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A preliminary application GIS in glaciological research along the traverse route from Zhongshan Station to Dome A, Antarctica

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Abstract GIS is applied in glaciological research along the traverse route from Zhongshan Station to Dome A, one of the key routes in ITASE project, to display, process, manage and analyze the data obtained mainly by the 3rd Chinese Inland Expedition, together with Antarctic databases provided by ADD and BEDMAP project. The ways of ADD data merging and clipping, and coordinate projection transformation of field data and BEDMAP data are introduced. Elevation data derived by GPS navigator are corrected using ADD and ArcView's contour interpolation. Sub-ice topography and ice thickness along the route are extracted from BEDMAP database. Slope and aspect data are derived at each positioning station. GIS is a convenient and useful tool for us to record, query and display a variety of data in detail along the traverse route.
Key words GIS, GPS, ADD, BEDMAP, Chinese inland ice sheet expedition, Antarctica.

1 Introduction

Geographical information system (GIS) is an efficient way and important technique to manage, display and analyze Antarctic spatial data. GIS can be used to make and renew map products quickly, evaluate environment, support logistic management and field operation, provide chance to extract new knowledge, and to promote information exchange among nations under the demand of the Madrid Protocol (AADC 2001; MAGIC 1998; 1999). Working Group of Geodesy and Geographic Information (WG-GGI) of Scientific Committee on Antarctic Research (SCAR) proposed several international cooperative programs involving GIS biennially. In addition, Antarctic research programs of many countries also contain a number of GIS research projects (Wen *et al*. 2001). Since most of the data in Antarctica collected and analyzed by scientists and logistics have spatial (address) feature, i. e., contain data-linked position information, GIS has been applied widely in Antarctic expeditions and researches at present.

GIS, together with remote sensing and GPS, has been also widely applied for glaciological researches (Gao and Liu 2001). Here we applied GIS in the expedition and research along the glaciological traverse route from Zhongshan Station to Dome A, an important route of International Trans-Antarctic Scientific Expedition (ITASE) project (ITASE 1992). Chinese Antarctic Research Expedition (CHINARE) has conducted the in-

land ice sheet expedition along the route four times since 1996/97 field season. Especially from October 1998 to February 1999, the 3rd Chinese Antarctic Inland Expedition covered 1100 km from Zhongshan Station towards Dome A, reached the furthermost point of up to 3900 m, with ice-core drilling, snow-pit sampling as well as extensive field measurements (Ren 1999; Huang *et al*. 2000; Ren *et al*. 2001). For the purpose of managing, analyzing and taking advantage of the valuable data from the inland expeditions, ArcView and Arc/Info GIS are used here to process data and extract information from the traverse route.

2 Data sources and processing

2.1 Data sources

The data sources for GIS analysis in this paper are mainly from field data, Antarctic digital database (ADD) and the surface elevation, sub-ice topography and ice thickness database provided by BEDMAP project (ADD 2001; BEDMAP 2003).

2.1.1 field data

The 3rd Chinese Antarctic Inland Expedition captured high-resolution GPS data at 23 stations, GPS navigator data at more than 600 stations, observed surface microrelief, snow layer feature, and measured ice thickness and snow accumulation.

High-resolution GPS observations were conducted on camps everyday. A double-frequency GPS receiver was employed to collect measurement data simultaneously with fixed point at Zhongshan Station. Coordinates with centimeter-level precision were obtained at each high-resolution GPS positioning point (Wang *et al*. 2001). During the expedition, advanced GPS navigator (GARMIN GPS 12XL type) was also used to collect elevation data repeatedly with the same interval to and fro along the route. The horizontal location precision positioned by single GPS navigator (using SA technique) was about ±50 m. The actual precision of surface elevation by using repeated measurement data was estimated to be around ±36 m (Huang *et al*. 2000).

