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MEASUREMENT OF ICE SHEET MOVEMENT AT S16, EAST ANTARCTICA USING GPS

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Abstract: Continuous observations using GPS were carried out on an ice sheet in East Antarctica, near Syowa Station for about 4 days to detect detailed movement of the ice sheet. It is possible to detect the short-time change of the location precisely by analyzing the differential GPS with data simultaneously acquired at a reference GPS continuous observation point, using precise ephemeris. We detected constant movement of the ice sheet toward the WNW of about 13 mm per day. The drift rate of the ice sheet movement coincides with the result of repeated differential GPS measurement over two years, so it is proved that the movement of the ice sheet is rather constant. This kind of GPS observation gives ground truth for geoscience.

key words: ice sheet movement, GPS

1. Introduction

During the 38th Japanese Antarctic Research Expedition (JARE-38), continuous observations using GPS (Global Positioning System) were carried out at point S16 (69° 1′47″ S, 40° 3′8″ E) at the edge of the Antarctic ice sheet about 19 km east of Syowa Station (69°0′25″ S, 39°35′1″ E, see Fig. 1). S16 is on an ice sheet having ellipsoidal relative height of 562 m from the GPS continuous observation point at Syowa Station, and S16 is used as the base for an inland traverse. The aim of this observation is to detect movement of the ice sheet precisely.

One of the purposes of the precise movement detection is to give absolute ground truth for synthetic aperture radar (SAR) interferometry for detection of ice sheet movement. As SAR interferometry is a remote sensing technique with high resolution, the advantage of this method has been demonstrated even in the Antarctic region (*e.g.* GOLDSTEIN *et al.*, 1993). However, SAR interferometry is not an absolute measurement and it needs ground truth with their absolute horizontal and vertical positions to ten-meter precision and their relative movements to centimeter precision because the SAR interferometry is more sensitive to surface deformation than to topography.

2. Outline of Observations

The observations were carried out by relative (differential) positioning between Syowa Station and S16, from December 20 to 24, 1996. The continuous GPS observation in Syowa Station had been started by JARE-36, and the GPS antenna was fixed on

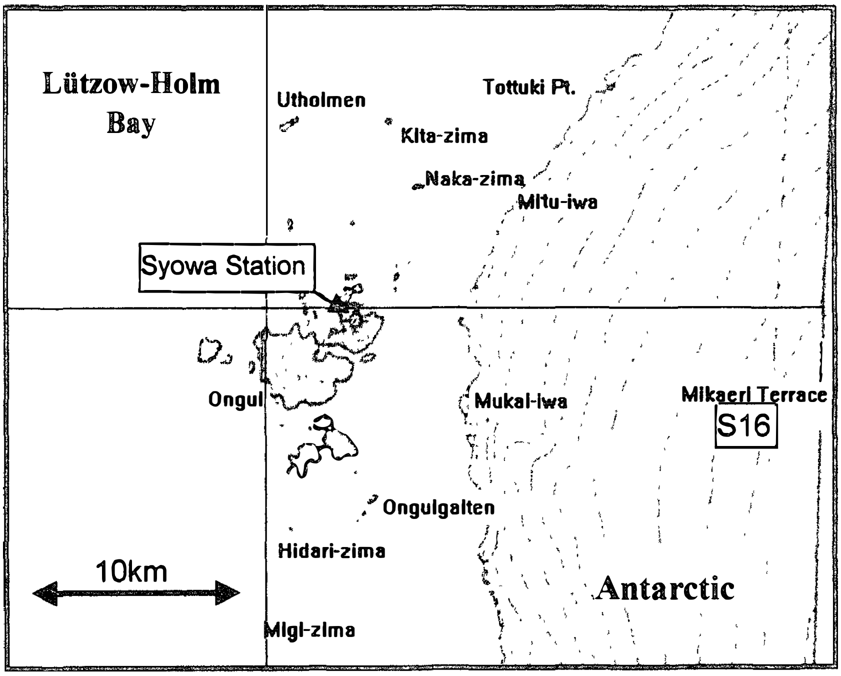

Fig. 1. Map around Syowa Station and S16.

