Displacement and maintenance of control points at Okinotorishima Island on Philippine Sea Plate

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(Published online: 26 December 2014)

Abstract

Okinotorishima Island is the southernmost island of Japan, located on the Philippine Sea plate. On the island, Geospatial Information Authority of Japan (GSI) set triangulation points and a GPS continuous observation station in 1989 and 2005, respectively, and has conducted GPS surveys since 1992 for surveying and crustal deformation monitoring. This report describes the displacement of Okinotorishima Island from 2005 to 2013 as a result of re-analyzing GPS data using GAMIT software. The displacement suggests that Okinotorishima Island has moved WNW at Vns = +21.6 mm/year and Vew = -58.0 mm/year, or moved N66.8°W at 61.9 mm/year. The rate of collection of data at the island is lower than that of the GSI's other GNSS stations because the station is an extremely isolated island in the Pacific Ocean. In order to monitor the movement of Philippine Sea plate, it is necessary to continue the maintenance of observation devices and enhance the station's data availability.

1. Introduction

GSI has conducted GPS surveys at triangulation points on Okinotorishima Island, the southernmost island of Japan, in order to understand the motion of the Philippine Sea plate and conserve these control points, which are important for maintenance of Japan's national land and exclusive economic zone (EEZ). Because the Philippine Sea plate is mostly covered by ocean, and almost all onshore areas of the plate edge are affected by subduction or volcanic activity, Okinotorishima Island, located in the center of the plate, is significant for monitoring the plate's motion (Kato et al., 1996). Previous studies estimated the amount of displacement of the island by analyzing GPS data obtained from annual GPS observations at the triangulation points from 1992 to 2009 (e.g. Kato et al., 1996; Aiba and Hamazaki, 2002; Takahashi, 2010).

In addition to the annual observations at triangulation points, GSI has operated a continuous GPS observation station at Higashi Kojima of Okinotorishima Island since 2005. This station is a part of GEONET (GNSS Earth Observation Network system) which consists of about 1,300 continuous GNSS observation stations in Japan. GEONET provides daily site coordinates of each station including Okinotorishima station using Bernese software. In this paper, we have re-analyzed the GPS data of Higashi Kojima from 2005 to 2013 using GAMIT software and compare time series and velocity of Okinotorishima Island with other results.

2. Okinotorishima Island and control points

Okinotorishima Island is located approximately 1,700 kilometers south of Tokyo and is covered by coral reef (Fig. 1). The island has two islands called Kita Kojima and Higashi Kojima. Because the Government of Japan intensively promotes stable preservation of islands demarcating EEZ including Okinotorishima Island (Government of Japan, 2013), this island has been maintained by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) instead of the Tokyo government since 1999.

GSI installed triangulation points and conducted GPS observation at Kita Kojima and Higashi Kojima in 1989. In addition to the purpose of surveying in Okinotorishima Island, the triangulation points were observed for monitoring the plate motion from 1992 to

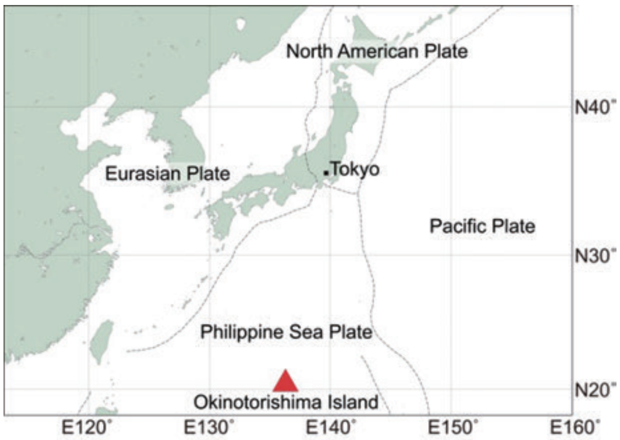

Fig. 1 Location of Okinotorishima Island

2009. GSI also started to deploy GEONET stations all over Japan from 1993. The number of stations reached about 800 in 1996, and it reached about 1,300 stations in 2014. GSI installed a GEONET station on Higashi Kojima in 2005. Because construction of infrastructure for power supply and telecommunications is insufficient on Okinotorishima Island, the GEONET station is powered by solar cell and transmits GPS data to GSI every 3 hours by satellite phone. Therefore, unlike most GEONET stations that collect 1 Hz data, this station collects data at 30-second intervals. The data and the daily positions of all GEONET stations are provided on GSI's website including the Okinotorishima Island station (http://terras.gsi.go.jp).

