Chinese Journal of Polar Science, Vol. 14, No. 1, 35 - 40, June 2003

GPS-derived horizontal ice flow velocities along the traverse route from Zhongshan Station to Dome-A, East Antarctica

Wang Qinghua(王清华)

The Key Laboratory of Geospace Environment and Geodesy, School of Geodesy and Geomatics, Wuhan University, Wuhan 430079, China

Receive March 18, 2002

Abstract The traverse route from Zhongshan Station to Dome-A is one of the most important expedition routes of ITASE Project. China carried out 3 inland traverses during the 1996/1997, 1997/1998, 1998/1999 austral summer field seasons. The field team reached inland 300 km, 500 km and 1100 km away from Zhongshan Station respectively. Some ice motion stakes were set up, occupied and reoccupied along the route by GPS technology. It showed that the ice along the traverse route flowed with an 8-25 ma^{-1} velocity to the northwest, the direction of the bottom of Lambert Glacier Basin. They coincide with the results along the eastern section from LGB59-70 of the LGB route deduced by Australia in both values and directions. Furthermore, the directions of the horizontal flow are perpendicular to the surface topography contour. The much larger velocity at the point of LT980 with an approximate value of 100 ma^{-1} was probed. It was caused by a 15 km wide trough on the bed beneath this point.

Key words Antarctic Inland Ice-sheet Expedition, ITASE, Dome-A, GPS, ice flow.

1 Introduction

From its original formulation in 1990, the International Trans-Antarctic Scientific Expedition (ITASE) has had as its primary aim the collection and interpretation of a continental-wide array of environmental parameters assembled through the coordinated efforts of scientists from several nations (Mayewski *et al*. *1996*). As a consequence ITASE has been focused to address two key scientific objectives: 1) To determine the spatial variability of Antarctic climate (eg. accumulation, air temperature, atmospheric circulation) over the last 200 years, and where the data are available the last 1000 years. These variations include: major atmospheric phenomena such as ENSO, snow accumulation variations, and extreme events such as volcanic eruptions and storms. 2) To determine the environmental variability in Antarctica over the last 200 years. Environmental proxies could include: sea ice variation, ocean productivity, anthropogenic impacts, and other extra-Antarctic continental influences.

A preliminary plan of proposed national and multinational over-snow traverses was prepared from the national reports presented in Cambridge. Twelve nations have proposed over-snow traverse activities for the period 1997 to 2003. The proposed traverses cover a significant part of East and West Antarctica, building on the existing coverage of glaciological traverses since the 1950's. It is proposed that firn/ice cores will be retrieved at 100 km intervals along these routes.

As one of the main participant nations of ITASE Project, China carried out her 3 inland traverses during the 1996/97, 1997/98, 1998/99 austral summer seasons along the route from Zhongshan Station to Dome-A. The field team reached inland 300 km, 500 km and 1100 km away from Zhongshan Station respectively.

2 Principle

Currently the GPS technique has to be considered as the main positioning tool to perform surveys in Antarctica (Frezzotti *et al*. 1997). GPS has become a standard tool for field measurement of ice kinematics (for example Ootaki *et al*. 1998; King *et al*. 2000a, 2000b) and surface topography (for example Frezzotti *et al*. 1998) in the interior of the Antarctic continent as it allows high precision measurements to be made relatively quickly and with minimum logistical support. GPS hardware, software and satellite constellation have been improved so that it is now reasonably simple to carry out remote ice movement surveys and produce high-quality results (Manson *et al*. 2000) even if in poor weather conditions (King *et al*. 2000a).

By using GPS, ice motion measurements can be started during ground-based sampling, and the second measurement of position needed to get displacement and velocity can be carried out on another visit a year or two later. The ice motion stakes were fixed in the firn to record absolute horizontal ice flow velocity. Along our whole 1100 km route, 25 ice motion stakes with an interval of 30-50 km were set up and occupied by high-precision static GPS measurements. But only 7 points named LT980, LT940, LT918, DT008, DT038, DT063 and DT085 respectively on the first 500-km route (see Table 1) were reoccupied. Some strategies were taken into account, the cm- even mm-level coordinates of the stakes can be easily achieved. Thus, the ice flow velocity could be calculated by comparing the coordinates between the different sessions of the same stake.

3 Calculation

The data were processed and analyzed using GAMIT (ver. 9.9, King *et al*. 2000c) and GLOBK (ver. 5.0) software under SUN workstation. These GPS analysis packages were developed at the Massachusetts Institute of Technology (MIT) and Scripps Institution of Oceanography (SIO) for estimation of three-dimensional relative positions of ground stations and satellite orbits.

The basic principle for data processing is to get the optimum results by utilizing the best processing strategy. On the basis of the above principle, the main factors considered in the processing can be described as follows:

(1) Both Zhongshan Station and Australian Davis and Mawson Stations are selected as the fiducial sites.