an exposed rock. At the S16 point, there is a pole for GPS observation on the ice sheet, set up from 1992, so it was used this time as well. Although there is a possibility of a tripod leaning during observations on the snow, it has never occurred, because the air and snow temperature were always low, and the snow was dug down about 30 cm; then the tripod was set up in the hole and the snow was tramped down. No drift was found in a bubble level on the tripod, or the distance between the center of the pole and that of the GPS antenna. The weather was fine at the observation time; the wind was rather strong in the morning and evening but helicopters for transportation could fly every day.

Types of instruments used, and observation conditions were as follows:

(a) Receivers GPS continuous observation point at Syowa Station
AOA Inc. TURBOROGUE
S16 observation point
TRIMBLE Inc. 4000-SSE

(b) Observation times Syowa Station
24 hours every day
S16
From 0946 December 20 to 0502 December 24, 1996

(c) Data sampling at 30 s intervals

(d) Elevation mask 15°

3. Analysis and Results

Analysis was carried out by 'GAMIT' analyzing software for GPS baseline, using IGS (International GPS Service) precise ephemeris. The coordinates of Syowa Station were fixed, and the observation period was divided into 12 sessions. The conditions of

Table 1. The conditions of each session.

Session	Date	Day of the year	Time	Epoch
1	December 20	355	0946-1600	748
2			1600-2349	938
3	December 21	356	0001-0800	960
4			0800-1600	960
5			1600-2349	938
6	December 22	357	0001-0800	960
7			0800-1600	960
8			1600-2349	938
9	December 23	357	0001-0800	960
10			0800-1600	960
11			1600-2349	938
12	December 24	359	0000-0500	600

Table 2. Baseline vectors from Syowa Station to S16.

Session	X (m)	SD (m)	Y (m)	SD (m)	Z (m)	SD (m)	L (m)	SD (m)
1	−13653.7065	.0074	12996.9553	.0072	−1408.2428	.0241	18903.1134	.0045
2	−13653.7083	.0086	12996.9500	.0071	−1408.2286	.0263	18903.1100	.0045
3	−13653.7018	.0117	12996.9500	.0088	−1408.2309	.0345	18903.1054	.0048
4	−13653.6965	.0069	12996.9481	.0064	−1408.2390	.0222	18903.1009	.0042
5	−13653.6959	.0096	12996.9473	.0087	−1408.2331	.0272	18903.0995	.0069
6	−13653.6925	.0107	12996.9400	.0084	−1408.2228	.0328	18903.0913	.0045
7	−13653.6874	.0070	12996.9387	.0067	−1408.2328	.0231	18903.0874	.0043
8	−13653.6850	.0108	12996.9366	.0084	−1408.2228	.0311	18903.0835	.0056
9	−13653.6859	.0177	12996.9287	.0149	−1408.2064	.0557	18903.0775	.0056
10	−13653.6775	.0131	12996.9309	.0112	−1408.2238	.0414	18903.0743	.0049
11	−13653.6634	.0252	12996.9387	.0212	−1408.2695	.0830	18903.0728	.0056
12	−13653.6940	.1022	12996.9164	.0751	−1408.1337	.2980	18903.0695	.0420

Where X, Y, Z are the components of ITRF94, L is the baseline length, and SD is standard deviation.

each session are shown in Table 1.

3.1. Each component and baseline length

Results of analysis in each session are shown in Table 2.

Session 12 has a rather large SD in each component and baseline length, because the observation time was shorter than the other sessions and a helicopter had been hovering over the antenna for slinging freight during a large part of the session 12.

3.2. Baseline change

Figure 2 shows the change of the baseline length for each session. The changes of the baseline seem almost linear with time, which means that the movement of the ice sheet was constant.

