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ESTABLISHMENT OF SURVEYING SYSTEM OF THE GREAT WALL STATION

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Abstract It is the main task of the antarctic surveying expedition to establish the surveying system. In three times of the antarctic surveying research expeditions, a complete and accurate surveying system has been established in the Chinese Great Wall Station area. The surveying system includes geodetic coordinate system, elevation system and gravity reference system. In this paper, the surveying methods and the mathematical models for establishing these systems are discussed, and the accuracy of results is analysed.

Key words Great Wall Station, geodetic coordinate system, elevation system, gravity reference system

1. The Establishment of the Geodetic Coordinate System of the Great Wall Station

The Chinese Great Wall Station is situated in the eastern part of the Fildes Peninsula. King George Island, south shetland islands. The distance between the station and China is about seventeen thousand kilometres. We could not tie in the station with China to form a unified geodetic coordinate system by traditional and ordinary geodetic methods. So it is necessary to set up a local geodetic coordinate system.

1. *Setting up the Origin and Determing the Geodetic Datum*

The datum point is set up on the West Mountain in the western area of the station. And a concrete observation pillar is established on it. In the spring of 1985, we used a MX-1502 Doppler receiver to perform Doppler observation and got the date of 210 successful satellite passes during five observation periods. The date were processed with J. Kouba Semi-Short-Arc Program to determine the position of the datum point. The geocentric rectangular coordinates of the datum point are as follows (E Dongchen *et al.* 1985):

$X=1536\ 848.80\ \text{m} \pm 1.63\ \text{m}$

$Y=-2554\ 169.62\ \text{m} \pm 0.86\ \text{m}$

$Z=-5619\ 835.53\ \text{m} \pm 0.53\ \text{m}$

Because there are errors in ephemeris, in time signal, in polar motion, in coordinate system and in each physical parameter, the geocentric coordinates calculated from broadcast ephemeris differ from the ones calculated from precise ephemeris. The relationship between these coordinates is (Leroy, 1982.):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PE} = \begin{bmatrix} 0 \\ 0 \\ -2.6 \end{bmatrix} + (1+2.2\times10^{-7}) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{BE} \tag{1}$$

Where the subscript BE indicates that the results are calculated from broadcast ephemeris, and the subscript PE indicate that the results are calculated from precise ephemeris.

The relationship between the coordinates calculated from precise ephemeris and the real geocentric coordinates is given by:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PE} + \begin{bmatrix} K & E_z & 0 \\ -E_z & K & 0 \\ 0 & 0 & K \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PE} + \begin{bmatrix} 0 \\ 0 \\ Z_0 \end{bmatrix} \tag{2}$$

Thus the absolute errors in the datum point of the Great Wall Station are:

$dX=-10.525$ m

$dY=-4.941$ m

$dZ=+2.248$ m

According to the relationship between rectangular space coordinate and geodetic coordinate (Xu Shaoquan, 1986), the geodetic coordinates of the datum point could be given as follows:

$B=62°12'\ 59''782$ S

$L=58°57'\ 52''546$ W

$H=44.081$ m

Thus the absolute errors in the datum point of the Great Wall Station are:

$dB=+4.''4773$

$dL=+3.''0989$

$dH=-2.514$ m

The direction of the geodetic coordinate system of the Great Wall Station is determined by observing the sun using a Wild T_2 theodolite ($m_\alpha=\pm 2''$).

After corrected, the geodetic azimuth from the datum point to the astronomical azimuth point is:

$A=139°03'\ 54''5$

2. The Rectangular Plane Coordinate of the Great Wall Station

The Gauss–Krüger coordinate is used as the rectangular plane coordinate of the Great Wall Station. Based on the geodetic coordinate of the origin of the Chinese Great Wall Station, the Gauss–Krüger coordinate of the origin and the initial grid azimuth have been calculated by using Gauss projection formula (Geodesy Section, WTUSM 1986.):

$X=98918.210$ m (additive constant 7000 km)

$Y=201841.083$ m (additive constant 200 km)

$T=139°05'47''5$ (to the astronomical azimuth point)

3. The Horizontal Control Network in the Great Wall Station Area

The horizontal control network in the Great Wall Station is shown in Fig. 1. Because of bad weather condition, the range observation was performed instead of angular observation. The distances were measured with EDMI DI 20. The coordinates of the points of the horizontal network were calculated by using rank defect free network adjustment.

