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Arctic glacier movement monitoring with GPS method on 2005

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Abstract During the 2005 Arctic Yellow River Station expedition, the research on monitoring the movement and mass balance of two glaciers around Ny-Ålesund, Austrelov•nbreen and Pedersenbreen, which were selected in the 2004 Yellow River Station expedition were conducted. This paper analyzes the feasibility and advantage in using GPS method to monitor the Arctic glaciers' movement, estimates the precision of first time measured GPS data and discusses the relevant problems in surveying on the Arctic Glaciers with GPS.

Key words Arctic, Yellow River Station, glacier, GPS, movement monitoring

During the first scientific expedition to Chinese Arctic Yellow River Station on 2004, Chinese scientists conducted multi-disciplinary research works, in which the glacier research group investigated the glaciers near Ny-Ålesund on basic features, preceding research works and the current research works, and two glaciers, Austre Lov•nbreen and Pedersenbreen were chosen for long time researching, focusing on mass balance and their movement monitoring. After one year, on the two selected glaciers mass balance poles, as well as high precise movement monitoring poles were set up (Ren and Yan 2005). It's the first time for Chinese to do quantitative research works with Arctic land glaciers by themselves.

The construction of Arctic GPS satellite tracking station was one of the primary programs of the first and second Arctic Yellow River Station expedition. During the first Arctic Yellow River Station expedition on 2004, the first Chinese Arctic GPS satellite tracking station was set up, which started operating and saving the acquired data in the server computer. One year later, the GPS tracking station was upgraded during the second Arctic Yellow River Station expedition, from then on the GPS tracking station could transfer the acquired data to Wuhan everyday via Internet. In the same time, differential GPS (D-GPS) surveying was carried through on the two glaciers with the GPS tracking station as reference station. Totally 25 high precise monitoring points on two glaciers were set up, and their coordinates with post D-GPS processing were firstly obtained. And the end edge position of Austre Lov•nbreen was measured, too.

1 Field Works

(1) Setting up mass balance poles and high precise GPS monitoring poles

In order to monitor the Arctic glaciers for acquiring their accumulating or melting data, mass balance poles on the two glaciers have been set up from source to end The poles are made of glass fiber reinforced plastic Every pole is composed of two sections, and each section is 2 meters long Considering that the glaciers are melting rapidly during summer time, the poles were buried deeply from 1 to 2 meters inside the ice So, there're 2-3 meters of the poles that are exposed above the ice-snow surface Hence the antenna cable should be longer more than 3 meters for the field GPS surveying works

From 25 th July to 1st August, drilling work was conducted at 20 points on the Austre Lov•nbreen, which is 6 km away from Yellow River Station, and 20 monitoring poles were set up (Fig 1).

Fig 1 Monitoring points on Austre Lov•nbreen Glacier

In the 20 poles on Austre Lovénbreen glacier, 11 poles are made of glass fiber reinforced plastic; and the other 9 poles is high precise GPS monitoring poles made of steel (A2、B2、C2、D3、E2、B2N、B2E、B2S、B2W). There' s a diamond observing array composed of 5 monitoring points (B2、B2N、B2E、B2S、B2W).

On 3rd August, field work started on another glacier, Pedersenbreen. Due to the simple glacier topography, only 5 monitoring points were set up (Fig. 2) there, which are composed of 4 glass fiber reinforced plastic poles and one high precise GPS monitoring pole (P3).

