MODIS Snow Products Collection 6.1 User Guide

Version 1.0

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The C61 MOD/MYD10 product is identical in format to the C6 product. This (C61) reprocessing does not contain any change to the science algorithm used to make this product. Any improvement or change in the C61 product compared to the product from the prior major collection reprocessing (C6) is from changes and enhancements to the calibration approach used in generation of the Terra and Aqua MODIS L1B products and changes to the polarization correction used in this collection reprocessing. For further details on C61 calibration changes and other changes user is encouraged to refer to the Collection 6.1 specific changes that have been summarized here: https://landweb.modaps.eosdis.nasa.gov/QA_WWW/forPage/MODIS_C61_Land_Proposed_Changes.pdf

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1.0 Overview

A few revisions were made in the MODIS snow cover algorithm with the objective to further minimize snow cover detection errors and increased data content relative to cloud masking for Collection 6.1 (C6.1). The daily cloud-gap filled (CGF) product M*D10A1F that provides a “cloud free” daily snow cover map is included in C6.1. The objective in C6.1 is to minimize snow cover detection errors of omission and commission for the purpose of mapping snow cover extent (SCE) accurately on the global scale. To reach that objective the same “snow-conservative approach” from C6 was continued in C6.1. The snow-conservative approach focuses on detection of snow wherever it might be present based on reflectance features, then screens for false snow detections. Detection of snow is pushed to algorithm limits e.g., under low illumination conditions, high solar zenith angles (SZAs) and shadowed surfaces.

As compared to C6, minor revisions were made in the Level 2 snow detection algorithm. The thresholds in the low visible reflectance screen of MODIS bands 2 and 4 are lowered by 0.03 to reduce the occurrence of “no decision” results in low illumination conditions. Users should expect to see fewer “no decision” results in C6.1 products. In general the lowering of the visible reflectance screen has been observed to result in no decision results changed to “snow” or “not snow”, with “no decision” results found for very low, < 0.07 reflectance situations. The MODIS cloud mask (M*D35_L2) flags for “probably cloudy” and “probably clear” are now included in the NDSI_Snow_Cover_Algorithm_Flags_QA dataset so they can be used to evaluate possible cloud/snow confusion situations.

Revisions for C6.1 are focused on improving snow detection in clear sky conditions vs. making dramatic improvements in cloud/snow discrimination. Some minor improvement in cloud/snow confusion was made in the C6.1 cloud mask product, M*D35_L2, but significant cloud/snow confusion situations remain. We have identified some situations in which cloud/snow confusion can be alleviated, though results have not been consistent. Therefore, cloud/snow confusion issues in C6.1 are very similar to those in C6. A notable cloud/snow confusion situation that can occur is associated with fringes of clouds that are not detected as “certain cloud” by the cloud mask. This occurs when the cloud cover consists of scattered popcorn-shaped cloud formations over vegetated surfaces where the cloud contaminated pixels are detected as snow and none of the data screens reverse or flag that snow commission error.

For the MODIS Aqua snow cover detection algorithm the Quantitative Image Restoration (QIR) algorithm (Gladkova et al., 2012) has been integrated with the Level 2 algorithm. The QIR restores the Aqua MODIS band 6 to scientifically usable data for the snow algorithm, thus allowing the same algorithm to be used for Terra and Aqua in C6 and C6.1. In C5, Aqua band 7 had been used instead of Aqua band 6 because of the non-functional detectors in band 6. Use of band 7 (vs. band 6) required empirical changes in the algorithm and increased the uncertainty of the Aqua MODIS snow product.

The following product is new in the chain of snow cover products in C6.1:

- The cloud-gap-filled (CGF) daily snow cover tiled product.

Production of the C6.1 MODIS snow cover products is expected to begin about May 2019. The MODIS Adaptive Processing System (MODAPS) generates the standard products and the Land Data Operational Products Evaluation (LODPE) conducts evaluation and quality assessment of the products (https://landweb.modaps.eosdis.nasa.gov/cgi-bin/QA_WWW/newPage.cgi). The snow products are archived at the National Snow & Ice Data Center (NSIDC) NASA Distributed Active Archive Center (DAAC) https://nsidc.org/daac. News regarding the C6.1 reprocessing is posted at https://modis-land.gsfc.nasa.gov/news.html.

This User Guide describes each product in the sequence from Level 2 to Level 3. In this guide, the MODIS snow products are referenced by their Earth Science Data Type (ESDT) name, e.g. M*D10A1. Throughout this guide M*D is used in ESDT names to indicate both Terra (MOD) and Aqua (MYD) products. The ESDTs are produced as a series of products in which data and information are propagated to the higher level products. The series of products is the same as it was in C6 but with addition of M*D10A1F. Details of algorithm refinements and QA data content, and commentary on evaluation and interpretation of data are given for each product.

2.0 New Snow Cover Data Product in C6.1

A daily cloud-gap-filled (CGF) tiled snow cover product, M*D10A1F is produced. The CGF snow cover product is produced from the daily tiled M*D10A1 and the previous day M*D10A1F. Daily gaps in observations caused by cloud cover are filled by retaining the previous clear view data for a cell if the current day is cloud obscured (Hall et al., 2010). A data layer that tracks the number of days since last clear view of a cell is included in the product. The algorithm and product are described in Section 12.0. A daily CMG CGF product, of composited M*D10A1F tiles is planned.

3.0 Revisions in C6.1 Snow Cover Products

M*D10_L2

1) The low visible reflectance screen for snow cover using bands 2 and 4 was lowered to 0.07 reflectance from 0.10 in C6. The result of lowering the threshold was a reduction in the occurrence of "no decision" results in the algorithm.
2) Two algorithm bit flags are set for M*D35_L2 cloud mask confidence flags of "probably cloudy" and "probably clear" in the algorithm flags QA dataset. These flags can be used to investigate cloud/snow confusion in some situations.

4.0 Production Sequence

The snow cover data products are produced in sequence. The sequence begins with a swath (scene) at a nominal pixel spatial resolution of 500 m with nominal swath coverage of 2330 km (across track) by 2030 km (along track), consisting of five minutes of MODIS scans. Products in EOSDIS are labeled as ESDT. The ESDT label *ShortName* is used to identify the snow data products. The EOSDIS *ShortName* also indicates what spatial and temporal processing has been applied to the data product. Data product levels briefly described are: Level 1B (L1B) is a swath (scene) of MODIS data geolocated to latitude and longitude centers of 1 km resolution pixels. A Level 2 (L2) product is a geophysical product that remains in the latitude and longitude orientation of L1B. A Level 2 gridded (L2G) product is in a gridded format of the sinusoidal projection for MODIS land products. At L2G the data products are referred to as tiles, each tile being 10° x 10°, of the global map projection. The L2 data products are gridded into L2G tiles by mapping the L2 pixels into cells of a tile in the map projection grid. The L2G algorithm creates a gridded product necessary for the level 3 products. A level 3 (L3) product is a geophysical product that has been temporally and or spatially manipulated, and is in a gridded map projection format and comes as a tile of the global grid. The MODIS L3 snow products are in either the sinusoidal projection or geographic projection.

To understand MODIS snow products at higher levels a user needs to understand how snow detection was done at L2 and how those results propagate to the higher level products.

Table 1. MODIS Terra and Aqua snow data products, Terra MOD and Aqua MYD products are indicted by M*D.

