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III. GEODETIC RESULTS OF THE EXPERIMENTS

III.1 MOVEMENT OF THE MINAMITORISHIMA STATION

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ABSTRACT

The motion of the Minamitorishima Very Long Baseline Interferometry station has been measured over the last five years in Western Pacific VLBI Network experiments. The results of 16 independent experiments indicated its steady motion of the station in the horizontal projection plane. The estimated velocity was 70.9 ± 3.0 mm/year toward N71.2 ± 2.2° W in the latest IERS Terrestrial Reference Frame, ITRF93. The high reliability and quality of the data obtained in the Western Pacific VLBI Network experiments was demonstrated by the estimated horizontal movement of the station being consistent with a constant-velocity linear motion.

1. Introduction

Minamitorishima island, lying in the Pacific Ocean at latitude 24°17′ N and longitude 153°59′ E, gives us a unique opportunity to study the behavior of the Pacific Plate because there are no other precise geodetic measurement sites in the northwestern region of the plate. A Very Long Baseline Interferometry (VLBI) station was established near the northern edge of the island in 1989 as one node of the Western Pacific VLBI Network (WPVN). Four nodes of this network—Minamitorishima, Kashima, Seshan, and Minamidaito—are shown in Fig. 1. Kashima and Seshan were already performing geodetic VLBI at the beginning of WPVN project, and the other two sites were chosen so that each node of the network is on a different plate. The Minamitorishima station is located far from the nearest plate boundary (≈800 km from that between Pacific Plate and the Philippine Sea Plate) and is thought to be out of the active deformation zone(1). The site velocity of the Minamitorishima station is thus considered to represent the motion of the Pacific Plate. Although there are many space geodetic stations on the Pacific Plate as shown in Fig. 2, many of them are located very close to the Pacific Plate-North American Plate boundary along the west coast of the United States. The plate boundaries in Fig. 2 are shown as narrow lines and some might argue about the location of these boundaries around Japan. As discussed by Gordon and Stein(1), however, plate boundaries are better described as variously wide zones of active deformation. Vandenberg and Fort Ord VLBI stations have been used in previous studies of the Pacific plate motion(2)-(6) under the assumption that these sites are on the stable interior of the Pacific Plate, but whether or not they are out of any active

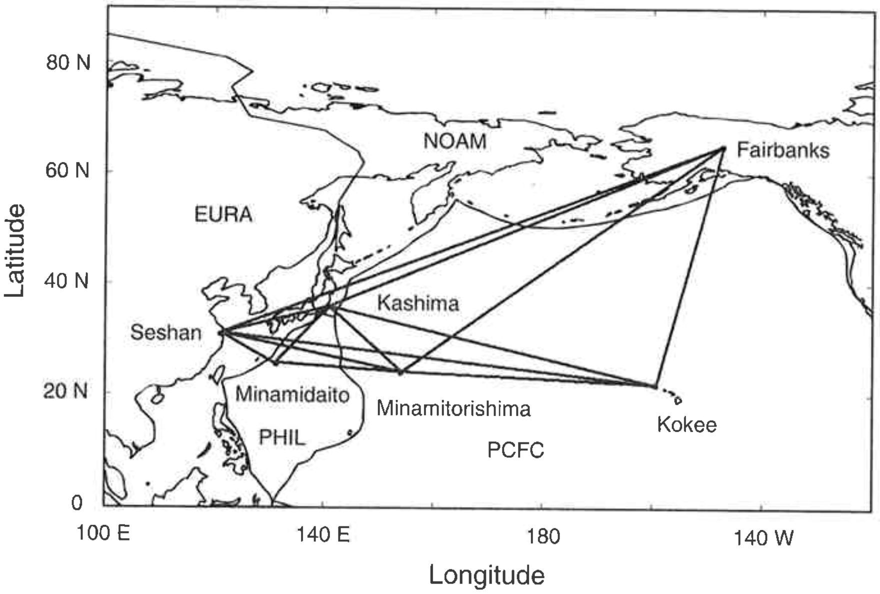

Fig. 1 Configuration of the Western Pacific VLBI network. Locations of Fairbanks station (Gilmore Creek Geophysical Observatory, Alaska) and Kokee station (Kokee Park Geophysical Observatory, Hawaii) are also shown. Lines indicating boundaries between the Eurasian Plate (EURA), the North American Plate (NOAM), the Philippine Sea Plate (PHIL), and the Pacific Plate (PCFC) are also shown.

deformation zone is not obvious. If these two stations are excluded, there were only two VLBI stations (Kauai and Kwajalein) and two SLR stations (Maui and Huahine) on the inner stable part of the Pacific Plate before Minamitorishima VLBI station was established. The addition of the site velocity data of the Minamitorishima VLBI station thus contribute a lot to the space geodetical study of Pacific Plate motion.