Almost all GEONET stations now support GNSS data including GPS, GLONASS and QZSS (Tsuji et al., 2013). However, since it is not easy to visit Okinotorishima Island for maintenance, the Okinotorishima station still uses a GPS receiver and antenna (Trimble NetRS and TRM39105.00), and does not support other GNSS.

3. Data and Analysis

The GEONET station on Okinotorishima Island has continuously observed since 20 June, 2005, except for days that the station could not observe data due to issues such as mechanical problems or observation conditions. In order to describe a time series of displacement of the island, we re-calculated the position every six months from June 2005 to December 2013. The dates of the data used are shown in Table 1. Note that we did not calculate the position in December 2007 because of a lack of data due to mechanical trouble in that period.

We used "GAMIT 10.4" and "GLOBK 5.19" developed by MIT for analysis software. We firstly analyzed the baseline vectors of each day of observation using 24 hour data and IGS precise ephemeris (IGSF), and then combined solutions of three days in every 6 months. As reference sites, we selected IGS stations of TSKB, TWTF and GUAM (Fig.2), and their velocities associated with each plate motion were preliminarily estimated by IGS. After the analysis, the calculated coordinates based on ITRF2005 (Table 2) were transformed to longitude,

Table 1 List of analysis date

year	date	doy
2005	06-30 , 07-01 , 07-02	181,182,183
	12-29 , 12-30 , 12-31	363,364,365
2006	06-30 , 07-01 , 07-02	181,182,183
	12-25 , 12-29 , 12-31	359,363,365
2007	06-30 , 07-01 , 07-02	181,182,183
2008	07-01 , 07-02 , 07-03	181,182,183
	12-28 , 12-29 , 12-30	363,364,365
2009	06-30 , 07-01 , 07-02	181,182,183
	11-02 , 11-03 , 11-04	306,307,308
2010	06-30 , 07-01 , 07-02	181,182,183
	12-16 , 12-19 , 12-20	350,353,354
2011	06-30 , 07-01 , 07-02	181,182,183
	11-13 , 11-14 , 11-15	317,318,319
2012	07-01 , 07-02 , 07-04	181,182,184
	12-25 , 12-26 , 12-30	360,361,365
2013	07-17 , 07-18 , 07-20	198,199,201
	12-23 , 12-24 , 12-25	357,358,359

