B-10 Clarification of Effects of Sea Level Rise Caused by Global Warming

(2)Absolute Sea Level Monitoring by Space Geodetic Techniques

2 Measurements of the Movements of Tide Gauge using Mobile VLBI Station

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Total Budget for FY1993-FY1995 8,983,000 yen (FY1995; 3,325,000 yen)

Key Words VLBI, Sea Level Change, Tidal Gauge Data, Reference points, Earth Warming

abstract

The measurements of the sea level change is important in order to cope with global warming and to predict the future sea level. The sea level change can be obtained by the tidal data. However, the tidal data includes the position of tidal station, and the pseudo sea level change is caused by the change in the position of the tidal gauge station. So the movement of the tide gauge station should correct the tidal data. We developed the mobile VLBI(Very Long Baseline Interferometry) system due to measure the movement of tidal station till FY1992. The mobile VLBI station measures the reference position in some districts, and GPS(Global Positioning System) is used to measure between the reference position and tide gauge station. We conducted the VLBI experiment between Kashima and Kanozan in FY1993 and FY1994. Kanozan is a important point for the geodetic coordinate in Japan. The precision of the Kanozan positions were about 1cm for X,Y,Z components, and 5mm for the baseline length. The new reference point at Tonami in Toyama was measured. CRL supports the mobile VLBI experiments conducted by GSI, and we are charged in 34m antenna. As concerning that this project is to establish the reference frame for sea level monitoring system, we presented the table of the station positions to be observed by GSI in cooperation with CRL using mobile VLBI systems.

1 Introduction

A rise in sea level by the Earth warming can be a severe problem to the human life, causing lowlands to flood, islands to disappear, and in general causing much damage, especially in central Asia. Specific information on the rate of rise in sea level is not extensive near Japan. Close monitoring, analysis and forecast of changes in sea level are indispensable for the future proceeding plan and warning. Barnett presented the mean rising rate of 2-3 mm/year for past 30 years (1). Recently, the altimeter measurement from satellite obtained the global sea information. Especially, TOPEX/POSEIDON satellite revealed the remarkable results in sea study to measure the sea temperature in high precision and the sea level change in global. In the presentations at AGU fall meeting in 1995, the global sea level is 4-6mm/year in 1993 using the data of TOPEX/POSIDON. The seal level change depended on the analysis. It is not clear to increase the rate of sea level change yet. Furthermore, there are regional differences in the sea level change (1). The change in sea level depends on the change in weather, local condition, tidal current , seasonal change in a complex fashion. It is important to distinguish global and local sea level change. The satellite data is useful for the global information, but the life period of satellite is not long and the cost is huge. We need the sea level change in long period since there is a annual variation and the variation of sea level change is desired. The tidal auge data is useful for the long period observation over 10 years, and it becomes the calibration data of altimeter to combine the data of different satellites. The reliability of tidal gauge data is also good for a long period.

The tidal gauge data includes not only actual change in sea level, but also the deformation of the earth and crustal deformation of each station. If the tidal gauge station rises up, the sea level appears to go down. Therefore, the movement of tidal gauge station is corrected for the tidal gauge data. Especially, in Japanese archipelago the crustal deformation was large, and it is important to correct the movements of tidal gauge stations in Japan.

2 Sea level monitoring system

The sea level change should monitor for a long period. The tidal gauge data is suitable to obtain the data for a long period regularly. The crustal deformation of each station should be corrected, and it is necessary to establish the reference point for the sea level monitoring. The reference point is connected with the international reference frame. New geodetic space techniques such as VLBI (Very Long Baseline Interferometry), SLR (satellite Laser Ranging) and GPS (Global Positioning System) are available to measure positions with high precision within 10 cm. The precision of VLBI is the best among these techniques, and it does not depend on baseline length. In VLBI, the radio sources far away from the Earth, such as quasers, are observed, and it is superior to keep the reference for a long period since the source in the long distance is immovable. As VLBI is the most desirable for measuring on baselines greater than 500 km, a few reference points in Japan was established by VLBI. The movement of each tidal gauge station against the VLBI reference point was measured by GPS on the short baseline. We adopted the international terrestrial reference frame (ITRF) of the results in 1993 by the International Earth Rotation Service (IERS) . It is a global geocentric coordinate system. Therefore the tidal gauge station is connected against the geocenter, and we can obtain the absolute sea level which includes the effect of earth deformation.

We had developed the mobile VLBI station for measuring the positions of the tide gauge stations since 1990 to 1992 together with GSI on the base of the budget of Earth Environment study of the Environment Agency. The antenna diameter of this antenna is 2.4m. This system has also K4 compact VLBI terminal developed by CRL and a compact hydrogen maser system for keeping a time. Therefore, it is smallest VLBI station in the world. The system has not the receivers of dual bands for S and X, but only for X band. The ionosphere correction was estimated as the adjustment of atmospheric delay correction since the elevation dependency is similar. The ionosphere measure equipment by GPS is useful for the correction of the ionospheric delay when the single band observation.