Since the first VLBI observations at Minamitorishima in July 1989, there has been 16 VLBI experiments involving the station (Table 1). Takahashi et al.(7) reported the first result of Minamitorishima VLBI station's site coordinate determined from two experiments in 1989, and a year later Koyama reported results of data analysis on two experiments in 1990(8). Site velocity of the station estimated from all the 16 VLBI experiments was reported by Koyama et al(9), and the present paper reports the results of analyzing the same data set using the *a priori* parameters which became available in the annual report of International Earth Rotation Service (IERS)(10) and in the report of ITRF93(11).

2. Experiments

Nearly all the experiments performed at the Minamitorishima station were scheduled, considering the calm weather conditions at the site, for the end of June or beginning of July. The only exceptions were in the first year, when two sessions were performed on 24 July and on 11 August. All of necessary VLBI equipment (including a data acquisition terminal, a control computer and a

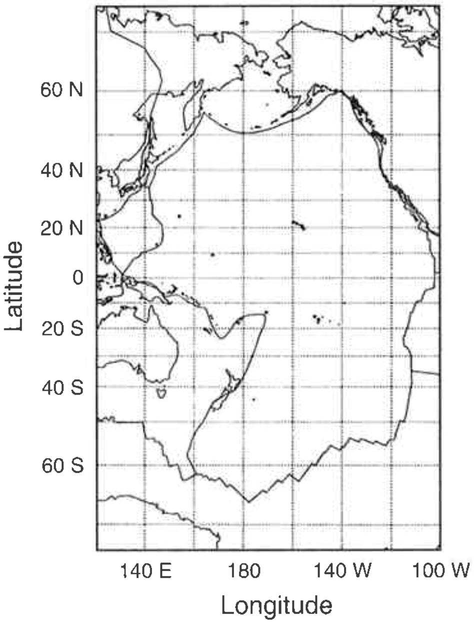

Fig. 2 Space Geodetic observation sites on the Pacific Plate (as specified in the ITRF93 site list).

frequency standard) system was transported to Minamitorishima from CRL before the first experiment each year and was kept on site for about a month. The frequency standard system used at Minamitorishima until 1992 was a hybrid system consisting of a highly stable crystal oscillator and a Cesium beam standard frequency source, whereas a hydrogen maser system was used in the three experiments in 1993. Each year, two experiments were scheduled as regular series with a three-station (Kashima, Seshan, and Minamitorishima) configuration. In 1991, five additional experiments were scheduled with a two-station (Kashima and Minamitorishima) configuration. An experiment with a five-station (Kashima, Seshan, Kokee, Fairbanks, and Minamitorishima) configuration was also organized in 1993. Since the Fairbanks station participated in the first session in 1990, there are two baseline length data for the Fairbanks-Minamitorishima baseline, whereas there is only one baseline length datum for the Kokee-Minamitorishima baseline.

Observation schedules for WPVN experiments were generated at Kashima Space Research Center of CRL, using the software SKED developed by Goddard Space Flight Center (GSFC) of the National Aeronautics and Space Agency (NASA). For experiments held in 1989–1992, the observation scan length was kept short (ranging from 150 to 196 seconds) because the frequency of the Crystal-Cesium system does not remain sufficiently stable during longer integration times. Because of this restriction, only strong radio sources were chosen. For the experiments in 1993, each observation scan length was determined to satisfy a certain signal-to-noise ratio, 20 for the X band and 15 for the S band calculated from the given flux densities of radio sources. This became possible in 1993 when a Hydrogen maser frequency standard system was transported to the station. In addition, SKED was revised by GSFC to generate schedule files automatically by optimizing the estimation of desired parameters. For the experiments in 1993, we used this function to optimize the observation schedules to minimize the estimation errors for Minamitorishima site position.