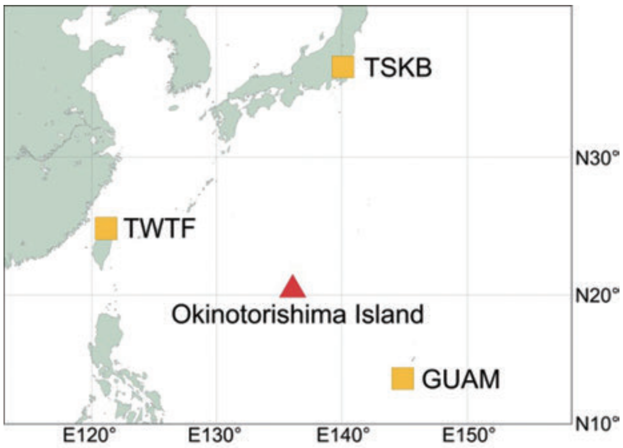

Fig.2 Location of reference sites

Table. 2 Result of the baseline analysis using GAMIT and GLOBK

analysis date		GLOBK chisq	X	Y	Z
2005	181 182 183	1.155	-4307239.97013	4147690.68054	2211923.03734
	363 364 365	1.069	-4307239.97315	4147690.70344	2211923.07110
2006	181 182 183	1.227	-4307239.95596	4147690.70279	2211923.06592
	359 363 365	1.104	-4307239.93666	4147690.73797	2211923.07880
2007	181 182 183	1.372	-4307239.90712	4147690.73205	2211923.09231
2008	181 182 183	1.110	-4307239.87095	4147690.78310	2211923.10583
	363 364 365	1.073	-4307239.84706	4147690.77378	2211923.10581
2009	181 182 183	1.188	-4307239.82291	4147690.78692	2211923.11695
	306 307 308	1.034	-4307239.83119	4147690.80655	2211923.12463
2010	181 182 183	1.239	-4307239.79173	4147690.82686	2211923.14700
	350 353 354	0.874	-4307239.78480	4147690.84241	2211923.14334
2011	181 182 183	2.678	-4307239.73368	4147690.87058	2211923.16723
	317 318 319	2.892	-4307239.71283	4147690.93545	2211923.18648
2012	181 182 184	3.832	-4307239.67346	4147690.93733	2211923.18955
	360 361 365	4.246	-4307239.63761	4147690.94504	2211923.20494
2013	198 199 201	5.010	-4307239.60685	4147690.97438	2211923.20642
	357 358 359	5.199	-4307239.59075	4147690.96567	2211923.20935

＊ Coordinate system is ITRF2005.

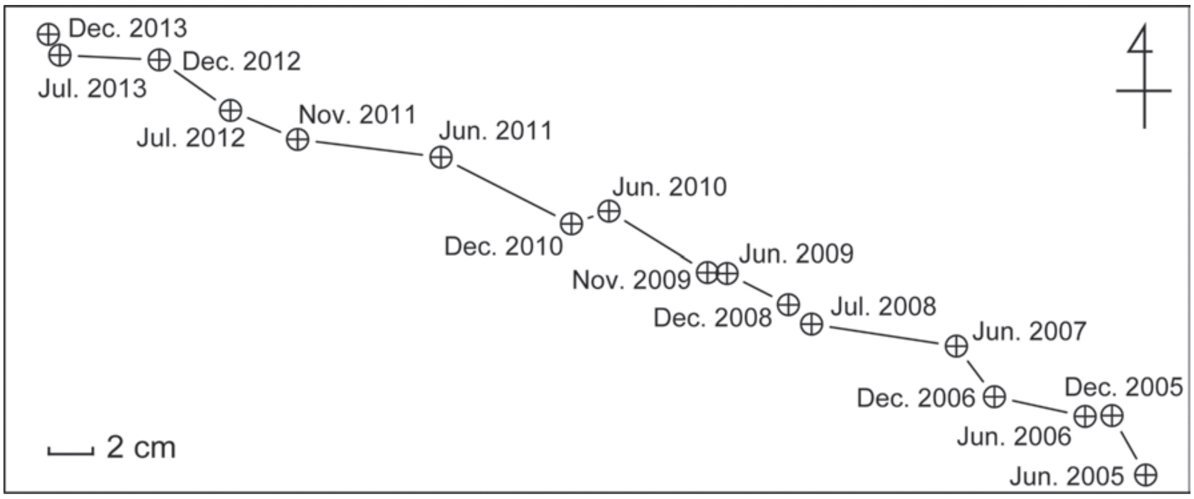

Fig. 3 Displacement of Okinotorishima Island from June 2005 to December 2013

latitude and ellipsoidal height of GRS80 ellipsoid by a coordinate transformation software “trns2000” (Tobita, 2002). Finally, we described the time series of horizontal displacement (Fig. 3) and estimated the velocity by applying the least squares line to the time series (Fig. 4).

Fig. 4. Time series of daily horizontal coordinates of the GEONET station on Okinotorishima Island calculated by GAMIT/GLOBK. NS (upper) and EW (lower) components are shown. The area between red and blue lines shows 95% confidence intervals. Note that the scale of the displacement is different with each graph.

Fig. 5. Time series of daily horizontal coordinates of the GEONET station on Okinotorishima Island. NS (upper) and EW (lower) components are shown. Area between red and blue lines shows 95% confidence intervals (they almost overlap each other).

