rotation rate

Model	Latitude(°N)	Longitude(° E)	Rotation rate(° /Myr)
This study	56.9	53.0	0.22±0.02
NNR-NUVEL-1A	63.0	64.1	0.24±0.02
ITRF2000	61.8	54.4	0.23±0.02
CGPS2004	60.7	54.3	0.22±0.01
REVEL2000	58.5	46.0	0.23±0.01

The speed of tectonic motion was small for SYOG and MAW1 station respectively, which are nearby rotation pole, while it was as big for OHI2 and MCM4 station respectively, which are the farthest ones from the rotation pole. All rotation poles are located close to one another between latitudes 56.9°N and 63.8°N and between longitudes 32.1°E and 54.5°E. As most of the results are estimated from stable, continuous observation, we propose that the real rotation pole can be located in this area.

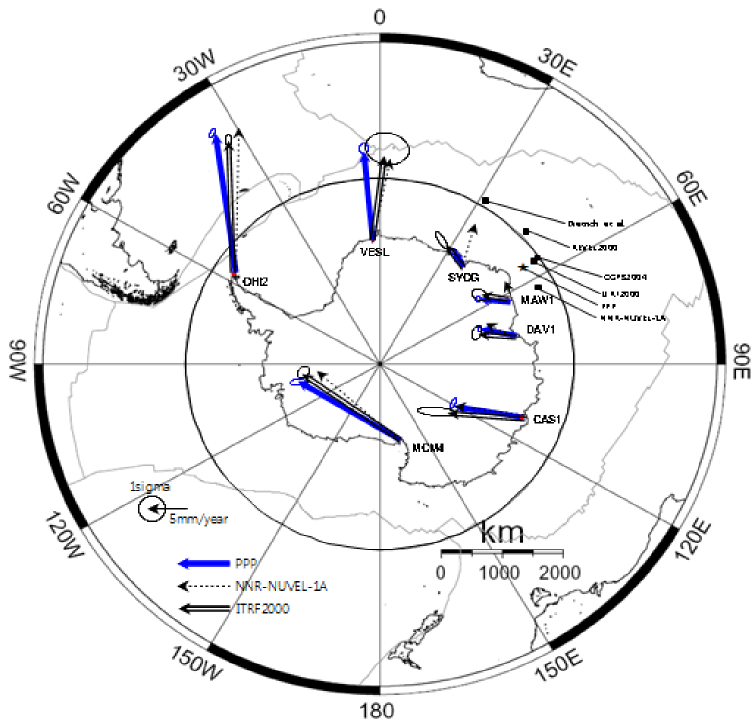

Figure 3. Comparison of Velocities and Rotation Pole

5. Discussion

Tectonic motion which constitutes the earth surface is one of the main causes which influence the earth rotation and also the location differences between points on earth. A number of models have been suggested using geological and geophysical information on the amount of tectonic motion sensed by modern scientific technology.

In Figure 3 we compare the velocity vectors that we computed with those tectonic motion model for verification of result. PPP solution is mostly consistent with the ITRF 2000 solution within 1-sigma except for OHI2 and VESL. On the other hand, there are systematic differences between our solution and that of the NNR-NUVEL-1A model, with the differences being significant at SYOG, MAW1, DAV1 and VESL. Table 1 presents a comparison of our velocity estimates with those of previous studies. NNR-NUVEL-1A is based on geologic as well as geodetic data, and ITRF 2000 was obtained as a weighted average of different space-geodetic techniques. The other results are based purely on GPS data. And with respect to the reference frame, REVEL refers to ITRF 97, while the other GPS results were based on ITRF 2000.

Five sets of velocity data presented in Table 1, PPP velocity results are closest to those of ITRF 2000, possibly indicating that different velocity solutions would converge towards one another as the analysis period is extended. The tectonic motion of Antarctica suggested in this study which was able to verify the results by comparing with existing study and proposed the standard deviation of less than 0.2mm/year. Figure 4 shows a comparison between PPP solutions and the predicted velocities based on PPP rotation pole.

