Chinese Journal of Polar Science, Vol. 21, No. 1, 100 - 112, June 2010

Progress in application of MODIS for remote sensing in Polar Regions

Zhang Xin(张　辛) and E Dongchen(鄂栋臣)

Key Laboratory of Polar Surveying and Mapping, State Bureau of Surveying and Mapping, Chinese Antarctic Center of Surveying and Mapping, Wuhan University, Wuhan 430079, China

Received March 23, 2010

Abstract The remote sensing technique is widely used in Polar Regions, and Moderate Resolution Imaging Spectroradiomete (MODIS) is one of the most important satellite sensors in the domain of remote sensing. In this article, MODIS sensor, including the information of its satellites, its system constitutes, its hardware characteristic, its large spectra and usual applications are briefly introduced first. Then, there is a particular introduction of MODIS's use in Polar Regions, which refers to the polar physiognomy, polar atmosphere and polar ocean, with citing many examples. At last, views about the development of MODIS and its series sensors in the future, including the improved applications in Polar Regions are given.

Key words MODIS, Polar Regions, polar physiognomy, polar atmosphere, polar ocean.

1 Preamble

Polar Regions are important fields for scientific explorations. The changes of the polar ice and snow, the features of the polar terrain, and the unique polar biology are all valuable topics for scientific researches. There are several methods can be used to inspect the changes in Polar Regions, such as the ground-based observation, the aerial photography and the remote sensing technology. As the Polar Regions are mostly covered by the ice and snow, ground-based observation is limited to small partial districts, compared to the aerial observation. The aerial photography is one of the methods for aerial observation. In this technique, airplanes or other aircrafts are always used as the flat roofs to load kinds of machines to take photographs on the grounds. But the aerial photography only can be used in the daytimes of the polar summers, and it is also impossible to be implemented in the Antarctic icecaps[1-2].

Remote sensing can detect and sense the objects and natural phenomenon without arrival the locale[3]. Therefore, it is not influenced by the rigorous weather and environment in Polar Regions. Additionally, the electromagnetic wave received by the sensors of remote sensing is not limited to the visible light, and the infrared and microwave sensors can obtain datum in the atrocious weather and nights of Antarctica and Arctic. For this reason, remote sensing is suitable for the special environment of Polar Regions. There are different types of Polar-Orbiting Satellites, such as the Landsat series, the SPOT series; the high resolution satellites: Ikonos, Quick Bird, Orbview; the Radarsat, the Synthetic Aperture Radar; the ICESat. All of these satellites can be used in the Polar remote sensing, which includes the polar mapping and cartography, the polar geologic prospect, the inspecting of the polar ice and snow, and the weather forecast in Polar Regions.

Compared to the above satellites, the high spectrum satellites have special advantages. Firstly, the imaging spectrometers work with hundreds wave bands, ranging from the visible light spectrum to the near infrared spectrum. Oppositely, the MSS and TM sensors in the Landsat only work with several wave bands in the same spectrum bound. Additionally, the data obtained by these satellites are highly relative, especially between the adjacent data. This character is propitious to the diversity of data processing. Thus, the high spectrum satellites can be widely used in the detecting in land, atmosphere and ocean. As representational sensor of this satellite, MODIS have successful applications in the polar physiognomy, polar atmosphere, and polar ocean.

2 Introduction of MODIS

MODIS is a large satellite sensor produced by NASA, aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. MODIS is a passive, imaging spectroradiometer carrying 490 detectors, arranged in 36 spectral bands that cover the visible and infrared spectrum (400-14500 nm)[4]. It can supply the day and night spectrograms of the entire Earth's surface every 1 to 2 days in 250-1000 m resolutions.

The multichannel data of MODIS will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. It refers land properties, land surface temperature, ocean color, phytoplankton biogeochemistry, cloud properties, atmospheric water vapor, atmospheric temperature, ozone, cloud top altitude and so on[5]. MODIS is playing a vital role in the development of validated, global, interactive Earth system models. Besides, MODIS is able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment. Because of its wide spectrum bound, numerous spectrum channels and high time-resolution, MODIS could be comprehensively applied in many regions of polar research. See the Table 1.