Table 1 VLBI sessions for the Minamitorishima station

Date	Stations
1989.7.24	Kas26[a], Minamitosrishima, Seshan
1989.8.12	Kas26, Minamitorishima, Seshan
1990.6.25	Kas34[b], Kas26, Minamitorishima, Seshan, Fairbanks
1990.6.30	Kas34, Kas26, Minamitorishima, Seshan
1991.6.27	Kas34, Minamitorishima
1991.6.28	Kas34, Minamitorishima
1991.6.30	Kas34, Minamitorishima, Seshan
1991.7.01	Kas34, Minamitorishima
1991.7.02	Kas34, Minamitorishima
1991.7.03	Kas34, Minamitorishima
1991.7.04	Kas34, Minamitorishima, Seshan
1992.6.25	Kas34, Minamitorishima, Seshan
1992.6.28	Kas34, Minamitorishima, Seshan
1993.6.24	Kas34, Minamitorishima, Seshan
1993.6.26	Kas34, Minamitorishima, Seshan
1993.6.28	Kas34, Minamitorishima, Seshan[c], Kokee, Fairbanks

a.) Kas34 = 34 m antenna at Kashima
b.) Kas26 = 26 m antenna at Kashima
c.) A preliminary database without Seshan was used for analysis

Experiments were basically successful but some portions of experiments were lost for various reasons. A special case was that the S band phase-cal signal was affected by spurious radiation from the receiving system. This prevented S band data gathered in the 1989 experiments from being used for the usual bandwidth synthesis processing. To solve this problem, the phase-cal signal phase in each frequency channel was fixed to its average value. This procedure successfully removed the effect of ionospheric delay from the data which are otherwise not as accurate as the data gathered in the following years.

3. Data Analysis

Data were analyzed by using the geodetic VLBI analysis software package CALC version 7.6 and SOLVE developed by GSFC(12). Since our primary intention was to estimate the site velocity of Minamitorishima VLBI station, we specified as many *a priori* parameters as possible: Earth rotation parameters (position of Earth's rotation pole with respect to a conventional pole, UT1-UTC, and an offset of celestial pole from the conventional celestial pole defined by the 1980 IAU Theory of Nutation), radio source coordinates, and site coordinates of three VLBI stations (Kashima, Seshan, and Fairbanks). This strategy is not common in usual geodetic VLBI data analysis where these values (except for a minimum set of defined parameters to resolve an arbitrariness) are also subject of estimation in the data analysis. In our case, however, considering the limited number of experiments performed at the Minamitorishima station and its poor sensitivity compared to that of the other stations, it does not seem worthwhile to follow the way of usual data analysis. This poor sensitivity

