Proc. of [illegible]
27 July - 1 Aug 1997
San Diego, CA

MODIS snow and ice products from the NSIDC DAAC

Greg R. Scharfen[a], Dorothy K. Hall[b], and George A. Riggs[c]

[a]National Snow and Ice Data Center, Campus Box 449, University of Colorado, Boulder, CO 80309
[b]Goddard Space Flight Center, Greenbelt MD 20771
[c]Research and Data System Corp., 7855 Walker Drive #460, Greenbelt, MD 20770

ABSTRACT

The National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) provides data and information on snow and ice processes, especially pertaining to interactions among snow, ice, atmosphere and ocean, in support of research on global change detection and model validation, and provides general data and information services to the cryospheric and polar processes research community. The NSIDC DAAC is an integral part of the multi-agency-funded support for snow and ice data management services at NSIDC.

The Moderate Resolution Imaging Spectroradiometer (MODIS) will be flown on the first Earth Observation System (EOS) platform (AM-1) in 1998. The MODIS Instrument Science Team is developing geophysical products from data collected by the MODIS instrument, including snow cover and sea ice products which will be archived and distributed by the NSIDC DAAC. The MODIS snow and ice mapping algorithms will generate global snow, lake ice and sea ice cover products on a daily basis. These products will augment the existing record of satellite-derived snow cover and sea ice products that began about 30 years ago. The characteristics of these products, their utility, and comparisons to other data sets are discussed. Current developments and issues are summarized.

Keywords: EOSDIS, MODIS, NSIDC, snow, ice, sea ice, cryosphere

1. INTRODUCTION

The EOS Project Science Office has identified 24 critical science measurements that are important for scientific research aimed at the understanding, analysis and monitoring of global climate change[1]. Two of these are snow cover (including snow cover extent and water equivalent) and sea ice (including sea ice extent, concentration, motion and temperature). Snow cover extent, sea ice extent and sea ice surface temperature will be provided as EOS Standard Products, using MODIS data, at the time of launch of the AM-1 satellite, or shortly thereafter. This paper describes the MODIS snow and ice products which have been developed by the MODIS Instrument Science Team and will be archived and distributed as part of the EOS Data and Information System (EOSDIS) by the NSIDC DAAC.

2. THE IMPORTANCE OF SNOW AND ICE IN CLIMATE

The global extent of snow cover is an important variable in the hydrologic cycle and is a key indicator of changes in the global climate system. Due to its high albedo and large spatial variability, snow cover is a primary factor controlling the amount of solar energy absorbed at the surface. Changes in the extent of snow cover have a direct effect on the earth's radiation budget. Snow cover also has significant effects on the seasonal temperature cycle due to its high latent heat of fusion. In many areas of the world, snow cover represents an important resource in terms of water supply and hydroelectric power. The U.S. National Weather Service and other agencies monitor snowpacks during the winter and spring months to forecast water supply and flooding potential[2]. The devastating 1997 flood event in the Red River Valley of the U.S. Upper Midwest was primarily due to an abnormally deep snow pack. Links between snow cover extent and atmospheric circulation have been demonstrated[3], and the extent of snow cover has been found to be inversely related to hemispheric surface air temperature[4].

Sea ice is an important variable affecting the energy balance of the polar regions. Sea ice greatly inhibits the exchange of heat and moisture between the atmosphere and ocean, dramatically increases the albedo of the polar oceans, and affects deep water formation and the circulation patterns of both the ocean and the atmosphere. In the Southern Ocean the annual cycle of sea growth and decay is very large, ranging from a maximum of 20 X 10^6 square kilometers in September to its minimum area of approximately 4 X 10^6 square kilometers in February [5]. During freeze up, large quantities of salt are ejected, altering the density structure and turnover within the water column. Commercial operations in many parts of the Arctic and Antarctic are dependent on the short summer breakup for yearly transport and resupply by ships.

Lake ice duration (including the dates of formation and decay) and thickness are also key indicators of climate, and are especially useful in the Arctic and sub-Arctic where other data collection is sparse[6]. Freeze-up brings to a halt shipping on many large lakes, such as the Great Lakes, where the regional economy depends heavily on water transportation. The extent of ice also affects the moisture supply for "lake effect storms", which regularly bury cities and towns located downwind of the ice-free parts of the lakes.