3 The application of MODIS in Polar Regions

3.1 Polar terrain

For the special terrain in Polar Regions, the MODIS snow product is aptly used. This product utilizes the spectral characteristic of snow, which has high reflectance in the visible and low reflectance in the short-wave infrared. Snow data products are generated using the MODIS band 1, 2, 4, 6, 31 and 32; coming with calibrated radiance data products, the geolocation product, and the cloud mask product as inputs. The first product, MOD10_L2, is a L2 level snow cover map for a swath. Then, it is used as the input for the latter L2G level product MOD10_L2G, and L3 level products MOD10A1, MOD10A2, MOD10C1 and MOD10C2[6]. All the mentioned products are at 500 m spatial resolution, and they can be divided into daily product, ten-day product and monthly product.

Table 1. The characteristic of wave bands in MODIS (Huang *et al*. 2003[4])

Applications	Band	Waveband(nm)	Spectrum sensitivity	SNR
Land/Cloud/Aerosol Properties	1	620-670	21.8	128
	2	841-876	24.7	201
Land/Cloud/Aerosol Properties	3	459-479	35.3	243
	4	545-565	29.0	228
	5	1230-1250	5.4	74
	6	1628-1652	7.3	275
	7	2105-2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405-420	44.9	880
	9	438-448	41.9	838
	10	483-493	32.1	802
	11	526-536	27.9	754
	12	546-556	21.0	750
	13	662-672	9.5	910
	14	673-683	8.7	1087
	15	743-753	10.2	586
	16	862-877	6.2	516
Atmospheric water vapor	17	890-920	10.0	167
	18	931-941	3.6	57
	19	915-965	15.0	250
Surface/Cloud Temperature	20	3660-3840	0.45	0.05
	21	3929-3989	2.38	2.00
	22	3929-3989	0.67	0.07
	23	4020-4080	0.79	0.07
Atmospheric Temperature	24	4433-4498	0.17	0.25
	25	4482-4549	0.59	0.25
Cirrus Clouds	26	1360-1390	6.00	150
Water Vapor	27	6535-6895	1.16	0.25
	28	7175-7475	2.18	0.25
	29	8400-8700	9.58	0.25
Ozone	30	9580-9880	3.69	0.25
Surface/Cloud Temperature	31	10780-11280	9.55	0.05
	32	11770-12270	8.94	0.05
Cloud Top Altitude	33	13185-13485	4.52	0.25
	34	13485-13785	3.76	0.25
	35	13785-14085	3.11	0.25
	36	14085-14385	2.08	0.35

3.1.1 MODIS create the Mosaic of Antarctica

Staffs from the National Snow and Ice Data Center (NSIDC) and the University of New Hampshire had assembled a digital snow-grain-size image of the Antarctic continent and surrounding islands. This image called Mosaic of Antarctica (MOA).

The MOA map is a composite of 260 swaths comprised of both Terra and Aqua MODIS images acquired between 20 November 2003 and 29 February 2004[7]. The products consists of two MODIS-derived image data sets: a digitally smoothed red-light image, which was compiled using Band 1; and a snow-grain-size image, that was compiled using the normalized difference of calibrated data from Band 1 and Band 2 data[8].

To assemble MOA, the staffs should take a series of work. First of all, they selected each image to keep the angle of sunlight in the final map would be the same. Synchronously, the researchers gave all of the maps the same shadows and contrast. Then, they checked each image for anything that would obscure the view of the land, such as the surface blemishes or noise in the data, the glare from the Sun, the clouds and their shadows, the fog, and blowing snow. Next step, they stacked the pieces of Swiss cheese to cover the continent. By stacking the images, the MOA team accomplished two things. First, the team managed to fill in all the holes left by the image-cleaning process so that no land surface was missing. Second, they stacked the images to increase the resolution (amount of detail) beyond what any single image included. On average, they stacked 15 images to make every part of the mosaic, the number of which is at least 4 and even reaches 38 in one area. Finally, the component images were de-striped, geo-registered, and re-sampled to the projection grid. To make MOA, the researchers started with MODIS' 250-meter-per-pixel resolution data, but the resulting image has even higher resolution, which can reach 150 meters per pixel.