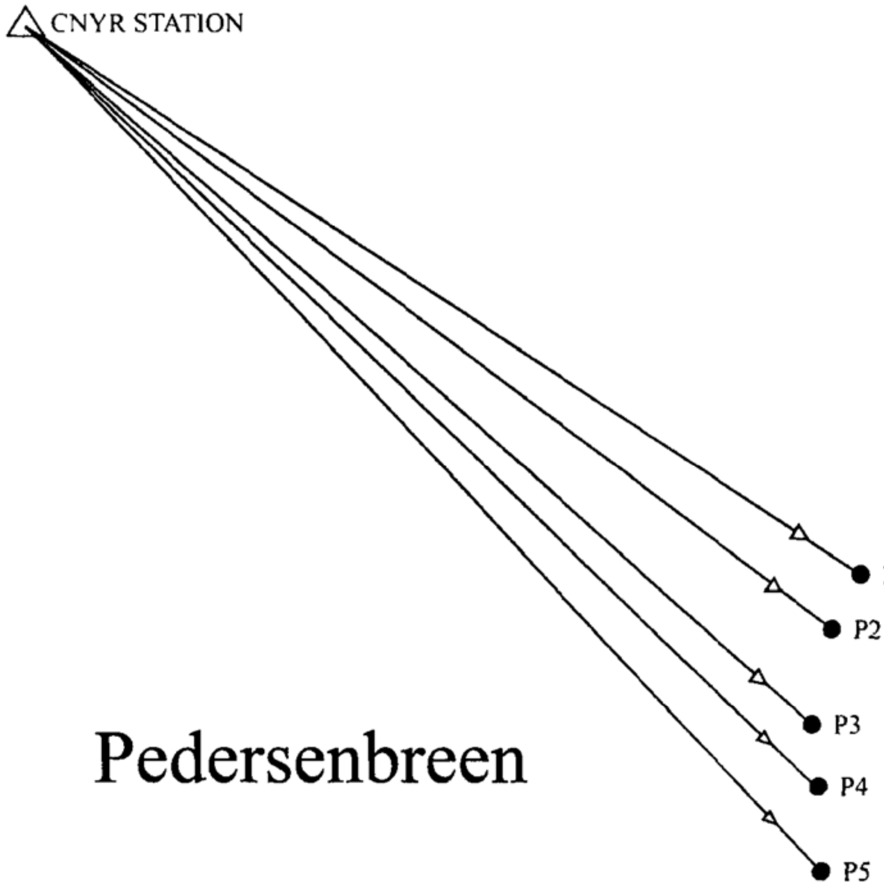

Fig. 2 Monitoring points in Pedersenbreen Glacier

(2) Field GPS surveying works

After several days fieldwork for setting up the monitoring poles, the GPS surveying work started simultaneously. From 31 st July to 12 th August, all the 25 monitoring points on the two glaciers were measured. Each point had been observed for more than one hour, and some points were measured repeatedly two or three times. During the poles' height measurement, for each yellow monitoring pole (made of glass fiber reinforced plastic) only one value H1 was got, which is the height of the pole from the ice-snow surface. During the GPS surveying period, one support pole was closely stick to the yellow pole, which was located on the glacier' s ascending way contrast to the yellow monitoring pole (Fig. 3).

Whereas, the height of precise steel monitoring poles was measured from the transfer knot to the ice-snow surface (H1). In the same time the steel monitoring pole had additional height H2 and H3 (Fig. 4). H2 was just referenced for measurement, because the part of pole above H3 maybe flexible. But the pole below H3 is fixed inside the glacier. The height from bottom of the transfer knot to the bottom of GPS antenna is 3 cm.