2.1.2 Antarctic digital database (ADD)

ADD is an important source of vector topographic data. Under the auspices of SCAR, ADD project started in 1990. SCAR published this database (ADD 1.0) in CD-ROM version in 1993 (Thompson and Cooper 1993). ADD 2.0 was released on the World Wide Web in 1998 after data corrections and other amendments for several years. ADD 3.0 was released through Internet in July, 2000 just before the 26th SCAR meeting (Thompson 2000). This database has high-resolution, with convenience to access and download. It has been widely applied in Antarctic scientific research, and become an essential database of spatial analysis for scientists from different countries.

All data provided in the ADD are projected into the Polar Stereographic projection, with a standard latitude of 71°S, and a central meridian of 0°. The co-ordinates are in metres with an origin at the South Pole. ADD 3.0 contains data in several kinds of scales including original scale (Scale0), 1∶1 000 000, 1∶5 000 000, 1∶10 000 000 and 1∶50 000 000. The tiling scheme used to divide the Scale0 and 1∶1 000 000 data corresponds to the boundaries of the International Map of the World (IMW) 1∶1 000 000 map

sheets. The data within each IMW sheet boundary are subdivided into 15 feature layers including contour, coast, cliff, elevation, human etc (British Antarctic Survey 1998). The contour interval of Scale0 is 50 m. After registration, users can download ADD 3.0 free of charge via the site below: http://www.nerc-bas.ac.uk/public/magic/add_home.html.

2.1.3 BEDMAP database

BEDMAP database contains data of more than 2.5×10^6 points collected by 12 countries on more than 100 surveys over past 50 years (BEDMAP 2003). The database can be downloaded freely via Internet, the site is http://www.antarctica.ac.uk/bedmap/. The data is saved as MS Excel format after downloaded and decompressed. The Excel table mainly contains mission ID, longitude, latitude, ice thickness, surface elevation, water depth, bed elevation etc. The survey information in detail can be found in Summary of Missions in BEDMAP database provided by the web site, which includes country, location, date and data type etc.

2.2 Data processing

2.2.1 ADD data processing

(1) Data format transformation. ADD database provides Arc/Info output file (.e00), which can be transformed into Arc/Info Coverage format using Import tool after ADD data is decompressed using WinZip and registration code.

(2) Data merging. The Scale0 and 1∶1 000 000 data adopt the IMW tiling scheme. Therefore, the data have to be merged according to themes such as contour, coast, elevation, human etc. before it can be properly used. The method is firstly to transform the Arc/Info Coverage into ArcView Shapefile in ArcView, then conduct Merge option in View/GeoProcessing Wizard command to merge the features. Since ADD is divided into a great number of tiles, merging of a feature has to be conducted several times.

(3) Data clipping. Because Antarctica is very large, ADD data should be clipped according to the research area after merging. The research area can be highlighted only after clipping, especially when the research area is small. In addition, ADD has very large amount of data, for example, the contour feature file of Scale0 is 224 MB, it takes much time when displaying, processing or analyzing every time. Data clipping method is to add a new theme, set the feature type as Polygon, use edit tool to draw a polygon you needed, and save the results; then open "View/GeoProcessing Wizard", choose "Clip the theme based on another" option, the clipping processing can be finished smoothly.

2.2.2 Processing of the field data and BEDMAP data

The coordinate data of field positioning points are in "degree/minute/second", which should be firstly transformed into decimal system. Then the data files usually in MS Excel format should be transformed into ".dbf" format or ".txt" format. These two formats can be directly used in ArcView to create event themes using "Add Event Theme" command.

BEDMAP data is saved as Excel table after decompressed, and the way to create a theme in ArcView is the same as above.

2.2.3 Projection transformation

ADD adopts the Polar Stereographic projection, but field measurements and BEDMAP data uses coordinates, thus if we want to add these data to Antarctic digital database, it is necessary to make projection transformation. The steps are outlined below:

(1) Open Arc/Info's Arc Extension, transform the traverse route and BEDMAP data in ArcView's Shapefile into Arc/Info's Coverage file format using "Shapearc" command. We can use ArcToolbox either, which has the same function.