The first experiment using this system was conducted at 1992 on the 55km baseline between Kashima and Tsukuba. The precision of the position is 5mm for horizontal component and 2cm for vertical component. It means that 2.4m smallest antenna is available for precise VLBI observations.

4 Result in FY1993

We conducted first mobile experiment using 2.4m antenna system on the baseline between Kashima 34m antenna and Kanozan station on 27th July 1993. Kanozan is one of the reference points for the official coordinate system in Japan (figure-1). The experiment was for 24 hours, and 15 radio sources were observed. The number of observations was 298, and the available data in the baseline analysis was 202. The r.m.s. of the residual delays after the baseline analysis was 0.12ns (3.5cm) which was similar to results in standard VLBI experiments, and there was no systematic trend. Table 1 shows the results of this experiment. The reference frame is the ITRF in 1993 (ITRF93)(2). The precision was 5mm for horizontal component and the baseline length. The precision for vertical component was 2cm.

5 Results in FY1994

We conducted the mobile experiments with Kanozan station again on 17th and 19th January 1995. Table 1 shows the results together with the results in FY1993. The repeatability was 1-2 cm for the horizontal component and 4cm for the vertical component that is twice of precision.

The deformation at Kanozan station was presented. ITRF reference frame is defined to be no-net-rotation model that the total rotation velocity of the surface on the Earth is zero. The plate motion was adopted NUVEL1-A model (3). ITRF coordinate system was used in the worldwide for VLBI, SLR and GPS. All plate was moved in the velocity fields of ITRF93, and the Kashima and Konozan station moved to south direction in ITRF93. This movements was not actual. The known movement of the plate motion against the ITRF93 velocity fields is removed at each station. The residual movement was the deformation or the unknown plate motion, We assumed that Kashima and Kanozan stations are on the North American plate. Table 2 shows the movements of Kanozan station against the North American Plate as to be the reference of the results in 1993. The difference of the movements was about 1.9±0.3cm for west movement, 1.5±1.8cm for north movement and 2.5±3.5cm for down movement during half and one year. The values were reasonable.

The four mobile experiments with Tonami station in Toyama prefecture were conducted on November in 1994. There was no VLBI points in the north area of middle Japan until this experiment. The result of the first experiment was shown in Table 3. The precision was similar to other results.

6 Results in FY1995

We cooperated to make the manual for the sea level monitoring which is responsible for GSI. We investigated the connection of the tidal gauge station with VLBI reference point in USA. Furthermore, we attended to the international meeting of Asian Pacific Telescope (APT) and of American Geophysical Union (AGU) to present the importance of sea level monitoring system in Asia and to know the recent study of sea level monitoring.

As concerning that this study is to establish the reference points for the sea level monitoring, we presented the VLBI station positions where the domestic VLBI experiments were conducted till 1995. We made baseline analyses for 55 domestic VLBI experiments in ITRF93, using the model of CALC version 8 and the international celestial reference frame of IERS in 1993 and final values of Earth Rotation information of IERS in 1993. The atmospheric adjustments was carried every 6 hours on the short baseline and every 4 hours on the long baseline. It was not in both sites, but in one site. The clock changes were estimated by the judgment of analyst. As the some experiments were conducted at single band (X band), the standard results was obtained without ionospheric correction. Table 4 shows the results of the antenna position as XYZ components. Only for Kanozan station, the position was the reference point on the surface since the antenna position was different after it transferred. The results with ionospheric correction were shown in Table 5. Table 6 shows the measurement precision for horizontal and vertical components.

The error of the movement are estimated. We assumed that we conduct n of 24hours experiments at once. The set repeats N times in the interval ΔT of each experiment. T is the period of whole experiments ($\Delta T(N-1)=T$). σ is the error of observation data. The rate error of the movements is as follows;

$$\sigma / T / \sqrt{(n \cdot N)} \cdot \sqrt{\{12(1-1/N) / (1+1/N)\}} .$$

If N is extremely greater than 1, the rate became 3.5・(error)/(period of whole experiments)/$\sqrt{}$ (number of data). The rate error is 1.4mm/year when 4 experiments were conducted every 5 years for 10 years as the assumption of 2cm for the vertical precision. In GPS, the rate error becomes 1mm/year for 4 years when observation were conducted every day even if the vertical percussion is 5cm. However, it is not clear whether GPS can keep the reference frame over a few years. VLBI can keep the reference over 10 years. Therefore, it is necessary to observe the positions in both methods.