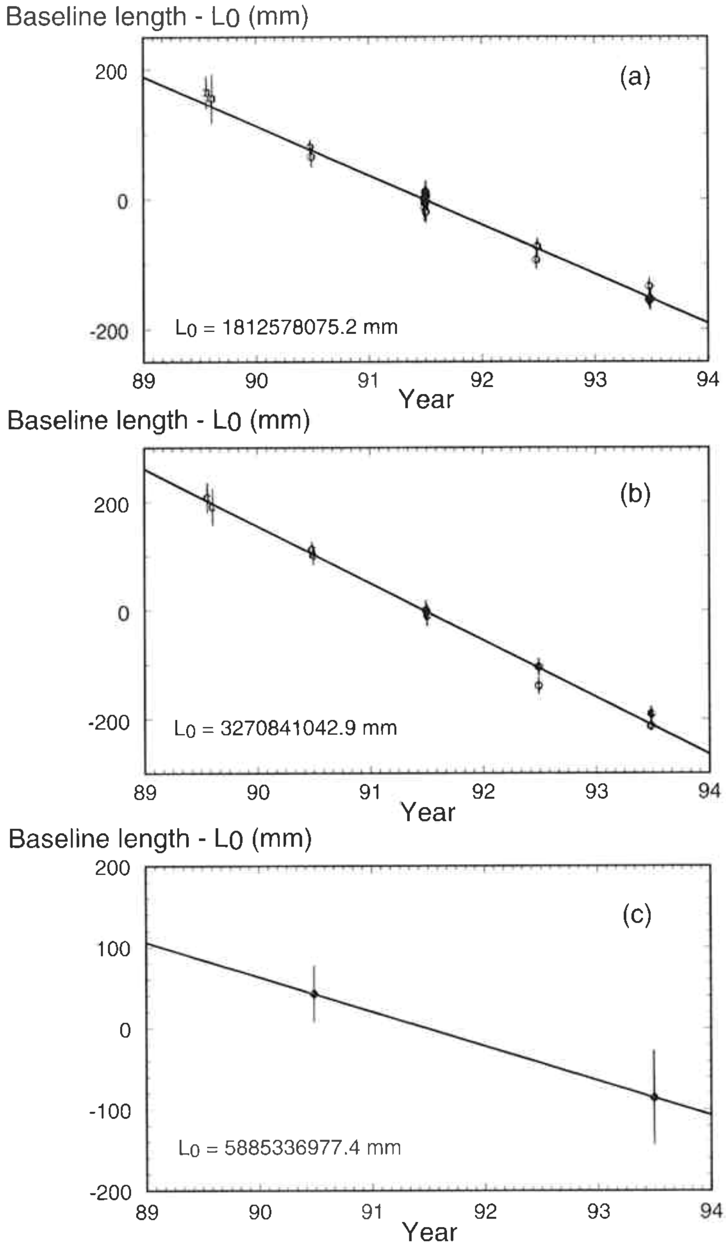

Fig. 3 Baseline length plots from WPVN experiments. Each point is plotted with 1 σ error bar. Straight lines are results of least-squares estimations by assuming a constant change of each baseline length. Two open squares in the Kas34-Minamitorishima baseline plot indicate these data were actually calculated from Kas26-Minamitorishima baseline lengths.

Table 2 Site coordinates of Minamitorishima VLBI station estimated from 16 VLBI experiments. Uncertainties are expressed by one standard deviations scaled by the square roots of the reduced chi-squares.

Date	Site coordinates (mm)			Correlation factors		
	x	y	z	x-y	x-z	y-z
1989.7.24	−5227446754.4 ±75.6	2551379274.6 ±51.1	2607604788.5 ±55.8	−0.86	−0.86	0.88
1989.8.12	−5227446632.0 ±104.0	2551379177.6 ±76.9	2607604730.7 ±83.4	−0.90	−0.86	0.94
1990.6.25	−5227446733.7 ±31.1	2551379326.6 ±15.9	2607604847.2 ±21.2	−0.79	−0.80	0.69
1990.6.30	−5227446729.3 ±39.3	2551379333.7 ±23.4	2607604861.4 ±27.4	−0.78	−0.79	0.79
1991.6.27	−5227446668.9 ±37.5	2551379375.5 ±26.8	2607604850.2 ±30.7	−0.79	−0.83	0.88
1991.6.28	−5227446763.0 ±50.2	2551379456.0 ±35.0	2607604919.8 ±39.6	−0.77	−0.81	0.87
1991.6.30	−5227446651.6 ±40.4	2551379350.4 ±23.9	2607604849.8 ±27.1	−0.75	−0.79	0.77
1991.7.01	−5227446664.0 ±40.7	2551379391.8 ±29.4	2607604841.7 ±33.4	−0.78	−0.80	0.87
1991.7.02	−5227446631.3 ±38.7	2551379361.7 ±29.1	2607604799.2 ±33.0	−0.80	−0.81	0.89
1991.7.03	−5227446693.5 ±35.2	2551379403.0 ±25.2	2607604891.3 ±28.9	−0.78	−0.80	0.87
1991.7.04	−5227446682.0 ±46.0	2551379400.7 ±28.5	2607604838.6 ±30.4	−0.79	−0.79	0.79
1992.6.25	−5227446614.5 ±38.5	2551379459.9 ±23.1	2607604863.7 ±25.7	−0.80	−0.81	0.81
1992.6.28	−5227446698.8 ±36.7	2551379488.3 ±28.5	2607604905.4 ±18.6	−0.79	−0.82	0.81
1993.6.24	−5227446631.1 ±28.4	2551379517.6 ±18.4	2607604922.7 ±16.8	−0.80	−0.81	0.82
1993.6.26	−5227446626.5 ±32.5	2551379484.3 ±20.3	2607604904.2 ±19.2	−0.79	−0.77	0.77
1993.6.28	−5227446508.0 ±45.0	2551379459.6 ±24.4	2607604821.6 ±31.9	−0.73	−0.72	0.40

comes partly from the relatively small aperture of the antenna and the limited integration time (~180 sec) due to the instability of the composite frequency standard system used from 1989 through 1992. This instability also requires more estimated clock epochs and causes a larger scatter in the residual of observed time delay. Using a large number of *a priori* parameters, on the other hand, risks inconsistency between them and the models on which the analysis relies, such as series of precession and nutation values and a model of site displacement due to ocean tides. Since inconsistent *a priori* parameters may produce inadequate results, it is important that their consistency and credibility be maintained over the period of experiments. IERS has been playing a central role in providing such consistent parameters and standard models, but in a sense of uniformity throughout the period of WPVN experiments, truly uniform series of Earth rotation parameters did not become available until

Table 3 Lengths of four baselines towards Minamitorishima station estimated from 16 VLBI experiments. Uncertainties are expressed by one standard deviations scaled by the square roots of the reduced chi-squares.