The adjusted coordinates of the points of the horizontal control network and their standard errors are listed in Table 1. And the error ellipse of each point is shown in Fig. 2. Thus it can be seen that the horizontal control network is very accuracy. All control points are satisfactory for surveying 1/1000 topographic map.

2. The Establishment of the Great Wall Station's Elevation System

1. Setting up the Origin of Heights and Determining its Height

The origin of the height of the Chinese Great Wall Station S_2 is set up on a bedrock near

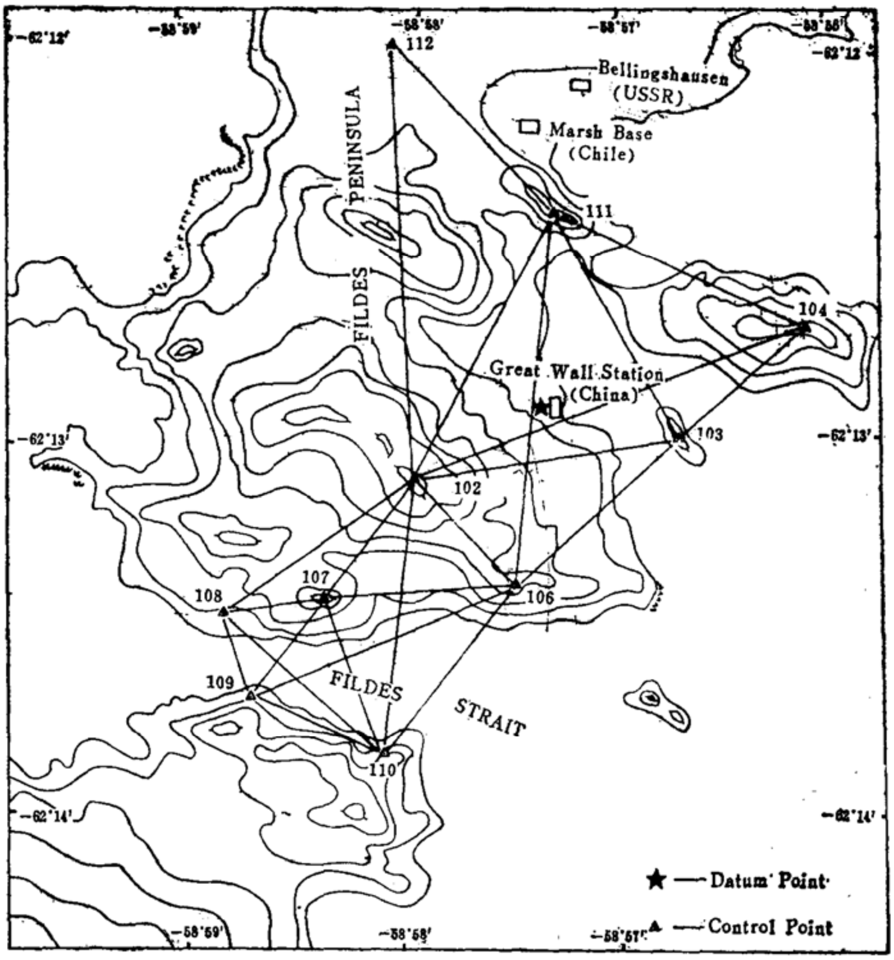

Fig. 1 The horizontal control network of Great Wall Station area.

Table. 1 The coordinates and mean squre of the points.

control point	x(m)	y (m)	M (mm)
102	98340.549	201320.925	±7.6
106	97475.247	202121.976	±6.9
107	97464.549	200459.691	±6.7
108	97518.500	199753.865	±8.7
110	96395.276	200868.977	±6.7
109	96858.765	199973.638	±8.2
103	98550.839	202899.258	±7.5
104	99230.502	203521.842	±8.2
111	100172.464	202343.431	±7.3
112	101264.656	201221.558	±12.7

