Crossover Analysis of Lambert-Amery Ice Shelf Drainage Basin for Elevation Changes Using ICESat GLAS Data

Dr. SHEN Qiang, Prof. E. Dongchen and Mr. JIN Yinlong (China P. R.

Key Words: remote sensing; Lambert-Amery System (LAS); ICESat; GLAS (The Geoscience Laser Altimeter System); elevation change; mass balance; crossover analysis

SUMMARY

In IPCC Report, the climate change issue has become important part of the larger challenge of sustainable development. The widespread retreat or dilation of glaciers is considered good response to the climate change, such as temperature rise, sea-level rise, etc.. As the largest glacier-ice shelf system in Antarctica, the Lambert Glacier-Amery Ice Shelf system plays an important role in contributions to ice drainage in East Antarctica, which may be make large contributions to rising sea level as well as climate environment. For the ICESat GLAS can determine ice-sheet elevation with an intrinsic precision of better than 10 cm and associated temporal change at the centimeter per year level. So it can be used to measure seasonal and interannual variability of ice-sheet topography in sufficient spatial and temporal detail. In general, Estimates of the global contribution of glaciers to sea level rise are traditionally based on labor-intensive mass-balance (snow/ice input minus ice/water output) measurements on the glacier surface. In this paper, crossover analysis method is addressed for detection of elevation change in Lambert-Amery system. It is differenced measurements at track intersection points that occur with the crossovers of ascending and descending orbit nodes. Common effects will cancel in the crossover formation but temporal effects will remain. It can better stand for change of glacier elevation so that accuracy of detection is much higher than direct comparison of surface profiles. Crossovers' geolocation will exactly coincide at the intersection point of the spot tracks by interpolating the spots on each repeat track to the intersection point, which has more advantage in comparison with direct comparisons of profiles collected along two or more repeat tracks in spot coincidence. The result reveals that this method is more powerful to detect the interannual variability of glaciers than direct one. The analysis of ICESat crossover data provided a new insight into the changes occurring in Lambert-Amery ice shelf system. The LAS are the negative elevation change (-0.6-0m) in comparison of two datasets acquired in 2003 and 2005 year respectively, but the other ice sheets are positive elevation change in the range of 0~0.4m .

Crossover Analysis of Lambert-Amery Ice Shelf Drainage Basin for Elevation Changes Using ICESat GLAS Data

Dr. SHEN Qiang, Prof. E. Dongchen and Mr. JIN Yinlong (China P. R.

1. INTRODUCTION

In 2001 IPCC report(Watson R.T. *et al*,2001), global mean sea level increased at an average rate of 1 to 2mm during the 20th century, which is consistent a warming climate near the Earth's surface. Since 20th century, much work has been done in non-polar glaciers, such as field expeditions, applications of remote sensing, exploiting and testifying the ice age theory, etc. it is certain that non-polar glaciers have widespread retreating over various time scales and the glaciers are another main contributions of global sea level rise besides thermal expansion of sea water during 20th century. Relationship between glaciers retreating and the rising of sea level have been analyzed and simulated; however, a large uncertainty of simulation exists for the lack of field measurement data of glaciers in large scale, the existing glacier's data are often measured in small glaciers, these data didn't represent well all glaciers. The more important reason is inadequate knowledge about the polar ice sheets and their drainage basins. As noted in the 1992 IPCC Supplement on Scientific Assessment of Climate Change, the largest uncertainty about sea level rise is rooted in our inadequate understanding of polar ice sheets，especially the Antarctic ice sheet for its remote distance and adverse climate environments, whose response to climate change also affects predictions of sea level rise. The huge ice sheets of Greenland and Antarctica hold enough fresh water to raise global sea level by 80 meters if they melted completely, which are only ice sheets in the earth. The National Academy of Sciences (1990) stated that "possible changes in the mass balance of the Greenland and Antarctic ice sheets are fundamental gaps in our understanding and are crucial to the quantification and refinement of sea-level forecasts."(GLAS Science Team,1997). With the development and their application of a series of new space technologies, space exploiting techniques can break through the traditional limitations of adverse climate condition of polar ice sheets and enable to exploit glacier's distributions and their changes in larger scale. The Geoscience Laser Altimeter System(GLAS)(Anita C. Brenner, et al, 2003), the first high-accuracy spaceborne laser altimeter, onboard the Ice, Cloud and land Elevation Satellite noted the ICESat was launched in January 2003, which can determine ice-sheet elevation with an intrinsic precision of better than 10 cm and associated temporal change at the centimeter per year level. So it can be used to measure seasonal and interannual variability of ice-sheet topography in sufficient spatial and temporal detail. Since its long ground track repeat cycle of 183-day, except for in the initial 90-day verification phase, produces a track separation of 2.5km at 80 degrees latitude, and 15km spacing between repeat tracks at the equator, so direct comparison of surface profiles acquired by GLAS in two or more repeat tracks with different time isn't appropriate and the uncertainty of its result may be exceed largely short-tem rates of elevation changes of glaciers. In the paper, crossover analysis method is introduced to determinate interannual variations of Lambert-Amery Ice shelf system in topography as a result of analysis of the sequence of track intersection points over time. It is differenced measurement at track intersection points that occur with the crossovers of ascending and descending orbit nodes. Common effects will cancel in the crossover formation but temporal effects will remain. It can better stand for change of glacier elevation so that the detection is more accurate than direct comparison of surface profiles for exact coincidence of their geolocations. The analysis reveals that method is more powerful to detect the interannual variability of glaciers than direct comparison; the ice stream area and stabile ice sheet have large differences in elevation change in 2003, 2005 respectively. The maximum difference over 9m is from the front of Amery ice shelf.