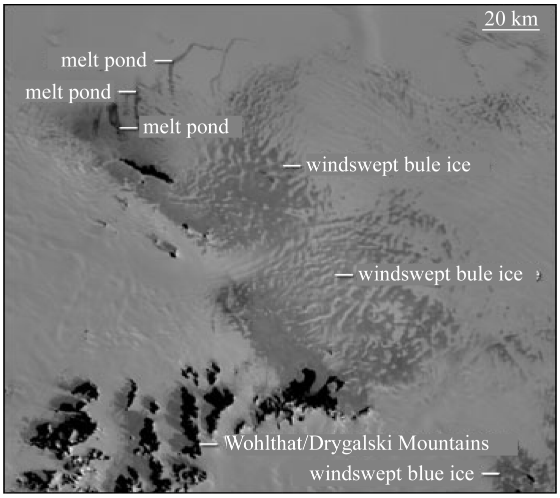


Fig. 1 the windswept blue ice and melt pond in the MOA (Mosaic of Antarctica[7]).

MOA has specific applications in Antarctic research. For example, MOA's grayscale imagery enables the user to identify blue ice. In the above image (Figure 1) of the Princess Astrid Ice Shelf, windswept blue ice appears a darker shade of gray, in swirling patchwork patterns. Near the blue ice are melt ponds, areas of water on the surface of the shelf. Because the formation of melt ponds can lead to ice shelf collapse, satellite images of these features can focus glaciologists' attention on potentially dynamic areas. This image also shows the Wohlthat / Drygalski Mountains and the shadows they cast. Detailed as it is, MOA is not intended to work in isolation; scientists designed it to integrate well with other images. For example, NASA and the Byrd Polar Research Center previously published an image of Antarctica based on radar data from the Radarsat Antarctic Mapping Project Antarctic Mapping Mission 1 (RAMP AMM-1). RAMP is great for looking at subsurface features, comparing with MOA focuses on the surface. As a result, more complete pictures can be combined by them.

3.1.2 MODIS participate in developing DEM of Antarctica

The images of MODIS have high spectral resolution. However it is limited to many applications because of its low spatial resolution. The data fusion method can be used to combine the high spatial resolution images with the images of MODIS to enhance the ability of feature extraction. Chinese researches have presented a methodology based on wavelet transform algorithm to fuse MODIS and ETM image (spatial resolution is 30 m) data, for improving the MODIS spatial resolution while keeping the advantage of MODIS hyperspectral information as much as possible. The experimental study suggested that this methodology can effectively achieve the goal as expectation, and the effects of topographical shadow to the fusion are analyzed with the example data[9]. The method offers a possibility to use MODIS data in high resolution land use or land cover mapping in Antarctica.

Besides, American scholars used image enhancement approach to develop a new DEM (digital elevation map) of West Antarctica, combining multiple MODIS images and Ice Cloud and Land Elevation Satellite (ICESat) laser altimetry profile data[1]. ICESat is earth's first polar orbiting satellite carrying a laser altimeter, which can acquire data as a series of spot elevations with the accuracy of 5-10 cm, averaging a 60 m diameter surface region every 172 m. However, ICESat track paths have wide spacing, which can reach 2 km at 85 degree, and 20-50 km at 75 degree[2]. As a result, some surface ice dynamical features, such as flowlines, undluations, ice rises are missed by the slope and track data. Additionally, ICESat only can cover the northern regions of 86°S, contrasting to the image coverage of MODIS has no limitation in Antarctica. The image enhancement method combines the wide image coverage of MODIS, and its high radiometric sensitivity (which equates to high sunward slope sensitivity), with the high precision and accuracy of ICESat track elevation data. By using pixel brightness for image data where ICESat tracks provide an accurate slope, the researchers calibrated brightness-to-slope for several MODIS images of the West Antarctic. Using the calibrations, they then created, first, a slope map of the entire ice sheet surface from the image data, and then integrated this to yield a complete DEM for the region[10-11].

3.2 Polar atmosphere

The atmospheric applications of MODIS mainly refer cloud, aerosol and water vapor. Thereinto, cloud plays an important role in the radiation balance of earth, and aerosol is the important reason of the uncertainty to the atmospheric model. Besides, water vapor is the main factor of understanding water cycle, climate forecast, and the reciprocity between cloud and aerosol[4]. MODIS have relative wave bands and data products to observe all the three important atmospheric factors, such as the 6700 nm water vapor band and the cloud mask product MOD35. For the polar application, MODIS aim at the low temperature and strong wind in this region to develop research.