7 Conclude

We developed the smallest VLBI station in the world for the sea level monitoring. We conducted the mobile experiments with Kanozan station using this system. Kanozan station is the important for the official coordinate system in Japan as the reference of the direction. We conducted the experiments with Tonami station. It is the first VLBI station in the north area of middle Japan. We succeeded the precise measurement of the position. Furthermore, we had many domestic VLBI experiments using mobile VLBI stations, such as this system. The main purpose of our research is to establish the reference points for the sea level monitoring. We presented the positions of VLBI stations where the domestic VLBI experiments were conducted since 1984 to 1994. These data will be useful for the initial data to keep the reference positions in future. We will continue the sea level monitoring in cooperation with GSI.

References

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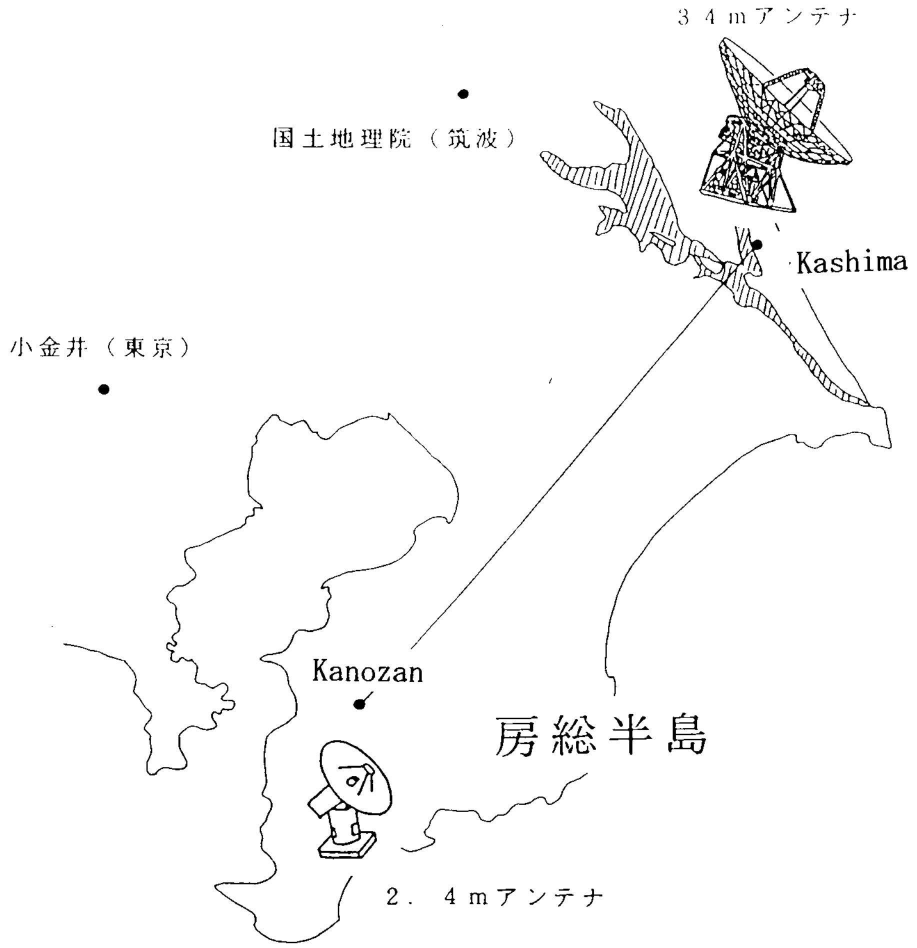