Earth Science Data Type (ESDT)	Product Level	Nominal data Array Dimensions	Spatial Resolution	Temporal Resolution	Map Projection	Approximate size (Mb)
M*D10_L2	L2	1354x2030 km	500 m	5 min swath	None, lat and lon referenced	12
M*D10GA	L2G	1200x1200 km	500 m	daily	Sinusoidal	6
M*D10A1	L3	1200x1200 km	500 m	daily	Sinusoidal	2
M*D10A1F	L3	1200x1200 km	500 m	daily	Sinusoidal	TBD
M*D10C1	L3	360°x180°, global	0.05° x 0.05°	daily	Geographic	4
M*D10A2		1200x1200 km	500 m	daily	Sinusoidal	1
M*D10C2	L3	360°x180°, global	0.05° x 0.05°	8-days	Sinusoidal	4
M*D10CM	L3	360°x180°, global	0.05° x 0.05°	monthly	Geographic	2

5.0 M*D10_L2

The snow cover detection algorithm is applied to generate the first product in the sequence M*D10_L2. The M*D10_L2 products are then input to the daily L2G and L3 products. Revisions in the algorithm to map snow cover extent (SCE) with high accuracy while minimizing snow cover errors of omission and commission were implemented in C6.1. The snow detection technique remains based on the Normalized Difference Snow Index (NDSI) (for a history of the NDSI, see Hall and Riggs, 2011) with data screens applied to alleviate snow detection commission errors and flag uncertain snow detection. The algorithm is the same as used in C6 with minor revisions made for the low visible reflectance screen. The surface temperature screen is linked with surface height and is used to reverse snow detections at low elevations and to flag warm snow detections at high elevations. Snow cover extent is output in the NDSI_Snow_Cover SDS. FSC is not calculated in C6.1. The QA data and information output are the same as in C6 but with the addition of two cloud mask flags in bits that were spares in C6. The QA output is a basic QA data array and a QA data array of algorithm bit flags, the results of data screens applied in the algorithm. The accuracy of snow mapping in C6.1 is consistent with C6. Changes in calibration of the MODIS L1B radiance data (https://mcst.gsfc.nasa.gov) and changes in the MODIS cloud mask (https://modis-atmosphere.gsfc.nasa.gov/products/cloud-mask/) may affect the quality of the snow cover algorithm.

Occurrence of ice/snow cover on inland water bodies is detected using the snow algorithm applied to inland water bodies mapped in the land/water mask. Inland water bodies are mapped by setting a bit flag in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS.

Aqua-specific processing

The Terra and Aqua MODIS instruments are very similar in design and performance, except for Aqua MODIS band 6 in which the majority of detectors are non-functional (MCST, 2014). In the Aqua MODIS band 6 (1.6 µm) focal plane about 75% of the detectors are non-functional, thus band 6 cannot be used in the snow algorithm, even though it is an integral part of the snow algorithm. In C6 and C6.1 the quantitative image restoration (QIR) algorithm developed by Gladkova et al., (2012) is applied to restore the missing Aqua MODIS band 6 data to scientifically-usable data for snow detection. When the MODIS snow algorithm was tested using QIR band 6 data it was found that the output snow cover maps are more accurate than the Aqua snow maps when band 7 was used to generate the snow cover maps. Therefore the QIR algorithm was integrated in the MYD10_L2 PGE for C6 and continues in C6.1. The same snow detection algorithm is run with both Terra and Aqua using band 6 data in C6.1 to make the NDSI_Snow_Cover and NDSI datasets.

Algorithm Description

A brief description of the algorithm approach for C6.1 is given here, and a detailed description can be found in the MODIS Snow ATBD (http://modis-snow-ice.gsfc.nasa.gov/?c=atbd&t=atbd). The purpose of this description is to describe the flow of the algorithm and the basic technique used to detect snow cover. The output is an NDSI snow cover map with clouds, water bodies and other features included as mask values on the map.

The C6.1 algorithm uses as input the M*D02HKM and M*D021KM band radiance data, the M*D03 geolocation data product, and the M*D35_L3 cloud mask. Inputs to the algorithm are listed in Table 2. The processing flow for a pixel is determined based on the land/water mask. Land and inland water bodies in daylight are processed for snow detection or ice/snow on water detection. MODIS radiance data is checked for nominal quality and converted to top-of-atmosphere (TOA) reflectance. (Specifics of L1B processing and documentation can be found at the MODIS Calibration Support Team (MCST) web page http://mcst.gsfc.nasa.gov/.)

Table 2. MODIS Terra and Aqua data product inputs to the MODIS snow algorithm.

ESDT	Long Name	Data Used
MOD02HKM	MODIS/Terra Calibrated Radiances 5-Min L1B Swath 500m	Radiance for MODIS bands 1 (0.645 μm) 2 (0.865 μm) 4 (0.555 μm) 6 (1.640 μm)
MYD02HKM	MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 500m	Radiance for MODIS bands 1 (0.645 μm) 2 (0.865 μm) 4 (0.555 μm) QIR 6 (1.640 μm)
MOD021KM	MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1km	Radiance for MODIS bands 31 (11.03 μm)
MYD021KM	MODIS/Aqua Calibrated Radiances 5-Min L1B Swath 1km	Radiance for MODIS band 31 (11.03 μm)
MOD03	MODIS/Terra Geolocation Fields 5-Min L1A Swath 1km	Land/Water Mask Solar Zenith Angle Latitude Longitude Geoid Height
MYD03	MODIS/Aqua Geolocation Fields 5-Min L1A Swath 1km	Land/Water Mask Solar Zenith Angle Latitude Longitude Geoid Height
MOD35_L2	MODIS/Terra Cloud Mask and Spectral Test Results 5-Min L2 Swath 250m and 1km	Unobstructed Field of View Flag Day/Night Flag
MYD35_L2	MODIS/Aqua Cloud Mask and Spectral Test Results 5-Min L2 Swath 250m and 1km	Unobstructed Field of View Flag Day/Night Flag

Snow typically has very high visible (VIS) reflectance and very low reflectance in the shortwave infrared (SWIR), a characteristic used to detect snow by distinguishing snow and most cloud types. Snow cover is detected using the NDSI ratio of the difference in MODIS VIS and SWIR reflectance:

NDSI = ((band 4-band 6) / (band 4 + band 6))

A pixel with 0.0 < NDSI ≤ 1.0 is considered to have some snow present. A pixel with NDSI ≤ 0.0 is a snow free land surface. The NDSI is calculated for all land and inland water bodies in daylight in a swath and is stored in the NDSI SDS.

The NDSI is effective at detecting snow cover on the landscape when skies are clear, and viewing geometry and solar illumination are good. Snow cover always has an NDSI > 0.0 but not all surface features with NDSI > 0.0 are snow cover. Some surface features, e.g. salt pans, or cloud contaminated pixels at edges of cloud, can have NDSI > 0.0 and be erroneously detected as snow cover, which results in a snow commission error (detecting snow where there is no snow). Snow commission errors are frequently associated with cloud fringes. Several data screens based on snow spectral features or other characteristics are applied in the algorithm to alleviate snow commission errors. Those screens are used to reverse snow cover detection or are used to flag uncertain, lower quality snow cover detection situations. Other data screens are applied to all pixels to flag certain situations that may affect the overall quality of the data products or be used to support interpretation or use of the data product.

Data Screens Applied

Data screens are applied for two purposes in the algorithm, one is to provide information specific to a snow or not snow result based on screens applied and the other is to provide other information relevant to evaluation of the snow cover product. Multiple screens are applied to a pixel so multiple bit flags may be set in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. The same data screens are applied to land and inland water pixels unless otherwise noted. The data screens are described in the following subsections. A user can use specific bit flags or combination of bit flags or all bit flags for analysis. More discussion of the data screens (bit flags) is in the *Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors* section.

Each screen has a bit flag in the QA algorithm flags SDS (described later in QA section) that is set to “on” if a screen was failed.

Inland water screen: bit 0

Inland water bodies from the land/water mask read from the geolocation data produc*t*D03 are mapped in bit 0 of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. This screen is applied to all pixels in a swath. It can be used as a mask to support analysis of inland water bodies.