3.2.1 MODIS detect the temperature inversions

Usually, in the lower atmosphere (the troposphere) the air near the surface of the earth is warmer than the air above it, largely because the atmosphere is heated from below as solar radiation warms the earth's surface, which in turn then warms the layer of the atmosphere directly above it. However, under certain conditions, the normal vertical temperature gradient is inverted such that the air is colder near the surface of the Earth. This phenomenon called temperature inversion. The thickness of the inversion layers changes from several meters to hundreds meters. An inversion can suppress convection between the ocean, ice and atmosphere[12]. Simultaneity, it also influences the refrigerant height of the icecap and the ozone photochemistry.

Temperature inversions exist essentially the entire year in Antarctica, with the maximum magnitude from March to October. The inversions are also obvious in the Arctic winter, and disappear from March to September. In 1996, some American researchers had found that strong inversions over the Antarctic continent can be detected by examining the Brightness Temperature Difference (BTD) between a water vapor absorption band at 6700 nm and the infrared window at 11000 nm[13]. Under clear sky conditions, this brightness temperature difference will be negative. Because, the water vapor band, with a weighting function that peaks near 500 hPa, senses the warmer atmosphere near the top of the inversion. While the infrared window channel temperature is controlled primarily by surface emission, which will be lower in the top of the inversion[14]. As a result, the BTD of $BT_{11000}-BT_{6700}$ should be negative, which can reach -15 K in the Antarctic winter. This method can be implemented again by using the data of MODIS. However, the method is not generally applicable to weaker (smaller temperature difference across the inversion) or shallower (lower altitude of inversion top) inversions that are common in some parts of the Antarctic continent.

In 2002, other American scholars extended the previous work on inversion detection by incorporating two spectral bands, whose weighting functions peak lower in the troposphere: the 7200 nm water vapor band and the 13300 nm carbon dioxide band[15]. MODIS level 1B data provides infrared channel brightness temperatures at 6700 nm, 7200 nm, 11000 nm, 12000 nm, 13300 nm, and 13600 nm. The BTD of $BT_{11000}-BT_{6700}$, $BT_{11000}-BT_{7200}$, $BT_{11000}-BT_{13200}$ are used to detect the presence and magnitude of low-level atmospheric temperature inversions under clear sky conditions during the Antarctic night[11]. The methods presented apply only to surface-based atmospheric temperature inversions. Both in situ and satellite data sets are used in this study. For only clear sky data are used, the standard MODIS cloud mask product (MOD35_L2) is used to find clear sky field. The MODIS Atmospheric Profile product (MOD07_L2) is used to do the comparison. As a result, over high-altitude surfaces, the large negative BTD of $BT_{11000}-BT_{6700}$ is a good indicator of temperature inversions, that is also shown in the research of 1996. Moreover the BTD of $BT_{11000}-BT_{7200}$ is more useful over low-altitude surfaces. Additionally, The BTDs are linearly related to the strength of the inversion under clear-sky conditions. This relationship can be used to estimate the magnitude of the temperature inversion during the Antarctic night. Empirical equations have been developed to estimate the inversion delta-T based on the observed MODIS BTDs.

3.2.2 MODIS observe the Cloud-Drift and Water Vapor Winds

Wind products from geostationary satellites have been generated for over 20 years, and they are now used in numerical weather prediction systems. However, geostationary satellites are of limited utility poleward of the midlatitudes. Recently, American researchers use the polar-orbiting satellites with MODIS sensor to obtain high latitude tropospheric wind information, which extend the atmospheric wind observation to the Polar Regions. The methodology is based on the algorithms currently used with geostationary satellites, modified for use with the MODIS infrared window and water vapor bands to observe the Cloud-Drift Wind and Water Vapor Wind. The Cloud-Drift Wind is detected from the movements of the cloud by the satellite cloud images. Correspondingly, the Water Vapor Wind is deduced by the water vapor absorption images[16-18].

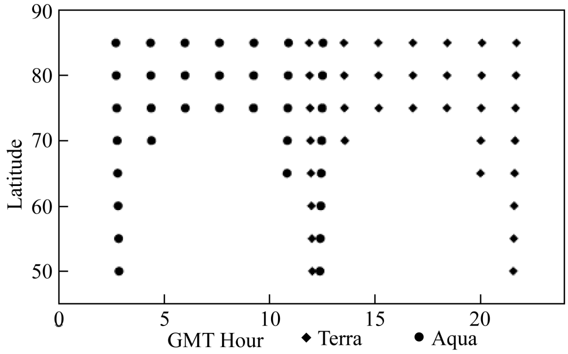


Fig. 2 Time differences between successive overpasses of the Terra and Aqua at the Prime Meridian(Jeffrey RK *et al*. 2003[16]).