2. ICESAT/GLAS AND LAMBERT-AMERY ICE SHELF SYSTEM

The ICESat mission, as a part of NASA's Earth Observing System(EOS), was launched in January 2003， its repeat cycle is every 8 days during the initial calibration-validation phase of the mission and every 183 days during the main multi-year mission(Anita C. Brenner, et al, 2003). The GLAS onboard ICESat is the first satellite laser with high-accuracy and it's primary science goal is to measure long-term changes in mass-balance of the Greenland and Antarctic ice sheets to sufficient accuracy to assess their impact on global sea level, and to measure seasonal and interannual variability of the surface elevation in sufficient spatial and temporal detail to permit identification of long-term trends and to help explain those trends(GLAS Science Team, 1997). The satellite can provide two levels data including 1evel-1A/1evel-1B (GLA01,GLA05, GLA06) and Level-2 altimetry data(GLA12-15). The all data are free and can get from the distribution server at NSIDC. In the experiment, the GLA12 data will be used in 2003, 2005 years for extracting the elevation change information.

Lambert-Amery ice shelf system situates 67-82°in south latitude and 40-95°in east longitude, which is the largest glacier/ice shelf system in east Antarctica. LAS's area is about 1/10 of all of Antarctica and the length of ice tongue is about 1/60 of entire Antarctic coastline, so the velocity of ice streams in the front of Amery ice shelf is faster than the other areas along the Antarctic coastline(Wang Qianghua, 2002). Lambert glacier located within the Lambert Graben, the Lambert Glacier is the largest valley glacier in the world, measuring up to 80 km in width and more than 500 km in length. As such, it drains one-fifth of the East Antarctic Ice Sheet and contributes over 35 km^2 of ice to Prydz Bay, via the Amery Ice Shelf, each year.

The Lambert Glacier - Amery Ice Shelf system is fed by a number of ice sheet outlet glaciers which pass through the Prince Charles Mountains from the polar plateau to the west. These include the Fisher Glacier in the southern Prince Charles Mountains and the Charybdis and Scylla Glaciers in the northern Prince Charles Mountains. These, as well as a number of smaller outlet and alpine-type valley or cirque glaciers, often serve as prominent physical barriers, separating mountain ranges and other rocky exposures within this region. As a result, the Lambert Glacier and its tributaries tend to dominate both the topography and scenery of the Prince Charles Mountains.

