# ASSESSING THE UTILITY OF MODIS
# FOR MONITORING SNOW AND SEA ICE EXTENT

*G. Scharfen, S. Khalsa*

*U.S. National Snow and Ice Data Center, University of Colorado UCB 449, Boulder, CO 80309-0449, United States, Tel. 01-303-492-6197, Fax 01-303-492-2468, Email scharfen@nsidc.org*

*L-3 Communications Corporation, 1801 McCormick Dr. Suite 170, Landover, MD 20774 USA*

## ABSTRACT

With the launch of the MODIS instrument on NASA's Earth Observing System (EOS) Terra satellite, a new era of cryospheric monitoring from space has begun. For the first time daily, global maps of snow cover and sea ice extent are being produced in a fully automated fashion from space-borne measurements in optical wavelengths. The capabilities and limitations of the MODIS instrument for measuring snow cover and sea ice extent will be highlighted in several case studies in which the MODIS products are compared with other available operational analyses. The 1 km resolution MODIS sea ice product, as determined from both solar reflective and terrestrial emissive bands, will be compared to relevant sea ice data sets and individual MODIS channel data. The 500 m MODIS snow cover product will be compared to both NOAA operational analyses based on multiple satellite sensors and individual channel data.

(see http://nsidc.org/modis)

## INTRODUCTION

With the launch of the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Earth Observing System (EOS) Terra satellite, a new era of cryospheric monitoring from space has begun. For the first time daily, global maps of snow cover and sea ice extent are being produced in a fully automated fashion from space-borne measurements in optical wavelengths.

MODIS has 36 bands in the 0.4 to 14 µm spectral region. These bands have a spatial resolution at nadir of between 250 m and 1 km. The swath width is 2,330 km and the spacecraft has an equatorial crossing time of 1:30 p.m. (1). Given this configuration, most areas of the earth are imaged at least once each day.

Owing to improved spectral, spatial and radiometric characteristics, MODIS represents a considerable improvement in the capability for global cryospheric monitoring over comparable existing systems. The MODIS snow and ice products augment the existing record of satellite-derived snow cover and sea ice products that began more than 30 years ago. Nevertheless, all current satellite-based snow and ice products have limitations which vary in significance, depending on the application.

The MODIS snow and ice data products are archived at the US National Snow and Ice Data Center (NSIDC). They include level 2 swath and level 3 gridded formats. Level 3 products consist of tiles of data, approximately 1,200 by 1,200 pixels, in the MODIS Integerized Sinusoidal Grid for snow and in the Lambert Azimuthal Equal-Area (EASE-Grid) projection for sea ice. All of the Level 3 products are available in daily and 8-day composites. The snow products are also available in a 0.05 degree resolution Climate Modeling Grid, as daily and 8-day composites (2). For details, and instructions on how to order through the EOS Data Gateway, visit: http://nsidc.org/daac/modis/. This paper provides an introduction to these products, and a qualitative comparison with other similar products.

## METHODS

The MODIS snow algorithm uses the low shortwave IR (SWIR) reflectance of snow which contrasts with its high visible reflectance (3). A Normalized Difference Snow Index (NDSI) is computed from Band 4 (green) and Band 6 (SWIR):

$$NDSI = \frac{\text{Band 4 - Band 6}}{\text{Band 4 + Band 6}}$$

The NDSI is computed on a pixel-by-pixel basis. Snow is determined if: NDSI ≥ 0.4, and the reflectance in Band 2 (near-IR) ≥ 0.11, and Band 4 (green) ≥ 0.10, to eliminate water and other dark surfaces from being classified as snow. A Normalized Difference Vegetation Index (NDVI) is computed from MODIS Band 1 (Red) and Band 2, and the NDSI and NDVI are used together to map snow in dense forests.

The NDSI is also used for MODIS sea ice products. In regions illuminated by the sun, the NDSI is used to differentiate sea ice from open water. A second method, one based on Ice Surface Temperature (IST), is also used for detection of sea ice. This is especially useful in areas lacking solar illumination. MODIS Bands 31 and 32, near 11.6 µm, are used in a split-window technique to derive IST, utilizing coefficients specific to sea ice.