Figure 1 Kashima and Kanozan station

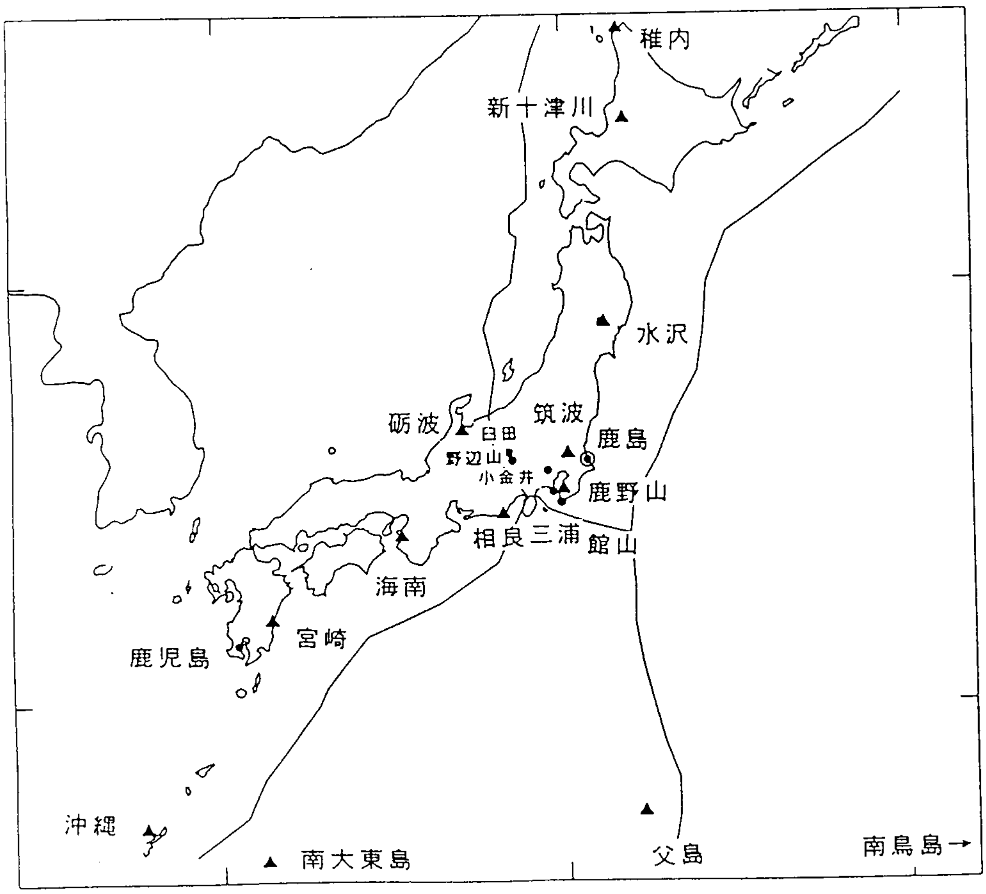

Figure 2 VLBI stations by domestic VLBI experiment in Japan

Table 1 Position of Kanozan station and estimated error in ITRF93

	1993.7.27	1995.1.17	1995.1.19
Position of Kanozan			
(Antenna position)			
X -3991747.0m	-0.425±0.014m	-0.465±0.017m	-0.505±0.016m
Y 3355061.0m	0.786±0.013m	0.806±0.016m	0.845±0.014m
Z 3661225.0m	0.309±0.013m	0.354±0.028m	0.361±0.015m
(reference point)			
X -3991745.0m	-0.806±0.014m	-0.781±0.017m	-0.821±0.016m
Y 3355060.0m	0.416±0.013m	0.385±0.016m	0.424±0.014m
Z 3661225.0m	0.814±0.013m	0.785±0.028m	0.790±0.015m
East movement *1	0.0 ±0.005m	0.007±0.005m	0.003±0.006m
North movement *1	0.0 ±0.006m	-0.004±0.008m	-0.030±0.008m
Vertical movement*1	0.0 ±0.022m	-0.050±0.028m	0.000±0.025m
Baseline between			
Kashima-Kanouzan			
Baseline vector			
X 5901.0m	0.819±0.014m	0.791±0.017m	0.751±0.016m
Y 78371.0m	0.014±0.013m	0.031±0.016m	0.070±0.014m
Z -63053.0m	-0.552±0.013m	-0.484±0.028m	-0.477±0.014m
Length 100760.0m	0.092±0.005m	0.069±0.007m	0.092±0.007m
Kashima 34m antenna			
X	-3997649.244m	-3997649.256m	-3997649.256m
Y	3276690.772m	3276690.775m	3276690.775m
Z	3724278.861m	3724278.837m	3724278.837m

*1 the east, north, vertical movements against the observed position in 27th July in 1993

Table 2 Movements of Kanozan station against the observed position for the noth american plate.

	1993.7実験	1995.1.17実験	1995.1.19実験
East movement	0.0 ±0.005m	-0.017±0.005m	-0.021±0.006m
North Movement	0.0 ±0.006m	0.028±0.008m	0.002±0.008m
Vertical movement	0.0 ±0.022m	-0.050±0.028m	0.000±0.025m

Table 3 Positions of Tonami station in Toyama in ITRF93

	Tonami Position	Baseline between Tonami and Kashima
X	-374898570.62±1.14cm	24866354.82cm
Y	349187590.01±1.11cm	21518512.59cm
Z	378642369.88±1.19cm	6214485.88cm
Length		33466428.27cm±0.30cm
East	±０．２７ｃｍ	
North	±０．３６ｃｍ	
Vertical	±１．９４ｃｍ	

Table 4 Observed Positions by Domestic VLBI experiments in ITRF93 (the results without ion correction)