3. METHODS

The mass change, called as the mass balance by glaciologists, is the difference between the mass of snow and ice that accumulates on the surface and the mass that is lost from melting and iceberg calving(GLAS Science Team, 1997). Although the mass changes taking place within these ice sheets may be in response to natural processes or a potential result of anthropogenically-induced processes. In order to known their response mechanism, at first its quantitative measurement of mass change of glaciers and ice sheets is necessary, then the contributions of net mass change in global sea level rise can be calculated using specific geology knowledge. However, it is apparent that temporal changes and mass balance of the Antarctic ice sheets cannot be directly measured, but change information can be inferred from measurements of topography or surface elevation collected as a function of time. In general, detection of elevation change can be implemented with two approaches: 1) The direct comparison is a traditional method, which accomplished by comparing the surface elevation from two or more repeat tracks, i.e., tracks that repeat in the same ground tracks. 2) The crossover analysis method uses differenced surface elevations at the intersection point to determinate of temporal changes in surface elevation that occur with the crossovers of ascending and descending orbit nodes. For ICESat's long repeat cycle (about 0.5-year), which makes the tracks yield large spacing, the second method crossover analysis will be introduced to determinate the elevation change (Benjamin E. Smith, et al, 2005).

In the experiment, the GLAS/ICESat L2 Antarctic and Greenland ice sheet altimetry data will be used to measure the elevation change of Lambert-Amery ice shelf system, the data was acquired in date10/13/2003~11/19/2003(Zwally,H.J.2003)(noted as Data1) and 10/21/2005 ~11/24/2005((Zwally,H.J.2005))(noted as Data2) in two sub-cycles respectively. the number of orbit revolutions of data1 is 541 and that of data2 is 493. The more details about the data are shown in Table 1.

Table1. The general information of GLA12 altimetry data

Code name	Start Date	End Date	Release Version	Num. of Revolutions	Code of laser	Num. of files
Data1	10/13/2003	11/09/2003	Release-26	541	Laser 2A	38
Data2	10/21/2005	11/24/2005	Release-28	493	Laser 3D	34

The datasets not only contain surface elevations of ice sheet, but also include the laser footprint geolocation and reflectance, as well as geodetic, instrument, and atmospheric correction for range measurements. All the variables are organized in single file with binary format. In addition, the TOPEX/POSEIDON ellipsoid is the ellipsoid used for all ICESat/GLAS elevations, so the ellipsoid must be convert to the WGS84 or other ellipsoids in real processing, in the experiment, the WGS84 ellipsoid will be used for all final results. The interest elevation information can be extracted with the help of NSIDC GLAS Altimetry elevation extractor Tool (NGAT) and the ellipsoid conversions can also be accomplished from the ellipsoid conversion package developed at NSIDC. Although they all are capable of batch, these works are yet very time-consuming and stuffy. A more automatic software package was developed based on existing NGAT and ellipsoid conversion tool, in which the surface elevation with geolocation reference and the ellipsoid conversion processing can be automatically extracted and processed in sequence. Because the software package isn't available for searching and processing intersection points at crossovers of ascending and descending orbit nodes, a new program was developed to search the approximate locate of intersection points, moreover, for the nadir spot track yields a separation of 1km at the equator and 179m at 79°latitude, a interpolation process must be done for finding the precise location of intersection points. Because LAS has a complicated surface in variety of 20-2500m in surface elevation, the interpolation method based on spline function was used for getting the precise coincidence of intersection points, in which 4 points neighborhood(x_{i-1}, x_i, $x_{i+1,}$ x_{i+2}) will be interpolated by fitting a cubic spline function. Two neighboring points will be interpolated with 100 sub points for meter-level spot accuracy. Considering different separation of track points with the different latitude, the 5 neighboring points will be select for interpolation.

4. CROSSOVER ANALYSIS

Based on the previous discussion, there are about 100,000 surface elevation points extracted in each datasets in coverage of Lambert-Amery ice shelf system (Fig1), Fig2 and Fig3 are shown their ground tracks.

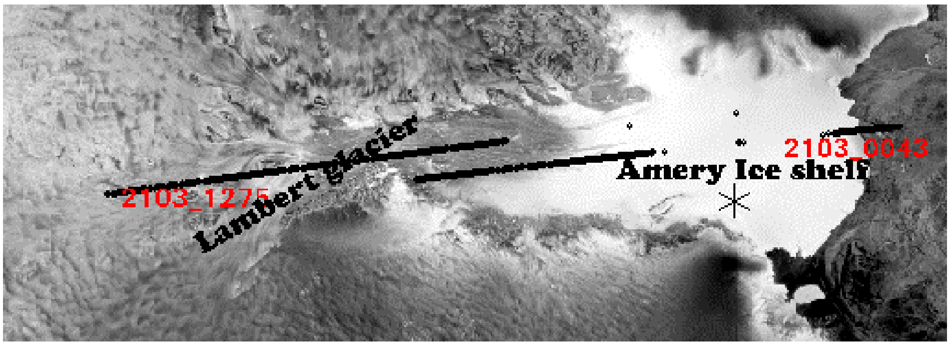
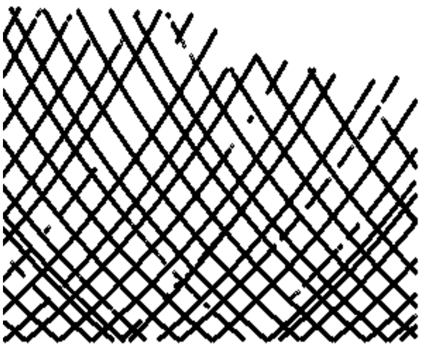