The MODIS products are compared with the U.S. National Oceanic and Atmospheric Administration (NOAA) Interactive Multisensor Snow and Ice Mapping System (IMS) Daily Northern Hemisphere Snow and Ice Analysis charts (available from: http://www.ssd.noaa.gov/PS/SNOW/), and NSIDC's Near real-time Ice and Snow Extent (NISE) product (available from http://nsidc.org/data/nise1.html). The NOAA product uses a combination of input data including optical and passive microwave wavelength data and surface observations. The NISE product is based entirely on passive microwave data. Both of these are operational products designed for use as??? snow and ice background field for numerical weather forecast models or as input to EOS satellite data production schemes. Neither of them were specifically intended as climatological products, but in fact the NOAA product is often used as such since it (as an evolutionary product) has been produced for more than 30 years.

## RESULTS

*Snow Cover:*

Snow cover is mapped at 500 m resolution for all land regions of the earth illuminated by the sun. One granule of the swath-based product is 2,030 km long and 2,330 km wide. Daily gridded data are in the MODIS Integerized Sinusoidal Grid, and are distributed in 1,200 km square tiles. An eight-day snow product is also available.

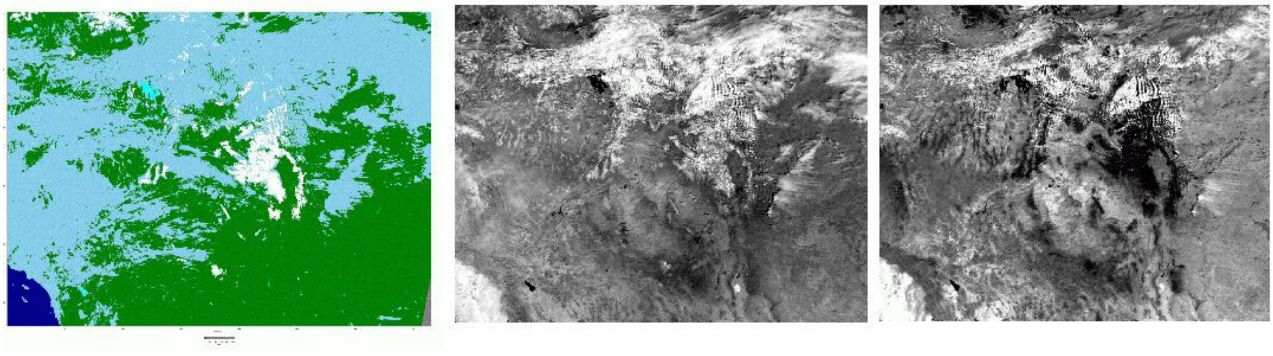

*Figure 1: MODIS snow product (left), MODIS Band 4 (0.5µm) (center), and MODIS band 6 (1.6µm) (right).*

Figure 1 shows cloud (blue) and snow cover (white) in the Southwestern US on 21 March 2001. The extensive cloud cover is typical and presents one of the major challenges for the MODIS snow products. A pixel classified as having a high probability of cloud of any type cannot subsequently be reclassified as snow, even if the cloud detected does not obscure the surface.

The MODIS snow algorithm correctly classifies snow in the forested mountains of the Southwestern US. Where a narrow band of cloud is seen surrounding regions of snow, a problem with the MODIS cloud mask arises that is being worked on.

