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ANALYSIS OF GPS DATA AT SYOWA STATION AND IGS TRACKING STATIONS

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Abstract: The 36th Japanese Antarctica Research Expedition (JARE-36, 1995) built a Global Positioning System (GPS) station, SYOG, at Syowa Station in Antarctica. We analyzed GPS data of Syowa Station and the tracking stations of International GPS Service for Geodynamics (IGS) for the quality check of Syowa GPS data.

GPS data were analyzed by Precise Point Positioning strategy implemented in GIPSY-OASIS II software developed by Jet Propulsion Laboratory. The site coordinates at the epoch of 1997.0 and velocities of these GPS stations were estimated by applying a velocity model to the obtained time series of site coordinates. The plate motion of the Antarctic plate and its internal deformation are discussed using these results. The Euler vector of the Antarctic plate was estimated from displacement velocities of SYOG and five IGS sites on the Antarctic plate. This result was derived only from GPS site velocities and supports the NNR NUVEL-1A model (C. DEMETS *et al.*: Geophys. Res. Lett., **21**, 2191, 1994).

key words: Syowa GPS station (SYOG), Precise Point Positioning, GIPSY-OASIS II, Antarctic plate

1. Introduction

A GPS station at Syowa Station in Antarctica, SYOG, was built by the 36th Japanese Antarctic Research Expedition (JARE-36) in February 1995, and has been operated since March 1995. At the beginning of the operation, GPS data at Syowa Station (SYOG) were stored on magnetic tape and handcarried by the members of JARE. Data every 10 days were experimentally sent by a communication satellite, INMARSAT. Currently, the data are sent to the server of National Institute of Polar Research (NIPR) every day by INMARSAT, and are transferred through the Internet to GSI within about two days.

On the Antarctic plate, there are only five International GPS Service for Geodynamics (IGS) GPS tracking Stations, Casey, Davis, Kerguelen Island, McMurdo and O'Higgins. There is no site around Syowa Station. Syowa GPS station will play an important role in determination of the plate motion.

There are mainly two kinds of estimation of the plate model. One is the models of current plate motions, NUVEL-1 (DEMETS *et al.*, 1990), NNR NUVEL-1 (ARGUS and GORDEN, 1991), NNR NUVEL-1A (DEMETS *et al.*, 1994) etc., which have been determined using seafloor spreading rates, azimuths of transform faults, slip vectors of earthquakes and so on. The other is the model estimated by space geodetic technique, and LARSON *et al.* (1997) estimated global plate model by using the site coordinate time series of IGS GPS stations, of which there is only two on the Antarctic plate. In this paper, motion of the Antarctic plate is modeled using six GPS stations, Syowa Station and the five IGS sites.

2. GPS Data

We used the data at Syowa (SYOG) and six neighboring IGS tracking stations. At the beginning of the observation, we obtained GPS data from SYOG sent by INMARSAT only every 10 days. GPS data for one year on magnetic tape were sent a year later. At present, we can obtain the data every day. About 95% of data of Syowa Station are available for the observational period. However, the SYOG receiver has a clock instability and less than 10% of the data have a large clock offset.

We selected six IGS tracking stations around Syowa Station, of which five stations are located on the Antarctic plate and the reminder is on the Macquarie Ridge, part of the plate boundary between Pacific and Australian plates. The site name, receiver, antenna, frequency standard and agency for each site are displayed in Table 1.

Table 1. Station information.

Site name	Receiver	Antenna	Clock	Agency
Syowa	ROGUE SNR-8000	DORNE MARGOLIN T	Rubidium	GSI
Casey	ROGUE SNR-8100	DORNE MARGOLIN T	Rubidium	AUSLIG
Davis	ROGUE SNR-8100	DORNE MARGOLIN T	Quartz/Internal	AUSLIG
Kerguelen	ROGUE SNR-8C	DORNE MARGOLIN T	Rubidium	CNES
McMurdo	ROGUE SNR-8000	DORNE MARGOLIN T	Internal	NASA/JPL
O'Higgins	ROGUE SNR-8000	DORNE MARGOLIN T	H-maser/Cesium	IFAG
Macquarie Is.	ROGUE SNR-8100	DORNE MARGOLIN T	Quartz/Internal	AUSLIG

3. Data Analysis

We used the Precise Point Positioning (PPP) strategy which is implemented in GIPSY-OASIS II developed by JPL (WEBB and ZUMBERGE, 1997).