Fig.1 the Lambert-Amery ice shelf system(from AMM)



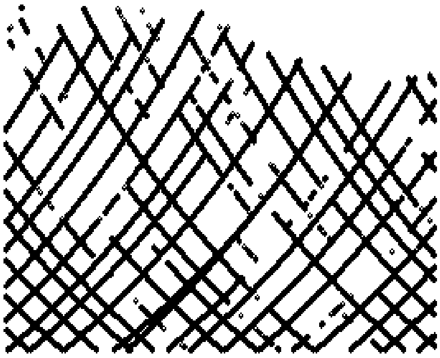
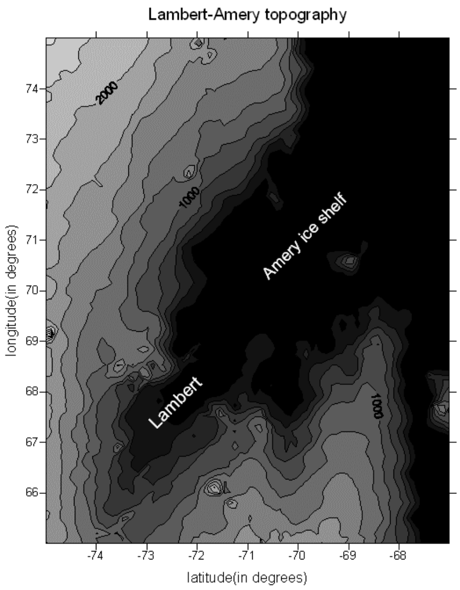


Fig.2 tracks of data1(10/13/2003-11/09/2003) **Fig.3** Tracks of data2 (10/21/2005-11/24/2005)

Since the data2(2005) yield many invalid samples along track (see Fig3), the 237 intersection points are collected for the crossover analysis. The distributions of the extracted intersection points are shown in Fig5. The Fig.4 shows the topography of Lambert-Amery. The overall elevation changes at intersection points also are shown in Fig5, in which the value of minimum, maximum and mean change is -9.579m ,2.878m and -0.092m respectively. The histogram of elevation changes is shown in Fig6. The minimum (denoted black asterisk in Fig.1) appears at -69.856880 in latitude and 72.214851 in longitude. The reason of causing the big change may be explained in three cases, 1) ice fissures appeared in the same spot for the movement of ice streams after 2 years, in which ice fissure didn't exist formerly, many ice fissures exist in the area from the knowledge of glaciology and remote sensing, 2) the existed ice dam disappeared after the melting or movements of ice streams, 3) another potential possibility is due to the errors of the GLA12 data. The elevation of Lambert-Amery and some glaciers in 2005 decrease in comparison of data acquired in 2003 year from the Fig.5 in reference to its topography (Fig4), In contrast, the elevations of the other ice sheet increase.



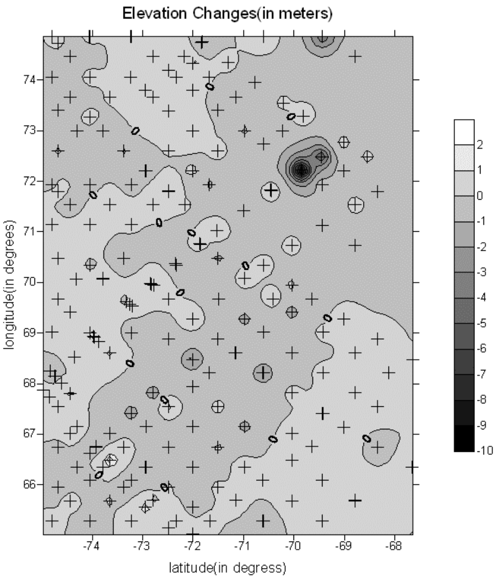


Fig.4 the topography of Lambert-Amery (from data2) **Fig.5** Distribution of height changes and intersection points