3. DEVELOPMENT OF THE MODIS SNOW AND ICE PRODUCTS

The EOS Standard Products are designed to provide long-term stable measurements of the 24 critical science measurements. To this end, the MODIS snow and ice product algorithms draw upon 30 years of experience in observing and monitoring snow and ice from earth observation satellites[7]. The remote sensing systems that are useful for snow and ice fall into three categories: optical wavelength systems, passive microwave systems and active microwave systems. Passive microwave systems, which measure the amount of microwave energy naturally emitted from the earth's surface, have proven particularly useful for monitoring the large scale sea ice distribution on a year-round basis, regardless of cloud cover. Active microwave systems (radars), which measure the return signal from pulses generated by the sensor, provide detailed, but localized information about sea ice age and type. The optical systems, which collect energy in the visible, near-infrared and thermal infrared wavelengths, have the longest history and the widest utility. The MODIS instrument is the latest and most advanced of the optical systems that are designed to monitor the globe daily.

Most notable of the optical systems that have been used to map snow and ice are NOAA's Advanced Very High Resolution Radiometer (AVHRR) and the Landsat Thematic Mapper (TM) instruments. AVHRR is primarily a meteorological applications sensor used by the National Weather Service for operational forecasting. It was designed to provide global coverage once per day at a spatial resolution of about 4 km. Landsat TM is an earth resources sensor used to monitor the earth's surface. It covers the earth about once in every eighteen days, but has a spatial resolution of 30m. Thus AVHRR data is suitable for frequent observation of large areas whereas TM is more appropriate for the study of smaller areas when the frequent coverage is not so important.

The design of the MODIS instrument incorporates characteristics of each of these systems. It will provide coverage of the polar regions on a daily basis, at intermediate spatial resolutions of either 250, 500 or 1000m. MODIS will collect data in 36 spectral bands, compared to the 5 or 7 on AVHRR and TM, respectively. The spatial and spectral resolution of MODIS will permit the routine collection of very detailed spectral information, which generally has only been available on much smaller scales, from aircraft or field measurements.

4. THE MODIS SNOW AND ICE ALGORITHMS

Much of the development work for MODIS algorithms has utilized the similar spectral bands of the Landsat TM. Table 2[8] shows wavelength center locations and spatial resolution of MODIS bands, and the corresponding TM bands.

The MODIS snow cover mapping algorithm identifies snow by its reflectance characteristics in the visible and near-infrared regions of the electromagnetic spectrum. For example, a key characteristic of snow is that its reflectivity is high in the visible part of the spectrum and low in the near-infrared at about 1.6 μm[9]. The reflectivity of most clouds remains high in both the visible and near-infrared regions. These features are accounted for in the calculation of the Normalized Difference Snow Index (NDSI)[8]. This is expressed for TM data as:

$$NDSI=(TM\ 2[0.56\ \mu m] - TM\ 5[1.65\ \mu m])/(TM\ 2 + TM\ 5). \quad (1)$$

An NDSI value of 0.4 is used as the threshold for snow. This value is based on comparisons between the analysis of many TM scenes mapped using the MODIS snow mapping algorithm, with manually derived snow maps for the same scenes[7]. A second test used is a near-infrared reflectance test to distinguish between ice-free water bodies and snow which are sometimes confused. For the TM data, a value of 0.11 or more in the near-infrared band 4 (0.85 μm) indicates at least 50% of the pixel is covered by snow[8]. In addition, forest-canopy modeling has led to an enhancement of the original snow mapping algorithm that allows more snow to be mapped in forests than is possible with the original algorithm[11]. The enhanced algorithm will be used in the at-launch time frame.

A cloud mask , developed by the MODIS Instrument Science Team for use in many MODIS products, will be used to screen out cloud covered areas before the snow mapping algorithm is run. This should reduce any misinterpretation of clouds for snow, especially cirrus clouds which contain frozen water droplets and may have a low near-infrared reflectance similar to snow.