Low VIS reflectance screen: bit 1

The reflectance thresholds for this screen were lowered in C6.1 to reduce the occurrence of “no decision” results in the algorithm. If the VIS reflectance from MODIS band 2 or band 4 is < 0.07 then an observation fails to pass this screen and a “no decision" is the result. In C6 the reflectance thresholds were set for MODIS band 2 ≤ 0.10 or band 4 ≤ 0.11 if an observation fails to pass that screen, and a "no decision" was the result. This screen is applied to non-cloud pixels with NDSI ≥ 0.0. This screen is tracked in bit 1 of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS.

Low NDSI screen: bit 2
Pixels detected with snow cover in the 0.0 < NDSI < 0.10 are reversed to a "not snow" result and bit 2 of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS is set. That bit flag can be used to find where a snow cover detection was reversed to "not snow." (See Section "Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors**"** for an explanation of this screen.)

Estimated surface temperature linked with surface height screen: bit 3
There is a dual purpose for this estimated surface temperature linked with surface height screen. It is used to alleviate snow commission errors on low elevations that appear spectrally to be similar to snow but are too warm to be snow. It is also used to flag snow detections on high elevations that are warmer than expected for snow. This screen is applied to non-cloud pixels with NDSI ≥ 0.0. If snow is detected in a pixel at height < 1300 m and that pixel has an estimated band 31 brightness temperature (BT) ≥ 281 K, that snow detection decision is reversed to "not snow" and bit 3 is set in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. If snow is detected in a pixel at height ≥ 1300 m and with estimated band 31 brightness temperature (BT) ≥ 281 K, that snow detection is flagged as unusually warm by setting bit 3 in the NDSI_Snow_Cover_Algorithm_Flags_QA.

High SWIR reflectance screen: bit 4
The purpose of this screen is to prevent non-snow features that appear similar to snow from being detected as snow but also to allow snow detection in situations where snow cover SWIR reflectance is anomalously high. This screen is applied to non-cloud pixels with NDSI ≥ 0.0. This screen has two threshold settings for different situations. Snow typically has SWIR reflectance less than about 0.20 however, in some situations, e.g. low sun angle, snow can have a higher reflectance. If a snow pixel has a SWIR reflectance in the range of 0.25 < SWIR ≤ 0.45 it is flagged as unusually high for snow and bit 4 of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS is set. If a snow pixel has SWIR reflectance > 0.45, it is reversed to "not snow" and bit 4 of NDSI_Snow_Cover_Algorithm_Flags_QA SDS is set.

Cloud possible screen: bits 5 & 6
The "Unobstructed FOV Quality Flag" from M*D35_L2 is used to mask clouds. If the cloud confidence flag is "confident cloudy" then the pixel is masked as "cloud." If the cloud confidence flag is set "confident clear," "probably clear" or "probably cloud" it is interpreted as "clear" in the algorithm. In C6.1 the cloud confidence flags of "probably cloudy" and "probably clear" are set as bits 5 and 6, respectively, in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. In C6 those were spare bits. These cloud confidence flags are included so that they can be used to evaluate the snow product especially in regards to cloud/snow confusion situations. See the Cloud Masking section below for more information.

Solar zenith screen: bit 7

Low illumination conditions exist at SZAs > 70° which is a challenging situation for snow cover detection. A solar zenith mask of > 70° is created for the entire swath, applied to all pixels, by setting bit 7 of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. This mask is set across the entire swath, all pixels. (Night is defined as the solar zenith angle ≥ 85° and pixels are mapped as “night” and this bit is also set.)

Lake Ice Algorithm

The lake ice/snow covered ice detection algorithm is the same as the NDSI snow cover algorithm, except that the low visible reflectance screen thresholds were kept at the C6 settings of band 2 ≤ 0.10 or band 4 ≤ 0.11. Inland water bodies are tracked by setting bit 0 of NDSI_Snow_Cover_Algorithm_Flags_QA. Users can extract or mask inland water bodies in the NDSI_Snow Cover output using that inland water bit flag. This algorithm uses the basic assumption that a water body is deep and clear and therefore absorbs all solar radiation incident upon it. Water bodies with high turbidity or algal blooms or mixed pixels along shorelines or banks may be erroneously detected as snow/ice covered.

Cloud Masking

The “Unobstructed FOV Quality Flag” from M*D35_L2 is used to mask clouds. The 1 km cloud mask is applied to the four corresponding 500 m pixels. If the cloud confidence flag is “confident cloudy” then the pixel is masked as “cloud.” If the cloud confidence flag is set “confident clear,” “probably clear” or “probably cloud” it is interpreted as “clear” in the algorithm. In C6.1 the cloud confidence flags of “probably cloudy” and “probably clear” are set in bits 5 and 6, respectively, in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS. In C6 those were spare bits. These cloud confidence flags are included so that they can be used to investigate cloud/snow confusion situations.

Abnormal pixel condition rules

If MODIS L1B data are missing in any of the bands used in the algorithm, that pixel is set to “missing data” and is not processed. Unusable L1B data are processed as a “no decision” result.

Quality Assessment (QA) Data

The approach to QA in C6.1 is similar to that of C6. A basic QA value is reported and the data screens applied in the algorithm are reported as bit flags. The basic QA value is a qualitative estimate of the algorithm result for a pixel based on L1B input data and SZA data. The algorithm bit flags are can be used to investigate results for all pixels processed.

The basic QA value is initialized to “best value” and is adjusted based on the quality of the MOD02HKM input data and the SZA screen. If the M*D02HKM radiance data is outside the range of 5-100% TOA but still usable, the QA value is set to “good.” If the SZA is in range of 70° ≤ SZA □85° the QA is set to “okay,” which indicates increased uncertainty in results because of low illumination. If input data is unusable the QA value is set to “other.” Conditions for a poor result are not defined. For features that are masked, e.g. night and ocean, the same mask values used in the snow cover data arrays are used.

The NDSI_Snow_Cover_Algorithm_Flags_QA is a bit flag dataset of data screen results applied in the algorithm. By examining bit flags a user can determine if a snow cover result was changed to a “not snow” result by a screen or screens, or if a snow covered pixel has certain screens set to on which is indicative of an uncertain snow detection. The screens and bit flags have a dual purpose; some flag where snow detection was reversed and some flag snow detection as “uncertain.” More than one data screen can be on for a snow detection reversal or for uncertain snow detection. The data screens are described in the algorithm section and interpretation of them is discussed in the *Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors* section. The inland water flag should be used for analysis of the inland water snow/ice cover result in the algorithm.

Scientific Data Sets

NDSI_Snow_Cover

NDSI_Snow_Cover is reported in the range of 0-100 with other features identified by mask values. The structure and partial list of local attributes and data content of the SDS are listed in Table 3. An example of the NDSI_Snow_Cover and MODIS imagery for a swath covering the boreal forest of Canada and the U.S. Great Plains is shown in Figure 1.

Snow and ice cover on inland water bodies is a product within the M*D10 product. Snow/ice cover on inland water bodies is also mapped using the same range of values as the NDSI_Snow_Cover. Inland water bodies have a value of 237 unless snow or ice was detected. The inland water flag is stored in bit 0 of the NDSI_Snow_Cover_Algorithm_Flags_QA; it can be used to map inland water bodies in the swath.