Date	Minamitorishima-Kas26 (mm)	Minamitorishima-Kas34 (mm)	Minamitorishima-Seshan (mm)	Minamitorishima-Fairbanks (mm)
1989.7.24	1812270600.66 ±25.3		3270841252.1 ±26.8	
1989.8.12	1812270591.23 ±37.6		3270841235.4 ±33.8	
1990.6.25	1812270516.30 ±10.8	1812578156.0 ±10.8	3270841157.3 ±13.2	5885336998.9 ±17.4
1990.6.30	1812270501.68 ±15.4	1812578141.2 ±15.4	3270841146.1 ±17.1	
1991.6.27		1812578076.1 ±15.9		
1991.6.28		1812578064.9 ±21.7		
1991.6.30		1812578078.8 ±15.9	3270841045.0 ±18.2	
1991.7.01		1812578071.3 ±18.3		
1991.7.02		1812578087.4 ±17.5		
1991.7.03		1812578056.3 ±15.7		
1991.7.04		1812578081.8 ±17.6	3270841035.3 ±19.7	
1992.6.25		1812577982.8 ±14.1	3270840906.4 ±16.1	
1992.6.28		1812578002.9 ±13.2	3270840940.8 ±15.4	
1993.6.24		1812577920.3 ±10.4	3270840832.3 ±11.9	
1993.6.26		1812577941.8 ±12.6	3270840854.1 ±14.1	
1993.6.28		1812577922.1 ±16.5		5885336934.8 ±29.0

the recent release of the 1993 Annual Report of IERS(10). We used this data set for *a priori* parameters, and we used the recent realization of standard models provided as IERS standards (1992)(13). Although the ocean tide coefficients for Minamitorishima and Seshan are not available from IERS standards (1992), they were obtained from Scherneck(14) by using the same model as in the IERS standards (1992). ITRF93 is a set of site coordinates and velocities that define a terrestrial reference frame, whereas ICRF93 is a set of radio source coordinates that define a celestial reference frame. ITRF93 was produced by a combination of independent analyses of data from three space geodetic techniques (VLBI, SLR, and GPS). Site coordinates of Kashima, Seshan, and Fairbanks were obtained from ITRF93 throughout the data analysis and only the Minamitorishima and Kauai site velocities were estimated. ICRF93 was also produced by a combination of independent data

Table 4 Lengths of three baselines towards Minamitorishima station and their rates of change. Uncertainties are expressed by the one standard deviations scaled by the square roots of the reduced chi-squares.

Baseline	Baseline length on 1991.5 (mm)	Rate (mm/year)	Reduced χ^2
Kas34-Minamitorishima	1812578075.2 ± 3.0	−75.9 ± 2.4	0.522
Seshan-Minamitorishima	3270841042.9 ± 5.1	−104.9 ± 3.7	0.854
Fairbanks-Minamitorishima	5885336977.4 ± 15.1	−21.3 ± 11.3	...

analyses but only from VLBI. Coordinates of all the radio sources observed in the WPVN experiments were fixed to the values from ICRF93. EOP93C02 is a series of Earth rotation parameters at five-day intervals through the end of 1993. These values, too, were derived from a combination of independent data analyses from three space geodetic techniques consistently with the ITRF93, ICRF93 and the IERS standards (1992). Interpolation of UT1-UTC was performed after removing short-term variation due to the ocean tides by using coefficients defined in IERS92 standards, and the same term was added again after the interpolation. The CALC software, which calculates theoretical time delays and their time derivatives based on *a priori* information and sets up a Jacobian matrix for the least-squares parameter adjustment to be performed by SOLVE, uses IERS standards (1992) and thus maintains the consistency with specified *a priori* parameters.