The MODIS Instrument Science Team estimates the overall accuracy of the snow mapping algorithm to be 91-95% globally and nearly 100% in tundra and prarie areas[12]. Performance in the boreal forests is not as good since the forest canopy darkens the scene reflectivity regardless of the presence of an underlying snow cover, but use of vegetation maps to be produced by the MODIS Land Team may improve this.

The snow cover algorithm may be updated pending the results from additional pre-launch tests using data from the MODIS Airborne Simulator (MAS) that has many of the same spectral characteristics as the MODIS sensor. In addition, the algorithm may be modified after launch of the AM-1 platform to incorporate other techniques.

Table 2. Corresponding MODIS and TM wavelengths (bands).

MODIS Band	Spatial Resolution (m)	Center Wavelength (μm)	Corresponding TM Band
1	250	0.645	3
2	250	0.858	4
3	500	0.469	1
4	500	0.555	2
6	500	1.640	5
7	500	2.130	7
13	1000	0.667	3
14	1000	0.678	3
16	1000	0.869	4
31	1000	11.030	6

The MODIS sea ice algorithm uses the same tests as does the original snow mapping algorithm since these have been shown to be acceptable for most ice types, except new thin ice[8]. Ice surface temperature (IST) will also be calculated as part of the sea ice algorithm. The calculation of IST is based on work by Key and Haefliger[13] and updated by Key and Collins[14]. This technique uses the clear sky brightness temperatures measured by the "split-window" thermal channels (at 10.8μm and 12.0μm) on the AVHRR instruments, corrected for atmospheric attenuation as a function of viewing angle, to derive IST. The AVHRR channels used here are comparable to MODIS channels 31 and 32 so this method is directly

applicable to MODIS data. The usefulness of the MODIS cloud mask during the polar night is being investigated since the IST algorithm requires clear skies, and low level stratus is sometimes confused for the surface by automated cloud screening techniques.

The snow and sea ice products will be available in orbital swath format (level 2) and in gridded formats (level 3). Both equatorial (equal area sinusoidal) and polar (equal area azimuthal) grids will be available. The level 3 gridded snow cover and sea ice products will have resolutions of 500m and 1000m respectively. Large inland lakes will be mapped at 500m.

The level 3 gridded products will be produced on a daily basis. There will also be an eight-day composite product which includes a maximum snow cover and sea ice extent and persistence statistics during the period. Several months after launch, software will be in place that will allow users to specify other compositing periods.

CURRENT ACTIVITIES

The MODIS Instrument Science Team and the NSIDC DAAC are preparing for the launch of the MODIS instrument on the first EOS platform. Hardware and software systems developed by the EOSDIS Core System (ECS) contractor have been installed at NSIDC and are being tested. The MODIS snow and ice products processing software will be integrated and tested beginning in mid-1997. Science Software Integration and Test (SSI+T) is a phased, iterative plan developed by MODIS, ECS and NSIDC that will continue until the products become operational after launch.

We are participating in the development of a Quality Assurance (QA) plan that will be implemented at the MODIS Team Leader Computing Facility (TLCF) and the DAACs. Both MODIS and NSIDC continue to seek a broad range of input from the cryospheric user community through a series of workshops, ad-hoc committees and user working group meetings. Several important modifications suggested through this process have been incorporated into the product design and distribution plan. For example, MODIS and NSIDC are exploring processing options to address the needs of operational users, such as providing products on a near-real time basis. A polar grid for level 3 products has been adopted. The IST algorithm has been included as part of the sea ice product.

CONCLUSIONS

The EOS MODIS Instrument Science Team is developing snow and ice products to be implemented at the time of the launch of the first EOS mission on the AM-1 platform in June 1998. A suite of atmospheric, oceanographic and land surface products from MODIS will be distributed via EOSDIS from the Goddard Space Flight Center, EROS Data Center and NSIDC DAACs. The MODIS snow and ice products will be archived and distributed by the NSIDC DAAC. These products will utilize the improved spatial and spectral resolution of MODIS over current visible and infrared sensors and they will represent a significant improvement over currently available similar products. They will complement related microwave and radar products. Daily maps of global snow cover extent and sea ice extent will be produced. In addition, the MODIS data offer the potential for other cryospheric products (for example sea ice surface motion and albedo) in the post-launch time frame. These may be developed and tested by the MODIS Instrument Science Team or the EOS Interdisciplinary Science Investigations. More information on these products may be found at the following World wide Web sites:

the MODIS Home Page (http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html),
the Algorithm Theoretical Basis Document Home Page (http://spso2.gsfc.nasa.gov/atbd/pg1.html),
and the MODIS Snow/Ice Global Mapping Project home page (http://ltpwww.gsfc.nasa.gov/MODIS_Snow/modis.html).