The wind retrieval methodology builds on the cloud and water vapor feature tracking approach used with geostationary satellites, which can continuously observe the fixed points. However, for polar-orbiting satellites, the frequency of obtaining wind vectors depends on the latitude and the number of satellites. Fig. 2 shows the frequency of time differences between successive overpasses at a given latitude-longitude point during one 24-hour period with two satellites: Terra and Aqua. The points show only those overpasses where the sensor would view the earth location at an angle of 50° or less. At larger scan angles the sensor would view the area near the pole on every overpass. At 60° latitude, there are only two overpasses for each satellite, which are not enough to obtain useful wind information at this latitude. At 80o there are many views separated by orbital period of 100 min, but there is still a 13 hour gap for each satellite. For other longitudes, the gap will occur earlier or later in the 24 hour period, so that the entire polar area will be covered by multiple overpasses over the course of a day. Although the 100 min temporal sampling is significantly longer than the optimal processing intervals for geostationary satellites, in theory wind vectors can be obtained during part of every day for the area poleward of approximately 70° latitude.

The wind retrieval has a series of setup, which includes choosing the targets for tracking, tracking the targets, surveying the wind vector heights and assessing the quality of the wind vectors[17]. With MODIS sensor, cloud features are tracked in the infrared window band at 11000 nm, and water vapor features are tracked in the 6700 nm band, in which the tracking targets can be easily determined. The tracking method searches for the minimum of the sum of squared radiance differences between the target and the search boxes in two subsequent images. A model forecast of the wind is used to provide guidance on the appropriate search area for each target feature. Displacement vectors are derived for each of the two subsequent images. They are then subject to consistency checks to eliminate accelerations that exceed empirically determined tolerances and surface features that may have been misidentified as cloud.

Wind vector heights are assigned by any one of three methods. First, the infrared window method assumes that the mean of the lowest brightness temperature values in the target sample is the temperature at the cloud top. This temperature is compared to a numerical forecast of the vertical temperature profile to determine the cloud height. The method is reasonably accurate for opaque clouds, but inaccurate for semitransparent clouds. Secondly, the CO_2 slicing method works well for both opaque and semitransparent clouds. Cloudy and clear radiance differences in one or more carbon dioxide bands and infrared window bands are ratioed and compared to the theoretical ratio of the same quantities, calculated for a range of cloud pressures. The cloud pressure that gives the best match between the observed and theoretical ratios is chosen[19]. Additionally, the H_2O intercept method of height determination can be used as an additional metric or in the absence of a CO_2 band. This method examines the linear relationship between clusters of clear and cloudy pixel values in water vapor-infrared window brightness temperature space, predicated on the fact that radiances from a single cloud deck for two spectral bands vary linearly with cloud fraction within a pixel. The line connecting the clusters is compared to theoretical calculations of the radiances for different cloud pressures. The intersection of the two gives the cloud height.

The study period is from March 5 to April 3, 2001. MODIS Level 1B data from the Terra satellite were acquired from NASA's Goddard Distributed Active Archive

Center (DAAC). The 1 km image data was normalized and destriped to reduce the effect of detector noise and variability, and the results are checked. There are two common approaches to quantitatively assessing the quality of the wind vectors: comparing the satellite-derived winds with collocated rawinsonde observations, and evaluating their impact on numerical weather prediction. The first method is not accurate, because the verifying observational network is sparse so that these statistics do not necessarily apply uniformly to the Polar Regions. The American scientists used the second approach. A 30-day case study dataset was produced and assimilated in the European Centre for Medium Range Weather Forecasts (ECMWF) and NASA Data Assimilation Office (DAO) models to assess forecast impact. When the MODIS winds are assimilated, forecasts of the geopotential height for the Polar Regions are improved significantly in both impact studies, especially in the Arctic regions[16].

3.3 *Polar Ocean*

The ocean products of MODIS are distributed at Level 2, 3, and 4, the latter being dedicated to Ocean Primary Productivity. The Level 2 are swath, whereas Level 3 and 4 are global gridded products. In contrast to Atmosphere, Ocean global gridded products are distributed in two formats. In the first, the data are mapped to Cylindrical Equidistant projection and are distributed as HDF-EOS grid files, and thus are known as “map” files. While in the others, the data is binned to global Integerized Sinusoidal Equal Area Grid (ISEAG), distributed as native HDF format files known as “binned” files.