4. Results

Table 2 gives the three-dimensional site coordinates for Minamitorishima VLBI station at the date of each session obtained after data analyses of 16 individual VLBI experiments. These site coordinates can be treated to be based on the ITRF93 terrestrial reference frame. Uncertainties in the table are one standard deviations scaled by the square root of the chi square estimated through the least-squares analysis. Correlation factors between the three components are also given for each experiment. Table 3 lists the lengths of four baselines towards Minamitorishima VLBI station. Uncertainties are the scaled one sigma standard deviations same as the case for the site coordinate results in Table 2. Values in Table 3 are also plotted in Fig. 3, where three baselines (except for Kas26-Minamitorishima) are shown. Instead, two sets of data for Kas26-Minamitorishima baseline length in 1989 are transferred to Kas34-Minamitorishima length by adding 307.6397 m, which is the difference of lengths between these two baselines according to the ITRF93 coordinates on 1993.0. A least-square estimation was used to obtain an epoch value and a rate of change for each baseline. Table 4 shows these results.

A site coordinate at an arbitrary epoch and a velocity can be estimated by the least-squares criteria. If we assume that the site is moving with a constant velocity, the obtained site position $\mathbf{r}_i$ from i-th VLBI session at the time t_i can be expressed by

$$\mathbf{r}_i = \mathbf{r}_0 + \mathbf{v}(t_i - t_0) + \mathbf{d}_i \qquad (1)$$

where $\mathbf{r}_0$ is the site position at the time epoch t_0 and $\mathbf{v}$ is the site velocity. The term $\mathbf{d}_i$ is a residual of the estimated site position from the $\mathbf{r}_0 + \mathbf{v}(t_i - t_0)$. The error matrix of the $\mathbf{r}_i$ is defined by

$$\Sigma_i = \begin{pmatrix} \sigma_{xi}^2 & \rho_{xyi}\sigma_{xi}\sigma_{yi} & \rho_{xzi}\sigma_{xi}\sigma_{zi} \\ \rho_{xyi}\sigma_{xi}\sigma_{yi} & \sigma_{yi}^2 & \rho_{yzi}\sigma_{yi}\sigma_{zi} \\ \rho_{xzi}\sigma_{xi}\sigma_{zi} & \rho_{yzi}\sigma_{yi}\sigma_{zi} & \sigma_{zi}^2 \end{pmatrix} \quad \text{(2)}$$

where (σ_{xi}, σ_{yi}, σ_{zi}) and (ρ_{xyi}, ρ_{xzi}, ρ_{yzi}) are one standard deviations of site coordinates and correlation factors between site coordinates, respectively, estimated from the data analysis. The estimates of $\mathbf{r}_0$ and $\mathbf{v}$, which we denote $\hat{\mathbf{r}}$ and $\hat{\mathbf{v}}$, are given by minimizing the sum of weighted square of the $\mathbf{d}_i$. Here the weighted squared $\mathbf{d}_i$ is given by $d_i^T\Sigma_i^{-1}\mathbf{d}_i$. The transverse of a matrix, or a vector in this case, is denoted by a superscript ‘T’. The solution is given by

$$\begin{pmatrix} \hat{\mathbf{r}}_0 \\ \hat{\mathbf{v}} \end{pmatrix} = \left(\mathrm{A}^{\mathrm{T}}\mathrm{W}_1\mathrm{A}\right)^{-1}\mathrm{A}^{\mathrm{T}}\mathrm{W}_1\mathrm{R} \quad \text{(3)}$$

where

$$\mathrm{R} = \begin{pmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \vdots \\ \mathbf{r}_n \end{pmatrix} \quad \text{(4)}$$

$$\mathrm{A} = \begin{pmatrix} 1\,0\,0 & t_1 - t_0 & 0 & 0 \\ 0\,1\,0 & 0 & t_1 - t_0 & 0 \\ 0\,0\,1 & 0 & 0 & t_1 - t_0 \\ 1\,0\,0 & t_2 - t_0 & 0 & 0 \\ 0\,1\,0 & 0 & t_2 - t_0 & 0 \\ 0\,0\,1 & 0 & 0 & t_2 - t_0 \\ \vdots & & \vdots & \\ 1\,0\,0 & t_n - t_0 & 0 & 0 \\ 0\,1\,0 & 0 & t_n - t_0 & 0 \\ 0\,0\,1 & 0 & 0 & t_n - t_0 \end{pmatrix} \quad \text{(5)}$$

and

$$\mathrm{W}_1 = \begin{pmatrix} \Sigma_1^{-1} & & & 0 \\ & \Sigma_2^{-1} & & \\ & & \ddots & \\ 0 & & & \Sigma_n^{-1} \end{pmatrix} \quad \text{(6)}$$

Table 5 Minamitorishima site coordinate in the ITRF93 reference frame and in the local NEU coordiante system. The origin of the local reference system is taken to be the 1993.0 site coordinate given in the ITRF93.

