Chinese Journal of Polar Science, Vol 20, No. 1, 64-71, June 2009

Monitoring snow-cover area change in Antarctic coastline region using MODIS product data

Chen Jing(陈静)[1,2,3], Li Rendong(李仁东)[1], Ye Ming(叶明)[1,2], and Lu Yang(陆洋)[1]

1 Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, China

2 Graduate University of the Chinese Academy of Sciences, Beijing 100049, China

3 Chongqin Geomatics Center, China

Received June 2, 2009

Abstract Based on MODIS snow products, this article studied the changes of snow cover area during 2003—2006 along the coastline of the Antarctic, and 18 typical regions were chosen for further analysis. The result showed that the change of snow cover area was in a fluctuant downward trend as a whole, and more fluctuated obviously in warm season than in cold season. In temporal scale: for the season cycle, the snow cover extent increased rapidly in cold season (Apr-Oct), while the performance in warm season (Nov-Mar) was not exactly the same during the four years, the snow cover extent decreased in the first and then increased in 2004 and 2006, however, increased firstly and then decreased but reduced as a whole in 2005, for the inter-annual cycle, snow cover extent was the largest in 2003, but reached to the lowest level in 2004, and then increased gradually in 2005 and 2006, whereas, it declined with fluctuant as a whole. In spatial scale, changes mainly centralized along the coastline, moreover, it was more remarkable in the West Antarctic than in the East Antarctic, especially in the Antarctic Peninsula region.

Key words MODIS, snow cover, Antarctic coast, NSIDC.

1 Introduction

Nowadays, the global climate change has attracted unprecedented attention all over the world, and Antarctica covered perennially by snow become the essential regions of the change[1]. The extent of snow cover and the inter-annual changes of the surface reflectivity have an obvious impact on the intensity of global moisture circulation and thermal equilibrium. Antarctica is an "amplifier" to the global climate, which has become the most remarkable and sensitive region. Thus, study on the distribution and change of snow cover in the Antarctic is of great importance in the research of global and regional climate change.

For the past several decades, remote sensing data have been the main data source for monitoring snow cover, in which the optical sensor data, such as TM/ETM+ (Thematic Mapper/Enhanced Thematic Mapper)、AVHRR (Advanced Very High Resolution Radiometer)、MODIS (Moderate Resolution Imaging Spectroradiometer), etc., has been utilized widely, as well as the microwave data, such as SSM/I and SAR-C, etc[2-3]. Terra/MODIS launched in 1999 acquires images in 36 discrete spectral bands between 0. 4 and 14. 3 μm electromagnetic spectrum scope, and in which bands 4, 6, 7, 13, 16, 20, 26, and 31 can be used as inputs for extracting the information of snow[4-7]. MODIS data have been widely applied in monitoring snow and mapping, with the high temporal, spatial and spectrum resolution, as well as free of charge for receiving[8-9]. Based on MODIS data, this article refers to the research on the change of snow cover area during 2003—2006 in the Antarctic coastline, and sums up the whole tendency and local characteristics of the change.

2 Study area and data

2. 1 Study area

Antarctica, composed by Antarctic continent and peripheral islands, covers approximately 14 million km2, and in which the continent covers about 12. 39 million km2, while islands cover 76, 000 km2, and the coastline measures 24, 700 km. In addition, many ice shelves about 1. 58 million km2 are contained, including Amery, Ross, and Ronne, etc. The Antarctic continent is divided in two by the Transantarctic Mountains close to the neck between the Ross Sea and the Weddell Sea, which is the highest mainland on the earth because of the snow and ice cover, and its average altitude above sea-level is 2, 350 m. There are no four seasons in Antarctica, but only two, which is the warm and the cold, and the former is from Nov to the next Mar, the later is from Apr to Oct. It is profound to study on the snow cover in the Antarctic, because it is the most significant and sensitive area of global climate change.

About 98% of the Antarctic continent is covered by snow and ice, and the permafrost and bare rock present mostly in the coastline, while the inland is covered perennially by snow and ice. Thus, in order to reduce data quantity, this article just concerns on the snow cover change of coastline. To monitor the snow melt and growth comprehensively, a 300 km buffer along both sides of the coastline was performed, and that is the proper study area, alternatively, the ringy region as the fig 1 showing.