ACKNOWLEDGEMENTS

This work was supported by NASA Contract NAS 5-32392.

REFERENCES

1. S. Wharton and M. Myers, *1997 MTPE EOS Data Products Handbook*, p.2, NASA, Washington, DC, 1997.

2. T. Carroll, J. Baglio, J. Verdin, and E. Holroyd, III, "Operational mapping of snow cover in the United States and Canada using airborne and satellite data", *Proceedings of the 12th Canadian Symposium on Remote Sensing*, **3**, 10-14 July 1989, Vancouver, Canada, 1989.

3. J. Walsh, W. Jasperson, and B. Ross, "Influences of snow cover and soil moisture on monthly air temperature", *Monthly WeatherRev.*, **113**, 756-768, 1985.

4. D. Robinson and K. Dewey, "Recent secular variations in the extent of northern hemisphere snow cover", *Geophysical ResearchLetters*, **17**, pp.1557-1560.

5. H. Zwally, J. Comiso, C. Parkinson, W. Campbell, F. Carsey, and P. Gloersen, *Antarctic Sea Ice, 1973-1976: Satellite Passive Microwave Observations*, NASA SP-459, Washington, D.C., 206pp, 1983.

6. M. Palecki and R. Barry, "Freeze-up and break-up of lakes as an index of temperature changes during the transition seasons: a case study in Finland", *Journal of Climate and Applied Meteorology*, **25**, pp893-202, 1986.

7. D. Hall, "Satellite Snow-Cover Mapping: A Brief Review", *First Moderate Resolution Imaging Spectroradiometer (MODIS) Snow and Ice Workshop*, D. Hall (Ed.), pp.15-22, NASA Goddard Space Flight Center, Greenbelt, MD, 1995.

8. G. Riggs, D. Hall, and V. Salomonson, "A snow index for the Landsat Thematic Mapper and Moderate Resolution ImagingSpectroradiometer", *IGARSS*, **4**, pp.1942-1944, 1994.

9. H. O'Brien and R. Munis, *Red and Near-Infrared Spectral Reflectance of Snow*, Research Report 332, U.S. Army Cold RegionsResearch and Engineering Laboratory, Hanover, NH, 18pp., 1975.

10. D. Hall, G. Riggs, and V. Salomonson, "Development of methods for mapping global snow cover using Moderate Resolution Imaging Spectroradiometer Data", *Remote Sens. Environ.*, **54**, pp127-140, 1995.

11. A. Klein, D. Hall, and G. Riggs, "Improving snow-cover mapping in forests through the use of a canopy reflectance model", submittedto *Hydrological Processes*.

12. World Wide Web Site: D. Hall (April, 1997). *The MODIS Snow/Ice Global Mapping Project* [Online]. Available HTTP:http://ltpwww.gsfc.nasa.gov/MODIS_Snow/modis.html [June 26, 1997].

13. J. Key and M. Haefliger, "Arctic Ice Surface Temperature Retrieval from AVHRR Thermal Channels", *Journal of Geophysical Research*, **97**(5), pp5885-5893, 1992.

14. J. Key and J. Collins, "High-latitude surface temperature estimates from thermal satellite data", submitted to *Remote Sensing of the Environment*.

Further author information -

G.R.S. (correspondence): Email: scharfen@kryos.colorado.edu; WWW: http://www-nsidc.colorado.edu/; Telephone: 303-492-6197; Fax: 303-492-2468

D.K.H.: Email: dhall@glacier.gsfc.nasa.gov; Telephone: 301-286-6892; Fax: 301-286-1758

G.A.R.: Email: griggs@ltpextreme1.gsfc.nasa.gov; Telephone: 301-286-6811; Fax: 301-286-1758