Station name Year.Mon.Day	X (mm)	Y (mm)	Z (mm)
Tsukuba5m			
1985. 8. 9	-3957172849.6±22.0	3310237961.0±21.2	3737709079.7±23.5
1986. 2.17	876.7±14.7	970.5±13.3	9093.3±15.0
1987. 2.23	894.8± 8.0	973.1± 6.6	9087.7± 7.6
1988. 2. 9	847.2±16.1	942.5±13.5	9022.7±16.8
1988. 8.25	819.3±17.9	935.2±15.5	9004.9±18.3
1989. 2.22	922.4±18.0	988.1±15.1	9073.1±17.0
1989. 9.29	860.0±17.9	928.2±15.4	8984.3±17.1
1990. 3. 1	903.2±14.1	973.8±11.8	9028.7±13.9
1991. 3.26	902.9± 9.0	970.0± 7.9	8999.3± 9.4
1991. 5.21	887.4±11.9	967.5± 9.9	8983.3±11.9
1991. 7.31	856.6±13.2	943.6±11.8	8962.9±14.3
1992. 3.19	912.6±11.9	957.3±10.2	8990.5±11.3
1992. 5.14	947.2±11.8	991.5±10.5	9001.3±11.6
1993. 8.24	922.5±17.9	960.0±15.4	8980.4±16.9
Tsukuba2.4m			
1992.10.15	-3957200592.1±21.5	3310182924.1±18.4	3737735060.8±22.5
Sintomi			
1986.10.14	-3582767638.8±17.4	4052033995.1±19.6	3369020559.2±18.8
1986.10.20	696.3±16.8	4017.6±19.5	608.3±16.3
1988.10. 6	721.5±31.6	4146.0±36.0	598.0±32.1
1988.10.12	791.8±31.6	4122.2±36.8	671.1±31.6
1993.11.16	866.9±18.5	4026.1±21.9	523.5±18.2
Titijima			
1987.11.18	-4489356825.6±37.4	3482989616.3±28.8	2887931274.0±25.9
1987.11.25	735.4±33.6	549.6±26.8	255.1±23.4
1989.11.28	698.1±46.2	580.1±37.8	191.0±34.3
1989.12. 6	721.6±45.2	607.9±36.0	308.6±31.1
Shintotugawa			
1990. 7.23	-3642141770.8±44.5	2861496450.7±35.3	4370361876.5±52.8
1990. 7.26	536.1±42.8	307.7±34.6	646.7±54.0
1990. 7.28	656.0±31.6	434.9±24.9	734.3±37.6
1990. 7.30	792.4±38.1	527.8±31.3	815.5±44.2
Mizusawa-GSI			
1991. 9.18	-3862411887.2±14.7	3105015008.2±12.9	4001944966.7±16.8
1991. 9.20	891.9±13.4	010.0±11.3	951.2±15.3
1991.10.18	841.6±11.8	000.7± 9.9	856.4±13.7
1991.10.20	887.7±12.6	016.1±10.8	946.1±15.2
1991.11.24	905.2±33.4	060.5±24.8	879.6±29.4
1991.11.26	896.5±13.0	017.5±11.0	931.2±15.0
Kainan			
1993. 9.28	-3751042933.0±29.4	3721054960.4±28.5	3560819201.9±27.5

Table 4 Observed Positions by Domestic VLBI experiments in ITRF93 (Continued)

Station name Year.Mon.Day	X (mm)	Y (mm)	Z (mm)
Sagara			
1992.11.23	-3913437727.2±16.4	3501122822.8±14.5	3608593538.3±17.5
1992.11.24	706.2±17.9	823.5±16.1	524.1±18.4
1992.12. 1	814.6±17.8	871.9±16.0	618.1±18.3
1992.12. 2	782.1±11.4	859.1±10.1	560.8±11.8
1993. 2.28	750.0±12.6	839.9±11.5	556.5±13.5
1993. 3. 1	788.8±11.2	865.7±10.2	579.0±11.7
Kanozan*1			
1993. 7.27	-3991745805.6±14.2	3355060415.7±12.5	3661223814.4±13.3
1995. 1.17	780.9±17.3	385.2±15.9	782.7±17.7
1995. 1.19	820.6±16.4	423.8±14.4	789.8±15.0
Tonami			
1994.11.15	-3748985706.2±11.4	3491875900.1±11.1	3786423698.8±11.9
Koganei3m			
1988. 9.19	-3942077364.1±19.6	3368332170.8±15.5	3701904929.1±17.2
1992. 3.19	360.2±12.3	141.3±10.9	860.7±11.7
1992. 5.14	415.9±21.8	171.7±19.3	891.1±20.6
1992.10.15	341.8±26.5	113.0±23.0	824.1±27.3
1992.11.26	327.7±33.4	074.6±28.3	796.5±31.7
1993. 8.24	344.3±24.9	142.4±20.4	835.6±24.8
1995. 1.17	382.2±23.0	109.8±20.0	811.8±20.0
1995. 1.19	382.5±10.1	111.4± 9.1	805.0± 9.0
Wakkanai-CRL			
1988.10. 5	-3520056214.5±87.8	2781823257.2±68.2	4518214800.6±106.2
Okinawa-CRL			
1989. 2. 3	-3507775541.5±59.7	4521403154.5±67.9	2807535178.4±51.3
1990.10.22	508.9±44.2	067.3±49.4	113.3±38.2
Minami-Daito			
1990.11.26	-3786460616.9±33.6	4320155895.6±34.1	2762038747.4±32.3
1990.11.28	791.2±33.9	6041.7±30.9	790.5±30.9
1991.12. 3	571.1±46.9	5951.6±52.5	807.7±37.1
1991.12. 5	639.1±43.4	6028.6±42.6	809.0±35.8
Nobeyama45m			
1986. 2.17	-3871025162.1±35.0	3428107814.4±33.5	3724038989.6±35.0
Usuda64m			
1990. 7.30	-3855355248.4±60.7	3427427591.9±54.4	3740971251.5±62.4