(2) Since ADD, the traverse route and BEDMAP data belong to different coordinate systems, therefore, before transformation, it is necessary to define their projections using Arc/Info. This can be realized by using "Define Projection Wizard" at "Projections" in "Data Management" after entering ArcToolbox Extension. Information of defined coordinate system has been saved in this wizard. Then we can match the projection with other coordinate systems.

(3) Open "Project Wizard" at "Projections", input the file paths of field measurement data and BEDMAP data, then we can finished projection transformation by setting the same parameters of ADD.

3 Preliminary results

These data can be overlaid for viewing and analyzing after the coordinate system and projection of ADD, field observation data and BEDMAP data are unified by data processing above.

3.1 A route feature from Zhongshan Station to Dome A

A route feature from Zhongshan Station to Dome A (line theme) was created using Avenue according to GPS navigator data. Then measurement data along the route can be added to the view for display, processing and analyzing. The attribute table of the route feature and GPS station contains a large number of data including coordinates, distance from Zhongshan Station, elevation, slope and aspect for each observing station, and distances between stations.

3.2 Correction of elevation data derived by GPS navigator

Table 1 lists that high-resolution elevation values (H_1, after rounded) derived by GPS, elevation data (H_2) acquired by GPS navigator and elevations (H_3) at the same positioning stations derived by using ArcView's interpolation after adding the stations to the contour theme of ADD Scale0. The maximum difference is 26 m and the average is 14.7 m between high-resolution GPS elevation values (H_1) and H_3 derived from ADD and ArcView. However, the maximum difference is 103 m and the average is 33.4 m between elevation values derived by GPS navigator (H_2) and H_3, which corresponds to the error (possibly up to 100 m) of a single station elevation derived by GPS navigator (Wang Qinhua, personnel communication, 2001), and the average error (around $\pm$36 m) of double observing values (Huang *et al* 2000). The relatively smaller differences between high-resolution GPS elevations and those derived from ADD and ArcView shows ADD has

higher precision along the traverse route from Zhongshan Station to Dome A, therefore, the GPS navigator data can be corrected by ADD and ArcView's contour interpolation:

(1) Add the themes including contour, GPS navigator stations and irregular triangle net (TIN) in ArcView;

(2) Load "3D Analyst" extension; and

(3) Make TIN theme active, choose the first button from "Contour", then, interpolate contour at each GPS navigator station and record the contour value along the traverse route. In this way, we can correct the elevation values captured by GPS navigator.

Table 1. A comparison between elevation data acquired by GPS(H_1), GPS navigator(H_2) and interpolating contours using ArcView and ADD(H_3)

Station	Distance from Zhongshan Station/ km	H_1/ m	H_2/ m	H_3/ m	$\lvert H_1-H_3\rvert$ / m	$\lvert H_2-H_3\rvert$ / m
LT980	92	1296	1256	1304	8	48
LT940	172	1870	1905	1845	25	60
LT934	184	1949	1938	1923	26	15
LT918	217	2097	2120	2078	19	42
LT907	239	2160	2150	2143	17	7
DT008	310	2374	2390	2348	26	42
DT038	370	2434	2437	2427	7	10
DT063	420	2547	2547	2550	3	3
DT085	464	2561	2577	2544	17	33
DT118	528	2644	2653	2628	16	25
DT132	556	2675	2767	2664	11	103
DT158	608	2739	2822	2724	15	98
DT177	647	2786	2861	2769	17	92
DT200	693	2807	2800	2800	7	0
DT217	728	2813	2800	2796	17	4
DT233	760	2794	2765	2799	5	34
DT263	820	2826	2800	2849	23	49
DT278	850	2879	2888	2883	4	5
DT294	882	2927	2922	2921	6	1
DT313	920	3026	3030	3006	20	24
DT338	970	3155	3145	3149	6	4
DT364	1022	3374	3381	3352	22	29
DT401	1098	3737	3677	3717	20	40
Average					14.7	33.4
Max.					26	103

The curve after correcting GPS navigator elevations is much more smooth, which presents the actual topography of the ice sheet surface. In contrast, the original curve that has not been corrected is zigzag, which is obviously caused by larger elevation errors (Fig. 1).