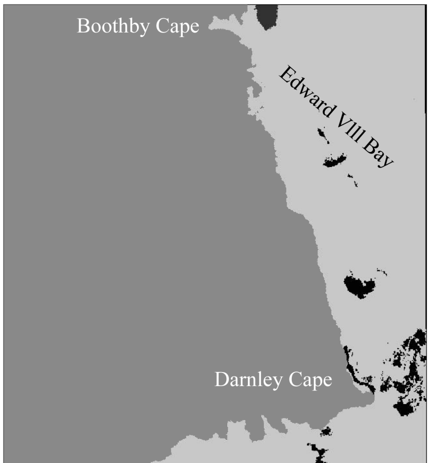
3.3.1 *MODIS inspect the variety of the polar sea ice and ice shelf*

MODIS have the sea ice products which utilize the different spectral characteristics between sea ice and seawater in the visible and near infrared wave band. Ice data products include the ice distributing data which are generated by the MODIS band 1, 2, 4, and 6; and the Ice Surface Temperature (IST) products, which are formed by the 31 and 32 bands. The first product is L2 level MOD29, which can be used as input to generate the following L3 level ice products: MOD29PGD, MOD29PGN, MOD29P1D and MOD29P1N (D: day, N: night). All the mentioned products are at 1km spatial resolution, with the IST data to assist the division of sea ice by the reflectivity[20].

The authors have used the sea ice data of MODIS, covering the period from 2000 to 2002, to investigate the surrounding sea ice of Chinese Antarctic Zhongshan station. Firstly, the observational area is determined, the latitude and longitude of which are 65°S-75°S, 55°E-80°E. Next step is dividing the sea ice data to the ice distributing data and the ice temperature products. Then the distributing data are synthesized, and the sea ice extents per ten days are surveyed. Finally, it is the process to distill the surface temperature of the sea ice. As a result, the authors can inspect the seasonal melting and freezing, and the variety of the ice surface temperature in this region. It indicates that the sea ice surrounding the Zhongshan station melts from October to February. From then to April is the time of freezing without airproof. Correspondingly, from May to the September is the time of airproof freezing, when the sea ice is bestrewed the sea area surrounding the Zhongshan station. The minimum of sea ice in this district appears in February. However the highest and lowest temperatures of the ice surface appear in January and August respectively. These results are partly validated by the former study of the Antarctic sea ice, and receive some more accurate data near the Zhongshan station. Besides, this study validated the feasibility of using the sea ice data of MODIS to inspect the variety of Antarctic sea ice. The whole research region and the sea ice boundary in example months are shown in the following Figure3. The pictures (a) and (b) are the distribution of the sea ice near the Zhongshan Station in the first ten days of November 2000, and the middle ten days of January 2001, respectively. In these pictures, the sea ice is silvery white, the land is gray and the sea is black[21].

The satellite images of MODIS are also used to inspect the polar ice shelves disintegration. On February 28 2008, NSIDC first revealed the collapses of the Wilkins ice shelf, using the MODIS’s images of 1km spatial resolution. Subsequently, the researchers in NSIDC use a series of the similar images on February 29, March 6 and March 8, to record the whole course of the ice shelf disintegration[22]. The images of MODIS also inspected the collapses of the Larsen B ice shelf in 2002. The continuous images record the total of about 3,250 square kilometers of shelf area disintegrated in a 35 day period from January 31 to March 5[23]. In general, the MODIS sensor can supply images with high time resolution and large areas, which are effective approaches to inspect the Antarctic ice shelves.

From 2003 to 2005, American scientists combined the images of MODIS and the laser altimetry profile data of ICESat to unveil a first-ever view of changes in the elevation of the icy surface above a subglacial lake the size of Lake Ontario. Comparing the images of the three years, they reached the result that the ice layers are ascending, which suggest the lake drained and its water relocated elsewhere. Furthermore, the researchers revealed a new three-dimensional look at an extensive network of waterways beneath an active ice stream that acts like a natural “plumbing system”, and clues to how “leaks” in the system impact the world′s largest ice sheet and sea level. They also documented for the first time changes in the height of the ice sheet′s surface as proof the lakes and channels nearly half a mile of solid ice below filled and emptied[24]. This discovery has radically altered our view of what′s happening at the base of the ice sheet and how ice moves in that environment. And this result is the most important scientific development in NASA recently.