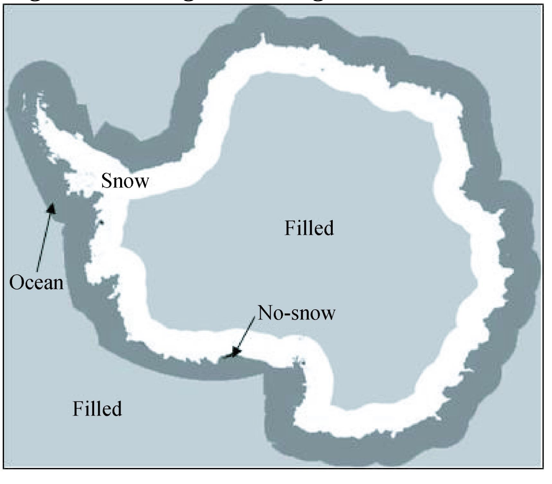

Fig 1 Snow cover map of Antarctic coastline region in Feb, 2005 (white: snow; black: no snow (Permafrost and Bare Rock); dark grey: ocean; fleet grey: filled).

2.2 Data source

The difference of spectrum characteristics between snow and cloud, bare soil, rock, vegetation, etc., is used to extract the information of snow. In the visible region of the spectrum, the high albedo of snow and cloud presents a good contrast with most other natural surfaces, and therefore which can be used to distinguish snow and cloud from others; and in the near-infrared (0.8—1.1 μm), the albedo of snow and cloud is always higher, contrarily, the albedo of water and bare soil is lower, and vegetation is situated between both. According to the properties of high albedo in the visible and high absorptivity in short-wave infrared of snow, whereas the high albedo of cloud in both, snow can be discriminated from clouds[10]. Therefore, the snow cover can be obtained due to the spectral difference between snow and other objects.

The MODIS Snow-cover products are used for research, which are provided as a sequence of products beginning with a swath product, and progressing, through spatial and temporal transformations, to an 8-day global-gridded product, and are distributed by the Distributed Active Archive Center (DAAC) located at the National Snow and Ice Data Center (NSIDC). That is the dataset MODIS/Terra Snow Cover 8-Day L3 Global 500 SIN Grid V004. And the study date is from Oct to next Mar (except Dec.) during 2003—2006. The MODIS snow mapping algorithm uses at-satellite reflectances in MODIS bands 4 (0.545—0.565 μm) and 6 (1.628—1.652 μm) to calculate the normalized difference snow index (NDSI) used for distinguishing snow from clouds and other surface types[11-12], and then further cloud discrimination is accomplished using the MODIS cloud masking product (MOD35) produced based on the existing algorithm for detecting the global cloud distribution using satellite data, according to the multi-spectral characteristics of MODIS. For a more detailed description of cloud detection algorithm, see references[13-14]. Considering the periodic change of the detecting area using solar synchronous satellite and the shortages of 8-day period for eliminate clouds thoroughly, and meanwhile the cycle of satellite orbit is 16 days, thus, two 8-day snow cover products were composited for a 16-day snow cover product to remove clouds as much as possible, using maximum snow cover synthesis through IDL programme. Because of mass data, this article used 16-day snow cover products to represent the monthly snow cover.

3 Data process and analysis

3.1 Data process and result

With the impact of polar night in Antarctica, the proper period for acquiring image is from Oct to the next March. According to the regular path of NSIDC snow-cover products and the location of Antarctica, there are 25 images terminally covering path columns h9-h26 and row v14-v26. Then reprojection, mosaic and clipping were conducted using MRT software provided by NASA. In order to keep the shape of the large Antarctica, snow cover was mapped in a polar stereographic projection, with parameters: Polar stereographic Projection, WGS_84 Datum, latitude: - 71, longitude: 0, which is one kind of plane perspective projection with seeing the South Pole from North pole. To compare snow cover area change accurately, the conformal projection above must be transformed into the equiareal projection, that is, South Pole Lambert Azimuthal Equal Area, Latitude_Of_Origin: - 90.000000, Geographic Coordinate System: GCS_WGS_1984, using ArcGIS software. To eliminate the influence of cloud, 16-day snow cover products were used representing the monthly snow cover. The snow cover map of coastline in Feb, 2005 is as fig 1, the white is snow cover, black is no-snow (Permafrost and Bare Rock), dark grey is ocean, fleet grey is filled.