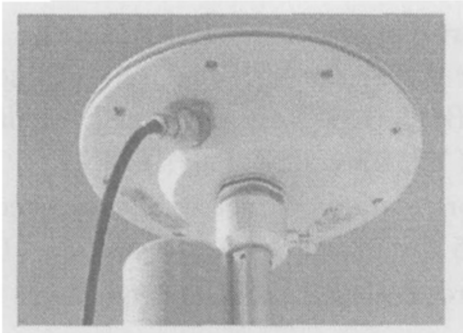

Fig 3 Relative position of both poles

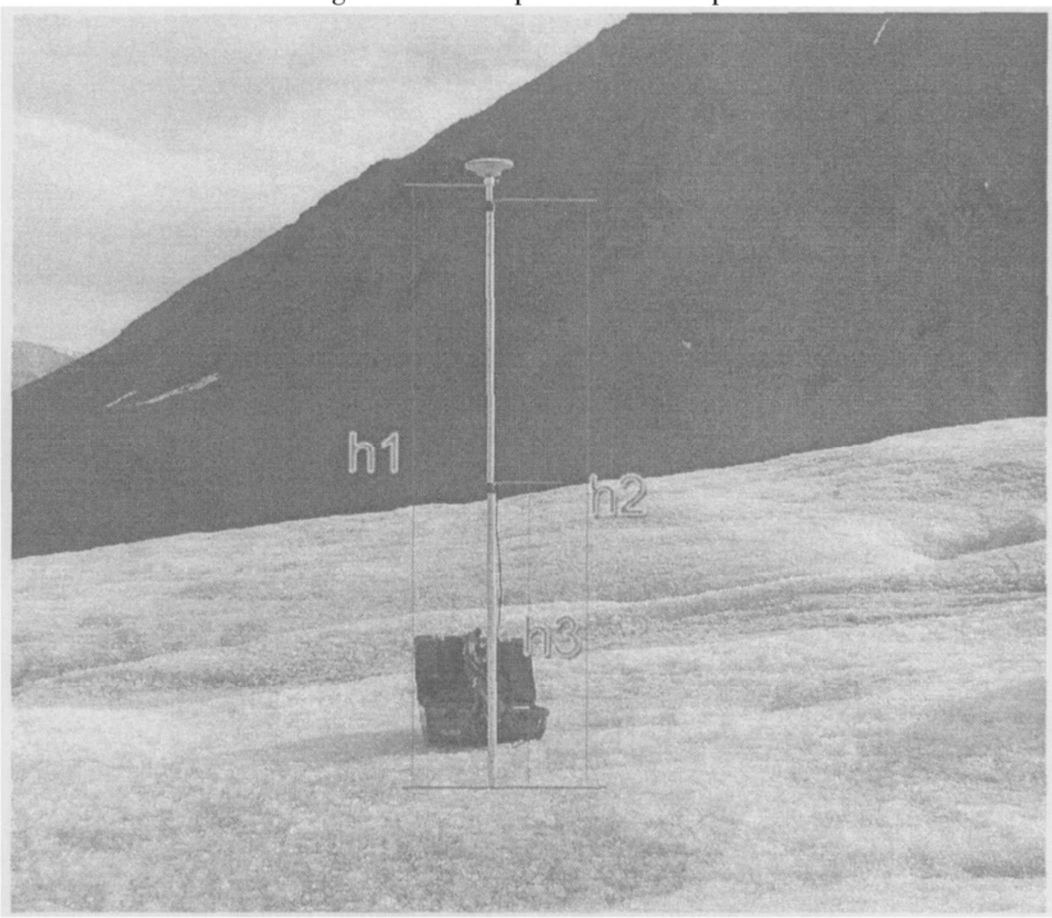

Fig 4 Height measurement for precise steel monitoring poles

With above works; all the monitoring poles' height list below (table1).

Table 1 List of time and monitoring poles' height of GPS measurement

Point Name	Time(UTC)	H1(m)	H2(m)	H3(m)
		Pedersenbreen		
P1	20050803 09:25	1.95		
P2	20050803 10:50	1.97		
P3	20050803 16:01	1.92	1.62	0.42
P4	20050803 12:57	1.94		
P5	20050803 14:21	2.53		
		Austre Lov•nbreen		
A1	20050806 11:43	2.85		
A2	20050806 10:28	1.91	1.86	0.97

A3	20050804 16:53	2.45		
B1	20050809 16:19	2.41		
B2	20050804 10:52	2.00	1.95	0.88
B2N	20050804 09:36	1.94	1.89	1.185
B2W	20050804 12:03	1.77	1.73	1.17
B2S	20050804 13:10	1.77	1.72	0.52
B2E	20050810 16:45	1.96	1.92	1.25
B3	20050804 15:37	2.15		
C1	20050806 14:19	2.20		
C2	20050809 09:02	1.94	1.94	0.75
C3	20050809 10:27	2.40		
D1	20050810 09:11	2.99		
D2	20050809 12:10	2.47		
D3	20050810 15:31	1.85	1.80	0.62
D4	20050731 15:07	2.34		
D5	20050731 16:56	2.73		
E1	20050810 11:04	2.62		
E2	20050810 13:26	2.31		1.40