Usually, GPS baseline analysis is conducted by forming double differences in order to cancel the common clock error from the phase data. For the data of this study, however, it was difficult to form double differences for two reasons. One is the lack of some GPS data. At first, there were only every 10 days of GPS data at Syowa Station. Also, sometimes there were no GPS data at some IGS tracking sites for the analysis. The second reason is that the baselines are too long to form double differences. PPP is advantageous for such situations because it analyzes the data site by site without taking double differences. Instead, we need a consistent set of global parameters, such as satellite clock, satellite orbit information and earth rotation parameters, analyzed from the global GPS tracking network. These parameters estimated in the JPL FLINN analysis are available from JPL by anonymous ftp.

The accuracy of PPP is higher than that of conventional point positioning. First, PPP uses not only pseudorange but also carrier phase. Usually, the point positioning method uses only pseudorange, which is noisy. Second, while normal point positioning uses the broadcast orbit, of quality less than about 40 cm, PPP uses the global solution as a transmitter parameter, such as the precise orbit and clock parameter, obtained by JPL FLINN analysis. The accuracy of these parameters is a few centimeters or better (ZUMBERGE *et al.*, 1997).

4. Reference Frame

The global parameters used in this paper are estimated by JPL in the IERS Terrestrial Reference Frame (ITRF). ITRF93 was used as the reference frame at the beginning of the observations in March 1995. It was changed into ITRF94 on June 30, 1996. Therefore, the analyzed site coordinates are based on two kinds of ITRF. In order to obtain the site coordinates in common reference frame, we converted site coordinates estimated in ITRF93 into ITRF94 by trans96 software with parameters of the International Earth Rotation Service (IERS) to assure the consistency of the results (TOBITA, 1997). However, even after this conversion, the combined time series of coordinates showed a jump on June 30, 1996 and a change of site velocities before and after the reference frame was changed. Since the conversion parameters were determined using global space geodetic sites, which are inadequately weighted in the northern hemisphere, this inconsistency may have been caused because these parameters are not adequate for these sites for the high latitude region in the southern hemisphere. Therefore, we used the data only after June 30, 1996, to keep the consistency of reference frames and estimated coordinates in ITRF94.

5. Result

Figure 1 shows the time series of the coordinates at Syowa (a) and McMurdo (b) Stations. Several outliers are shown in the time series of Syowa Station, especially in height component, and the standard deviations of some coordinates are larger than the others. Although we used 24-hour phase data for our analysis, only one-third of the SYOG data were used in some SYOG analysises as compared with other SYOG analysises. We checked a clock offset using Bernese version 4.0 analysis software (ROTHACHER and MERVART, 1996). The result is shown in Table 2. Though the clock offset of other stations where rubidium is used is about 10^{-4}–10^{-5}, the clock offset of Syowa Station is about 10^{-4}–10^{-2}, which is two orders of magnitude bigger than the others. This was caused by receiver time-tag trouble. Thus, in this paper, only good SYOG results are used for further analysis.

From the time series of the coordinates, the coordinates at epoch 1997.0 and the displacement velocities are estimated on the assumption that the velocities are constant (Tables 3–6). Table 3 and Table 4 show XYZ component and BLH component of site