The snow cover mappings of coastline region were produced for monitoring the changes during 2003—2006. The area of each classified category is result that each pixel area (0.25 km^2) multiplied the number of pixels, and statistic results as table. 1 and fig 2, fig 3 show.

Table 1. Area Statistic of Ice-Snow Cover in Antarctic coastline Region during 2003—2006 (units: km^2)

year	Jan		Feb		Mar		Oct		Nov	
	snow	No-snow	snow	No-snow	snow	No-snow	snow	No-snow	snow	No-snow
2003	5127618	11143.5	5124801	16399.25	5116378	20670.5	5110198	8954	5099154	15150.5
2004	5059811	58825	5065508	53054	5080283	38083.25	5096370	22713.25	5060846	24575
2005	5074294	43562.75	5079969	38894.5	5059044	60245.75	5108711	10643.75	5084670	30636.75
2006	5059710	57328	5066136	52456.75	5081761	35896.25	5100675	18438.75	5103048	15629.75

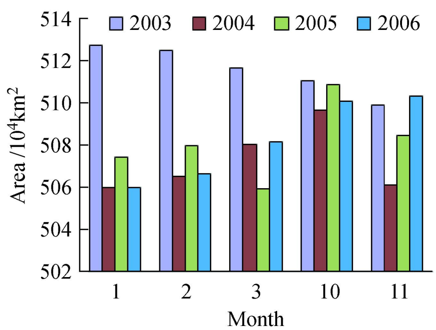

Fig 2 Area Statistic of Snow cover in Antarctic Coastline Region during 2003—2006.

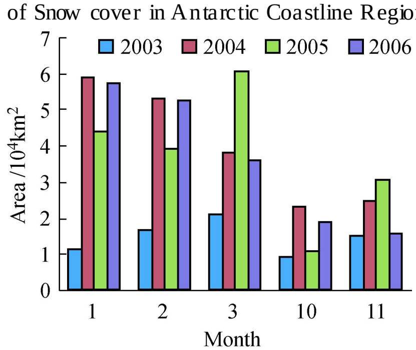

Fig 3 Area Statistic of no Snow (Permafrost and Bare Rock) in Antarctic Coastline Region during 2003—2006.

3.2 Trend analysis

According to statistic tables and Figs above, the data of each period were compared using tools ENVI, ERDAS, ArcGIS, etc. Then temporal and spatial characteristics are as follows:

(1) In Fig 2, the snow-covered area covered maximum in 2003, but sharp decreased in 2004, then increased gradually during 2005—2006, which shows an overall trend of "decrease-increase" during 2003—2006.

(2) The snow cover shows a biggish fluctuation in a year. And the monthly snow-covered area presents a decline with fluctuation during the four years. According to the inter-monthly variation (the difference divided by the sum between maximum and minimum in one month during the four years) of snow cover, the maximum of snow cover change was in Jan, while the minimum in Oct, which illustrated the change of snow cover area was more marked in warm season than in cold season. And in Fig 3, the area of no-snow (permafrost and bare rock) shows a opposite tendency, which tallies with the common sense.

(3) As Fig 2 shows, the snow cover area in cold season (taking Oct as a representation) was larger than in warm season as a whole. And in Table 1, the difference of average snow cover area between seasons of cold (Oct) and warm (Jan.) is approximately 23,500 km^2.

(4) Comparing the image data every period, area with no-snow cover, that is, permafrost and bare rock, mainly centralized along the coastline and nearby islands, especially in the Antarctic Peninsula. This is may be consist with the conclusion of obviously temperature-rising in Antarctic Peninsula and the glaciers in Antarctic Peninsula and subantarctic islands retreated by a White Paper "State of the Antarctic and Southern Ocean Climate System (SASOCS)" published by the programme on Antarctica and the Global Climate System (AGCS) subordinate to Scientific Committee on Antarctic Research (SCAR).

(5) Dividing the research area into East Antarctica and West Antarctica, there was more no-snow (just permafrost and bare rock) area in the West Antarctic coastline than in the East Antarctic, and the no-snow area in West Antarctica accounted for 70% of the total no-snow area, which is related to the comparatively high temperature of the West Antarctica.