*1 Kanozan is the reference position on the ground. Other positions are the antenna position.

Table 5 Observed Positions by Domestic VLBI experiments in ITRF93
(the results with ion correction)

Station name Year.Mon.Day	X (mm)	Y (mm)	Z (mm)
Tsukuba5m			
1984. 7.18	-3957172750.9±53.4	3310237928.7±50.5	3737709048.3±53.8
1985. 8. 9	803.1±25.0	909.0±24.5	9033.5±25.8
1986. 2.17	880.7±16.6	974.1±15.3	9098.7±16.7
1987. 2.23	896.3± 9.5	972.1± 7.9	9088.6± 8.8
1988. 2. 9	840.4±18.7	937.0±15.4	9020.6±19.4
1988. 8.25	795.4±18.8	915.5±16.2	8983.9±19.3
1989. 2.22	904.3±19.6	965.9±16.6	9056.5±18.2
1989. 9.29	853.7±19.5	916.6±16.8	8973.4±18.6
1990. 3. 1	893.1±14.9	962.2±12.4	9018.9±14.6
1991. 3.26	911.0± 9.6	973.4± 8.4	9007.6± 9.9
1991. 5.21	910.4±13.0	982.4±10.9	8998.3±12.6
1991. 7.31	849.5±13.3	934.2±11.9	8949.8±14.4
1993. 8.24	941.6±27.2	957.5±23.4	8979.2±23.6
Shintomi			
1986.10.20	-3582767757.6±37.1	4052034069.3±42.1	3369020669.5±33.3
1988.10. 6	682.1±39.5	4025.3±44.0	522.4±38.8
1988.10.12	774.2±35.1	4081.5±41.3	616.8±36.9
1993.11.16	849.1±18.2	3962.1±21.2	441.7±17.4
Titijima			
1987.11.18	-4489356805.6±49.7	3482989620.8±38.7	2887931231.3±34.4
1987.11.25	693.7±38.0	518.9±30.6	199.0±25.6
1989.11.28	624.1±43.1	532.1±35.1	152.3±32.2
1989.12. 6	651.5±23.5	554.4±18.9	193.9±16.5
Shintotugawa			
1990. 7.26	-3642141545.0±41.1	2861496314.1±33.3	4370361627.1±51.8
1990. 7.28	697.5±28.6	464.9±22.4	719.3±33.8
1990. 7.30	865.9±49.8	582.4±40.3	871.2±55.8
Mizusawa-GSI			
1991. 9.18	-3862411917.3±13.5	3105015046.5±11.9	4001944993.3±15.5
1991. 9.20	926.2±13.2	040.0±11.5	966.1±15.1
1991.10.18	852.9±11.9	003.2± 9.9	874.0±13.7
1991.10.20	890.2±12.7	026.3±10.9	928.7±15.4
1991.11.24	881.8±29.9	036.5±22.1	889.7±26.5
1991.11.26	900.4±13.6	019.9±11.6	944.3±15.8
Kainan			
1993. 9.28	-3751042945.5±32.5	3721054957.4±31.2	3560819207.1±29.8
Sagara			
1992.11.23	-3913437725.7±17.8	3501122811.7±15.2	3608593534.2±19.5
1992.11.24	714.0±22.2	826.7±19.6	521.8±22.5
1992.12. 1	783.4±29.2	847.2±26.2	596.7±26.9
1992.12. 2	790.3±20.1	862.4±17.4	553.9±18.6
1993. 2.28	752.6±15.6	829.1±14.0	564.0±15.9
1993. 3. 1	824.0±21.2	890.7±20.4	599.7±19.1

The position is the antenna position.