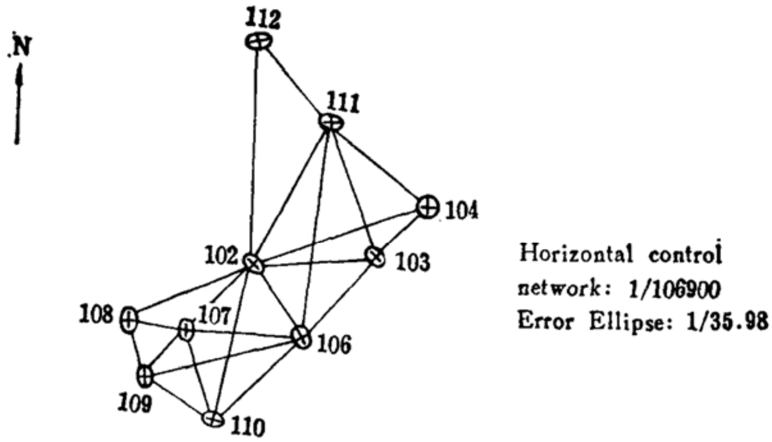

Fig. 2 The standard error ellipse of the points.

the Great Wall Bay Dock (See Fig. 3). An extra origin of height S_1 is set up on a huge stone in the beach. The copper marks are set up on S_2 and S_1. From December 1984 to January 1985, the manual tide-gauge was performed, and from December 1985 to April 1986, automatic tide-gauge was performed in Great Wall Bay. Thus we have got the heights of the origins (S_2, S_1) by performing precise level tie-in. They are: $S_2=6.741$m $S_1=2.673$m

2. *The Normal Height System*

Besides S_2 and S_1, the other three level points (S_5, S_3 and S_4) are set up on the bedrock in the north part, south part and central part of the station area respectively. There are copper marks on all level points. The first-order precise level was performed between these points (see Fig. 3). After the observations were adjusted, and the corrections for the slope of level surface were added, the normal height of each leveling point was obtained (Xu Shaoquan, Wang Shengding, 1988)

$S_1=2.673$ m $S_2=6.741$m $S_3=10.223$m $S_4=15.325$m $S_5=13.432$m

3. *The Elevation Control Network*

In Great Wall Station area, the elevation control points coincide with horizontal control points (see Fig. 1). The heights of these points were obtained by triangulated height method. The distances were observed by EDMI DI 20, and the elevations were observed by theodolite Wild T_2. The following fomula was used to calculate height differences:

$$H_B-H_A=D\left(1+\frac{\Delta H_m}{N_A}\right)\cdot\sin\alpha_{12}+\frac{D^2}{2N_A}(1+\eta^2\cdot\cos^2\beta_{12})+i_1-v_2 \tag{3}$$

where D: the slope distance with meteorological corrections; $\Delta H_m=\frac{1}{2}(H_A+H_B)$; H_A: approximate geodetic height of the station; H_B: approximate geodetic height of sighting point; α_{12}: elevation with the vertical deflection correction (δ_μ) and the atmospheric refraction correction (δ_ν); $\eta^2=e^2\cdot\cos^2B$.

