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# The first geodetic investigation at the summit of Dome A, Antarctica

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**Abstract** Dome A is the highest ice feature in the Antarctica, up to now, little is known about surface topography at Dome A. The first Chinese ITASE expedition was carried out from Zhongshan station to Dome A during the 1996/1997 austral summer. During the 2004/2005 austral summer, the traverse was extended to the summit of Dome A which is 1228 km from Zhongshan Station by 21st Chinese National Antarctic Research Expedition (CHINARE). The real-time kinematic (RTK) GPS survey was carried out in the summit of Dome A during 2004/05 austral summer. The surface topography of Dome A was drawn up using the kinematic double-frequency GPS data covering an area of about 70 $km^2$. The accuracy of the kinematic survey is in the range of 0.20 m. Precise surface topography, bedrock morphology and internal layering geometry are important for the future selection of the best site for deep drilling at Dome A.

**Key words** Antarctica, Dome A, GPS, topographic map.

## 1 Introduction

Dome Argus, the highest ice feature in the Antarctica, comprising a dome or eminence of just over 4000 m elevation, located near the center of East Antarctica and approximately midway between the head of Lambert Glacier and the South Pole. At first called "Dome A", details of the morphology of this feature were determined by the SPRI-NSF-TUD airborne radio echo sounding program, 1967-1979. Named by SPRI from Greek mythology; Argus built the ship in which Jason and the Argonauts traveled. The Gamburtsev subglacial mountains which underlie and extend beyond the area of Dome A were discovered by a Soviet Union Seismic party in 1958[1].

Surface topography is very important in many geoscientific and environmental studies of the Antarctica. Surface topographic measurement can be used as an important input to estimate the surface temperature, precipitation, and katabatic wind intensity and direction[2]. Elevation data can be used to infer the locations of ice divides, drainage basins, ice flow direction[3], and together with ice thickness data, to calculate driving stresses and ice deformational velocity, and to give a measure of subsurface and basal conditions[4]. Ice flows very slowly around Dome regions and thus the dynamics of Dome structure is difficult to measure and/or to characterize. The surface and bed topography at Dome C[5-7], Dome F[8] and the summit of Greenland[9] areas have been determined in recent years. Up to now, little is known about surface topography at Dome A.

In the framework of the International Trans-Antarctic Scientific Expedition (ITASE) and Chinese Antarctic glaciological research program, glaciological studies have been conducted along the transect from Zhongshan station to Dome A. The first expedition was carried out to a inland point 296 km away from Zhongshan station during the 1996/1997 austral summer (13th Chinese National Antarctic Research Expedition (CHINARE)). The traverse was extended southwards to 464 km during the 1997/1998 (14th CHINARE) and to 1128 km during the 1998/1999 (15th CHINARE) field season[10-13]. On 22 January 2002, an automatic weather station (AWS) was installed at LGB69 which is 160km away from the Zhongshan Station by the 18th CHINARE[14,15].

During the 2004/2005 austral summer season, the traverse was extended to the summit of Dome A which is 1228 km from the Zhongshan Station by 21st CHINARE. Along the traverse route, more than 20 GPS sites were established at approximately 50 km intervals to monitor the surface ice velocity, which will be reported in another paper. This paper presents the result of surface topography of the summit of Dome A from kinematic GPS. The surface mass balance was measured along the traverse by snow stakes established at 2 km intervals, the position of each stake was measured by a hand-held GPS navigator, the elevation of the profile was drawn from the GPS navigation data (Figure. 1).

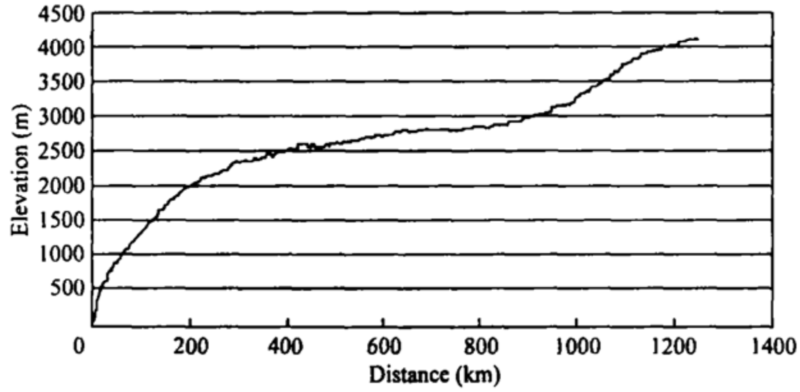


Fig. 1 The elevation curve of the transect from Zhongshan Station to Dome A (The distance is from Zhongshan Station).