Table 6 Measurement precision of the position for east, north, vertical components (for the results without ion correction)

Station name Year. Mon. Day	Vertical (mm)	East (mm)	North (mm)
Tsukuba5m			
1984. 7.18	(±85.9)	(±12.7)	(±27.4)
1985. 8. 9	±36.9 (±41.6)	± 6.8 (± 7.7)	± 8.8 (±10.2)
1986. 2.17	±23.7 (±26.6)	± 4.0 (± 4.7)	± 6.7 (± 7.7)
1987. 2.23	±12.3 (±14.5)	± 2.0 (± 2.4)	± 3.1 (± 3.7)
1988. 2. 9	±25.9 (±29.8)	± 3.9 (± 4.4)	± 6.3 (± 7.4)
1988. 8.25	±28.8 (±30.2)	± 4.7 (± 5.0)	± 6.6 (± 7.2)
1989. 2.22	±28.2 (±30.5)	± 4.4 (± 4.8)	± 5.4 (± 6.0)
1989. 9.29	±28.2 (±30.8)	± 4.3 (± 4.6)	± 5.9 (± 6.4)
1990. 3. 1	±22.3 (±23.5)	± 3.3 (± 3.4)	± 4.6 (± 5.0)
1991. 3.26	±14.1 (±15.0)	± 3.2 (± 3.3)	± 4.6 (± 4.9)
1991. 5.21	±18.5 (±20.0)	± 4.1 (± 4.3)	± 4.9 (± 5.4)
1991. 7.31	±20.9 (±21.1)	± 5.1 (± 5.1)	± 7.3 (± 7.5)
1992. 3.19	±18.6	± 3.5	± 3.9
1992. 5.14	±18.6	± 4.1	± 4.7
1993. 8.24	±26.7 (±38.6)	± 6.6 (± 7.9)	± 9.3 (±10.1)
Tsukuba2.4m			
1992.10.15	±35.2	± 5.0	± 6.6
Shintomi			
1986.10.14	±30.8	± 5.7	± 7.6
1986.10.20	±29.3 (±63.2)	± 4.1 (± 9.2)	± 7.1 (±13.5)
1988.10. 6	±56.2 (±68.8)	± 8.4 (± 9.6)	± 9.8 (±13.4)
1988.10.12	±55.6 (±62.6)	± 9.2 (±10.3)	±12.8 (±16.7)
1993.11.16	±31.7 (±30.2)	± 8.4 (± 8.5)	± 9.3 (± 9.9)
Titijima			
1987.11.18	±52.0 (±69.7)	± 6.6 (± 9.0)	±12.1 (±14.9)
1987.11.25	±47.7 (±53.8)	± 6.1 (± 6.7)	± 9.0 (± 9.8)
1989.11.28	±66.7 (±61.8)	±10.1 (±10.2)	±13.7 (±14.1)
1989.12. 6	±63.7 (±33.3)	± 8.6 (± 4.6)	±13.2 (± 7.5)
Shintotugawa			
1990. 7.23	±73.1	±14.7	±21.3
1990. 7.26	±73.8 (±70.6)	±12.5 (±11.9)	±18.3 (±18.5)
1990. 7.28	±52.9 (±47.6)	± 8.5 (± 7.5)	±12.7 (±11.8)
1990. 7.30	±64.4 (±83.2)	± 9.3 (± 9.6)	±12.3 (±14.1)
Mizusawa-GSI			
1991. 9.18	±24.2 (±22.2)	± 5.6 (± 5.1)	± 7.0 (± 6.7)
1991. 9.20	±21.9 (±21.8)	± 4.9 (± 4.8)	± 6.1 (± 6.1)
1991.10.18	±19.5 (±19.5)	± 4.2 (± 4.3)	± 5.2 (± 5.7)
1991.10.20	±20.9 (±21.0)	± 4.9 (± 4.9)	± 6.7 (± 7.1)
1991.11.24	±47.1 (±42.2)	±12.3 (±11.1)	±15.1 (±13.6)
1991.11.26	±21.1 (±22.1)	± 4.9 (± 5.3)	± 6.8 (± 7.5)
Kainan			
1993. 9.28	±47.8 (±52.1)	± 7.9 (± 8.9)	± 9.2 (±10.9)

( ) is the precision in the results with ion correction.

Table 6 Measurement precision of the position for east, north, vertical components (continued)