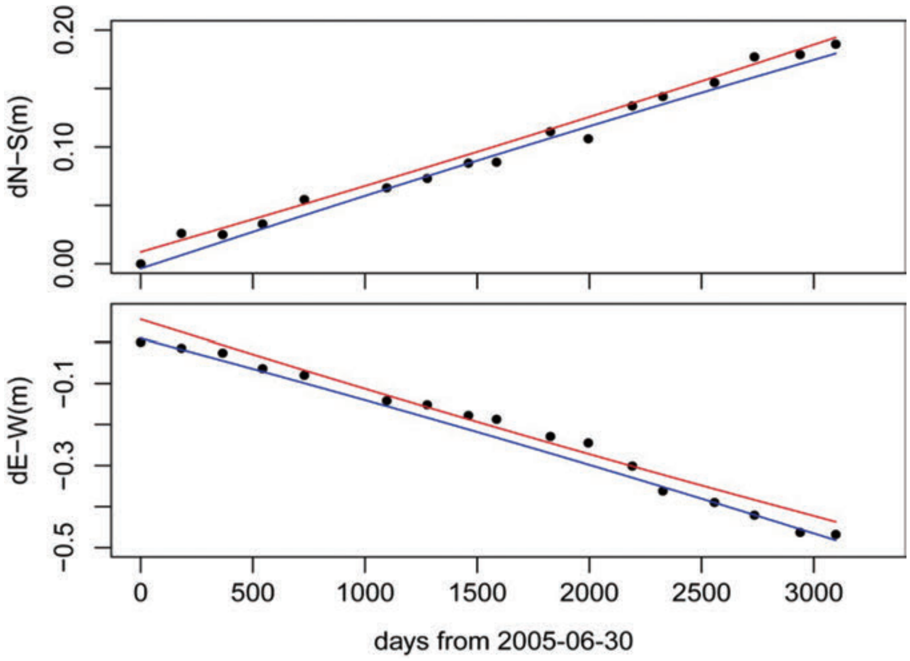

Fig. 4 Time series of daily horizontal coordinates of the GEONET station on Okinotorishima Island calculated by GAMIT/GLOBK. NS (upper) and EW (lower) components are shown. The area between red and blue lines shows 95% confidence intervals. Note that the scale of the displacement is different with each graph.