$$\delta_\mu=-(\xi\cdot\cos\beta_{12}+\eta\cdot\sin\beta_{12}) \tag{4}$$

$$\delta_\nu=K\cdot\frac{D}{2N_A}\cdot\rho'' \tag{5}$$

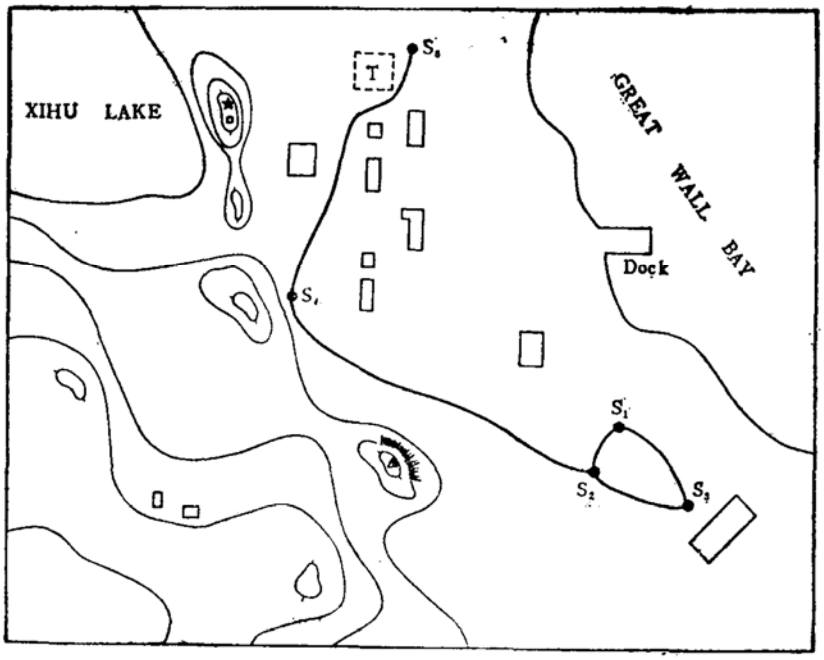

Fig. 3 The first-order Level of Great Wall Station.

where $K=1+\frac{N_A}{D}(\alpha_{12}+\alpha_{21})$, the result of test indicats that in the Great Wall Station area $K=0.1$; β_{12}: the azimuth of each direction; B: the geodetic latitude of each station; N_A: radius of curvation in the prime vertical at each station; ξ-η: deflection components.

When the height of EDMI does not equal the height of the theodilite, the following formula is used to get the distance D:

$$D=(D'^2+d^2\cdot\sin^2\alpha_{12}-d)^2+2d.\sin\alpha_{12} \tag{6}$$

where $d=(v_2-v_2')-(i_1-i_1')$; v_2:the height of the signal; v_2':the height of the optical reflector; i_1: the height of the theodolite; i_1': the height of the EDMI; D': observed slope distance.

The successive approximation method was used in adjustment of elevation control network. The table 2 lists the adjusted normal heights of the points and their accuracy. The deflection of the vertical correction is neglected in calculation, thus the heights in table 2 are approximate normal heights.

Table 2. The normal heights and accuracy of the points.

points	H (m)	m_H (mm)	points	H (m)	m_H (mm)
102	154.64	0	109	25.52	±66
106	65.18	±82	103	31.95	±66
107	95.48	±30	104	61.95	±98
108	70.16	±30	111	51.29	±100
110	49.26	±56	112	60.49	±63

3. The Establishment of Great Wall Station Gravity Reference System

1. The Gravity Base Point of Great Wall Station

The gravity base point of Chinese Great Wall Station is set up in front of office building. During 1985, 11 to 1986, 4, two Lacoste-Romberg mode G gravimeter were used to make joint measurements between Great Wall Station and two International Gravity Standard Network Points ($ISGN_{71}$) in Santiago and Punta Arenas respectively in Chile. The computed gravity value is: 982208.682 mgal ± 0.04 mgal.

2. The Gravity Network in Great Wall Station Area

The gravity network points in Great Wall Station area coincide with its horizontal control network points. The gravity of the points was measured with two Lacoste-Romberg mode G gravimeter G–584, G–589 and by using loop observation method with base point as reference. In order to improve the accuracy, electronic reading was used, and G–584 was directed to north, G–589 to east respectively permanently.

Tide factor 1.16 and zero phase delay of theory tide (IAG, 1980) were assumed to compute the correction for each observation. The Zero-point correction for each loop is computed with the function of time. The observation equation for adjustment is the RMS of unit weight

$$g'_{\ell \cdot k} \cdot (T_k) - g_{\ell \cdot 1} - D_k \cdot (T_k) - d_k = 0 \tag{7}$$

is ± 0.05 mgal after adjustment. The gravity values of all points are listed in Table 3.

Table 3. The gravity values, geoid undulation, vertical deflection, free-air anomaly of the points.

points	g (mgal)	N (m)	ξ (s)	η (s)	$(g_0\text{-}r_0)_{air}$ (mgal)
102	982 175.116	23.931	1.17	1.60	134.676
106	982 196.331	24.280	1.17	1.61	128.414
107	982 188.836	23.875	1.17	1.61	130.232
108	982 195.389	23.858	1.19	1.58	129.019
110	982 200.760	24.077	1.18	1.60	127.956
109	982 205.186	23.940	1.19	1.58	125.066
103	982 193.340	22.948	1.18	1.57	124.439
104	982 201.885	24.301	1.17	1.60	123.763
111	982 196.656	24.019	1.17	1.60	124.466
112	982 192.105	23.657	1.18	1.60	122.743