Syowa Station July 1996 - June 1997

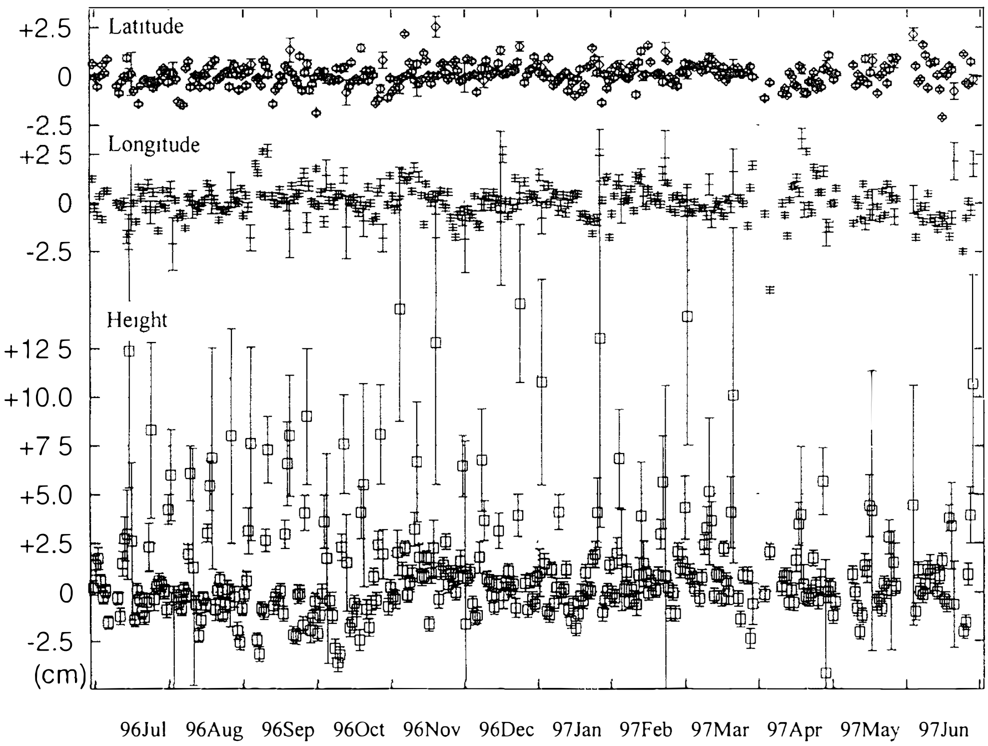

Fig. 1a. Time series of Syowa Station (1996. 7. 1-1997. 6. 30).

McMurdo July 1996 - June 1997

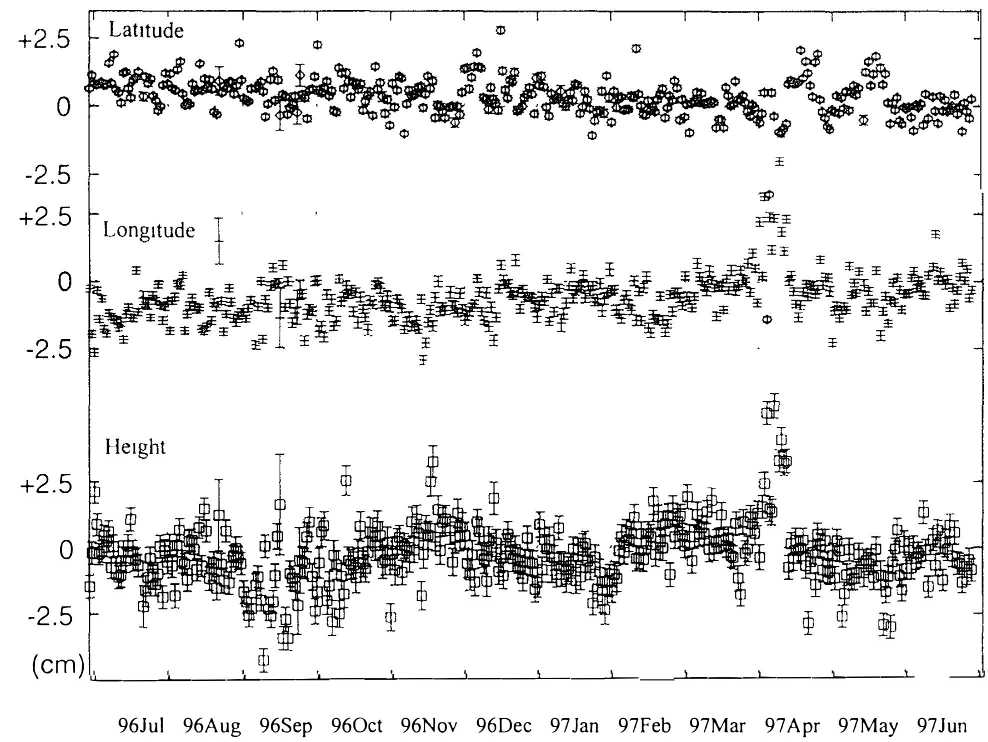

Fig. 1b. Time series of McMurdo Station (1996. 7. 1-1997. 6. 30).

Table 2. Clock offset (s).

	Syowa	Casey	Davis	Kerguelen	McMurdo	O'Higgins
260	1.109E−02	1.364E−04	4.167E−04	−1.842E−05	1.540E−07	−3.000E−09
261	1.496E−02	1.607E−04	4.418E−04	−1.910E−05	3.800E−08	−1.170E−07
262	1.882E−02	1.851E−04	4.688E−04	−2.001E−05	1.580E−07	0.000E+00
263	2.269E−02	1.848E−05	4.919E−04	−2.056E−05	−1.260E−07	−1.500E−08
264	2.655E−02	4.172E−05	5.170E−04	−2.067E−05		−8.500E−08
265	4.197E−04	6.513E−05	5.422E−04	−2.049E−05	1.100E−08	−1.760E−07
266	4.280E−03	8.860E−05	5.673E−04	−2.106E−05	−1.450E−07	4.100E−08
267	8.141E−03	1.121E−04	5.923E−04	−2.094E−05		−1.360E−07
268	1.200E−02	1.353E−04	1.750E−05	−2.065E−05	−8.500E−08	1.780E−07
269	1.588E−02	1.587E−04	4.273E−05	−1.964E−05	−1.100E−08	3.700E−08

Table 3. XYZ coordinates and their standard deviations (dx, dy, dz), ITRF94, epoch 1997. 0.