2 Data process

2.1 GPS data preprocess

With field GPS surveying, multi-segment GPS observing data file of the 25 monitoring points were obtained. After data format exchange and period choice, the standard RINEX format GPS data of the 25 points were acquired. In order to get high precise positioning result with post process D-GPS method, the simultaneous GPS observing data files from Arctic Yellow River Station GPS tracking station were selected. In addition, it's was also very important work to preprocess the GPS antenna height, and to uniform the coordinate system, the coordinates of control point for future data process.

2.2 Data process

Post process D-GPS method was used, with Yellow River Station GPS tracking station as reference station, for processing the GPS observing data according to carrier phase differential theory. The mathematical model (Zhou *et al.* 2002) of GPS carrier phase differential theory is as below:

$$\varphi_i^j(t_i) = \frac{f}{c}\rho_i^j(t_i) + f[\delta t_i(t_i) - \delta t^j(t_j)] - N_i^j(t_0) + \frac{f}{c}\delta_i\rho_{trop} - \frac{f}{c}\delta_i\rho_{ion} + \frac{f}{c}\varepsilon_{\varphi i}^j(t_i) \qquad (2.1)$$

$$P_i^j(t_i) = \rho_i^j(t_i) + [\delta t_i(t_i) - \delta t^j(t_j)] + \delta_i\rho_{trop} + \delta_i\rho_{ion} + \varepsilon_{Pi}^j(t_i) \qquad (2.2)$$

Formula (2.1), (2.2) are original observing equations which only consider the L1 and CA code of GPS signal, where $\varphi_i^j(t_i)$ is the carrier phase observing value from receiver i to

GPS satellite j (unit is circumference); $P_i^j(t_i)$ is the pseudo distance value from receiver i to GPS satellite j (unit is meter); f is the frequency of the carrier; c is the velocity of light; $\delta^j(t_i)$ and $\delta_i(t_i)$ is the clock error of satellite j and receive i respectively; $\delta_i^j\rho_{trop}$ is the troposphere delay error from receiver i to satellite j; $\delta_i^j\rho_{ion}$ is the ionosphere delay error from receiver i to satellite j; $\rho_i^j(t_i)$ is the geometrical distance from receiver i to satellite j; $N_i^j(t_0)$ is the integer ambiguity at the time t_0 from receiver i to satellite j, which will keep invariable if no circumference jump; $\varepsilon_{\varphi i}^j(t_i)$ is the surveying noise and other error (including ephemeris error, multi-path error) during the carrier phase observing from receiver i to satellite j. By differential process between receivers and satellites with single epoch observing equations, and ignoring the troposphere delay as well as the ionosphere delay in fast short distance measurement, the double differential equations of carrier and pseudo observing value between receivers and satellites can be obtained:

$$\nabla\Delta\varphi_{12}^{jl}(t_i) = \frac{f}{c}\nabla\Delta\rho_{12}^{jl}(t_i) - \nabla\Delta N_{12}^{jl}(t_0) + \frac{f}{c}\nabla\Delta\varepsilon_{\varphi 12}^{jl}(t_i) \qquad (2.3)$$

$$\nabla\Delta P_{12}^{jl}(t_i) = \nabla\Delta\rho_{12}^{jl}(t_i) + \nabla\Delta\varepsilon_{P12}^{jl}(t_i) \qquad (2.4)$$

In formula (2.3), (2.4):

$$\nabla\Delta\rho_{12}^{jl}(t_i) = \rho_1^j(t_i) - \rho_2^j(t_i) - \rho_1^l(t_i) + \rho_2^l(t_i)$$

$$\nabla\Delta N_{12}^{jl}(t_0) = N_1^j(t_0) - N_2^j(t_0) - N_1^l(t_0) + N_2^l(t_0)$$

Because the clock errors of receivers and satellites are removed in double differential equations, and the influences of troposphere and ionosphere are greatly reduced or eliminated during the fast short distance static relative positioning, the ideal precision can reach mm level (Liu 2002). So this method is good enough for the glaciers' monitoring works whose required precision only in several centimeters.