## 2 Topographic survey and data processing

The first approximate summit of Dome A (Figure 2) was obtained from the RAMP DEM developed by Liu et al from Byrd Polar Research Center (BPRC). The RAMP DEM is a complete, seamless DEM of the Antarctica that has spatial resolution ranging from 200 m to 5 km. The vertical accuracy of the DEM is estimated to be about 100-130m over the rugged mountainous area, better than 2 m for the ice shelves, better than 15 m for the interior ice sheet, and about 35 m for the steeper ice sheet perimeter[16].

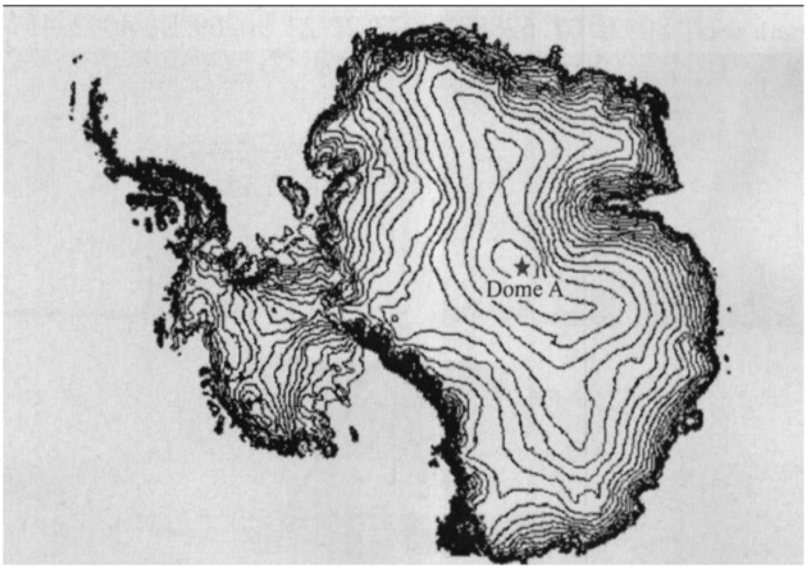


Fig. 2 Map of the Antarctic ice sheet showing location of Dome A.

GPS has become a standard tool for field measurement of surface topography in the interior of the Antarctic continent as it allows high precision measurements to be made relatively quickly and with minimum logistical support. Kinematic surveys are the most productive in those the greatest number of points can be determined in the least time. The use of radio links among the baseline stations leads to the real-time kinematic (RTK) technique. The kinematic method is best suited for wide open areas where there are few obstructions. The three-dimensional coordinates of vehicle-mounted receiver can be determined with high accuracy (few centimeters) so that accurate topographic map of the area can be rapidly prepared[17]. The real-time kinematic (RTK) GPS technique was chosen to map the surface topography of the summit area of Dome A.

Around this first approximate summit of Dome A, the survey was carried out using the Total Station during 9-11 January 2005 in order to obtain the second approximate summit of this area. The Dome A camp was set up at the second approximate summit, then the survey was carried out utilizing Real-Time Kinematic (RTK) GPS technique.

Two Leica SR530 dual frequency GPS receivers were used for the kinematic survey, with high sampling rates. Pseudorange and carrier-phase data on both frequencies were stored at every epoch. With a detachable terminal, plug-in batteries and slot-in PCMCIA cards, the receiver can be efficiently used for kinematic detail surveys. The receiver adopts the ClearTrakTM receiver technology. In a good environment with 5 or more satellites, the SR530 will initialize on-the-fly within 30 seconds on short and medium lines up to about 5 to 10 km. Also, the system 500 RTK has a comprehensive, easy-to-use man-machine-interface (MMI) [18].

One GPS receiver was located for reference at the camp. The GPS receiver was installed in the cabin, the antenna was mounted on the tripod approximately 10m from the cabin, the transmitting radio antenna which connected with the GPS receiver through a hole was mounted on the roof of the cabin. First, the reference station was occupied for 36 hours. The approximate location of the reference station was calculated utilizing LEICA Geo Office V1.0 (LGO) software-the point positioning program. The corresponding WGS84 ellipsoid coordinate was: 80°22′01.62888″S, 77°22′22.90269″E, 4092.457 m.