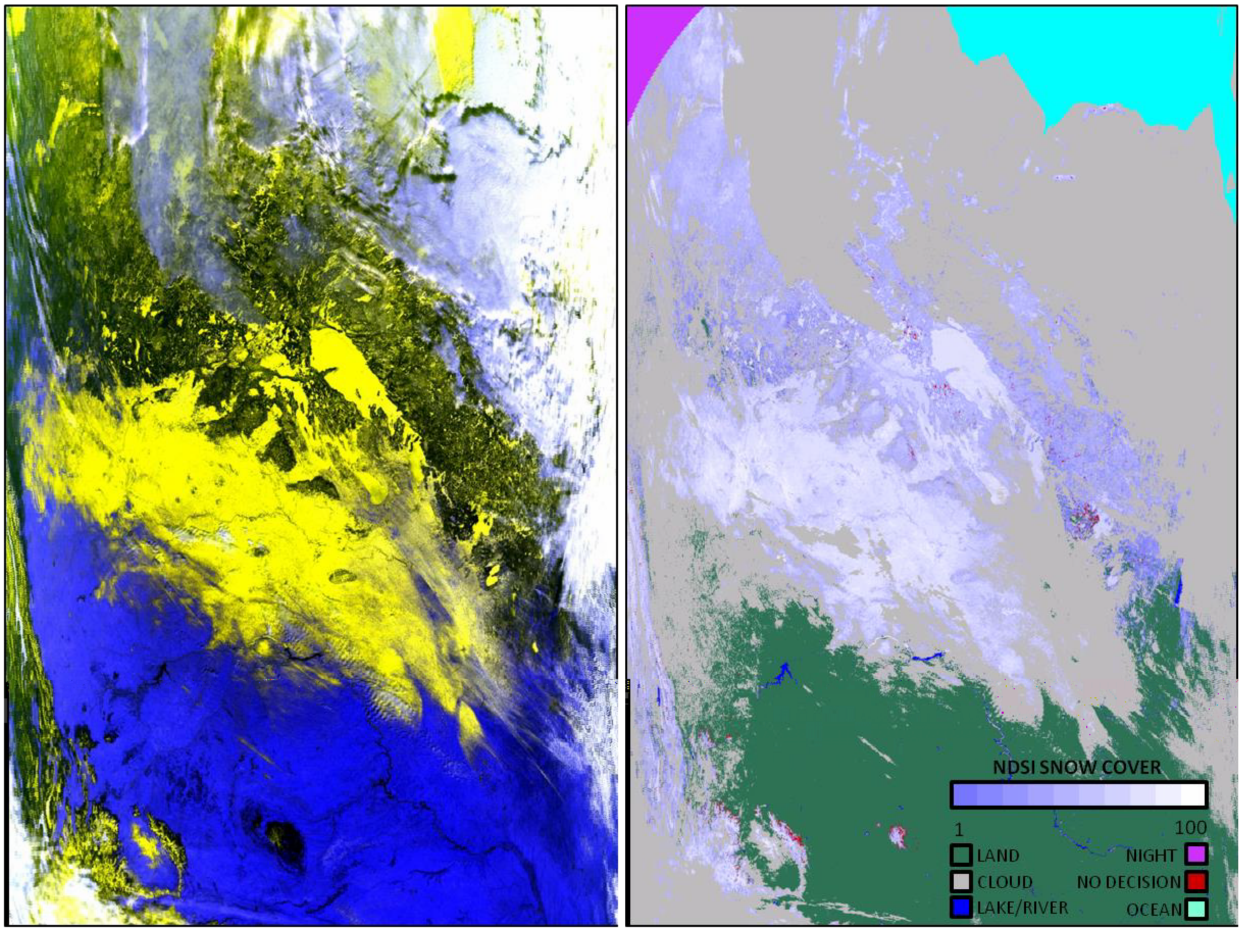

Figure 1. MODIS C6.1 MOD10_L2 swath covering the boreal forests of Canada and the U.S. Great Plains shown on this Terra MODIS acquisition of 10 January 2003, 1750 UTC. False color image of MOD02HKM bands 1,4,6 as RGB, left image; in this band combination snow appears in hues of yellow to blackish-yellow on the landscape. MOD10_L2 C6.1 NDSI_Snow_Cover product, right image, with snow cover shown as a color-scaled map with clouds and ocean and night masks.

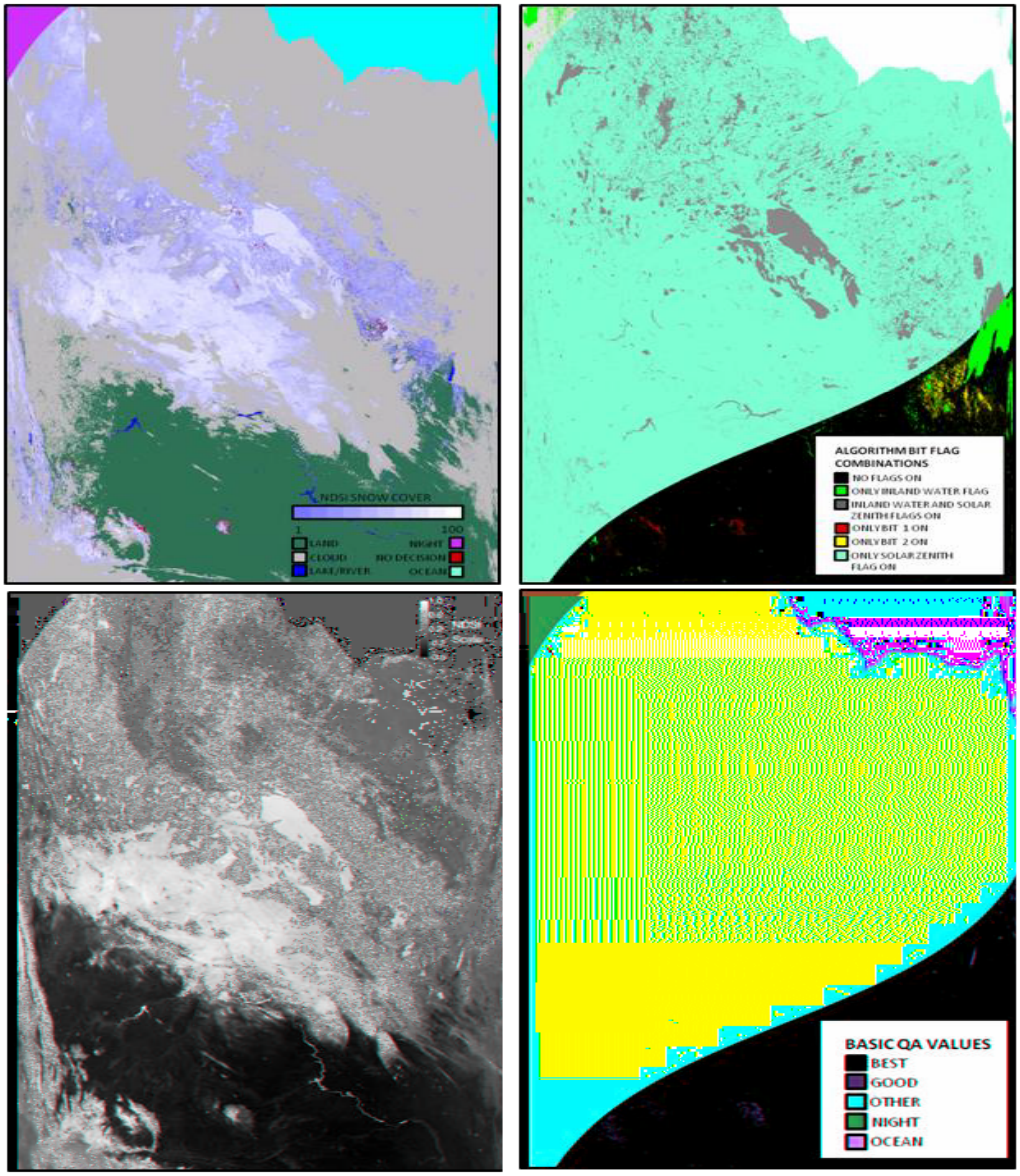

Figure 2. MOD10_L2 C6.1 snow cover data arrays. Terra MODIS acquisition of 10 January 2003, 1750 UTC. The four data arrays in the product are: NDSI_Snow_Cover (upper left), algorithm QA bit flags (upper right), basic QA values (lower right) and NDSI data for the swath (lower left). A select combination of algorithm QA bit flags is shown. A user can select an individual bit flag or various combinations of bit lags for their use.