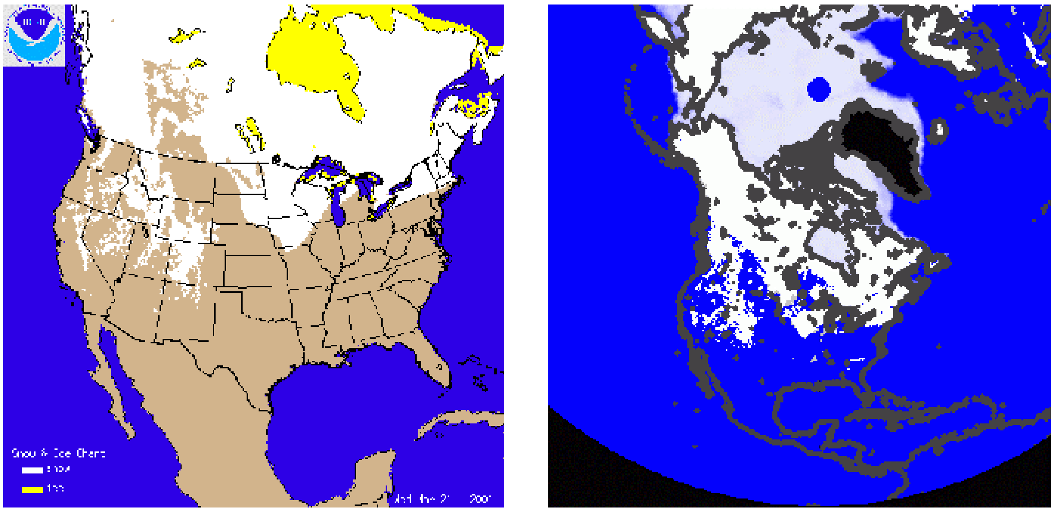

*Figure 2: Near real-time Ice and Snow Extent, or NISE product (left), and NOAA operational snow cover product (right).*

Comparisons with the NOAA IMS and the NSIDC NISE product (Figure 2) show that MODIS provides a more detailed mapping of snow cover, but is limited by cloud cover. The NOAA IMS and the NSIDC NISE products are not hampered by cloud cover since the passive microwave data they use as input permit observation of the surface through most clouds. Also, the NOAA IMS uses the previous day's analysis when the surface is obscured by clouds (4). These products have a considerably coarser spatial resolution of about 25 km, vs. about 500 m for the MODIS snow product. The MODIS cloud mask, which is used as an input to the MODIS snow product algorithm, masks out areas with any observable cloud, even thin transparent clouds, resulting in extensive areas that are masked out and not analysed by the snow algorithm. Improvements to the MODIS cloud mask are currently being investigated by the MODIS Science Team.

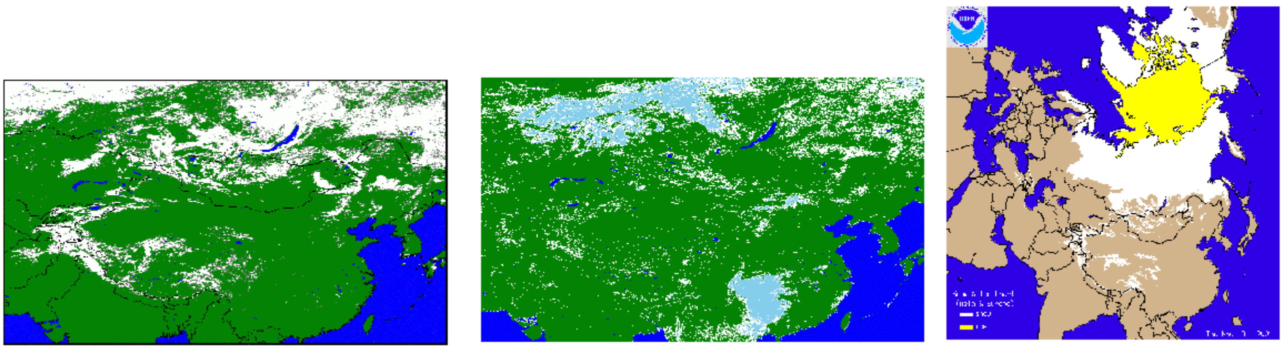

*Figure 3: MODIS Climate Modeling Grid (CMG)(left), MODIS 8-day cloud cover (center), and NOAA operational snow cover product (right).*

An example of the Climate Modeling Grid (CMG) product for 1-8 November 2001 is shown in Figure 3. Comparisons with the NOAA operational product (just one day shown) are favourable, with slightly more snow by MODIS in regions like Kazakstan and Manchuria. The composite cloud cover (which unlike that for the level 2 or level 3 gridded data is in a separate array) shows persistently cloudy regions (cloudy for more than 6 days in the 8 day period) in blue. This limits the extent of snow cover mapped by MODIS in Central Russia. Thus persistent cloud cover can be a limitation for mapping snow cover with optically-based sensors like MODIS, even with time-averaged products like the CMG.