Fig. 3 The GPS reference station at Dome A.

The rover receiver was installed on the over-snow vehicle. The GPS receiver was held by the surveyor inside the vehicle, both of the GPS antenna and the receiving radio antenna were mounted on the roof of the over-snow vehicle which would afford optimum satellite visibility and tracking conditions.

Fig. 4 The rover receiver installed on the over-snow vehicle.

The survey was carried out on a "star" grid, centered around the camp, with radius of 4 ~ 5 km. The trajectory is shown in Figure 5. The square-shaped points are navigated coordinates derived using the uncorrected code solution of a single epoch, and the circular points are coordinates that have been differentially corrected. The sampling space is 200 m. The velocity of the vehicle ranges from 4 km/hour to 8 km/hour. During 5 days field work, more than 1000 points were measured altogether.

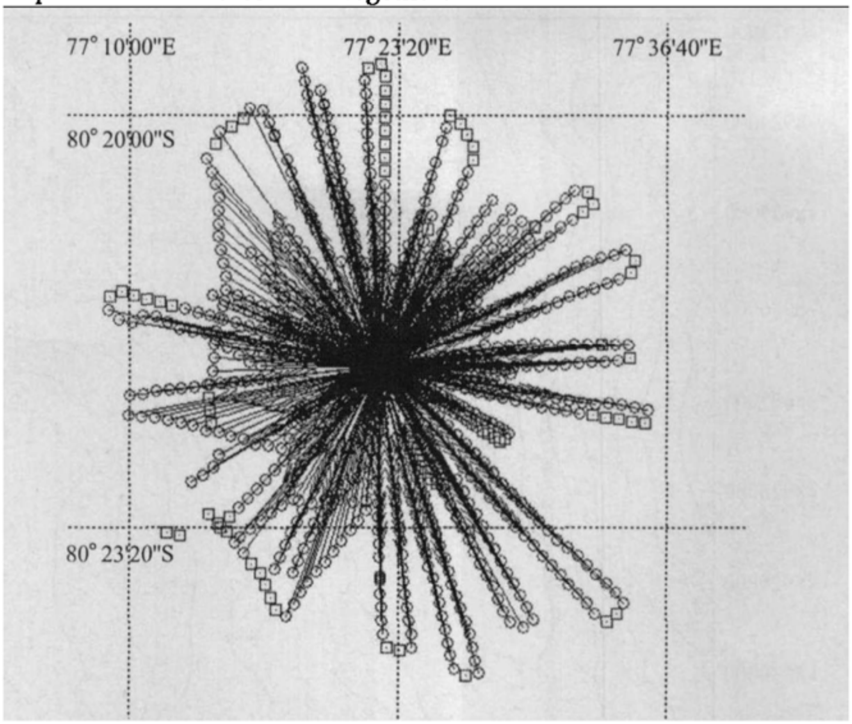


Fig. 5 The trajectory of 2005 kinematic GPS survey at Dome A.

GPS coordinates obtained in the kinematic survey were used to build the topography of the Dome A surface. Those points with an accuracy higher than 0. 10 m were eliminated from the dataset. Taking into account the tracked-vehicle penetration into the ice between one passage and the next, whose value was evaluated in the range of 0. 10 m, the accuracy is in the range of 0. 20 m. Finally, 480 points were used to build the topographic map of the summit of Dome A.

Surfer V7. 0 software was used to generate the contour map as the "kriging" gridding technique was chosen. The contour levels were plotted every 0. 25 m with highly smoothed contours. This was done in order to obtain a smoother topographic surface. A contour interval of 0. 25 m was adopted based on the tested accuracy of the GPS data. The map is shown in Figure 6.

## 3 Data post-processing

When back to China, the GPS data of the reference station at Dome A was processed using GAMIT/GLOBK software. GAMIT/GLOBK is a comprehensive GPS analysis package developed at MIT and Scripps for the estimation of three-dimensional relative position of ground stations and satellite orbits. The analysis software is composed of distinct modules, which perform the functions of preparing the data for processing, generating reference orbits for the satellites, computing residual observations and partial derivatives from a geometrical model, detecting outliers or breaks in the data, and performing a least squares analysis.

GAMIT uses both carrier phase and pseudorange observables. The most precise information can be obtained by the carrier phase, but with ambiguities on the integer number of wavelengths[19].

