Surface topography around the summit of Dome A, Antarctica, from real-time kinematic GPS

Knowledge of the surface topography of the Antarctic is very important because it is used as input to estimate the surface temperature, precipitation and katabatic wind intensity and direction (Marsiat and Bamber, 1997). Elevation data can be used to determine the locations of ice divides, drainage basins and ice-flow directions (Drewry, 1983). In addition, together with ice-thickness data, driving stress, deformational velocity and subsurface and basal conditions may be inferred (Bamber and Bindschadler, 1997).

Ice flows very slowly in the flat, inland polar summit regions, and thus the dynamics are difficult to measure. The surface and bed topography at Dome Concordia, Antarctica, (Dome C; Tabacco and others, 1998; Capra and others, 2000; Rémy and Tabacco, 2000), Dome Fuji, Antarctica, (Dome-F Deep Coring Group, 1998) and the summit of Greenland (Hodge and others, 1990; Hvidberg and others, 1997) have been determined in recent years. So far, however, little has been published on the surface topography at Dome Argus (Dome A), Antarctica.

Dome A, the highest ice feature in Antarctica at just over 4000 m elevation, is located near the centre of East Antarctica. Details of its morphology were first determined by the Scott Polar Research Institute (SPRI)–US National Science Foundation (NSF)–Technical University of Denmark (TUD) airborne radio-echosounding program, 1967–79. As a contribution to the International Trans-Antarctic Scientific Expedition (ITASE), Chinese National Antarctic Research Expedition (CHINARE) glaciological studies were conducted along a traverse line from Zhongshan station to Dome A during the austral summers from 1996/97 (13th CHINARE) to 2004/05 (21st CHINARE) (Qin and others, 2000, 2004; Xiao and others, 2001, 2004; Zhang and others, 2002; Ren and others, 2004).

During the 21st CHINARE, more than 20 global positioning system (GPS) sites were established at approximately 50 km intervals along the 1228 km traverse route, to monitor the surface ice velocity, which will be reported elsewhere. Here, we present the surface topography of the summit of Dome A measured by real-time kinematic (RTK) GPS, a tool that is well suited to surface topography measurements in the interior of the Antarctic as it allows high-precision measurements to be made relatively quickly and with minimum logistical support.

Based on an estimate of the summit position from the topography around Dome A, obtained from the RADARSAT-1 Antarctic Mapping Project (RAMP) digital elevation model (Liu and others, 1999), a survey was carried out during 9–11 January 2005 using a total station to obtain a second estimate of the summit position. A camp was set up at this new position which was established as a reference station, initially occupied by a GPS receiver for 36 hours. The location of the reference station was calculated using Leica Geo Office (LGO) V1.0 point positioning software. The World Geodetic System 1984 (WGS84) ellipsoid coordinates were 80°22′01.62888″ S, 77°22′22.90269″ E, 4092.457 m.

Two Leica SR530 dual-frequency GPS receivers were used for the kinematic survey. A rover receiver was installed on an over-snow vehicle. The survey was carried out on a ‘star’ grid, centered on the camp, with a radius of 4–5 km. The sampling space was 200 m. The speed of the vehicle ranged from 4 to 8 km h^{-1}. After 5 days of fieldwork, more than 1000 points had been surveyed.

GPS data were processed using GAMIT/GLOBK software (King, 2002). During the data processing:

1. International GPS Service (IGS) precise ephemerides were used;
2. several IGS stations around Antarctica (e.g. CAS1, DAV1, MAW1, MCM4, PALM, SYOG and VESL) were tightly constrained (within 1 cm) at their ITRF2000 values while the site at Dome A was loosely constrained (within 100 m);
3. an elevation cut-off angle of 15° was set;
4. antenna phase centre variation corrections were applied;
5. the ionospheric-free linear combination of the L1 and L2 frequencies was used;
6. corrections were applied for both the solid-Earth and frequency-dependent tides;
7. the dry component of the zenith tropospheric delay was estimated by the Saastamoinen model; and
8. the wet component was estimated during the inversion, with zenith-delay adjustments every 2 hours.

The coordinates of the reference station were 80°22′01.64502″ S, 77°22′22.90070″ E, 4092.528 m. The difference between the GAMIT result and the LGO result was <1.0 m horizontally, and <0.1 m vertically. All topographic point coordinates were corrected, based on the GAMIT result.

GPS coordinates were used to build the topography of the Dome A surface. Points with GPS errors >0.10 m in the vertical were eliminated. Taking into account the tracked-vehicle penetration into the ice between one passage and the next (estimated at ~0.10 m), our topography accuracy is estimated to be ~0.20 m. Eventually, 480 points were used to build the topographic map of the Dome A summit area.

Surfer V7.0 software was used to generate a contour map of surface elevation (Fig. 1). The ‘kriging’ gridding technique was chosen. Contour levels are plotted at every 0.40 m, with highly smoothed contours based on the tested accuracy of the GPS data. The dome surface and the topographic summit are defined. The lowest surface height within the grid is 4090.2 m, giving an elevation range of 2.7 m over the entire 60 km^2 area. The surface slope is $<0.08\%$ in the summit area, indicating a very flat and smooth surface.

Because of logistical constraints, an area of only ~60 km^2 was measured during 2005. A larger area is expected to be mapped during the expeditions of the International Polar Year (IPY, 2007–08). In addition to the kinematic GPS survey, ground-based ice-penetrating radar measurements were made. As ice flow is related to ice thickness and bedrock slope, precise surface morphology is important to determine the ice divide and ice-flow parameters. Precise surface topography, bedrock morphology and internal layering geometry are all important for the future selection of the best site for deep ice-core drilling at Dome A. The GPS data and precise topography at Dome A will also provide ground truth for satellite missions such as ICESat (Ice, Cloud and land Elevation Satellite), GRACE (Gravity Recovery and Climate Experiment) and CryoSat.