As the two glaciers are all less than 10 km away from Yellow River Station GPS tracking station, the surveying there can be seen as short distance measurement. With the post differential D-GPS process, good results of high quality were got. The software used for processing the GPS data is TGO1.5, under WGS84 coordinate system, and elevation mask set 15 degree. The Yellow River Station GPS tracking station (code: CNYR) is reference station, which is located at 78°55′21.36″N, 11°56′07.81″E, 46.116m. After data process, the glacier monitoring points' coordinates are listed below (Table 2).

Table 2 Coordinates of the monitoring points get at first time

Point Name	Latitude	N error	Longitude	E error	Height	h error
CNYR	78°55′21.36000″N	.000m	11°56′07.81000″E	.000m	46.116m	.000m
			Austre Lov•nbreen			
D4	78°52′13.88821″N	.002m	12°10′58.49441″E	.002m	407.091m	.008m
D5	78°52′17.95681″N	.002m	12°12′56.54788″E	.002m	474.835m	.009m
A3	78°53′04.07419″N	.002m	12°09′42.02856″E	.002m	195.329m	.008m
B2	78°52′55.68222″N	.002m	12°08′42.18749″E	.002m	249.052m	.008m
B2N	78°52′57.37322″N	.002m	12°08′43.96118″E	.002m	243.329m	.008m
B2S	78°52′53.73068″N	.002m	12°08′40.11264″E	.002m	255.380m	.008m
B2W	78°52′56.08386″N	.001m	12°08′32.05113″E	.001m	249.902m	.005m

B3	78°52′52.37265″N	.003m	12°09′17.47730″E	.002m	253.432m	.009m
A1	78°53′06.43612″N	.002m	12°08′38.68545″E	.002m	203.223m	.007m
A2	78°53′06.54920″N	.002m	12°09′12.19707″E	.002m	200.884m	.008m
C1	78°52′34.96545″N	.002m	12°07′59.78995″E	.002m	315.439m	.008m
B1	78°52′56.94152″N	.002m	12°08′08.58737″E	.002m	248.480m	.011m
C2	78°52′33.58071″N	.002m	12°08′36.46295″E	.002m	313.735m	.007m
C3	78°52′33.75541″N	.002m	12°09′13.05403″E	.002m	308.979m	.007m
D2	78°52′18.55582″N	.002m	12°07′40.14233″E	.001m	360.465m	.006m
B2E	78°52′55.27178″N	.002m	12°08′52.46330″E	.002m	248.353m	.007m
D1	78°52′15.30490″N	.002m	12°06′29.13238″E	.002m	413.181m	.007m
D3	78°52′18.22709″N	.003m	12°09′32.59366″E	.002m	367.152m	.009m
E1	78°51′47.55313″N	.002m	12°09′09.35655″E	.001m	470.912m	.013m
E2	78°51′48.73665″N	.001m	12°10′38.78124″E	.001m	445.456m	.006m
			Pedersenbreen			
P1	78°52′33.41423″N	.002m	12°18′18.20146″E	.002m	197.917m	.009m
P2	78°52′17.13132″N	.002m	12°17′33.24910″E	.002m	275.790m	.008m
P3	78°51′48.08060″N	.003m	12°17′00.44056″E	.002m	361.499m	.009m
P4	78°51′29.07536″N	.002m	12°17′09.38360″E	.002m	421.296m	.008m
P5	78°51′03.20327″N	.002m	12°17′15.29366″E	.001m	495.950m	.007m

2.3 *Error analyze*

The data process results above indicated that the errors of the entire glacier monitoring points are below 1.5 cm. The errormost point in elevation is E1, which is 1.3 cm; the errormost point in plane is D3, and their error ellipses are showed below (Fig 5). In generally speaking, the precision of the data process results is fully satisfied with the planed glacier monitoring and research work.