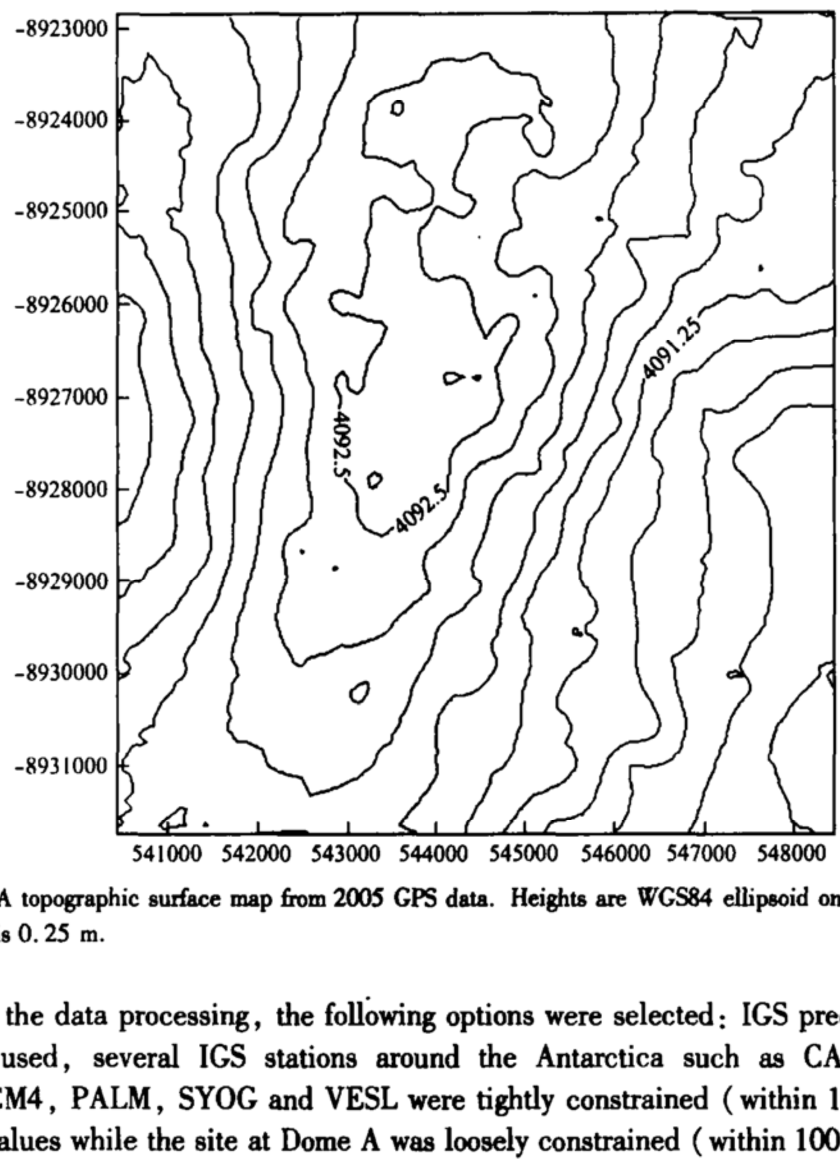


Fig. 6 Dome A topographic surface map from 2005 GPS data. Heights are WGS84 ellipsoid ones. Contour interval is 0.25 m.

During the data processing, the following options were selected: IGS precise ephemeredes were used, several IGS stations around the Antarctica such as CAS1, DAV1, MAW1, MCM4, PALM, SYOG and VESL were tightly constrained (within 1cm) at their ITRF2000 values while the site at Dome A was loosely constrained (within 100 m), an elevation cutoff angles of 15° was set, antenna phase center variation corrections were applied, the ionospheric-free linear combination of the L1 and L2 frequencies was used, corrections were applied for both the solid earth and frequency dependent tides, the dry component of the zenith tropospheric delay is implemented by Saastamoinen model, the wet component is estimated during the inversion, with zenith-delay adjustments every 2 hours etc. The coordinate of the reference station was: 80°22′01.64502″S, 77°22′22.90070″E, 4092.528 m, the difference between GAMIT result and LGO result is less than 1m. Based on the GAMIT result, all of the coordinates of the topographic points were corrected. The resulted map of Dome A was build from the corrected coordinates, shown as Figure 7.