(2) The most updated International Terrestrial Reference Frame ITRF97 (except

for the ITRF2000 being built by IERS) is adopted.

(3) J2000 is selected to be the Inertial Reference System.

(4) Final precise ephemeris from IGS is used.

(5) The current Earth Rotation Parameters (ERP) available from SOPAC is included in the processing.

(6) Model corrections for satellite clock offsets (the clock parameters are taken from Broadcast Ephemeris).

(7) Model corrections for receivers clock offsets (the clock offset are computed from pseudoranges).

(8) Ionospheric effects are eliminated using LC observations.

(9) Standard atmospheric model is used as default Saastamoinen model correction together with bias parameters estimate that is employed in the tropospheric refraction computation.

(10) Antenna phase center corrections for satellite and receivers.

(11) Site earth tide corrections.

(12) Elevation mask is 15 degrees and the interval is 60 seconds.

Due to long-term data collection, and the above processing strategies taken into account, the cm- and even mm-level coordinates of the stakes were achieved by using GLOBK software. Horizontal velocities at each of stakes along the traverse route were extracted from our multi-year GLOBK solution (see Table 1 and Figure 1).

4 Conclusion and discussion

Results show that most of horizontal velocities along the traverse route vary between 8 ma^{-1} and 25 ma^{-1}. Ice flows to the northwest, the direction of the bottom of Lambert Glacier Basin (LGB). They are consistent with the results (Manson *et al*. 2000) along the eastern section from LGB59-70 of the LGB route deduced by Australia in both values and directions (see Figure 1 and Table 1). Furthermore, the directions of the horizontal velocities are nearly perpendicular to the surface topography contour with the interval of 100m deduced from Radarsat Antarctic Mapping Project Digital Elevation Model data with 1-km resolution (Liu *et al*. 2000, see Figure 2). Specially, the velocity at the Point LT940 (also named LGB69) we achieved, is the exact same as that of Manson et al. (2000) in both value and direction. On the steep coastal, the velocity increased to 52.9 ma^{-1} at LGB72 and 62.6 ma^{-1} at LGB71. But, the velocity of Point LT980 looks a little strange. It locates between LGB71 and LGB72, about 14 km away from LGB71 and 24 km away from LGB72, but the velocity of 97.1 ma^{-1} is much larger than that of the above two points. Why?

Paterson (1994) showed that in Antarctica, buried mountain ranges caused irregularities in the ice surface in the interior and, near the perimeter, much of the flow was channeled either by mountains or by distorted sediments beneath the ice. From Figure 2 it sounds reasonable and possible. The subglacial profile beneath LT980 is much lower, below the mean sea level. There is a 15 km wide trough on the bed beneath LT980, so the horizontal velocity along the channel is much faster.

Table 1. The GPS-derived horizontal ice flow velocities along the traverse route from Zhongshan Station to Dome-A (The rows in Bold for the results of this paper, compared with the others, which are the results for the Australian LGB Traverses during 1993/94 and 1994/95 Antarctic summer seasons, adapted from Manson *et al*. 2000)

Point	Latitude	Longitude	Velocity / $m \cdot a^{-1}$	Azimuth / (°)	Distance / km	Surveyor
LGB72	−69.920833	76.493333	52.9	306	68	AUS
LT980	−70.1322	76.60056	97.1	305	92	CHN
LGB71	−70.258833	76.683167	62.6	318	106	AUS
LGB70	−70.575667	76.866333	25.5	331	142	AUS
LGB69 LT940	−70.835167	77.077833	17.3	324	172	AUS CHN
LGB68	−71.095333	77.288667	14.1	310	202	AUS
LT918	−71.2222	77.39667	13.4	300	217	CHN
LGB67	−71.360667	77.511167	14.8	287	232	AUS
LGB66	−71.6205	77.7305	22.6	292	262	AUS
LGB65	−71.880833	77.951	22.5	295	292	AUS
DT008	−72.014167	77.9261	23.6	296	310	CHN
LGB64	−72.1505	77.949333	24.2	297	324	AUS
LGB63	−72.410667	77.723	21.0	304	354	AUS
DT038	−72.54194	77.5872	20.9	306	370	CHN
LGB62	−72.671167	77.4935	21.3	306	384	AUS
LGB61	−72.931167	77.263167	8.6	310	412	AUS
DT063	−72.98139	77.29	8.4	308	420	CHN
LGB60	−73.191333	77.026833	7.6	265	442	AUS
DT085	−73.3675	77.015	8.2	268	464	CHN
LGB59	−73.452	76.78767	10.6	276	475	AUS

Due to no repeating GPS data, the ice flow velocity of the other 18 GPS points along the last 600 km traverse route couldn't be available. These velocities can be carried out on another visit during 2002/03 austral summer season or later, and then the ice dynamics characteristics along the whole route will be more completely represented.