3. The Computation of Geoid Undulation and Vertical Deflection

The geoid undulation and vertical deflection in Great Wall Station area were determined with gravimetry method. The formula computing geoid undulation is (Guan Zeling, Ning Jingsheng, 1981):

$$N = \frac{R}{4\pi\bar{r}} \int_0^{2\pi} \int_0^{\psi_0} (g_0 - r_0) \cdot s(\psi) \cdot \sin\psi d\psi d\alpha + \frac{R}{2\bar{r}} \sum_{n=2}^{n} Q_n \Delta g_n \tag{8}$$

where

$$Q_n = \int_{\psi_0}^{\pi} s(\psi) \cdot P_n \cdot \sin\psi d\psi.$$

The vertical deflection is computed with the following equation:

$$\begin{bmatrix} \xi \\ \eta \end{bmatrix} = \frac{1}{4\pi\bar{r}} \int_0^{2\pi} \int_0^{\psi} (g_\circ - r_\circ) \frac{ds(\psi)}{d\psi} \cdot \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix} \cdot \sin\psi d\psi d\alpha + \frac{1}{2\bar{r}} \sum_{n=2}^{n} A_n \begin{bmatrix} \dfrac{\partial \Delta g_n}{\partial \psi} \\ \dfrac{\partial \Delta g_n}{\cos\psi \cdot \Delta\lambda} \end{bmatrix} \quad (9)$$

where

$$An = Qn + \frac{S(\psi_0)}{n+1} \left[P_{n-1}(\psi_0) - \cos P_n(\psi_0)\right].$$

$\psi_0 = 7$, $N_{max} = 50$ were used while computing (transformed into WGS–72 system). Global $1° \times 1°$ mean anomaly is used to make up the insufficient of practical measurements. The results are listed in Table 3. The geoid undulation figure (Fig. 4) is drawn using N in Table 3.

Then free-air gravity anomaly is computed using the following equation:

$$(g_0 - r_0)_{air} = g + \Delta_1 g - r_0 \quad (10)$$

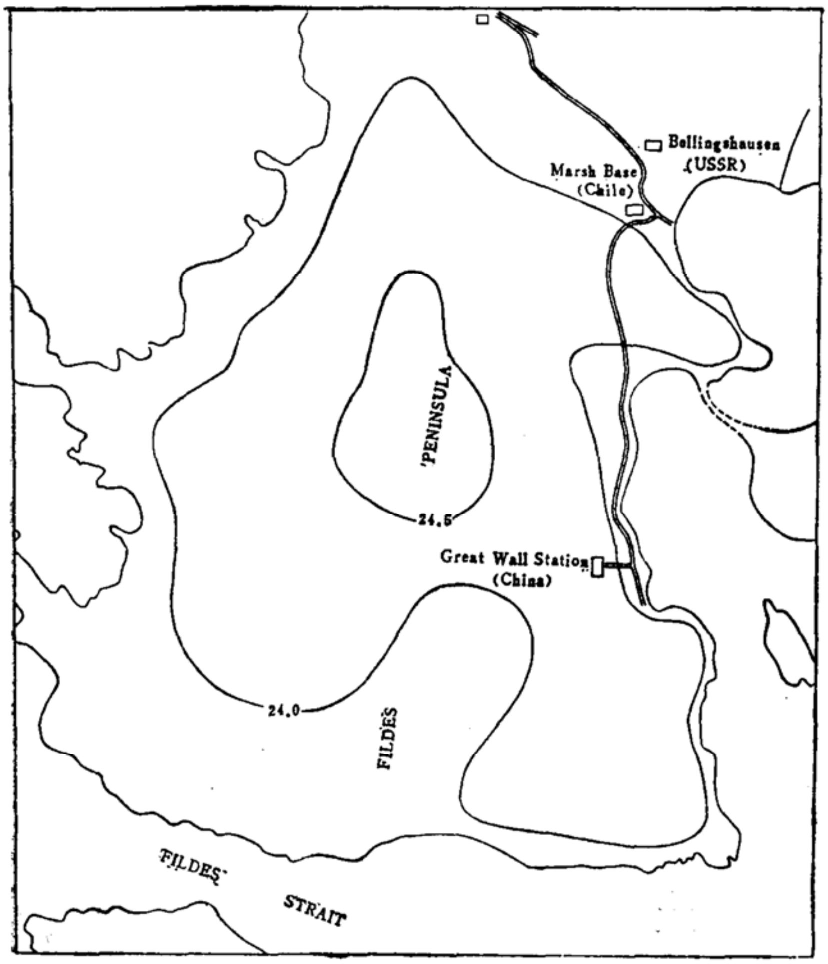

Fig. 4 The Geoid map of Great Wall Station area.