Table 3. Definition and partial listing of local attributes of the NDSI_Snow_Cover SDS

SDS name	NDSI_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	4060, 2708 (AlongTrack, CrossTrack)	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover, 500m
units	DFNT_CHAR8	none

valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Key:	DFNT_CHAR8	0-100=NDSI snow 200=missing data 201=no decision 211=night 237=inland water 239=ocean 250=cloud 254=detector saturated 255=fill

NDSI_Snow_Cover_Basic _QA

An estimate of the quality of the algorithm result for a pixel is reported in this SDS. The quality estimate is given as a value for each pixel processed; an example is shown in Figure 2. Local attributes are listed in Table 4. The purpose of the basic QA is to allow a user to easily visualize the general quality of the NDSI_Snow_Cover. In depth-analysis/evaluation of the NDSI_Snow_Cover should utilize the algorithm-specific bit flags QA data.

Table 4. Definition and partial local attributes listing of the NDSI_Snow_Cover_Basic_QA SDS.

SDS name	NDSI_Snow_Cover_Basic_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	4060, 2708 (AlongTrack, CrossTrack)	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover general quality value
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 4
_FillValue	DFNT_UINT8	255
Key:	DFNT_CHAR8	0=best, 1=good, 2=ok, 3=poor-not used, 211=night, 239=ocean, 255=unusable L1B data or no data

NDSI_Snow_Cover_Algorithm_Flags_QA

Algorithm bit flags are set for data screen results. The data screens serve two purposes: 1) they indicate why a snow detection was reversed to “not snow,” and 2) they represent a QA flag for uncertain snow detection or challenging viewing conditions. More than one bit flag may be set because all data screens are applied to a pixel. The inland water mask is also set in a bit flag to support analysis of inland waters for snow/ice cover. Bits for the data screens are set to on if the screen was failed. The cloud confidence flags of “probably cloudy” and “probably clear” are set in bits 5 and 6 respectively. An example of some of the bit flags and combinations of bit flags is shown in Figure 2. Many combinations of bit flags may be set. A user can investigate any bit flag or combinations of bit flags. Table 5 lists local attributes.

Table 5. Definition and local attributes listing of the NDSI_Snow_Cover_Algorithm_Flags_QA SDS.

SDS name	NDSI_Snow_Cover_Algorithm_Flags_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	4080, 2708 (AlongTrack, CrossTrack)	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover algorithm flags
units	DFNT_CHAR8	none
format	DFNT_CHAR8	bit flag
valid_range	DFNT_UINT8	0, 254
_FillValue	DFNT_UINT8	255
Key:	DFNT_CHAR8	bit on means: bit 0: inland water flag bit 1: low visible screen failed, reversed snow detection bit 2: low NDSI screen failed, reversed snow detection bit 3: combined temperature and height screen failed, snow reversed because too warm and too low. This screen is also used to flag a high elevation too warm snow detection, in this case the snow detection is not changed but this bit is set. bit 4: too high SWIR screen and applied at two thresholds: QA bit flag set if band6 TOA > 25% & band 6 TOA <=45%, indicative of unusual snow condition, or snow commission error; snow detection reversed if band 6 TOA > 45% bit 5 : MOD35_L2 probably cloudy bit 6 : MOD35_L2 probably clear bit 7 : solar zenith screen, indicates increased uncertainty in results

NDSI

An NDSI value is calculated for all land and inland water pixels in daylight in the swath. An example of the NDSI data is shown in Figure 2. A listing of local attributes is provided in Table 6.

Table 6. Definition and partial listing of local attributes of the NDSI SDS.

SDS name	NDSI
Data type	DFNT_INT16
Number of dimensions	2
Dimensions--HDF order--	4060, 2708 (AlongTrack, CrossTrack)

Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Raw NDSI (Normalized Difference Snow Index) layer
units	DFNT_CHAR8	none
_Fillvalue	DFNT_INT16	-32768
valid_range	DFNT_INT16	-10000, 10000
scale_factor	DFNT_FLOAT32	0.0001

Latitude and Longitude

Latitude and longitude data at 5 km resolution are provided to enable geolocation of the swath, and to support browse product generation. The latitude and longitude data correspond to a center pixel of a 5 km by 5 km block of pixels in the snow SDSs. The mapping relationship of geolocation data to the snow data is specified in the global attribute StructMetadata.0. The mapping relationship was created by the HDF-EOS SDPTK toolkit during production. Geolocation data is mapped to the snow data with an offset = 5 and increment = 10. The first element (1,1) in the geolocation SDSs corresponds to element (5,5) in NDSI_Snow_Cover SDS; the algorithm then increments by 10 in the cross-track or along-track direction to map geolocation data. Listing of local attribute for latitude and longitude datasets is given in Table 7.

Table 7. Definition and local attributes listing of Latitude and Longitude SDSs.

SDS name	Latitude	
Data type	DFNT_FLOAT32	
Number of dimensions	2	
Dimensions--HDF order--	406, 271	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Coarse 5 km resolution latitude
units	DFNT_CHAR8	degrees
valid_range	DFNT_FLOAT32	-90.00000, 90.00000
_FillValue	DFNT_FLOAT32	-999.0000
source	DFNT_CHAR8	M*D03 geolocation product; data read from center pixel in 5 km box
SDS name	Longitude	
Data type	DFNT_FLOAT32	
Number of dimensions	2	
Dimensions--HDF order--	406, 271	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Coarse 5 km resolution longitude
units	DFNT_CHAR8	degrees
valid_range	DFNT_FLOAT32	-180.0000, 180.0000
_FillValue	DFNT_FLOAT32	-999.0000
source	DFNT_CHAR8	M*D03 geolocation product; data read from center pixel in 5 km box

Interpretation of Snow Cover Detection Accuracy, Uncertainty and Errors

Research and applications have tended to focus on monitoring SCE, onset and duration of snow cover, and snowmelt for hydrologic or climate change studies. Revisions in the C6.1 algorithm and data product focus on reducing snow commission and omission errors, and providing users with a greater amount of data and QA information to evaluate, analyze and interpret.

Though challenging, the MODIS snow algorithm was designed to identify snow globally in all situations. The NDSI technique for snow detection has proved to be a robust indicator of snow around the globe as evidenced by the numerous investigators who have used the MODIS snow products and reported accuracy statistics in the range of 88-93%, and who have derived snow covered area maps from the snow cover products. (See listing of publications at http://modis-snow-ice.gsfc.nasa.gov/?c=publications). For a revised explanation of the NDSI snow cover algorithm theory see the NASA VIIRS Snow Cover ATBD (Riggs et al., 2016) which gives a detailed explanation of the algorithm. The MODIS and VIIRS snow cover algorithms both use the NDSI snow detection algorithm, albeit adjusted for sensor and input data product differences. The MODIS snow cover ATBD will be updated but the VIIRS ATBD (Riggs et al., 2016) will probably be available sooner.

The diversity of situations where snow may be found makes it challenging to develop a globally-applicable snow cover detection algorithm. Snow cover is mapped with high accuracy when illumination conditions are near ideal, skies are clear, and several centimeters or more of snow are present on the landscape. Snow cover can occur on many different landscapes including forests, plains and mountains, and under all types of viewing conditions. Viewing conditions change from day to day and across the landscape.