Acknowledgments The author is grateful to Dr. David G Vaughan of British Antarctic Survey (BAS) who made the Radio Echo Sounding (RES) data available, to Mr. Glenn Johnstone of Australian Survey and Land Information System (AUSLIG) who help author achieve the GPS data of Australian Stations Davis and Mawson. Thanks are also to US National Snow and Ice Data Center (NSIDC) for their RAMP 1km DEM data. The author also thanks field teammates for their help with GPS data collection. Two open research fund programs provide the financial support of this work. One is the Open Research Fund Program of the Key Laboratory of Ice Core and Cold Regions Environment, Chinese Academy of Sciences; the other is the Open Research Fund Program of the Key Laboratory of Geospace Environment and Geodesy, Ministry of Education, China (02-09-09).

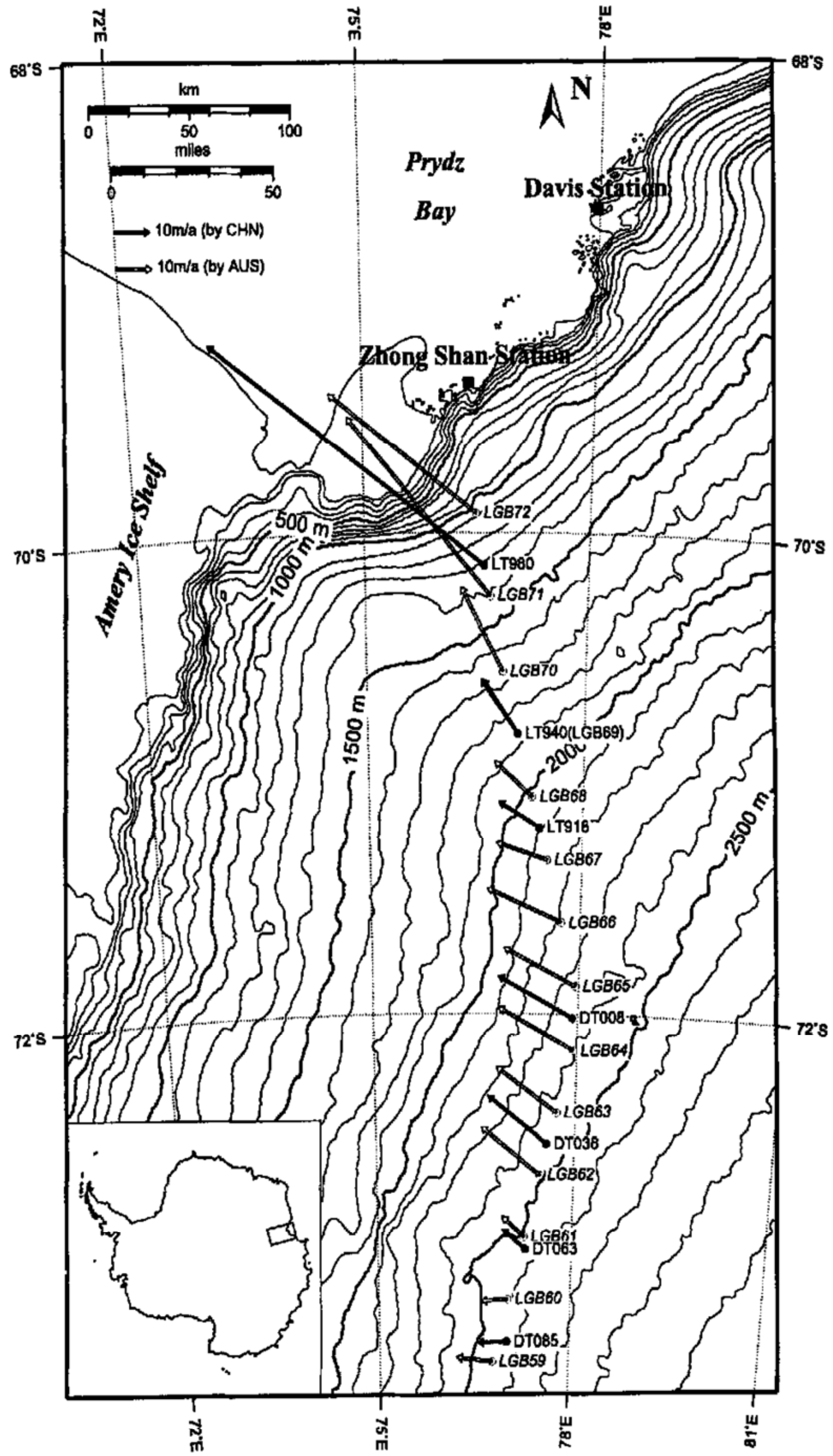

Fig. 1. Horizontal ice flow velocities for the GPS points along the pre-500 km traverse route from Zhongshan Station to Dome-A (The ice surface topography contours deduced from Radarsat Antarctic Mapping Project Digital Elevation Model data, Liu *et al*. 2000).