There are 218 points of elevation change points, 92% of 237 total points(see Fig.6) , which are limited the range of -1m to +1.2m, so statistical information of these data could represent well the tendency of elevation change. The minimum, maximum, mean and standard deviation of these data are -1.010m, 1.171m, 0.059m and 0.380m respectively. The standard deviation (0.380m) reveals that the entire area is in the status of positive mass balance despite the ice streams region is negative. The distribution of these data is shown in Fig.8 and the elevation changes are mapped to the contour. The blue and green areas in Fig8 represent the decreasing of elevation in comparison of data acquired in 2003, where the code #1 and #2 stand for the Mellor glacier and Lambert glacier respectively, the elevation of glacier area has a clear decline comparing Fig7 and Fig8. The total elevation change in LAS's glacier region is in range of -0.6~0m.

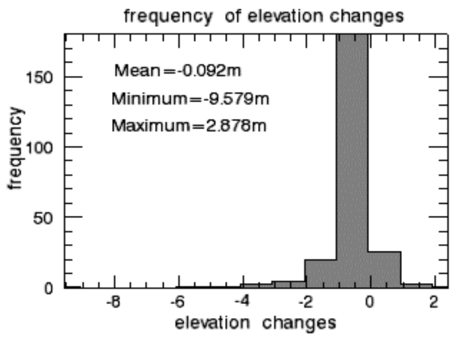


Fig.6 the histogram of elevation changes

Fig.7 sketch of glaciers

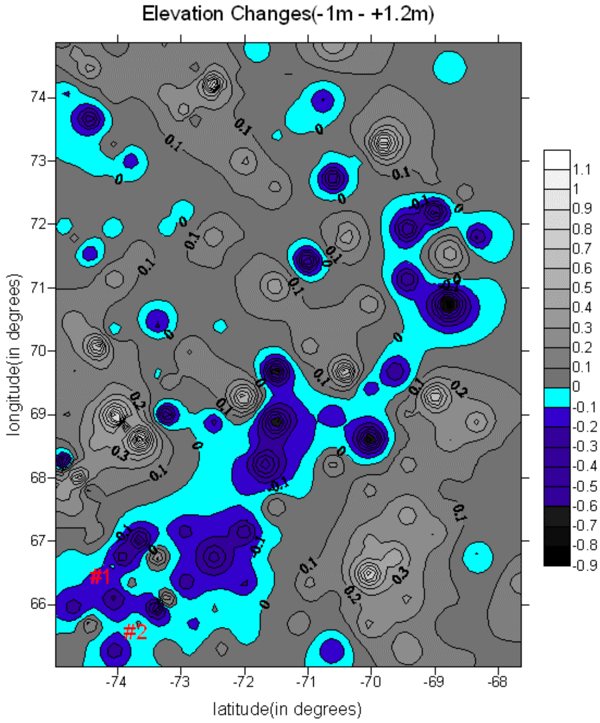
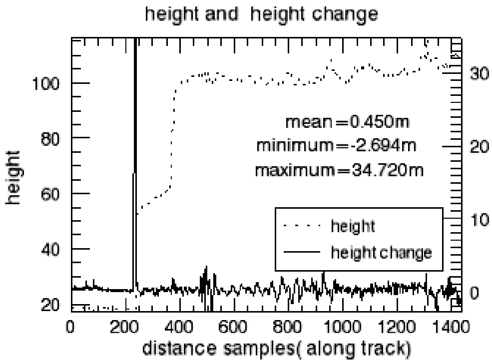