Station name Year. Mon. Day	Vertical (mm)	East (mm)	North (mm)
Sagara			
1992. 11. 23	±25.4 (±27.1)	± 7.0 (± 7.6)	± 9.8 (±11.6)
1992. 11. 24	±28.3 (±34.6)	± 6.2 (± 7.8)	± 8.7 (±11.1)
1992. 12. 1	±28.4 (±45.0)	± 6.0 (± 9.1)	± 8.3 (±12.5)
1992. 12. 2	±17.6 (±30.2)	± 4.4 (± 6.2)	± 6.6 (±10.0)
1993. 2. 28	±19.9 (±23.7)	± 5.4 (± 6.7)	± 6.8 (± 9.3)
1993. 3. 1	±17.5 (±32.9)	± 4.6 (± 6.6)	± 6.2 (±10.4)
Kanozan			
1993. 7. 27	±21.7	± 5.1	± 6.4
1995. 1. 17	±27.8	± 5.3	± 8.0
1995. 1. 19	±24.5	± 5.6	± 8.1
Tonami			
1994. 11. 15	±19.4	± 2.7	± 3.6
Koganei3m			
1988. 9. 19	±29.4	± 4.5	± 5.9
1992. 3. 19	±19.5	± 3.6	± 3.7
1992. 5. 14	±35.0	± 4.8	± 5.0
1992. 10. 15	±43.6	± 5.9	± 6.8
1992. 11. 26	±53.1	± 6.8	± 7.3
1993. 8. 24	±38.5	± 7.9	±10.1
1995. 1. 17	±27.8	± 5.2	± 8.0
1995. 1. 19	±15.4	± 3.1	± 4.5
Wakanai-CRL			
1988. 10. 5	±150.3	±18.7	±26.5
Okinawa-CRL			
1989. 2. 3	±99.7	±19.9	±21.9
1990. 10. 22	±72.0	±15.8	±20.3
Minami-Daito			
1990. 11. 26	±52.9	±14.0	±18.3
1990. 11. 28	±56.7	±13.3	±18.9
1991. 12. 3	±74.6	±15.6	±22.8
1991. 12. 5	±66.3	±15.5	±18.3
Nobeyama45			
1986. 2. 17	±58.2	± 7.1	±11.5
Usuda64m			
1990. 7. 30	±97.8	±19.0	±24.7

( ) is the precision in the results with ion correction.

Table 7 Position of Kashima as the reference position in ITRF93

Station Name Year.Mon.Day	X (mm)	Y(mm)	Z (mm)
Kashima26m			
1985. 8. 9	-3997892215.0	3276581276.4	3724118392.4
1986. 2.17	219.1	277.3	383.9
1986.10.14	224.1	278.4	373.5
1986.10.14	224.3	278.5	373.2
1987. 2.23	226.9	279.0	367.7
1987.11.18	232.6	280.3	355.9
1987.11.25	232.7	280.3	355.6
1988. 2. 9	234.3	280.7	352.3
1988. 8.25	238.5	281.6	343.6
1988. 9.19	239.0	281.7	342.5
1988.10. 5	239.4	281.8	341.8
1988.10. 6	239.4	281.8	341.8
1988.10.12	239.5	281.8	341.5
1989. 2. 3	241.9	282.4	336.5
1989. 2.22	242.3	282.4	335.7
1989. 9.29	246.9	283.5	326.1
1989.11.28	248.2	283.7	323.5
1989.12. 6	248.4	283.8	323.1
1990. 3. 1	250.1	284.2	319.4
1990. 7.26	253.2	284.9	313.0
1990. 7.28	253.3	284.9	312.9
1990. 7.30	253.3	284.9	312.8
1991. 3.26	258.4	286.0	302.3
1991. 5.21	259.5	286.3	299.9
1991. 7.31	261.0	286.6	296.8
1991. 9.18	262.1	286.8	294.6
1991. 9.20	262.1	286.8	294.5
1991.10.18	262.7	286.9	293.3
1991.10.20	262.8	287.0	293.2
1991.11.24	263.5	287.1	291.7
1991.11.26	263.5	287.1	291.6
1992.10.15	270.4	288.6	277.4
1992.11.23	271.2	288.8	275.7
1992.11.24	271.2	288.8	275.7
1992.11.26	271.2	288.8	275.6
1992.12. 1	271.4	288.9	275.3
1992.12. 2	271.4	288.9	275.6
1993. 2.28	273.2	289.3	271.4
1993. 3. 1	273.3	289.3	271.4
1993. 8.24	277.0	290.1	263.7
1993. 9.28	277.7	290.3	262.1
1993.11.16	278.7	290.5	260.0

Table 7 Position of Kashima as the reference position in ITRF93 (Continued)

Station Name Year.Mon.Day	X (mm)	Y(mm)	Z (mm)
Kashima34m			
1988. 9.29	-3997649214.9	3276690765.5	3724278922.1
1990. 7.23	221.2	766.8	909.1
1990.10.23	223.1	767.3	905.1
1990.11.26	223.9	767.4	903.5
1990.11.28	223.9	767.4	903.5
1991.12. 3	231.7	769.2	887.3
1991.12. 5	231.7	769.2	887.3
1992. 3.19	233.9	769.7	882.6
1992. 5.14	235.1	769.9	880.1
1993. 7.27	244.4	772.0	860.9
1994.11.15	254.4	774.2	840.0
1995. 1.17	255.8	774.5	837.3
1995. 1.19	255.8	774.5	837.2