Notable changes in the MODIS C6.1 snow products as compared to C6 are: 1) change in the low visible screen thresholds in the M*D10_L2 algorithm and addition of two algorithm QA bit flags and 2) the M*D10A1F cloud-gap filled (CGF) L3 data product. The L2 algorithm changes have reduced the occurrence of “no decision” results in low reflectance situations and have been observed to result in an increase around 1% in snow cover observation pixel count in mountainous regions with snow cover. An increase in snow commission errors associated with the visible screen threshold change has not been observed.

The algorithm logic is as follows: snow cover always has an NDSI > 0 but not all features with NDSI > 0 are snow. Snow detection is applied to all land pixels in a swath then snow detections are screened to reverse possible snow commission errors, flag uncertain snow detections and set QA flags. Results of the data screens are set as bit flags in the NDSI_Snow_Cover_Algorithm_Flags_QA. Multiple data screens are applied so it is possible that more than one bit flag is set for a pixel.

The snow cover map and data screens, i.e. bit flags, should be used together. The data screens that are specifically applied to pixels processed for snow, i.e. pixels with NDSI ≥ 0.0, that may cause reversal to a “no snow” or “no decision” result apply to NDSI_Snow_Cover in the valid range of 0 – 100 and to the “no decision” value of 201. Those data screens provide information on the result. The data screens that provide other information, e.g. the inland water screen or solar zenith screen are applied across all land and inland water pixels in daylight in the swath. The masked features of ocean (239) and night (211) have that value in the NDSI_Snow_Cover and NDSI_Snow_Cover_Algorithm_Flags_QA SDSs with the exception that in regions of night, inland water bodies are not masked as night, only as inland water in the NDSI_Snow_Cover_Algorithm_Flags_QA SDS which provides some spatial reference.

Some situations associated with snow commission errors and possible ways to interpret the algorithm bit flags are discussed in following subsections.

Surface Temperature and Height Screen

The surface temperature and height screen is unchanged from C6. The surface temperature screen is combined with surface elevation and is used in two ways. This combined screen reverses snow cover detection on low elevation < 1300 m surfaces that are too warm for snow and the algorithm QA bit flag is set. Snow cover detection at ≥1300 m on a surface that is too warm for snow is not reversed but that snow cover detection is flagged as too warm by setting the algorithm QA bit flag. This combined screen has alleviated the problem of “disappearing” snow cover on mountain ranges in the spring and summer that was observed in the C5 product.

The effectiveness of the “surface temperature and height” screen varies as the surface changes over seasons. It is effective at reversing snow commission errors of some surface features, and cloud contaminated pixels over some landscapes when the surface is warm, however when the surface is below the threshold temperature, or cloud contamination lowers the estimated surface temperature, this screen is not effective. A surface feature that is spectrally similar to snow, for example the Bonneville Salt Flats, will have snow detection reversed by this screen when the surface is warm but may not be reversed when the surface is cold and snow free in the winter.

Low Illumination or Low Reflectance

Low solar illumination conditions occurring when the SZA is > 70° and when a swath is near the day/night terminator represent a challenge to snow detection. Low reflectance situations in which reflectance is <~30% across the VIS bands is also a challenge for snow detection. Low reflectance across the VIS and SWIR bands can result in relatively small differences between the VIS and SWIR bands and can give an NDSI > 0. Very low visible reflectance is cause for increased uncertainly in detection of snow cover. If VIS reflectance is too low, a pixel is set to “no decision” and the “low VIS data” screen bit flag is set. This is considered a low limit for accurate detection of snow cover on the landscape. Low reflectance associated with low illumination, landscape shadowed by clouds or terrain, and unmapped water bodies or inundated landscape can exhibit reflectance characteristics similar to snow and thus be erroneously detected as snow by the algorithm. The NDSI is calculated for those “no decision” results so a user can see the NDSI value by using the low visible QA bit flag and NDSI data.

Low NDSI

Low VIS reflectance situations where the difference between VIS and SWIR is very small can result in very low but positive NDSI values. Those low positive NDSI results can occur where visible reflectance is low or high and where the associated SWIR is low or high but slightly lower than the VIS so that the NDSI is a very low positive value. In our analysis of many such situations we found that very uncertain snow detections or snow commission errors were common when the NDSI was $0.0 \leq NDSI < 0.1$. Based on that analysis a low NDSI screen is applied. If NDSI is < 0.1 a snow detection is reversed to “not snow,” and the low NDSI bit 2 flag is set in the QA. That bit flag can be used to determine the NDSI value for pixels where snow detection was reversed.

High SWIR Reflectance

Unusually high SWIR reflectance may be observed in some snow cover situations, from some types of clouds not masked as certain cloud or from non-snow surface features. A SWIR screen is applied at two thresholds to either reverse a possible snow commission error or flag snow detection with unusually high SWIR. A user can check this bit flag to find where uncertain snow cover detections occurred or where snow detection was reversed to “not snow.”

Cloud and Snow Confusion

Cloud and snow confusion in C6.1 is similar to that of C6. The snow cover algorithm reads the “Unobstructed FOV Quality Flag” from the M*D35_L2 product which has four values: “confident cloudy”, “probably cloudy”, “probably clear” and “confident clear”. If the cloud mask is “confident cloudy” for a pixel, then that pixel is set to “cloud” in the snow algorithm, and the other three cloud are interpreted as clear. Cloud/snow confusion in the snow algorithm can be associated with situations where the cloud mask algorithm fails to correctly identify clouds, or confuses snow with clouds, or subpixel clouds flagged as “not cloudy” become cloud contamination observations in the snow cover algorithm and may be detected as snow instead of cloud or not snow. The use of only the “Unobstructed FOV Quality Flag” from M*D35_L2 is an underutilization of the data available in M*D35_L2. The M*D35_L2 includes data on background flags, processing paths, and results of all the cloud spectral tests applied in the algorithm, all which could be used to potentially reduce cloud and snow confusion in the snow cover algorithm. For C6.1 the cloud confidence flags of “probably clear” and “probably cloudy” are included in the algorithm bit flags QA dataset so that they can be used to evaluate or investigate cloud/snow confusion. Ways to alleviate cloud/snow confusion by using more data from M*D35_L2 is an ongoing area of investigation.

In situations where the cloud mask fails to identify a cloud as “confident cloudy”, and the cloud reflectance characteristics are similar to snow, it may be detected as snow which will result in a commission error. Snow commission errors associated with the periphery of clouds where the subpixel clouds are not detected as “confident cloudy” are caused by a cloud contamination problem in the snow cover algorithm and may result in snow commission errors. In addition, clouds that lay in shadow of other clouds can pass as “probably cloudy” in the cloud mask algorithm, and can then be detected as “snow” in the snow algorithm. In these types of cloud cover conditions the subpixel contaminated clouds and cloud shadowed clouds are spectrally indistinct from snow in the algorithm. Snow commission errors associated with those cloud conditions can be seen in situations of scattered clouds, streaming cloud formations or, popcorn-like cloud formations over vegetated landscapes. An example of cloud/snow confusion associated with those types of conditions is shown in Figure 3 over the boreal landscape of north central Canada.