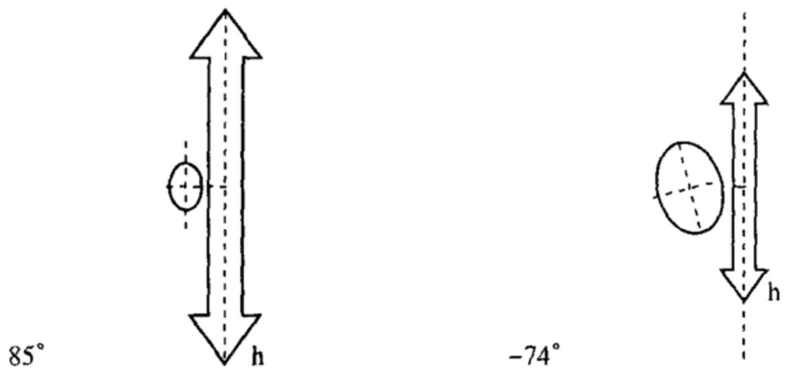

Fig 5 Error ellipse of monitoring point E1 and D3

3 Conclusion and discuss

The GPS monitoring for Austre lov•nbreen and Pedersenbreen on 2005 is the first time to research the Arctic land border glaciers by Chinese scientists, there may be more relevant research works in the future. As for this expedition, the conclusions are as the following.

(1) Due to the obvious multi-path influence on the glaciers, the GPS antenna height should be increased as higher as possible in fieldwork, and the elevation mask should be appropriately increased in data process. (2) It is found that during the period 2-3 o' clock pm, the quality of the field GPS surveying data is worse than other time period in one day. Maybe it is caused by the relatively strong ionosphere activity near by after noon time (Hu *et al.* 2001), which interferes the receiver in GPS signal receiving. Yet it needs to be studied deeply. So, it's better that field GPS surveying work is out of this time period or to increase the observing time length in this period. (3) In addition, the GPS equipment in field works should better be able to show the current satellite state. For example, the GPS receiver can show the GDOP value of current satellites. When GDOP is larger than 5, it indicates that the geometrical intensity of GPS constellation is bad, then it is need to extend the observing time length according to the practical status, waiting for better geometrical intensity of GPS constellation and getting better positioning effect.

Additionally, the author propose the followings for future work according to above conclusion and the unsolved problems this time. (1) The quantitative movement of the glaciers. The authors repeatedly measured the points D3, E2, and D1 on Austre Lov•nbreen glacier, and the repeat period was 10 days or so. After data process, it was found that the glacier is moving toward downriver 1–1.5 cm everyday at middle glacier in August. The movement tendency is evidently, but the glacier will not move so rapidly in the wintertime. At least it can be inferred that the glacier will move more than 1 meter every recent year. Of course it's need to be verified in the future work. Some future works were also needed to testify whether or not the glacier is in its leaping period as moving so rapidly. (2) Multi-technique cooperated to research on the glaciers.

Although the authors can get high precise monitoring data using GPS method, the results is some separated points, and the fieldwork is very hard. The followings are recommended for future research:

i. Application of multi-period large area satellite images, with which the researchers can monitor the whole two glaciers in long time period; ii. Application of aviation photogrammetry method to get the three-dimensional photos and to acquire the digital elevation model (DEM) of the whole glacier drainage area; iii. Setting up automatic weather station on the glacier, so the researchers can get the accurate glacier meteorological data, which is good for improving the GPS measure precision and monitoring area; iv. Application of wireless communication method, to set up sensor on glacier and transfer gathered data to Yellow River Station, then researchers can remotely download the monitoring data via Internet connected to Yellow River Station, which will greatly improve the updated rate of research work.

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