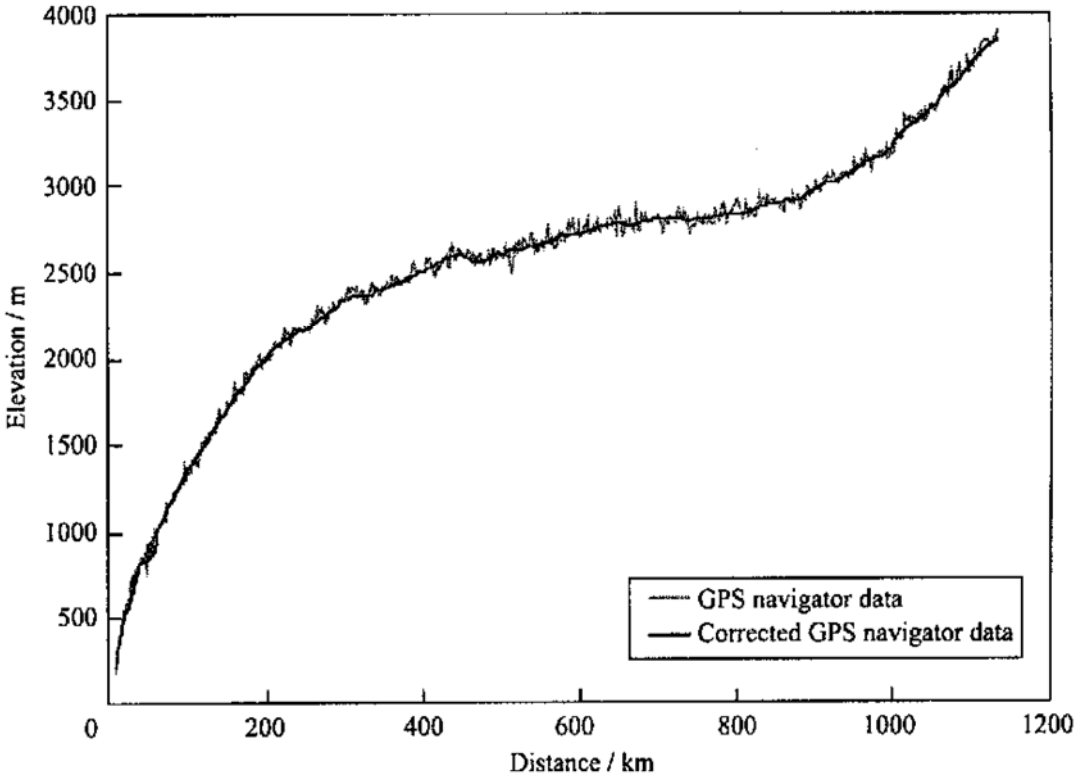

Fig. 1. Surface elevation change along the traverse route from Zhongshan Station to Dome A.

3.3 Surface microrelief distribution

Ice sheet surface microrelief, or surface feature is the result of erosion-deposit processes on the ice sheet surface mainly caused by wind. The spatial distribution and combination of different microrelief types synthetically represent the local wind direction and wind speed, slope and aspect, and large scale sub-ice topography. Types of surface microrelief also represent the local accumulation regime, for example, a glazed surface is thought to be a long-term (more than a few years) accumulation-free surface (Watanabe 1978; Furukawa *et al*. 1992; 1996). Therefore, understanding of the surface microrelief distribution is important to study mass and heat balance on the Antarctic ice sheet (National Institute of Polar Research 1997). Microrelief observation was conducted along the traverse route from Zhongshan Station to Dome A during the third inland ice sheet expedition. Ren and others (2001) concisely delineated the basic characteristics of its spatial distribution. The types are merely classified here according to the height and frequency of snow domes: (1) Smooth surface, snow domes lower than 30cm can be seen occasionally; (2) Sub-smooth surface, snow domes lower than 30 cm are dominant; (3) unsmoothed surface, snow domes between 30-50 cm are dominant; (4) Rough surface, snow domes higher than 50 cm are dominant. We can overlay the microrelief data observed along the route to the view of contour and traverse route theme (Fig. 2) using ArcView, and then it's convenient for us to know the surface condition anywhere along the traverse route using zooming and inquiring tools. This will be useful for us to choose the proper sites for ice-core drilling and snow-pit sampling, and avoid the long-term accumulation-free surface.