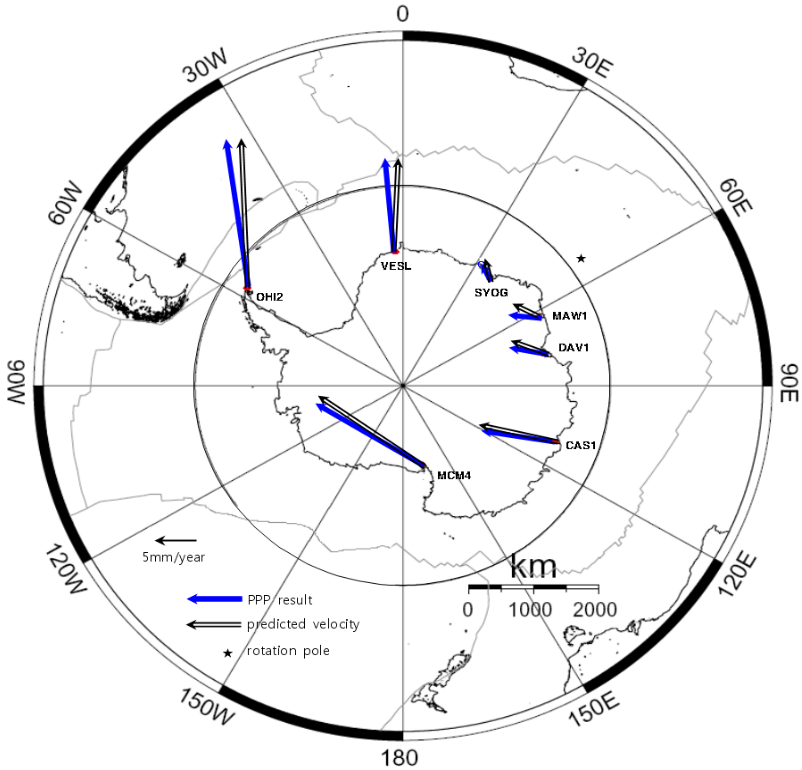

Figure 4. PPP Velocity Vectors and Predictions from the Rigid Plate Motion Model

Two velocity vectors are highly consistent each other, with discrepancies of less than 1 mm/year at all the sites. This comparison clearly demonstrates a high rigidity of the Antarctic plate. Since the Antarctic plate is 6,000~10,000 km wide in diameter, discrepancies of less than 1 mm/year from the rigid plate motion. Therefore, we can say that the Antarctica moves as a rigid plate with almost no inner deformation.

6. Conclusion

In this study, recent data (from 2004 to 2012) was used to monitor Antarctic tectonic motion. Thus, the result of this study would sense Antarctic motion in recent years.

This study calculated tectonic motion of Antarctica based on GPS data processing. The data were collected for 8.5 years in the 7 GPS CORS in Antarctica among those registered in IGS and the tectonic motion by GPS data processing was also compared with the results by the 4 tectonic motion models for verification. The results are summarized as follows:

After estimating the speed by GPS network for 8 years and 6 months from July 2004 until December 2012, tectonic motion in Antarctica was determined with average ±0.1~±0.3mm/year standard deviation. This result confirms that use of GPS network could enable determination of tectonic motion vector with high accuracy. The assumed result of tectonic motion of Antarctica implied that Antarctica rotates as in the same direction as the earth rotation centering on the outline of Mawson station. The approximate rotation amount based on X-Y plane was 0.001±0.0001 per year. Based on this analysis, we were able to estimate the motion of the whole Antarctica with the high reliability. The assumed result implied that Antarctica rotates as in the same direction as the earth rotation centering on the outline of Mawson station. Further use of GPS data at other stations in Antarctica together with the GPS data of the above 7 CORS may ensure more precise monitoring on the movement of Antarctica. The horizontal component of the Antarctic tectonic motion can be explained as a rigid plate motion. It is expected that the tectonic motion of Antarctica can be used as the basic data on various scientific purposes.

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References

[1] http://www.anta.canterbury.ac.nz.
[2] Y. -S. Shim and I. -K. Lee, “Interference Analysis from Non-communication Device into GPS Service”, IJMUE, vol. 7, no. 1, **(2012)**, pp. 15-22.
[3] M. A. Qadeer, A. Chandra and S. Jain, “Design and Implementation of Location Awareness and Sharing System using GPS and 3G/GPRS”, IJMUE, vol. 7, no. 4, **(2012)**, pp. 125-140.
[4] A. M. Hasan, K. Samsudin and A. R. Ramli, “GPS/INS Integration Based on Dynamic ANFIS Network”, IJCA, vol. 5, no. 3, **(2012)**, pp. 37-46.
[5] L. P. Zonenshain and L. A. Savostin, “Geodynamics of the Baikal rift zone and plate tectonics of Asia”, Tectonophysics, vol. 76, no. 1, **(1981)**, pp. 1-45.
[6] A. Caporali, C. Aichhorn, M. Becker, I. Fejes, L. Gerhatova, D. Ghitau, G. Grenerczy, J. Hefty, S. Krauss, D. Medakh, G. Milev, M. Mojzes, M. Mulic, A. Nardo, P. Pesec, T. Rus, J. Simek, J. Sledzinski, M. Solaric, G. Stangl, F. Vespe, G. Virag, F. Vodopivec and F. Zablotskyi, “Geokinematics of Central Europe: New insights from the CERGOP-2/Environment Project”, Journal of Geodynamics, vol. 45, **(2008)**, pp. 246-256.
[7] C. DeMets, P. E. Jansma, G. S. Mattioli, T. H. Dixon, F. Faina, R. Bilham, E. Calais and M. Paul, “GPS geodetic constraints on Caribbean-North America plate motion”, Geophysics Research Letters, vol. 27, no. 3, **(2000)**, pp. 437-440.
[8] M. H. Ahmed, P. Pil-Ho and L. Hyung-Chul, “Horizontal deformation in South Korea from permanent GPS network data, 2000-2003”, Earth Planets Space, vol. 57, **(2005)**, pp. 77-82.
[9] http://cddis.nasa.gov/gnss_datasum.html.
[10] D. D. McCarthy, “IERS Technical Note 21: IERS Conventions, Central Bureau of IERS”, Observatoire de Paris, **(1996)**, pp. 95.
[11] C. DeMets, R. G. Gordon, D. F. Argus, and S. Stein, “Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions, Geophys”, Res. Lett. 21, pp. 2191-2194, **(1994)**.
[12] C. Boucher, Z. Altamimi, P. Sillard and M. Feissel-Vernier, “The ITRF 2000”, IERS Tech., Note 31, **(2004)**.
[13] L. Prawirodirdjo and Y. Bock, “Instantaneous global plate motion model from 12 years of continuous GPS observations”, Journal of Geophysical Research-Solid Earth 109(B08405), doi:10.1029/2003JB002944, **(2004)**.
[14] G. F. Sella, T. H. Dixon and A. Mao, “REVEL: A model for recent plate velocities from space geodesy”, Journal of Geophysical Research-Solid Earth 107(B4), doi:10.1029/2000JB000033, **(2002)**.

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