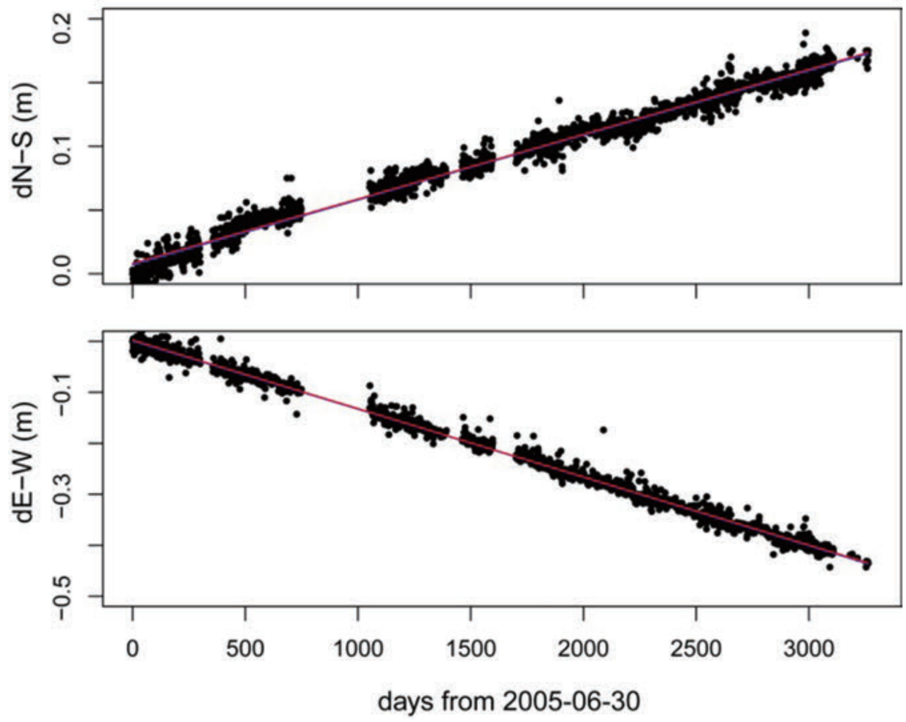

Fig. 5 Time series of daily horizontal coordinates of the GEONET station on Okinotorishima Island. NS (upper) and EW (lower) components are shown. Area between red and blue lines shows 95% confidence intervals (they almost overlap each other).

4. Result and Discussion

As shown in Fig. 3, Okinotorishima Island has moved a few centimeters northward to westward every six months, and approximately 50 centimeters west-northwestward over nine years. The velocities of north and east components calculated based on the least squares line show +21.6 mm/year (R^2 = 0.987) and -58.0 mm/year (R^2 = 0.980) respectively with a good degree of confidence, and the integrated velocity is 61.9 mm/year in the direction N67°W. Before installation of the GEONET station on this island, GSI had conducted GPS surveys at triangulation points on Kita Kojima and Higashi Kojima from 1998 to 2009. The velocity and direction of the island based on the GPS observations were 61.3 mm/year and N65°W, respectively (Takahashi, 2010) , which are correspond to the movement of the GEONET station. Another study also showed the velocities of north and east components were +30.0 ± 0.84 and -51.7 ± 10.6 mm/year respectively (Kato et al., 1996), which agree with the velocity estimated above. These results indicate that Okinotorishima Island has been moving with constant velocity and direction since 1992.

The value of GLOBK chi square is useful for evaluating the solution. As shown in Table 2, the values increased after 2011. This seems to suggest that the velocity of TSKB as a reference point has been changed by the after slip of the 2011 earthquake off the Pacific coast of Tohoku.

As mentioned in the previous section, GSI provides daily site coordinates of all GEONET stations calculated by Bernese 5.0 as "F3" solutions. In this calculation the positions of all stations are determined by baseline analysis from one reference station referred to the coordinates of VLBI (Hatanaka et al., 2003; Nakagawa et al., 2009). Fig. 5 shows the time series of the daily positions of Okinotorishima Island from GEONET F3 solutions. To compare the result of this analysis with that of GAMIT/GLOBK analysis, we estimated the velocity based on this time series in the same way as above. North and east components of the velocity are +18.5 mm/year (R^2 = 0.983) and -48.9 mm/year (R^2 = 0.994), respectively, and integrated velocity is 52.3 mm/year in the direction of E62°W. This is slightly lower than the velocity estimated from the GAMIT analysis. We consider the difference of these velocities comes from the difference of analysis strategy, such as the selection of reference sites, the number of baselines, distances of baselines, and so on.

5. Maintenance of control points for stable GNSS data collection

Lack of daily site coordinates of GEONET stations occasionally occurs due to observation failures. The station of Okinotorishima Island, in particular, shows a lower data collection rate than other stations because of its severe environment. This island is directly affected by weather and it is impossible to visit the island immediately in response to the station’s problems. Fig. 6 describes the data collection rate of Okinotorishima Island. The average rate is 75.0% during the period from 2005 to 2013. In comparison with the average rate of all GEONET stations