[Epoch] Component	Value (mm)	Correlation		Rate (mm/year)	Correlation	
[1991.5]						
x	−5227446679.5 ± 10.3	*x–y*	−0.790	35.9 ± 8.8	*x–y*	−0.802
y	2551379386.5 ± 6.3	*x–z*	−0.799	57.2 ± 5.3	*x–z*	−0.792
z	2607604856.9 ± 7.1	*y–z*	0.811	21.9 ± 5.6	*y–z*	0.780
n	−17.6 ± 3.9	*n–e*	−0.331	22.9 ± 2.9	*n–e*	−0.227
e	91.7 ± 3.6	*n–u*	0.327	−67.1 ± 2.8	*n–u*	0.161
u	−61.9 ± 13.5	*e–u*	−0.181	2.5 ± 11.0	*e–u*	−0.154
[1993.0]						
x	−5227446626.6 ± 13.4	*x–y*	−0.790	35.9 ± 8.8	*x–y*	−0.802
y	2551379473.4 ± 8.3	*x–z*	−0.799	57.2 ± 5.3	*x–z*	−0.792
z	2607604891.3 ± 8.0	*y–z*	0.811	21.9 ± 5.6	*y–z*	0.780
n	19.34 ± 4.2	*n–e*	−0.210	22.9 ± 2.9	*n–e*	−0.227
e	−10.79 ± 4.6	*n–u*	0.051	−67.1 ± 2.8	*n–u*	0.161
u	−51.87 ± 16.5	*e–u*	−0.183	2.5 ± 11.0	*e–u*	−0.154

This procedure was used to estimate the site velocity and site coordinates at two time epochs (1991.5 and 1993.0), and these values are presented in Table 5. The time epoch at 1991.5 gives a minimal uncertainty of $\mathbf{r}_0$ because it is nearly the middle of the period in which the 16 sessions were performed. The estimate at the epoch 1993.0 was also given to follow ITRF93 specification where all the site coordinates are specified at the epoch 1993.0. The site velocity estimate remains unchanged regardless of the selection of t_0. The chi-square (χ^2) of the least-squares fit was calculated as

$$\chi^2 = \mathrm{B}^{\mathrm{T}}\mathrm{W}_{\mathrm{l}}\mathrm{B} \qquad \mathrm{B} = \mathrm{R} - \mathrm{A}\begin{pmatrix}\hat{\mathbf{r}}_0 \\ \hat{\mathbf{v}}\end{pmatrix} \cdots\cdots\cdots\cdots \quad (7)$$

This value is calculated as 50.7 which, divided by the 42 degrees of freedum, gives the reduced chi-square (χ^{-2}) of 1.21. 95% of the reduced chi-square statistically distribute between 0.62 and 1.47 in the case where the degree of freedum is 42. The fact that the reduced chi-square is very close to a unity indicates two things. First, the uncertainties given in Table 2 were adequately evaluated. Second, the assumption that the site is linearly moving with a constant velocity was consistent with the observed time series of site positions. This result is rather exceptional, since there is a tendency in various VLBI data analyses for the reduced chi-square to be significantly greater than unity and for the uncertainties obtained to be underestimated. One possible explanation of the large reduced chi-square is an annual fluctuation of site coordinate estimates as a result of unmodeled seasonal variation, such as a tropospheric delay. Such an annual fluctuation, would cause systematic but similar errors in the 16 site coordinate estimates and thus the estimated site velocity would not be affected because all the VLBI sessions for Minamitorishima were done in the same season of a year.