where $\Delta_1 g = 0.3086H - 0.72 \times 10^{-7} H^2$

The value of $(g_0 - r_0)_{air}$ for each point is listed in Table 3. Figure 5 showes the free-air gravity anomaly in Great Wall Station area.

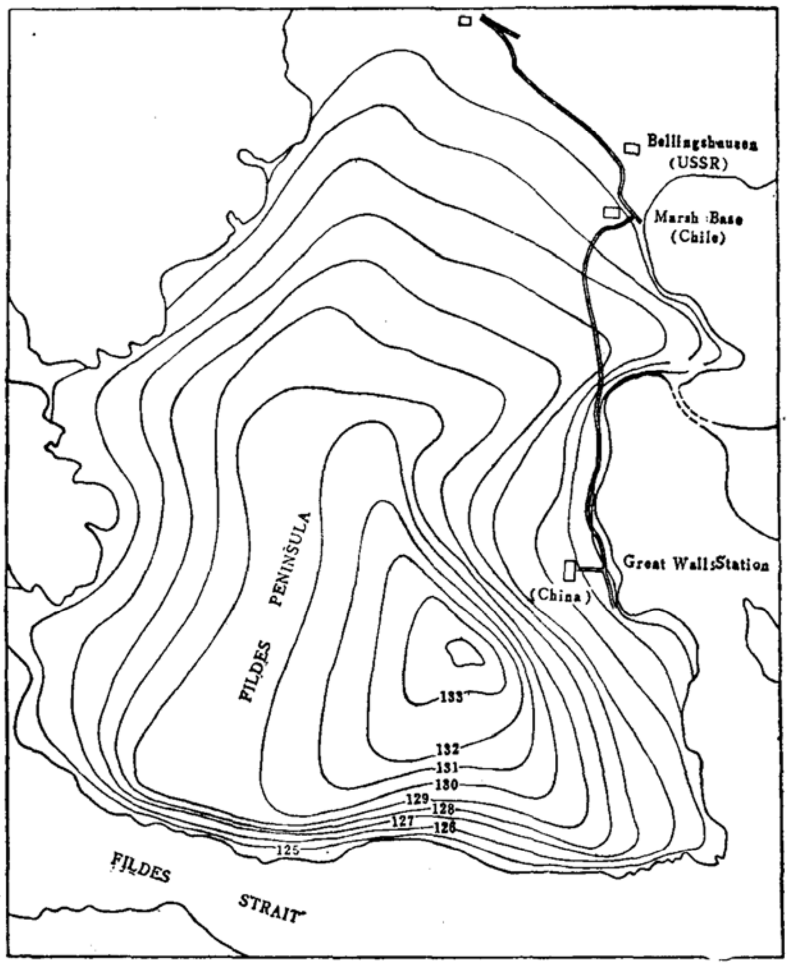

Fig. 5 The free-air gravity anomaly map of Great Wall Station area.

Summary

China has just begun to make the Antarctic surveying and mapping, so no examples can be followed. In this paper, the method of establishing surveying and mapping reference system in Chinese Great Wall Station is introduced systematically, the theory is precise and the accuracy of the reference is high. This is a successful experiment. The survey strategy is integral and appropriate for our Country in the special conditions of Antarctic. It also can be adopted and used for reference while establishing station in east Antarctic. The surveying and mapping in Antarctic will develop and improve further in the future with the Chinese Antarctic expedition in progress. The participants in the establishment of Surveying and Mapping reference system in Chinese Antarctic Great Wall Station are senior engineer E Dongcheng, Senior engineer Liu Yongnuo, Engineer Guo Xiaogang, Lecturer Wang Shengding and the author.
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