Site name	X (m)	Y (m)	Z (m)	dx (mm)	dy (mm)	dz (mm)
Syowa	1766207.8686	1460290.3801	−5932297.7652	0.1067	0.1023	0.2454
Casey	−901776.1544	2409383.4235	−5816748.4185	0.1009	0.1049	0.1961
Davis	486854.5517	2285099.3093	−5914955.6820	0.1138	0.1141	0.2242
Kerguelen	1406337.3652	3918161.1731	−4816167.4263	0.0956	0.1226	0.1401
McMurdo	−1311703.2518	310815.1077	−6213255.1830	0.1291	0.1328	0.4036
O'Higgins	1525872.5117	−2432481.3391	−5676146.1890	0.1114	0.1151	0.1993
Macquarie Is.	−3464038.5430	1334172.7888	−5169224.4013	0.1503	0.1303	0.1930

Table 4. BLH coordinates, ITRF94, eqoch 1997. 0.

Site name	B (degree)	L (degree)	H (m)
Syowa	−69.006957330	39.583744391	50.0902
Casey	−66.283358733	110.519705456	22.4518
Davis	−68.577322583	77.972613661	44.4048
Kerguelen	−49.351466540	70.255521424	73.1270
McMurdo	−77.838348580	166.669324892	98.0671
O'Higgins	−63.320723546	−57.900340695	30.7840
Macquarie Is.	−54.499532741	158.935833723	−6.6746

Table 5. XYZ rates and their standard deviations (dV_x, dV_y, dV_z), ITRF94.

Site name	V_X (mm/yr)	V_Y (mm/yr)	V_Z (mm/yr)	dV_x (mm/yr)	dV_y (mm/yr)	dV_z (mm/yr)
Syowa	6.86	−0.56	−5.89	0.37	0.36	0.87
Casey	−3.91	6.05	−44.92	0.31	0.33	0.63
Davis	−0.97	−6.40	1.18	0.37	0.37	0.74
Kerguelen	−7.47	−1.60	2.79	0.33	0.41	0.47
McMurdo	3.55	−14.53	−7.99	0.25	0.25	0.79
O'Higgins	10.97	3.90	16.89	0.38	0.40	0.71
Macquarie Is.	−32.77	18.85	5.36	0.47	0.42	0.61

Table 6. BLH rates and their standard deviations (dV_B, dV_L, dV_H), ITRF94.

Site name	V_B (mm/yr)	V_L (mm/yr)	V_H (mm/yr)	dV_B (mm/yr)	dV_L (mm/yr)	dV_H (mm/yr)
Syowa	2.49	−4.80	7.26	0 21	0.34	0.93
Casey	−11.62	1.54	43.95	0.18	0.32	0.69
Davis	−5.59	−0.38	−3.46	0.22	0.37	0.79
Kerguelen	−1.24	6.49	−4.74	0.14	0.30	0.62
McMurdo	−8 34	13.32	6.38	0.18	0.26	0.81
O'Higgins	9.84	11.36	−13.96	0.21	0.35	0.80
Macquarie Is.	33.52	−5.81	17.33	0.19	0.40	0.76