3.3 Typical area analysis

In order to further analyze the detailed difference of the snow-covered regions along the coastline, we selected 18 typical regions of snow cover change (Fig 4) based on the studies above, and investigated the regional difference of snow cover change. Because the snow cover area fluctuated obviously in warm season, the data of Jan. were studied and analyzed. The regions selected occupied 85% of the total no-snow area in the whole study region. During the four years, the fluctuation quantity of typical regions contributed more than 80% of the all. As Fig 4 shows, the typical areas R1-R8, R16 located in the West Antarctica, and the others in the East Antarctica.

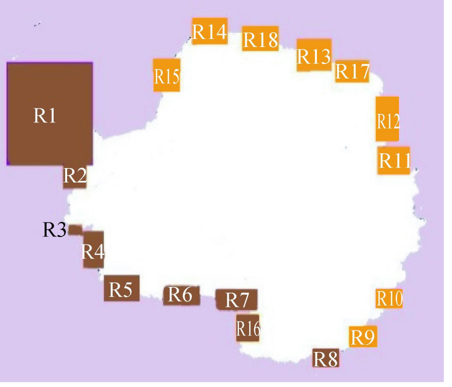

Fig 4 Distribution of 18 Typical Regions

According to the statistic of typical regions in the East Antarctica and West Antarctica, the maximum inter-annual variation (the difference between maximum and minimum divided by the mean of annual snow cover) was in Jan., and it was larger in the West Antarctica than in the East Antarctica; it shows obvious different trends of snow cover change between East Antarctica and West Antarctica, as Fig 5 shows: in the East Antarctica, the snow cover extent was larger in 2003 and 2005, but lower in 2004 and 2006; in the West Antarctica, it sharp decreased in 2004, then increased gradually in 2005 and 2006, consisting with the whole performance; whereas it shows especial "trapezia" in the Antarctic Peninsula (typical region R1), that is, the snow cover extent was the lowest in 2003, while higher in 2004 and 2005, and then dropped to a lower value in 2006. In Fig 6 (a) and (b), there are the snow cover schematic diagrams of R3 in the West Antarctica and R17 in the East Antarctica during 2003—2006, and the characteristics showing is accordant with the curves in Fig 5.

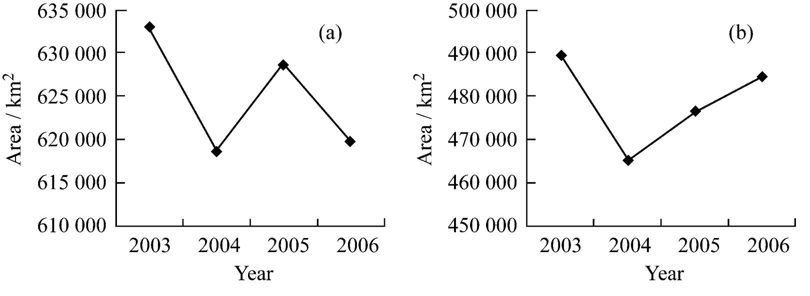

Fig 5 Changes of snow cover in East Antarctica (a) and West Antarctica (b).

4 Conclusion

Based on MODIS snow products, this article studied the changes of snow cover area during 2003—2006 along the coastline of the Antarctic, and 18 typical regions were chosen for further research. The result showed that the change of snow cover area was in a fluctuant downward trend as a whole, and more fluctuated obviously in the warm season than in the cold season. In temporal scale: for the season cycle, the snow cover extent increased rapidly in cold season (April-Octomber), while the performance in warm season (November-

March) was not exactly the same during the four years, that is, the snow cover extent decreased at first and then increased in 2004 and 2006, however, increased firstly and then decreased but reduced as a whole in 2005, and the characteristics of change in cold and warm season were the feedbacks for seasonal climate; for the inter-annual cycle, the extent was largest in 2003, but reached the lowest level in 2004, and then increased gradually both in 2005 and 2006, whereas, it declined with fluctuant as a whole. In spatial scale, changes mainly centralized along the coastline, while the change could be ignored for the teeny change in hinterland, moreover, the change was more remarkable in the West Antarctica than in the East Antarctica, especially in Antarctic Peninsula.