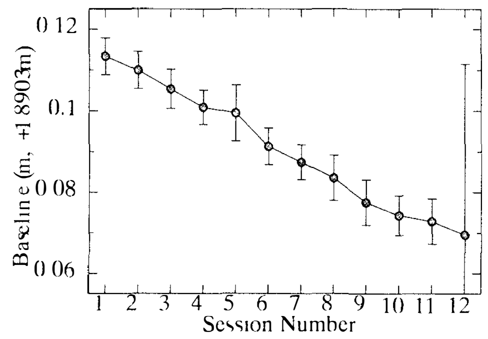

Fig. 2. The change of the baseline length for each session between Syowa Station and S16.

3.3. Horizontal movement of the ice sheet

The coordinates of the GPS continuous observation point at Syowa Station were calculated from one-year observations. Based on these coordinates, the change of S16 coordinates was calculated. Figure 3 shows the change of the coordinates for each session, and the point moved toward the WNW generally. To calculate the rate of movement, we take the differences of the sessions from 1 to 11, the longest time interval, and from 2 to 10, for comparison (we neglected session 12 because of its large error); the results are shown in Table 3. From these calculation results, it is obvious that point S16 moved 13 mm/day toward the direction of 285° in azimuth. If we assume that the drift rate is constant, the drift rate is 4.7 m/year. MOTOYAMA *et al.* (1995) observed the position of the same point at S16 three times from 1992 to 1994 by differential GPS, and they showed that horizontal drift was about 5.1 m/year toward the azimuth direction of about 290°. The principal error sources seem to be slanting of the pole, used the broadcast ephemeris, and centering of the instrument. In addition, there is a time difference of 3 to 5 years, so that a simple comparison is not possible, but generally our result coincides with their result. The azimuth is the same as the direction of the dominant wind in this region and perpendicular to the topographic contour lines, and the ice sheet moves toward the ocean.

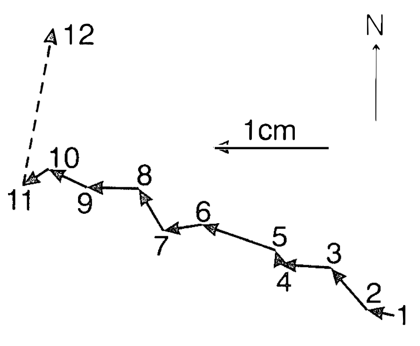

Fig. 3. The change of relative position of S16 for each session. The session 12 data are bad, but from others, the ice seems to move toward the WNW generally.

Table 3. The horizontal drift rate of the ice sheet at S16.

From session	To	Days	Azimuth (degree)	Drift (m)	Drift per day (m)	Drift per year (m)
1	11	3.296	282.75	0.0421	0.0128	4.66
2	10	2.733	290.42	0.0355	0.0130	4.74

3.4. Vertical movement of the ice sheet surface

The vertical movement measurements fluctuated by several centimeters in each session, because the accuracy of the vertical component of GPS is 3 to 4 times worse than that of the horizontal component. Therefore, the four-day observation period is too short to detect the change of several centimeters, so that conclusive results will be obtained in the near future. In the Antarctic region, since the amount of water vapor in the troposphere, which is the largest error source for the vertical component of GPS observation, is much smaller than that in Japan, it is possible to detect the vertical movement of the ice sheet over several tens of days of observation.

4. Conclusions

From the four-day GPS observation, we detected the temporal horizontal drift at S 16 on the ice sheet by continuous GPS observations using precise ephemeris data. Each 8-hour session has a precision of position of several millimeters for the baseline between Syowa Station and S16. The drift toward the WNW of about 13 mm per day was constant with time, and the drift rate and the direction coincide with those obtained from a two-year observation. If ice sheets have constant drift rates, it will be possible to construct a digital elevation model (DEM) using a multi-pass interferometric SAR technique. Therefore, GPS observations are important for ground truths of interferometric SAR.

In the future, JAREs will carry out the observations at intervals of about 40 days, though it was canceled during JARE-38. Therefore, it is considered possible to detect the vertical component of the ice sheet drift.

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