(b) the middle ten days of January 2001

Fig. 3 The distribution of the sea ice near the Zhongshan Station (Zhang *et al*. 2008[2

3.3.2 *MODIS observe the halobios*

The Southern Ocean has been identified as critical in the global carbon cycle and will unequivocally be affected by changes in global temperature. As the main unicellular plant in the ocean, the Phytoplankton is one of the important factors to affect the carbon dynamics in the Southern Ocean. However, for the long-term snow and ice covering, the observation of the Phytoplankton in Southern Ocean is more difficult than the other regions.

Recently, American scientists combined the images of MODIS and the ship based station data to estimate Phytoplankton processes in the Ross Sea, Antarctica. Two different levels of MODIS image processing were utilized. Daily (1 km pixel resolution) Level 2 images were used for validation of ship-based station data. Level 2 are images that have been, atmospherically corrected, and adjusted according to the products specific algorithm. These swath images were geolocated, quality filtered and sub-sampled using Interactive Data Language (IDL). A regression will be established between the value of the MODIS and ship based product. This algorithm offset will then be applied as a post- processing correction to Level 3 images. Level 3 mapped images (global; 8-day temporal bin) at approximately 5 km resolution were used as the primary data product[25].

An exciting advancement for the MODIS sensor is that the quantum yield of photochemistry as well as the concentration of chlorophyll A can be estimated. In the previous research, when the amounts of the Chlorophyll A increase, the reflected spectrum of the water will change. For Chlorophyll A has obvious absorbability near the blue wave band (440 nm) and red wave band (678 nm), the spectral reflex curve of water will appear absorbable peak values near the blue and red wave bands when density of the Phytoplankton is high. Additionally, in the bound of 685-715 nm and 550-570 nm, the water with the Phytoplankton will appear reflex peaks, the positions and values of which are quantitive indicates of Chlorophyll A[26]. For different water areas, the remote sensing of Chlorophyll A will choose the optimal combinations of wave bands from the experiments between the above wave bands. In the researches of Ross Sea, the ratio of absorption at 443 nm to that at 551 nm in the water leaving spectral radiance is chosen. On the other hands, for the high time resolution of MODIS, data from images were sea-truthed with discrete measurements made in conjunction with a field program called interannual variability in the Ross Sea. Several years (2000-2004) were then compared in order to ascertain and constrain interannual variability. These data were put into the context of a larger field program in order to determine what drives the potential and magnitude of the seasonal phytoplankton bloom[27-28].

4 Summarize and prospect

From 1999 on when its first carrying satellite was launched, the global image data of MODIS was widely applied to land, atmosphere and oceans with stable. The multichannel data of MODIS improves our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. As an important sensor aboard on the polar-orbiting satellites, it is a certain choice to use MODIS in the Polar Regions. To some extent, the authors are transferring the successful applications of MODIS in the low latitude regions to the high latitude areas, such as Antarctica. The multiplicate abilities of MODIS can cover the most domains of the polar scientific research, which includes the polar terrain, polar atmosphere and polar ocean. The series and the next generation satellites of MODIS are in the works.

Nowadays, the remote sensing sensors are developing in the high spectral resolution technology. Such as the American imaging spectroradiomete Hyperion, aboard on the Earth Observing-1, has 220 wave bands ranging from 300 nm to 2500 nm. At the same time, the spatial resolutions of the imaging spectroradiometes are improving. The Orbview-4 is one of the satellites that combine the high spectral resolution and high spatial resolution. It can obtain the multiple spectrum image data of 8 m resolutions with 280 wave bands covering 400-2500 nm, and the panchromatic images of 1m resolution[29]. Though with the limitation of technology, the advanced sensors with the highest spectral resolution and highest spatial resolution synchronously can not produce yet, the remote sensing technology of high spectral resolution and observations of high frequencies, as the use of MODIS in the Polar Regions, will achieve further development in the future.

References

[1] Haran TM, Scambos TA, Fahnestock MA, Yi D, Zwally HJ(2006): A Digital Elevation Model of West Antarctica from MODIS and ICESat: Method, Accuracy, and Applications. American Geophysical Union, Fall Meeting, 12.

[2] E DC *et al*. (2006): Preliminary study of application of Satellite Laser Altimetry technology in Polar Region. Chinese Journal of Polar Research, 18(2):148 - 155.

[3] Liu YJ *et al*. (2001): Elements and arithmetic of Remote sensing information treatment. Beijing: Science publishing company, 1 - 2.