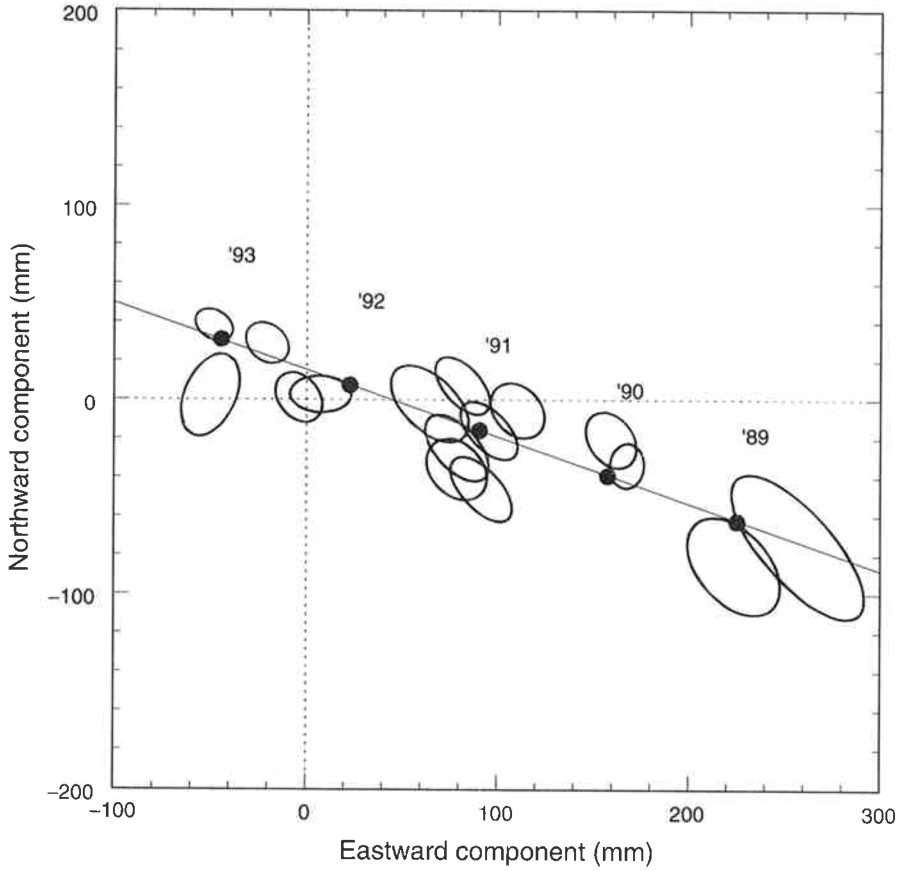

Fig. 4 Estimated Minamitorishima site position projected on to the horizontal plane with the origin of the 1993.0 position of the Minamitorishima site according to ITRF93. Each point is plotted with 1 σ error ellipse. Straight line and five dots on the line indicate linear motion of the site and site positions on 1989.5, 1990.5, 1991.5, 1992.5, and 1993.5 calculated from the least-squares estimation.

Table 5 also gives the same site velocity expressed in the local coordinate system defined by east, north, and vertically upward directions. According to these results, the horizontal movement of the Minamitorishima station is 70.9 ± 3.0 mm/year toward N71.2 ± 2.2° W. The estimated site positions of Minamitorishima VLBI station listed in Table 2 are shown in Fig. 4 projected on the horizontal plate. The estimated epoch positions and velocities in the local coordinate system listed in Table 5 are expressed in Fig. 4 by a gray line with five dots on the line indicating the epoch positions of the site on 1989.5, 1990.5, 1991.5, 1992.5, and 1993.5.

5. Conclusions

The movement of the Minamitorishima station is evident in both the baseline length data and station positions projected on the horizontal plane. On the other hand, vertical movement was not evident given under our limit of vertical position uncertainties. As shown in Fig. 3, the lengths of Kas34-Minamitorishima and Seshan-Minamitorishima baselines are well represented by linear functions of time. These data are consistent with the station moving horizontally with a constant velocity. The results also demonstrated the high reliability and quality of the data obtained from WPVN experiments. Values of reduced χ^2 in Table 4 can be used to evaluate the quality of the least-squares estimate and are very close to and even smaller (better) than unity. This suggests that the assumption that the Minamitorishima station is moving linearly with a constant velocity is correct (within the present uncertainties of estimates), and that the estimated uncertainties of data are consistent with the repeatability of measurements.

Residual RMS values can be considered to represent the repeatability of the obtained data, and these values indicate that horizontal components of the Minamitorishima station position and baseline lengths were determined with an uncertainty of 4 mm, whereas the vertical component was determined with an uncertainty of 13 mm. It is also seen that data from experiments in 1989 are not as good as the other years. This is thought to be an effect of the problem in S band interference signal that year.

6. Acknowledgements

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