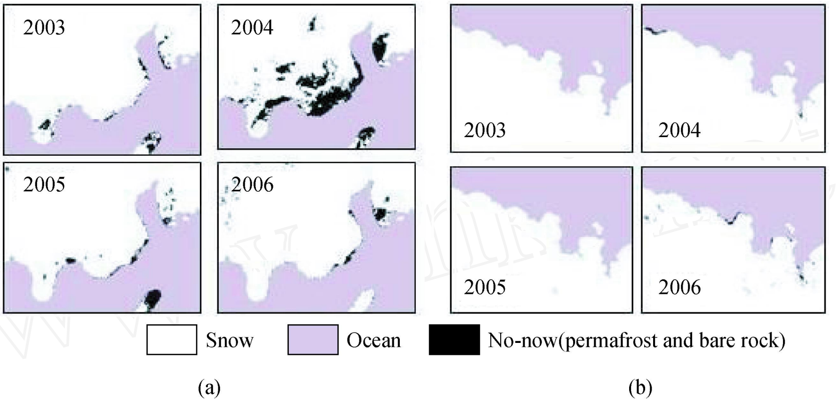

Fig 6 Sample of Snow Cover Change in Eights Coast (R3), West Antarctica (a) and in Syowa Prince Olav Coast (R17), East Antarctica (b).

There are obvious advantages of MODIS data used for research, with the influence of polar night, the period for receiving available data is from Oct to the next Mar every year, so, microwave data could be combined for monitoring consecutively the snow cover in the Antarctica.

References

[1] Kang JC, Wang F, Zheng YM, *et al* (2005): Antarctic Snow-Ice Sphere and Global Change Research-Ice Sheet and Records of Global Climate-Environment Chinese Journal of Nature, 27 (6): 351-356.

[2] Wang GY (1990): Introduction to Satellite sensor on Remote Sensing of Ice and Snow. Journal of glaciology and geocryology, 12 (4): 359-364.

[3] Huang XY, Feng Y (2004): The Development of study on the Snow Ice Using Microwave Remote Sensing Data [J]. Remote sensing technology and application 19 (6): 533-536.

[4] Ji Quan (2005): Snow Remote Sensing Monitoring By Means of MODIS Data. Journal of guangxi meteorology, 26 (4): 21-22.

[5] Hall DK, Riggs GA, Salomonson VV (1995): Development of methods for mapping global snow cover using Moderate Resolution Imaging Spectroradiometer (MODIS) data Remote sensing of environment, 54: 127-140.

[6] Liu YJ, Yang ZD *et al* (2001): The Theory and Algorithms of Processing MODIS Remote Sensing Information Beijing: Science Press

[7] Yan H (2005): A Comparison of MODIS and Passive Microwave Snow Mappings Journal of glaciology and geocryology, 27 (4): 515-519.

[8] Wang J (1999): Comparison and Analysis on Methods of Snow Cover Mapping by Using Satellite Remote

Sensing Data. Remote sensing technology and application, 14 (4) : 29-36.
[9] Wang XW, Xie HJ, Liang TG (2008) : Evaluation of MODIS snow cover and cloud mask and its application in Northern Xinjiang, china. Remote Sensing of Environment. 112 (4) : 1497-1513.
[10] Nolin A, Liang S (2000) : Progress in bidirectional reflectance modeling and applications for surface particulate media: snow and soils. Remote Sensing Reviews, 14: 307-342. [11] Riggs GA, Hall DK, Salomonson VV (1994) : A snow index for the Landsat Thematic Mapper and Moderate Resolution Imaging Spectroradiometer. Proceedings of the international Geoscience and Remote Sensing Symposium (IGARSS 1994) , 8-12 August 1994, Pasadena, California, USA, 1942-1994.
[12] Riggs GA, Hall DK, Salomonson VV (1996) : Recent progress in development of moderate resolution imaging spectroradiometer snow cover algorithm and product. proceedings of the international geoscience and remote sensing symposium (IGARSS 1996) , Lincoln, NE, 139-141.
[13] Ackerman SA *et al.* (1998) : Discriminating clear sky from clouds with MODIS. Journal of Geophysical Research, 103 (D24) : 32141-32157.
[14] Ackerman SA *et al.* Discriminating clear-sky from cloud with MODIS algorithm theoretical basis document (MOD35). http: //cimss. ssec. wisc. edu