Fig.8 distribution of elevation changes

In addition, the direct comparison also has been done using two specific selected tracks coverage of the Lambert glacier and Amery ice shelf with two periods, the tracks of the data were shown in Fig.1, denoted 2103_0043 and 2103_1275 respectively. The data of 2103_0043 were acquired in 10/25/2003 and 10/30/2005 respectively. The elevations change in range of 0-120m along the track in coverage of the Amery ice shelf. The data of 2103_1275 were acquired in 10/17/2003 and 10/22/2005 respectively, the corresponding elevations change in range of 80-1800m along the track in coverage of Lambert glacier. The elevation changes of the data were exhibited in Fig.9 and Fig.10 with their statistical information. The very large change appear 2103_0043 track, the values change in range of 32-34m and happened to occur at the margin of Amery ice shelf, which reveal the ice tongue of Amery ice shelf move forward about 1km on the assumption that the geolocations of two data are in coincidence. The mass balance is positive in Fig.9 and is negative in Fig.10. So the value of mass balance can’t be made certain according these results because the uncertainty of detection may be exceed largely the rates of elevation change in the two periods . In the other place, the elevation change is fluctuating for large slope caused by complicated surface; the measurements have a large uncertainty for non-coincidence of geolocation



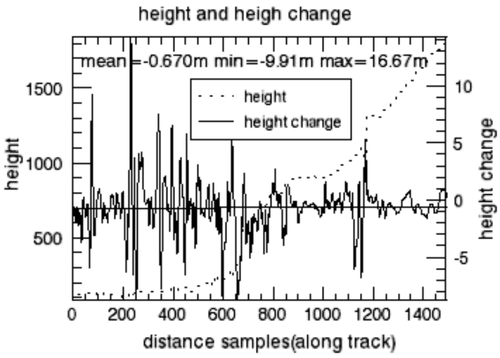


Fig.9 2103_0043 **Fig.10** 2103_1275

5. CONCLUSIONS

The result reveals that crossover analysis is more powerful to detect interannual variability of glaciers than direct comparison of surface profiles, the analysis of ICESat crossover data provided a new insight into the changes occurring in Lambert-Amery ice shelf system. The LAS are the negative elevation change (-0.6-0m) in comparison of two datasets acquired in 2003 and 2005 year respectively, but the other ice sheets are positive elevation change in the range of 0~0.4m .Since the crossover error budget is dependent mainly on the single shot errors and the interpolation error, in the paper, the geolocation uncertainty of interpolation is about 2m, which cause the elevation change's uncertainty of about three centimeters based on the statistics. But the individual error with different slope can't be done. In addition, the surface details in Lambert-Amery ice shelf system, the interpolation method based on spline function are used to extract precise geolocation and elevation for all datasets, which may not be appropriate.

REFERENCES

Anita C. Brenner, et al, 2003,Derivation of range and range distributions from laser pulse waveform analysis for surface elevations, roughness, slope, and vegetation heights[M]. Algorithm theoretical basis document. Version 4.1,

Australian Government Antarctic Division, http://www.aad.gov.au/default.asp?casid= 2504

Benjamin E. Smith, et al, 2005,Recent elevation changes on the ice streams and ridges of the Ross Embayment from ICESat crossovers, GEOPHYSICAL RESEARCH LETTERS, VOL. 32,P1-5.

GLAS Science Team, 1997,Geoscience Laser Altimeter system Science Requirements[M], Version 2.01, Center for Space Research, University of Texas at Austin

Wang Qianghua , 2002,Ice kinematics of the Lambert glacier-Amery shelf System, East Antarctica[M]

Watson R.T. *et al*,2001, Climate Change 2001. Synthesis Report. IPCC, Cambridge University Press, Cambridge.

Zwally, H.J., R. Schutz, C. Bentley, J. Bufton, T. Herring, J. Minster, J. Spinhirne, and R. Thomas. 2003, updated current year. GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data V026, 13 October to 9 November 2003. Boulder, CO: National Snow and Ice Data Center. Digital media.

Zwally, H.J., R. Schutz, C. Bentley, J. Bufton, T. Herring, J. Minster, J. Spinhirne, and R. Thomas. 2005, updated current year. GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data V028, 21 October to 24 November 2005. Boulder, CO: National Snow and Ice Data Center. Digital media.

BIOGRAPHICAL NOTES

SHEN Qiang, Feb. 1980, Ph.D candidate, received the M.S. degree of engineering in Geodesy and Surveying Engineering in 2002, nowadays mainly engaged in the application of remote sensing in snow and ice.

CONTACTS

Dr. SHEN Qiang
Chinese Antarctic Center of surveying and mapping, SGG, Wuhan University
29 Luoyu Road, Wuhan University 430079, Wuhan, P.R.China
Wuhan
CHINA
Tel. + 86 27 68778030
Fax + 86 27 68778030
Email: cl980606@hotmail.com
Web site: http://dreamspace.bokee.com/