*Sea Ice:*

Sea ice extent is mapped at 1 km resolution for the world's oceans. One granule of the swath-based product is 2,030 km long and 2,330 km wide. Daily gridded data are in the Lambert Azimuthal Equal-Area (EASE-Grid) projection, and are distributed in 1,200 km square tiles.

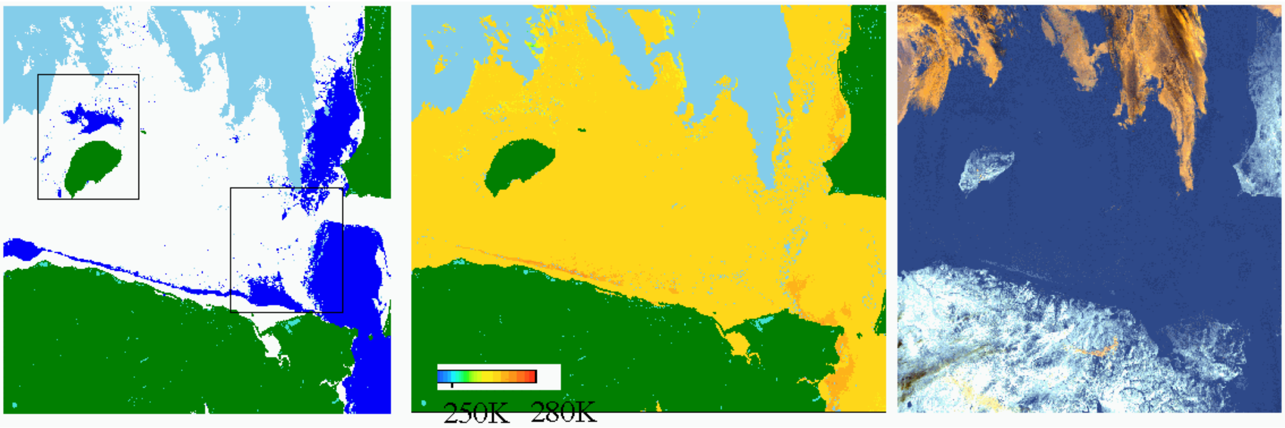


*Figure 4: MODIS sea ice product by NDSI method (left), IST method calculated temperatures (center), and a composite image made from MODIS Bands 20 (3.7µm), 22 (3.9µm) and 23 (4.0µm) to highlight clouds (right).*