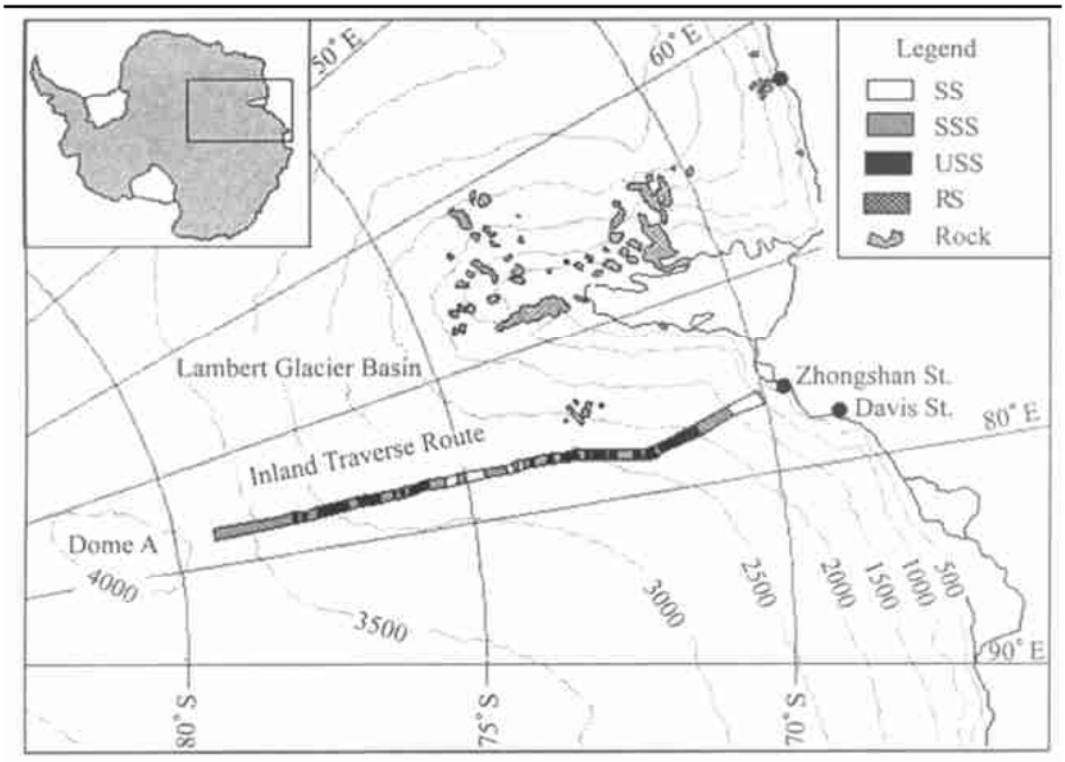

Fig. 2. Distribution of microrelief along the traverse route from Zhongshan Station to Dome A. Abbreviations in the legend are as follows: SS (smooth surface), SSS (sulr-smooth surface), USS (unsmoothed surface), RS (rough surface).

3.4 BEDMAP data extraction

Ice thickness is a key parameter for studying ice sheet thermodynamics, ice core and mass balance. Radio echo sounding was conducted to obtain ice thickness along the traverse route during the third inland expedition. To analyze these data, firstly it is necessary to know the previous work in the region, and previous data can also be used to compare and calibrate our ice thickness data. We downloaded more than sixty thousand records within a certain range along the route. Though these records contain coordinates, their spatial distribution is hardly known if they aren't added to the view of ADD's contour and traverse route theme using GIS. After overlaying (Fig. 3), it is easy to find that the BEDMAP measurement points are mainly distributed lower than 2300 m at the side of Zhongshan Station, and the inland plateau is basically a blank area for ice thickness measurement. Details can be shown using ArcView's inquiring tool, for example, it can be obtained that, using ArcView's spatial inquiring and statistic tools, there are totally 971 records of previous ice-thickness measurement within 1 km along the route, which are almost distributed from ice sheet margin to 300 km (2300 m a. s. l.) inland. The maximum ice thickness measured by previous work is 2212 m, average thickness is 1172 m. Information about how to acquire these records including country, date, location, instrument (method) can be inquired via mission number (Table 2).