[4] Huang JJ, Wan YC, Liu LM(2003): The Character and Application of MODIS. Geospatial Information, 1(12): 20 - 24.

[5] Wu KQ *et al*. (2005): Application in sea ice remote sensing of MODIS data. Marine Forecasts, May, 22(supplement):44 - 49.

[6] George AR, Dorothy KH, Vincent VS(2003): MODIS Snow Products User Guide for Collection 4

Data Products, 1.

[7] Mosaic of Antarctica(2005): http://earthobservatory. nasa. gov/Study/MOA/[EB/OL].

[8] Sccambos TA, Haran TM, Fahnestock MA, Painter TH, Bohlander J(2007): MODIS-based Mosaic of Antarctica (MOA) data sets: Continent-wide surface morphology and snow grain size. Remote sensing of environment, 111:242 - 257.

[9] Yu JH, Zhang WC, Le TC(2004):Fusion of MODIS and ETM Images by Using Wavelet Transform. Remote sensing Information,4:39 - 42.

[10] Sun JB(2001):Antarctic technology and scientific research. Remote Sensing Information, 1:40 - 43.

[11] Zhang SK, E DC, Zhou CX, Shen Q(2006):Progress on the Antarctic Digital Elevation Model. Chinese Journal of Polar Science, 18(4):301 - 309.

[12] Zhou LB *et al*. (2003):An Analysis of a Strong Temperature Inversion Process over the Chukchi Sea Region in Arctic. Climatic and Environmental Research, 8(2):189 - 195.

[13] Ackerman SA(1996):Global Satellite Observations of Negative Brightness Temperature Differences between 11 and 6. 7 μm. Journal of the atmospheric sciences, 53(19):2803 - 2812.

[14] Cheng X *et al*. (2002): Application of GPS technology to meteorology in Antarctica. Chinese Journal of Polar Research, 14(2):136 - 144.

[15] Liu YH, Jeffrey RK(2002): Detection and Analysis of Low-Level Temperature Inversions with MODIS. Geoscience and Remote Sensing Symposium.

[16] Jeffrey RK *et al*. (2003): Cloud-Drift and Water Vapor Winds in the Polar Regions From MODIS. IEEE Transactions on Geoscience and Remote sensing, 1(2):482 - 491.

[17] Bai J *et al*. (1997): The Deriving of Cloud Motion Winds from IR Images of GMS. Universitatis Pekinensis (Acta Scientiarum Naturalium), 33(1): 85 - 92.

[18] Yang WK *et al*. (2007): Deriving Winds from Vapour Images of Geostationary Meteorological Satellite. Remote sensing technology and application, 22(1):31 - 34.

[19] Lin L *et al*. (2006): Retrieval of Cloud top properties from MODIS data. Sciential meteorological sinica, 26(6):655 - 661.

[20] George AR, Dorothy KH, Vincent VS(2003): MODIS Sea Ice Products User Guide, 1.

[21] Zhang X, E DC(2008): MODIS inspect the seasonal variety of the surrounding sea ice of Zhongshan station. Chinese Journal of Polar Reasearch,20(4):346 - 354.

[22] http://nsidc. org/news/press/20080325_Wilkins. html. [EB/OL] 2008. 4.

[23] http://nsidc. org/news/press/larsen_B/2002. html. [EB/OL] 2002.

[24] http://www. nasa. gov/vision/earth/lookingatearth/Antarctic_plumbing. html. [EB/OL] 2007.

[25] Jill AP: Using the moderate resolution imaging specteoradiometer(MODIS) to estimate phytoplankton processes in the Ross Sea, Antarctica. Virginia Institute of Marine Science.

[26] Brivio PA, Giardino C, Zilioli E(2001): Determination of chlorophyll concentration changes Landsat TM images. Remote Sensing, 22(2): 487 - 502.

[27] Pang XP, Wang ZX, E DC(2006): Ecological Environment Classification and Frangibility Analysis of South Polar Region. Geomatics and Spatial in information technology, 29(6):1 - 8.

[28] Zhu LY *et al*. (2006): Determination of Chlorophyll-a Concentration in Taihu Lake Using MODIS Image Data. Remote Sensing Information, 2:25 - 28.

[29] Tang P *et al*. (2006): Imaging Spectrometry remote sensing technology and its applications in geology. Mineral Resources and Geology, 20(2):160 - 165.