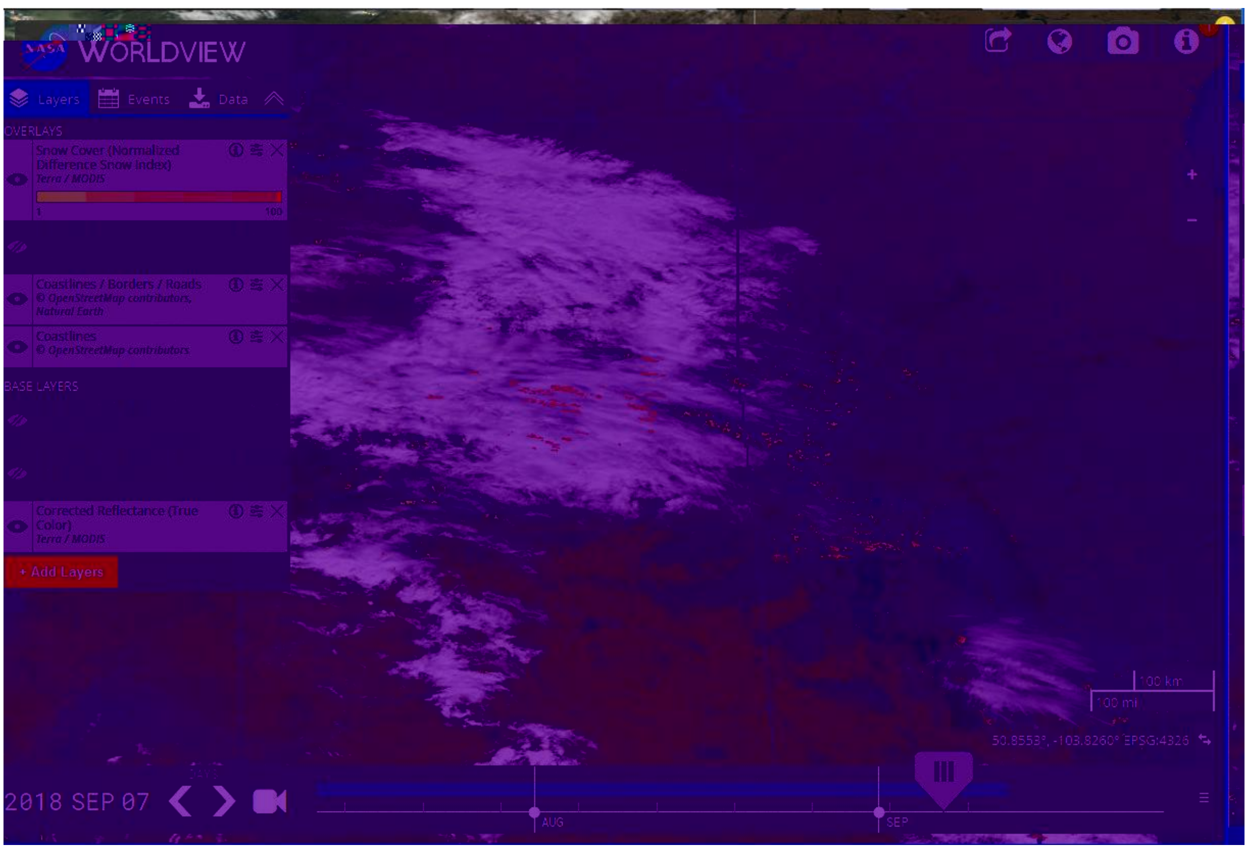

Figure 3. An example of snow commission errors associated with cloud conditions over boreal forests of Saskatchewan and Manitoba, Canada. Worldview [https://worldview.earthdata.nasa.gov/] is used to display MODIS true color imagery with the MOD10_L2 snow cover overlay. Snow errors range from low to moderate NDSI snow cover values depending on amount of cloud contamination in a pixel or undetected clouds, respectively.

The cloud mask algorithm initializes a snow/ice background flag which is used to determine the processing path for cloud detection. In some situations of thin or sparse snow cover on the plains under clear a clear sky, the cloud mask may incorrectly initialize the snow/ice background flag to “not snow” and as a result detect that snow cover as “certain cloud”. An example of that situation on the plains of central Nebraska, USA is shown in Figure 4. In this image the thin or sparse snow cover appears as dull hues of yellow and deeper snow cover as brighter yellow in the MOD02HKM false color image of bands 1, 4 and 6, top image. The MOD35_L2 snow/ice background flag is set to “white” for snow in the center image but flags only the “brightest”, deeper snow cover as snow, leaving all the thin, sparse snow cover as “snow free land”. In this situation the thin, sparse snow cover that is not flagged as snow by the snow/ice background flag is masked as “confident cloudy” in the cloud mask algorithm. The snow cover algorithm reads the cloud mask and sets those thin, sparse snow covered areas to “cloud” in the NDSI_Snow_Cover, the bottom image in Figure 4. Snow cover along the periphery of the plains snow cover, not masked as “confident cloudy” in the cloud algorithm is detected as snow cover in the snow cover algorithm. This cloud mask snow/ice background setting situation has been investigated and it was found that the snow was detected as “confident cloudy” by only a single visible cloud test of the several cloud spectral tests applied in the cloud mask processing path. That association of data was found by examining the cloud mask snow/ice background flag, algorithm processing path and results of all cloud spectral tests applied. In this situation the cloud mask could be reinterpreted as “clear” in that specific situation and the snow could then be detected correctly. That reinterpretation test was partially effective at resolving this specific cloud/snow confusion situation. However applying the reinterpretation of the cloud mask in other situations resulted in inconsistent results, indicating that more research is needed. Use of the M*D35_L2 algorithm processing path flags and individual cloud spectral tests has potential for resolving some snow/cloud confusion situations and continues to be investigated.

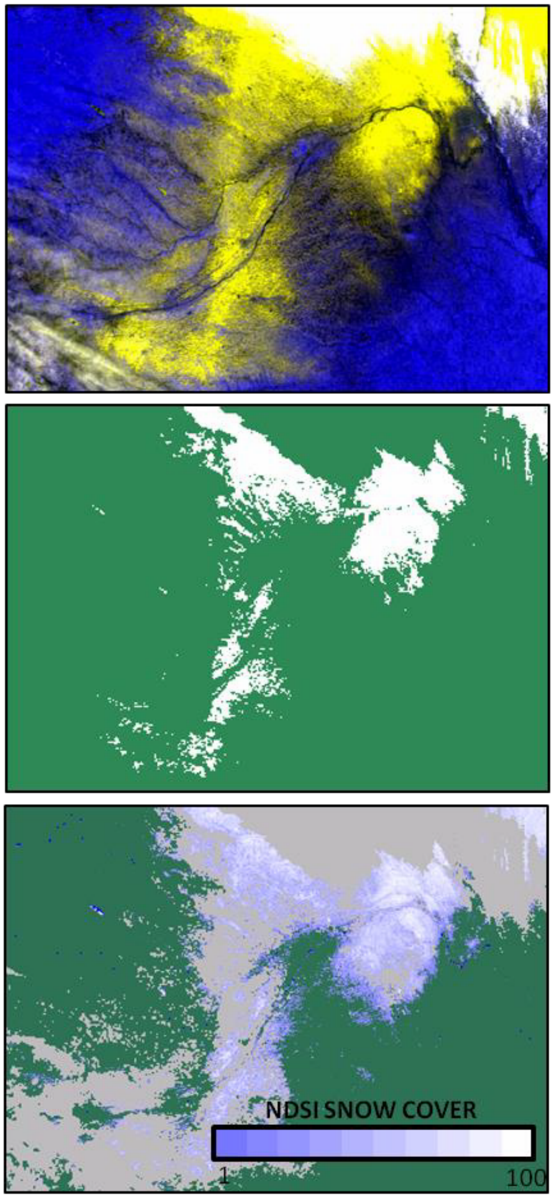

Figure 4. Cloud mask snow/ice background flag setting. These image subsets of the plains of central Nebraska, USA are from 17 February 2016, 1740 UTC. Top image is false color MODIS bands 1, 4, and 6 showing snow cover in hues of yellow. Center image is the snow/ice background flag, white is snow background, extracted from MOD35_L2 and converted from 1 km resolution to 500 m resolution. NDSI_Snow_Cover product is the bottom image, with “confident cloudy” from MOD35_L2 shown in gray.