3.5 Extraction of slope and aspect data

The digital terrain model of Lambert Glacier Basin is created with irregular triangle

net (TIN) by using ArcView's 3D analyst and spatial analyst extensions, then the slope and aspect at any point along the traverse route can be acquired via this model. The procedures are as follows:

Table 2. A summary of previous ice thickness measurements along the traverse route from Zhongshan Station to Dome A

Mission_ ID	Region	Description	Data Type	Country	Data Vol.
LAMBERT_ 8995	Lambert Glacier basin	ANARE Lambert Glacier Basin Traverse 1989/90 to 1994/95. Study of the mass budget and dynamics of the interior basin.	Ground-based RES	AU	1806
AMERY_ 89B	Lambert Glacier, Amery Ice Shelf	ANARE Aerial RES of Amery Ice Shelf, December 1989, Second Phase. 14 sorties.	Airborne RES	AU	7189
AMERY89	Lambert Glacier, Amery Ice Shelf	ANARE Aerial RES of Amery Ice Shelf 1989, December 1989, First Phase. 8 sorties.	Airborne RES	AU	5401
SPRI_ 7778	Ross Ice Shelf, George V Land, Wilkes Land Victoria Land, Marie Byrd Land	SPRI NSF TUD programme of aerial RES, 1977-78 season, 11 sorties flown. 1977/78 season covered the International Antarctic Glaciological Project sector of East Antarctica, West Antarctica and some other areas.	Airborne RES	UK	30931
SAE_ 8687	Amery Ice Shelf & Ingrid Christensen Coast	Soviet Antarctic Expedition (SAE32) airborne RES survey - Amery Ice shelf and Ingrid Christensen Coast (1986-87). Trackline spacing 5km.	Airborne RES	RU	16766
SAE_ 9091	Princess Elizabeth Land	Soviet Antarctic Expedition (SAE36) airborne RES survey - Princess Elizabeth Land (1990-91). Trackline spacing 5km, 77 sorties.	Airborne RES	RU	63138
SAE_ 5859	Inland Plateau East Antarctica	Soviet Antarctic Expedition (SAE3) seismic survey along a traverse from Mirny to the Pole of Relative Inaccessibility and between Komsomolskaya and Vostok (1958-59). 27 seismic shots made. Traverse distance 2300km.	Seismic reflection	RU	65

(1) Add the themes of contour and positioning points along the route in ArcView;
(2) Open 3D analyst and spatial analyst extensions;
(3) Make the contour theme active, and create TIN by contour. This step takes time

because of a large number of data to be processed;

(4) Make TIN active, and files can be exported by running Derive Slope and Derive Aspect commands, and;