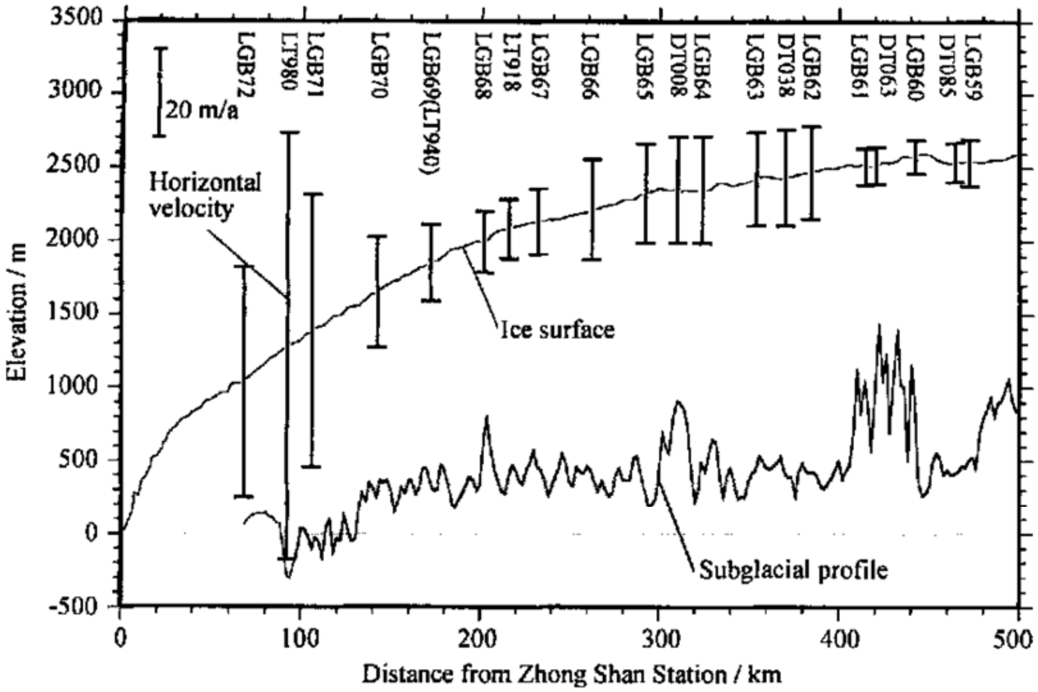

Fig. 2. Ice surface topography, subglacial profile, and horizontal ice flow velocities along the traverse route.

References

Frezzotti M, Vittuari L, Maggi V (1997): Preliminary GPS measurement of David Glacier and Drygalski Ice Tongue. Terra Antarctic Reports, 1: 13 - 17.

Frezzotti M, Flora O, Urbini S (1998): The Italian ITASE expedition from Terra Nova Station to Talos Dome, Terra Antarctic Reports, 2: 105 - 108.

King M, Coleman R, Morgan P (2000a): Treatment of horizontal and vertical tidal signals in GPS data: A case study in a floating ice shelf. Earth Planets and Space, 52(11): 1043 - 1047.

King M, Nguyen LN, Coleman R *et al*. (2000b): Strategies for high precision processing of GPS measurements with application to the Amery Ice Shelf, East Antarctica. GPS Solutions, 4(1): 2 - 12.

King RW, Bock Y (2000c): Documentation for the GAMIT GPS analysis software (ver. 9.9), Massachusetts Institute of Technology.

Liu H, Jezek KC, Li B (2000): Radarsat Antarctic Mapping Project Digital Elevation Model. Boulder, Cororado: National Snow and Ice Data Center, USA.

Manson R, Coleman R, Morgan P *et al*. (2000): Ice velocities of the Lambert Glacier from static GPS observations. Earth, Planets and Space, 52(11): 1031 - 1036

Mayewski PA, Goodwin ID (1996): ITASE (International Trans-Antarctic Scientific Expedition): "200 Years of Past Antarctic Climate and Environmental Change" Science and Implementation Plan, on home page of Scientific Committee on Antarctic Research, Global Change and Antarctic (GLOCHANT), http://www.antcrc.utas.edu.au/scar/itase/toc.html.

Ootaki O, Fujiwara S (1998): Measurement of ice sheet movement at S16, east Antarctic using GPS. Polar Geoscience, 11: 9 - 13.

Paterson WSB (1994): The physics of glaciers. 3rd edition, Pergamon, Trowbridge (Oxford), 241 - 247.