The dome surface and the topographic summit is defined. The lowest surface height is 4090.2 m, giving a maximum surface height range of 2.7 m over the entire 70 km2 area. The surface slope value is less than 0.0008 in the summit area of Dome A. In other words, the surface topography of Dome A is very flat and smooth, which is similar to Dome C, Dome F and the summit of Greenland.

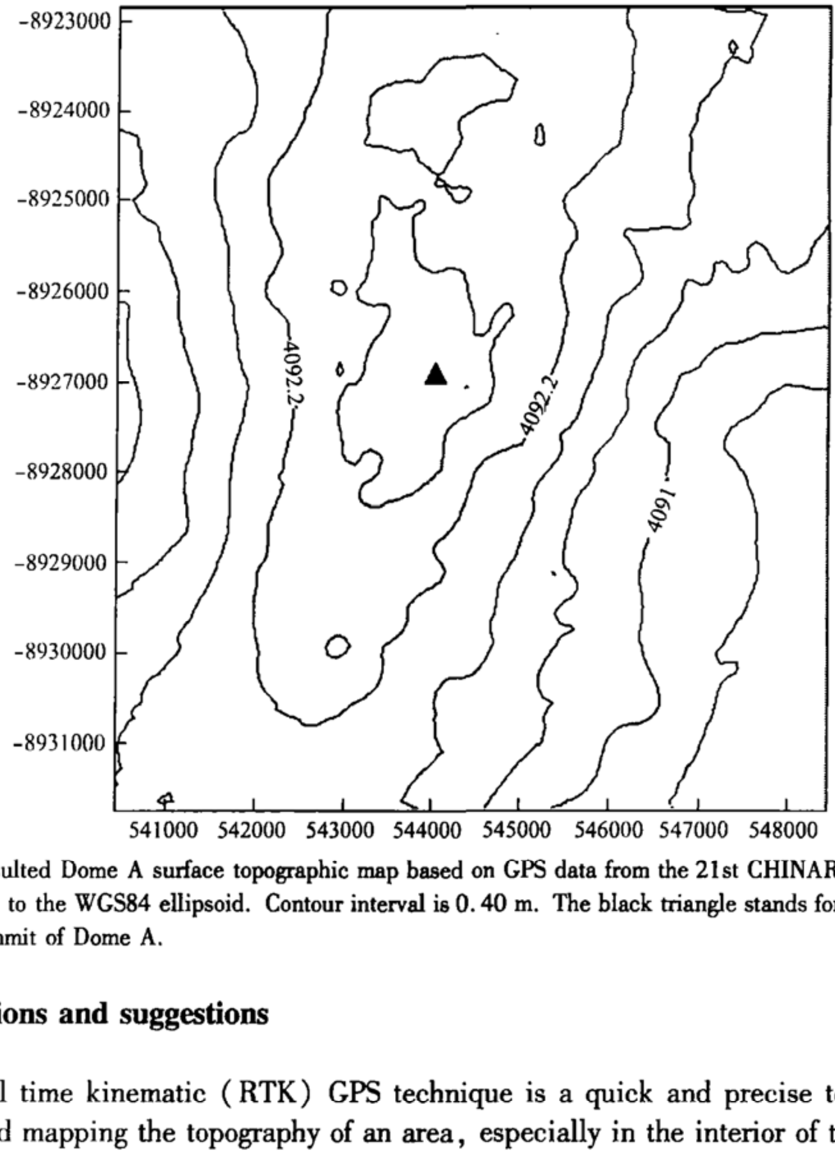


Fig. 7 The resulted Dome A surface topographic map based on GPS data from the 21st CHINARE. Heights are relative to the WGS84 ellipsoid. Contour interval is 0.40 m. The black triangle stands for the position of the summit of Dome A.

## 4 Conclusions and suggestions

The real time kinematic (RTK) GPS technique is a quick and precise technique for surveying and mapping the topography of an area, especially in the interior of the Antarctic continent. The main advantages of the method are high productivity and reliability of measurements, even in extreme environmental conditions.

The 2005 kinematic GPS data were used to map the topographic surface of the Dome A area, with an accuracy in the range of 0.20 m. The resulted map can be considered as the Dome A topographic reference map for the 2004/2005 austral summer. Because of the logistical restraint, only about 70 $km^2$ area was accomplished in 2005, the larger area is expected to be mapped in the next Chinese Dome A expedition.