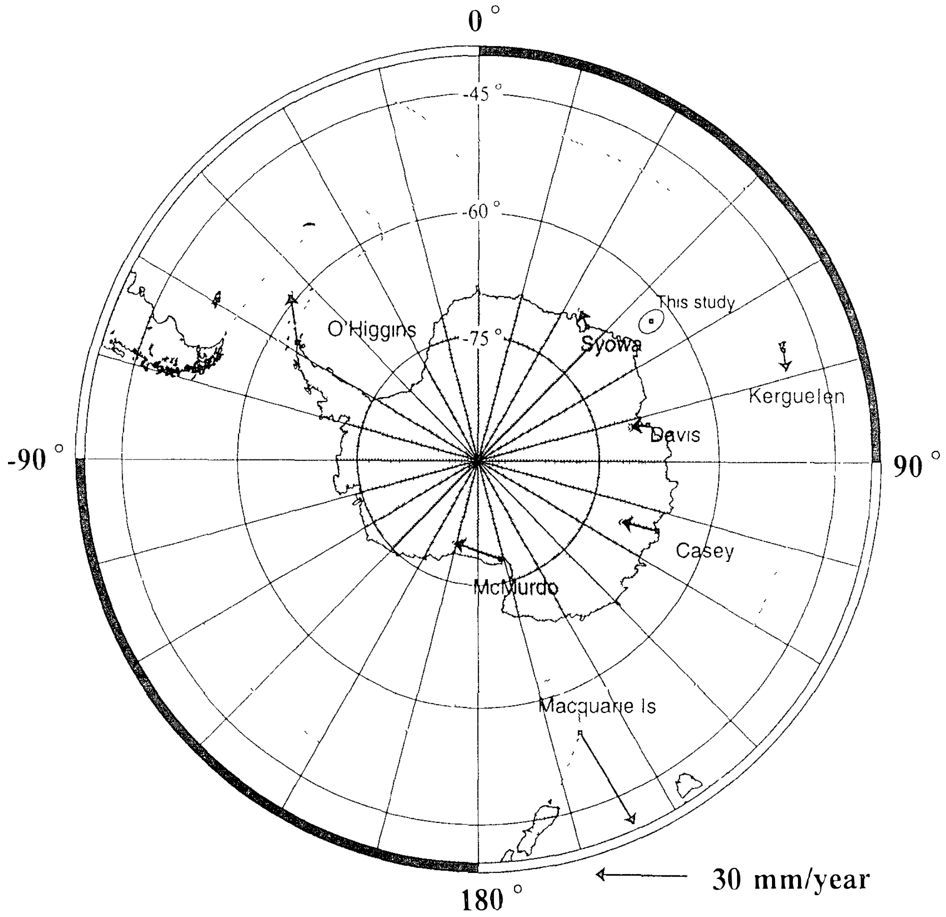

Fig. 2. Velocity vector of the stations in Antarctica and the Euler Pole of the Antarctic plate (ITRF94, epoch 1997.0).

coordinates, respectively. XYZ and BLH components of the site velocity are listed in Table 5 and Table 6, respectively. Figure 2 shows the velocity vectors in ITRF94.

6. Plate Motion

We estimated the motion and the internal deformation of the Antarctic plate. First, strain rates are estimated to be about 10^{-9}–10^{-10} y^{-1} from site coordinates

Table 7. Euler vectors of the Antarctic plate.

	Latitude N (deg)	Longitude E (deg)	ω (deg/m.y.)
This study	62.7	−128.4	0.22
LARSON *et al.*	60.5	−125.7	0.24
NNR-A	63.1	−115.9	0.24

Table 8. Comparison between the observations and the Euler vector model.

Site name	This study		NNR NUVEL-1A		LARSON *et al.*	
	north	east	north	east	north	east
Syowa	0.2	−2.4	−2.2	−3.2	−0.4	−1.7
Casey	−2.2	−1.8	−3.4	−0.3	−2.2	−0.7
Davis	−0.7	1.0	−2.9	1.7	−1.0	2.0
Kerguelen	2.3	0.5	0.0	0.5	1.9	1.7
McMurdo	1.6	4.3	2.7	6.2	2.2	4.9
O'Higgins	−0.5	−1.5	0.2	−4.1	−0.7	−1.5

and velocity. This result shows that the Antarctic plate moves as an almost rigid plate.

Second, regarding the rigidity of the Antarctic plate, the Euler pole and angular velocity were estimated using velocity data at SYOG and the five IGS sites on the Antarctic plate (Table 7). The Euler pole is plotted in Fig. 2. Our result was compared with NNR NUVEL-1A (DEMETS *et al.*, 1994) and LARSON *et al.* (1997) (Table 8). Since there is no significant difference among these results, it is confirmed that the Antarctic plate follows the NNR NUVEL-1A model, and Syowa Station is located on the stable interior of the Antarctic plate.

7. Conclusion

The GPS data at Syowa Station and IGS stations were analyzed by the Precise Point Positioning strategy using GIPSY-OASIS II. Data of Syowa Station have a time-tag trouble. Coordinates and site displacement velocities were estimated from time series of estimated coordinates in ITRF94. Internal deformation and the Antarctic plate Euler vector were estimated from SYOG and five IGS stations which are located on the Antarctic plate. The Antarctic plate does not show any significant internal deformation. Our Antarctic plate Euler velocity is compared with NNR NUVEL-1A (DEMETS *et al.*, 1994), and an other result obtained through GPS analysis (LARSON *et al.*, 1997). Since there is no significant difference among these three results, we confirmed that Syowa Station is located on the stable interior of the Antarctic plate.

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