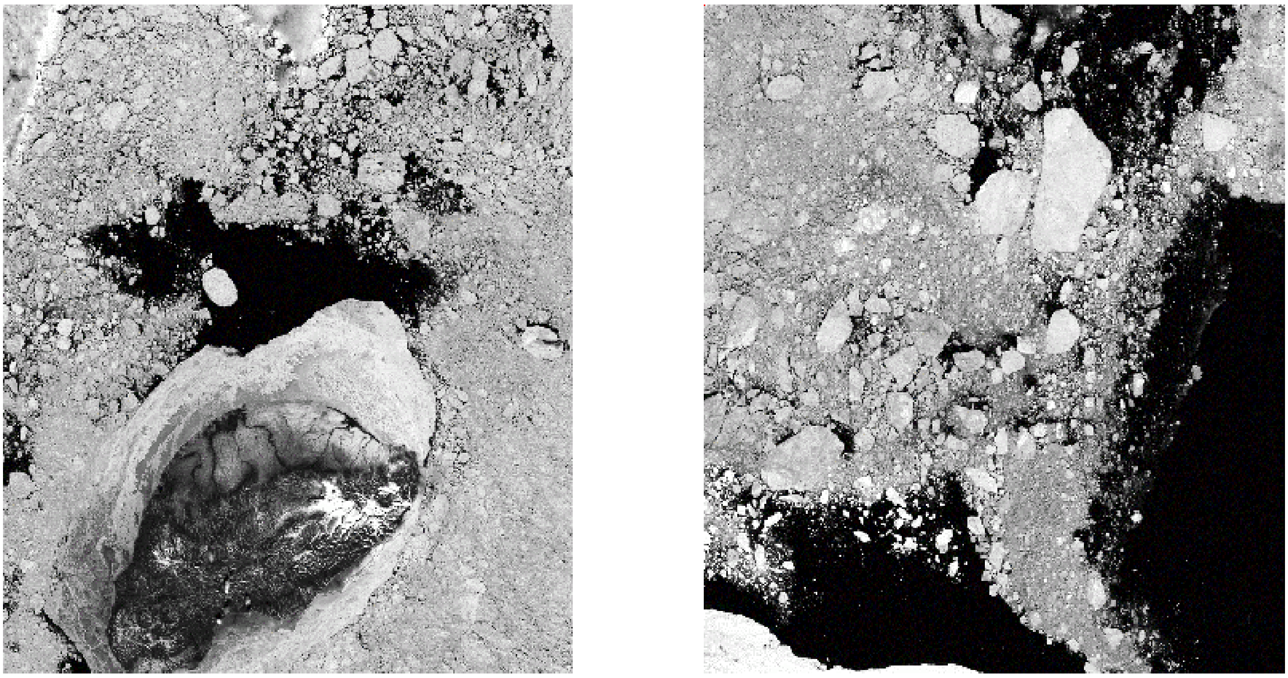

*Figure 5: MODIS Band 4 (0.5µm) enlargements of Wrangel Island (left), and Chukchi Sea (right). Box insets in Figure 4 indicate coverage of these images.*

Figures 4 and 5 show sea ice in the Chukchi Sea and Bering Strait on 3 June 2001. This example was chosen to show a variety of ice types, and MODIS' ability to successfully classify sea ice for all of them using the NDSI. The classification based on IST is less successful. Using a value of 271.4ºK for the freezing point of seawater, the extent of sea ice is not discernable since the temperatures of the sea ice and open water are nearly the same.

The US National Ice Center (NIC) charts show a large increase in open water in the Chukchi Sea between the two dates. The date of the MODIS images (3 June) is in the middle of the 3 days of Radarsat data used in the NIC analysis. This makes specific comparison of the MODIS and NIC charts difficult, especially in the Chukchi Sea.

This example illustrates the strengths and weaknesses of the two MODIS sea ice algorithms. The MODIS NDSI method demonstrates an excellent ability to distinguish sea ice in the daylight conditions at this time of year. The NDSI method does not perform as well during the low light seasons, particularly during fall, and is not used at all when there is no solar illumination. This example also illustrates the difficulty in using derived ice surface temperature to map sea ice extent during the melt season when the temperature of the ice surface and nearby open water are similar. At most other times of the year the thermal signatures of these two surfaces are significantly different and the IST method performs well. Thus, while each of these methods has limitations, reasonable results can be expected by selecting one product or the other depending on the time of year. In both cases, the MODIS sea ice products have notably higher spatial resolution than any of the available passive microwave products.

## CONCLUSIONS

The MODIS snow and ice products utilize the improved spatial, spectral, and radiometric characteristics of the MODIS instrument relative to other systems. The MODIS snow and ice products complement, and in some cases improve, the range of satellite-derived products that are available for monitoring snow and sea ice. Problems associated with the MODIS snow and ice products, including the performance of the MODIS Cloud Mask, and the IST algorithm are being worked on. Validation efforts are underway.

NSIDC archives and distributes the MODIS snow and ice products and other products useful for cryospheric research. For more information, contact:

NSIDC User Services
CIRES, 449UCB, University of Colorado
Boulder, CO. 80309-0449, USA
E-mail: nsidc@nsidc.org
Phone: +1 (303) 492-6199
Fax: +1 (303) 492-2468
Web: http://nsidc.org/,

or visit the MODIS snow and ice products web site at http://nsidc.org/data/modis/.

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