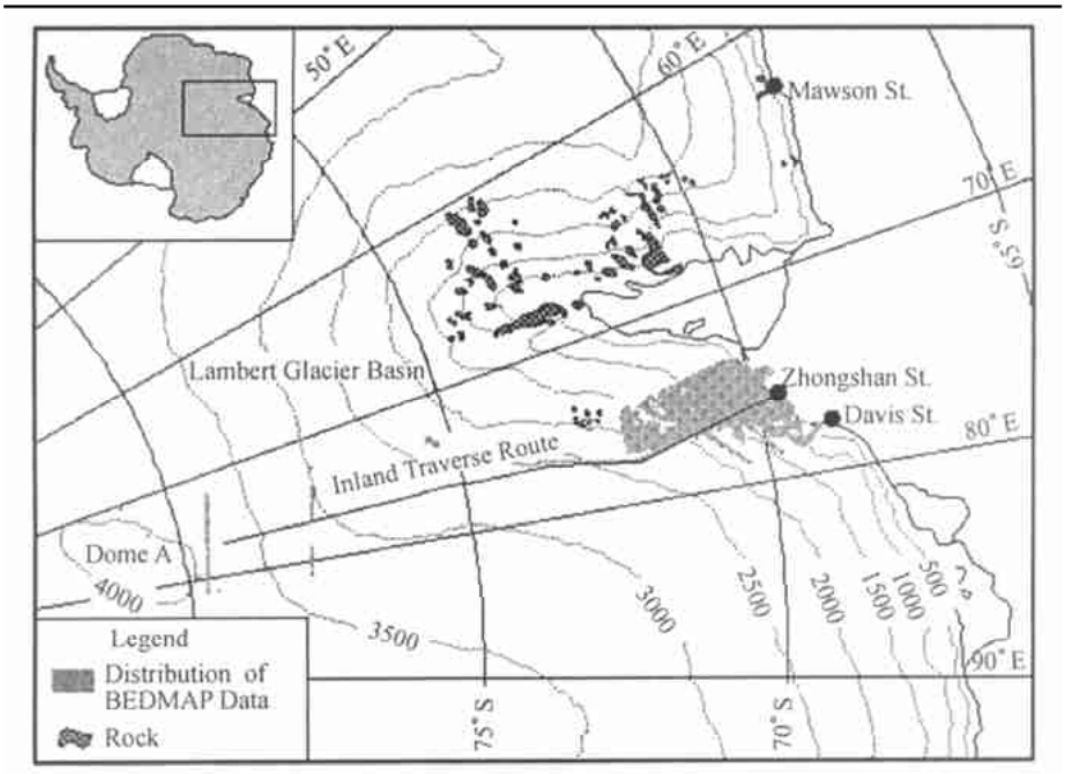

Fig. 3 Distribution of previous ice thickness measurements within 100 km of the traverse route from Zhongshan Station to Dome A.

(5) Make slope and aspect themes active, slope and aspect information can be acquired at each positioning points along the route, then the data can be added into the attribute table of positioning points.

4 Concluding remarks

A preliminary application of GIS for the traverse route has been conducted to display, process, manage and analyze the data obtained mainly by the 3rd Chinese Antarctic Inland Expedition.

The field data acquired along the traverse route from Zhongshan Station to Dome A, ADD and BEDMAP data were processed and analyzed preliminarily using ArcView and Arc/Info. The major conclusions achieved are below:

(1) The route feature is created from GPS navigator data using Arc/Info. Then features defined by measurements along the route can be added to a map.

(2) ADD has a higher resolution along the route from Zhongshan Station to Dome A. GPS navigator data are revised to promote the resolution using ADD and ArcView's contour interpolation.

(3) The BEDMAP data along the traverse is an important reference to our research on ice thickness sounding. The spatial distribution of BEDMAP data can be shown clearly after adding to ADD. It can be obtained that, using ArcView's spatial inquiring and

statistic tools, there are totally 971 records of previous ice-thickness measurements within 1 km along the route, which are almost distributed from ice sheet margin to 300 km (2300 m a. s. l.) inland. The maximum ice thickness measured by previous work is 2212 m, average thickness is 1172 m.

(4) The triangulated irregulated network (TIN) of a region including Lambert Glacier Basin is created from the surface topography using 3D Analyst and Spatial Analyst extensions. Then the aspect (slope direction) and slope data along the traverse route can be derived from TIN.

GIS is a convenient and useful tool for us to record, inquire and display a variety of data in detail along the traverse route. We have primarily selected inland GPS stations for the Chinese 18th Antarctic expedition using GIS indoor. And GIS, combining with remote sensing technique, should be further applied in Antarctic glaciological research, to establish multidisciplinary GIS system of inland ice sheet expedition from Zhongshan Station to Dome A. This system can be used to scientific research as well as logistic management, scheme planning, routing, and sampling deployment. And the system should be further extended to all Lambert Glacier-Amery Ice Shelf system, to study the climate and mass balance in the region.

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