Besides the kinematic GPS survey, the ground-based ice penetrating radar measurement was also deployed at the summit area of Dome A. As ice flow is related not only to the ice properties but also to ice thickness and bedrock slope, the precise surface morphology is important to detect the ice divide and the main ice-flow. Precise surface topography, bedrock morphology and internal layering geometry are all important for the future selection of the best site for deep drilling at Dome A. The GPS data and precise topography at Dome A will provide ground truth for the satellite mission such as ICESat, GRACE and Cryosat etc.

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## References

[1] ENEA(2006): Composite Gazetteer of Antarctica. 1217:1541.

[2] Marsiat I, Bamber JL (1997): The climatic of Antarctica in the UGAMP CGM: Sensitivity to topography. Annals of Glaciology. 25:79 - 84.

[3] Drewy D(1983): Antarctica: Glaciological and Geophysical Folio. Scott Polar Res. Inst., Univ. of Cambridge, Cambridge, U. K.

[4] Bamber JL, Bindschadler RA (1997): An improved elevation data set for climate and ice-sheet modeling: Validation with satellite imagery. Annals of Glaciology, 25: 430 - 444.

[5] Tabacco IE, Passerini A, Corbelli F, Gorman M (1998): Determination of the surface and bed topography at Dome C, East Antarctica. Journal of Glaciology, 44(146): 185 - 191.

[6] Capra A., Cefalo R, Gandolfi S, Manzoni G, Tabacco IE, Vittuari L (2000): Surface topography of Dome Concordia (Antarctica) from kinematic interferential GPS and bedrock topography. Annals of Glaciology, 30: 42 - 46.

[7] Remy F, Tabacco IE (2000): Bedrock features and ice flow near the EPICA ice core site (Dome C, Antarctica). Geophysical Research Letters, 27(3): 405 - 408.

[8] Dome F Deep Coring Group (1998): Deep ice-core drilling at Dome Fuji and glaciological studies in east Dronning Maud Land, Antarctica. Annals of Glaciology, 27:333 - 337.

[9] Hodge SM, Wright DL, Bradley JA, Jacobel RW, Skou N, Vaughn B(1990): Determination of the surface and bed topography in central Greenland. Journal of Glaciology, 36 (122): 17 - 30.

[10] Qin DH, Ren JW, Kang JC, Xiao CD, Li ZQ, Li YS, Sun B, Sun WZ, Wang XX(2000): Primary results of glaciological studies along an 1100km transect from Zhongshan station to Dome A, East Antarctic ice sheet. Annals of Glaciology, 31:198 - 204.

[11] Xiao CD, Ren JW, Qin Dahe, Li ZQ, Sun WZ, Allison I (2001): Correspondence. Complexity of the climatic regime over the Lambert Glacier Basin of the East Antarctic ice sheet: firn-core evidences. Journal of Glaciology, 47(156): 160 - 162.

[12] Zhang MJ *et al.* (2002): A continuous 250-year record of volcanic activity from Princess Elizabeth Land, East Antarctica. Antarct. Sci., 14(1): 55 - 60.

[13] Ren JW, Sun JY, Qin DH (2004): Preliminary results of ionic concentrations in snow pits along the Zhongshan-Dome A traverse route, Antarctica. Annals of Glaciology, 39: 155 - 160.

[14] Qin D, Xiao CD, Allison I, Bian LG, Rod S, Ren JW, Yan M (2004): Snow surface height variation on the Antarctica ice sheet in Princess Elizabeth Land, Antarctica: 1 year of data from an automatic weather station. Annals of Glaciology, 39: 181 - 187.

[15] Xiao CD, Allison I, Ren JW, Qin DH, Zhang MJ, Li ZQ (2004): Meteorological and glaciological evidence for different climatic variations on the east and west sides of the Lambert Glacier Basin, Antarctica. Annals of Glaciology, 39: 188 - 194.

[16] Liu HX, Kenneth CJ, Li BY (1999): Development of an Antarctic digital elevation model by integrating cartographic and remotely sensed data: A geographic information system based approach. Journal of Geophysical Research, 104(B10): 23199 - 23213.

[17] Hofmann-Wellenhof B, Lichtenegger H, Collins J (2001): Global Positioning System Theory and Practice, Fifth, revised edition. Springer, Wien New York.

[18] Peter J(1999): A high-performance, easy-to-use GPS surveying system. Technical paper published by Leica Geosystems AG.

[19] King RW(2002): Documentation for the GAMIT GPS analysis software (Version 10. 05). Unpublished, Massachusetts Institute of Technology.