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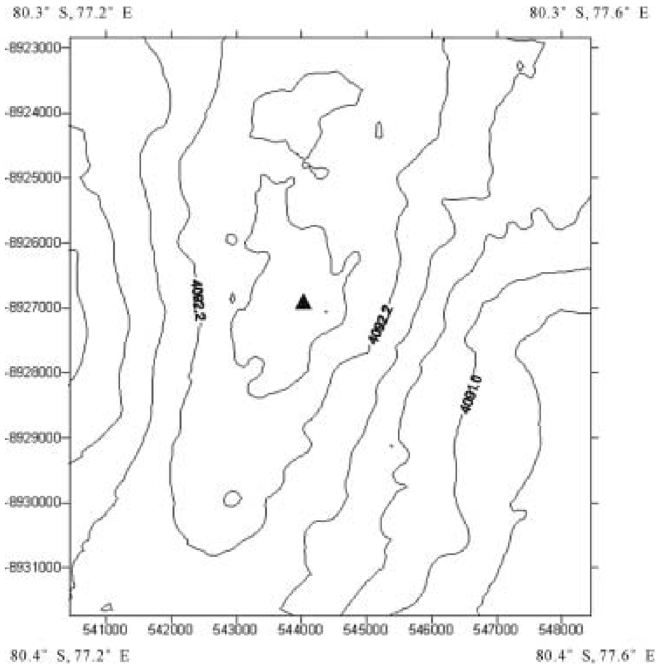

Fig. 1. Dome A surface topographic map based on GPS data from the 21st CHINARE. Heights are relative to the WGS84 ellipsoid. Contour interval is 0.40 m. The black triangle indicates the position of the summit of Dome A.

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REFERENCES

Bamber, J.L. and R.A. Bindschadler. 1997. An improved elevation dataset for climate and ice-sheet modelling: validation with satellite imagery. *Ann. Glaciol.,* **25**, 439–444.

Capra, A., R. Cefalo, S. Gandolfi, G. Manzoni, I.E. Tabacco and L. Vittuari. 2000. Surface topography of Dome Concordia (Antarctica) from kinematic interferential GPS and bedrock topography. *Ann. Glaciol.,* **30**, 42–46.

Dome-F Deep Coring Group. 1998. Deep ice-core drilling at Dome Fuji and glaciological studies in east Dronning Maud Land, Antarctica. *Ann. Glaciol.,* **27**, 333–337.

Drewry, D.J. 1983. *Antarctica: glaciological and geophysical folio.* Cambridge, University of Cambridge. Scott Polar Research Institute.

Hodge, S.M., D.L. Wright, J.A. Bradley, R.W. Jacobel, N. Skou and B. Vaughn. 1990. Determination of the surface and bed topography in central Greenland. *J. Glaciol.,* **36**(122), 17–30.

Hvidberg, C.S., K. Keller, N.S. Gundestrup, C.C. Tscherning and R. Forsberg. 1997. Mass balance and surface movement of the Greenland ice sheet at Summit, central Greenland. *Geophys. Res. Lett.,* **24**(18), 2307–2310.

King, R.W. 2002. *Documentation for the GAMIT GPS analysis software, release 10.05.* Cambridge, MA, Massachusetts Institute of Technology.

Liu, H., K.C. Jezek and B. Li. 1999. Development of an Antarctic digital elevation model by integrating cartographic and remotely sensed data: a geographic information system based approach. *J. Geophys. Res.,* **104**(B10), 23,199–23,213.

Marsiat, I. and J.L. Bamber. 1997. The climate of Antarctica in the UGAMP CGM: sensitivity to topography. *Ann. Glaciol.,* **25**, 79–84.

Qin, D. *and 8 others*. 2000. Primary results of glaciological studies along an 1100 km transect from Zhongshan station to Dome A, East Antarctic ice sheet. *Ann. Glaciol.,* **31**, 198–204.

Qin, D. *and 6 others*. 2004. Snow surface height variations on the Antarctic ice sheet in Princess Elizabeth Land, Antarctica: 1 year of data from an automatic weather station. *Ann. Glaciol.,* **39**, 181–187.

Ren, J., J. Sun and D. Qin. 2004. Preliminary results of ionic concentrations in snow pits along the Zhongshan–Dome A traverse route, Antarctica. *Ann. Glaciol.,* **39**, 155–160.

Rémy, F. and I.E. Tabacco. 2000. Bedrock features and ice flow near the EPICA ice core site (Dome C, Antarctica). *Geophys. Res. Lett.,* **27**(3), 405–409.

Tabacco, I.E., A. Passerini, F. Corbelli and M.R. Gorman. 1998. Determination of the surface and bed topography at Dome C, East Antarctica. *J. Glaciol.,* **44**(146), 185–191.

Xiao, C., J. Ren, D. Qin, H. Li, W. Sun and I. Allison. 2001. Correspondence. Complexity of the climatic regime over the Lambert Glacier basin of the East Antarctic ice sheet: firn-core evidences. *J. Glaciol.,* **47**(156), 160–162.

Xiao, C., I. Allison, J. Ren, D. Qin, M. Zhang and Z. Li. 2004. Meteorological and glaciological evidences for different climatic variations on the eastern and western sides of Lambert Glacier basin, Antarctica. *Ann. Glaciol.,* **39**, 188–194.

Zhang, M.J. *and 6 others*. 2002. A continuous 250-year record of volcanic activity from Princess Elizabeth Land, East Antarctica. *Antarct. Sci.,* **14**(1), 55–60.