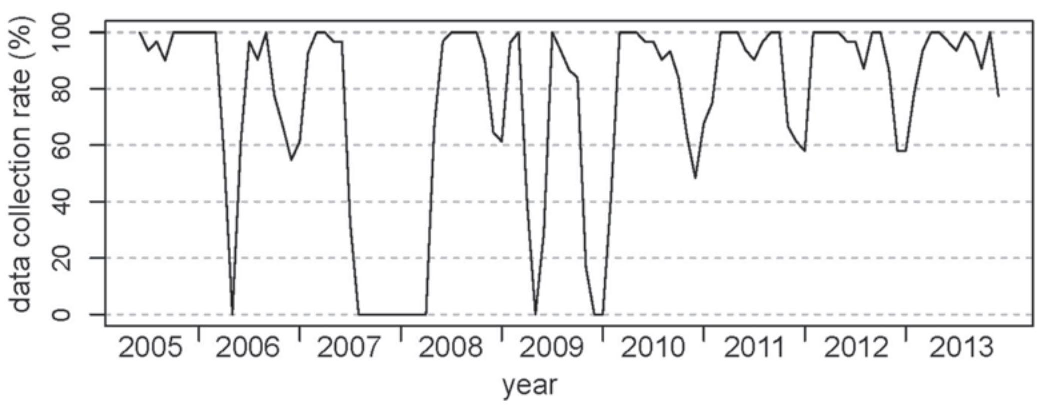

Fig. 6 Data collection rate of GEONET station at Okinotorishima Island. Rate is calculated for each month

of 99.6%, that of Okinotorishima Island is extremely low.

The lack of data caused by observation failures occurs frequently between November and March each year which seems to be because the power supply from the solar cell does not work due to the reduced duration of sunshine. Observation failure, however, can be induced not only by the shortage of sunshine but also by breakdown of the receiver due to typhoons, internal battery degradation, and so on.

GSI visits the Okinotorishima station every year for maintenance of the GEONET station, which was mainly a replacement of observation devices. In 2010, we replaced the solar cell and internal battery, and as a result, the data collection rate increased (Fig. 6). In order to realize more stable GNSS data collection, we will conduct further improvements of power supply system and communication system as well as an update to a GNSS receiver in 2014.

6. Summary

Monitoring of geodetic location of Okinotorishima Island is very important for demarcating EEZ and understanding the movement of the Philippine Sea plate. Thus, GSI installed triangulation points and a GEONET station in 1989 and 2005, respectively. Time series data of the coordinates of these control points indicates that the island has been moving west-northwesterly with approximately 6 cm/year. Based on the experience and the result described above, GSI will continue GNSS data collection as well as regularly maintain the control stations on Okinotorishima Island.

Acknowledgements

Figures were drawn using GMT software (Wessel and Smith, 1998) and R software (R Core Team, 2014).

References

Aiba, M. Hamazaki, H (2002): Displacement of the Okinotorishima Island From February, 1999 to February, 2002, Journal of Geospatial Information Authority of Japan, 99, 21-25. (in Japanese)

Government of Japan (2013): Basic Plan on Ocean Policy

Hatanaka, Y. Iizuka, T. Sawada, M. Yamagiwa, A. Kikuta, Y. (2003): Improvement of the Analysis Strategy of GEONET, Bulletin of the Geospatial Information Authority of Japan, 49, 11-37.

Kato, T. Kotake, Y. Chachin, T. Iimura, Y. Miyazaki, S. Kanazawa, T. Suyehiro, K. (1996): An Estimate of the Philippine Sea Plate Motion Derived from the Global Positioning System Observation at Okino Torishima, Japan, Journal of the Geodetic Society of Japan, 42, 233-243.

Nakagawa, H. Toyofuku, T. Kotani, K. Miyahara, B. Iwashita, C. Kawamoto, S. Yutsudo, T. Ishikura, N. Sugawara, Y. (2009): Development and Validation of GEONET New Analysis Strategy (Version 4), Journal of Geospatial Information Authority of Japan, 118, 1-8. (in Japanese)

R Core Team (2014): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/ (accessed 18 Jun. 2014).

Takahashi, S. (2010): Result of GPS observation of Okinotorishima island in 2008, Technical Report of Geospatial Information Authority of Japan in 2009 (not published)

Tobita, M. (2002): Coordinate transformation and the World Geodetic System, Japan Association of Surveyors.

Tsuji, H. Miyagawa, K. Yamaguchi, K. Yahagi, T. Oshima, K. Yamao, H. Furuya, T. (2013): Modernization of GEONET from GPS to GNSS, Bulletin of the Geospatial Information Authority of Japan, 61, 9-20.

Wessel, P. and Smith, W.H.F. (1998): New, Improved Version of the Generic Mapping Tools Released, EOS Trans. AGU, 79, 579.