Lake Ice

A lake ice detection algorithm is implemented in C6.1 to map ice or snow and ice covered lakes and rivers. Location of lakes and rivers is taken from the MODIS land/water mask in the M*D03 product. The lake ice algorithm is the same as the NDSI snow detection algorithm, except that in the low visible screen the C6 thresholds were kept, and not changed as they were for snow on land in C6.1. Lake ice is included in the NDSI_Snow_Cover data array. To enable users to extract or mask the lake ice or inland waters their location is mapped in bit 0 of the NDSI_Snow_Cover_Algorithm_Flags_QA data array.

Visual analysis of MODIS imagery and MOD10_L2 products acquired during the boreal winter or spring when lakes are frozen or during ice breakup and melt reveals that the snow/ice cover can be detected with very good accuracy. An example of lake ice detection during spring break up and melt on Great Slave Lake, Northwest Territories, Canada, on 25 May 2016 is shown in Figure 5. On that date (Fig. 5) ice cover remains on the west end, north bay and east arm of the lake, ice in hues of yellow on the MODIS display of bands 1,4, and 6, top image. The ‘brightest' of the ice cover is detected as lake ice in MOD10_L2, bottom image of Figure 5, scale is same as used for NDSI_Snow_Cover on land, some of the areas that appear to be a mix of water and ice on the west end of lake are not detected as lake ice. During the ice free seasons, changes in physical characteristics of a lake such as sediment loads, high turbidity, aquatic vegetation and algal blooms can change reflectance characteristics which may cause erroneous lake or river ice cover detection in the spring or summer. A lake-ice-specific algorithm should be developed for a future Collection.

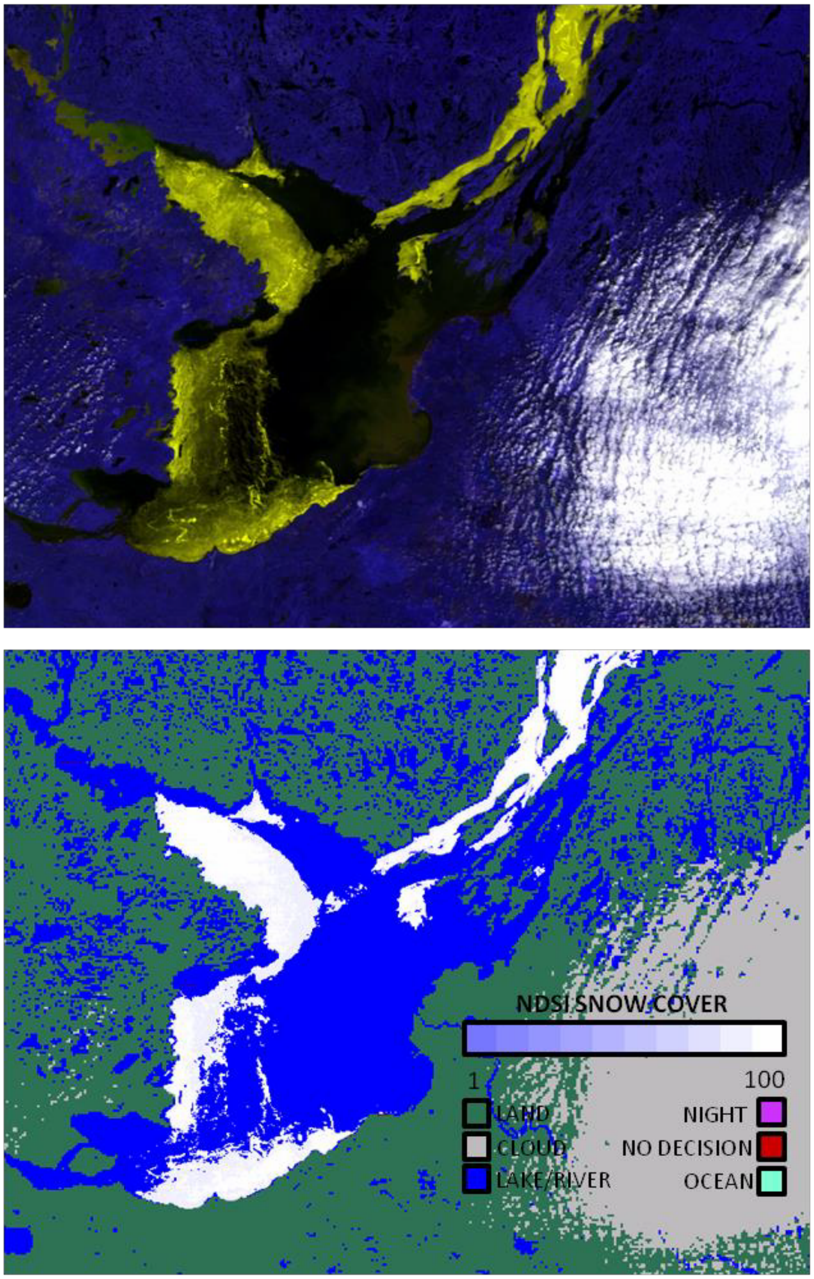

Figure 5. Great Slave Lake spring ice breakup and melt on 25 May 2016. Top image is MOD02HKM.A2016146.1900.006.* RGB color composite of bands 1, 4, and 6, in which lake ice appears in hues of yellow. Lake ice detected in MOD10_L2.A2016146.1900.006.* is shown in the bottom image. The NDSI snow cover scale is used for lake ice. The "brightest" lake ice is detected by the algorithm but some regions on west end of the lake which appear to be a mix of ice and water, are not detected.

Lake ice is included in the NDSI_Snow_Cover so that a spatially-coherent image of a snow covered landscape can be seen. A user can extract the inland water mask from bit 0 of the NDSI_Snow_Cover_Algorithm_Flags_QA data for use in analysis or to apply as a static water mask.

Bright Surface Features

Surface features such as salt flats, bright sands, or sandy beaches that have VIS and SWIR reflectance characteristics similar to snow maybe detected as snow cover based solely on the NDSI value thus resulting in errors of commission. Screens specifically for bright surfaces were not developed for C6.1 but the screens in C6.1 can reduce the occurrence of snow commission errors in some situations, e.g., a low elevation; too-warm surface can be blocked by the "surface temperature and height" screen. These surface features are static so a user can easily mask or flag these surfaces relevant to their research or application.

Land/water Mask and Geolocation Uncertainty

In MODIS C6 the land/water mask was derived from the UMD 250m MODIS Water Mask data product (University of Maryland (UMD) Global Land Cover Facility http://glcf.umd.edu/data/watermask/description.shtml). Location of lakes and rivers is greatly improved compared to the land/water mask used in C5. Users may notice an increase in the number of lakes mapped, especially in regions of small lakes, e.g., northern Minnesota to the Northwest Territories, and that many larger rivers are more continuous. The improved quality of the land water mask is seen through all product levels. The UMD 250 m Water Mask was converted to a 500 m seven class land/water mask for use in the production of MODIS products in C6 and C6.1. That was done to maintain continuity in the land/water mask used in all the land products in C5 to C6 but with greatly improved accuracy in location of water bodies resulting from the UMD 250 m Water Mask (http://landweb.nascom.nasa.gov/QA_WWW/forPage/MODIS_C6_Water_Mask_v3.pdf).

Geolocation accuracy in C6.1 is similar to that of C6 (Wolfe and Nishihama, 2009; Wolfe, 2006). There will be some uncertainty in geolocation of land/water mask features but within an expected range. Geolocation uncertainty through the processing levels to Level 3 may be observed in M*D10A1, notably how water bodies are mapped from day to day; for more information, see the section *7.0 M*D10A1*.

Antarctica

Though the M*D10_L2 and M*D10A1 products are generated for the Antarctic continent, they must be carefully scrutinized for accuracy and quality. The Antarctic continent is nearly completely ice and snow covered year 'round, with very little annual variation though some variation can occur on the Antarctic Peninsula. In the M*D10C1 product Antarctica is masked as 100% snow cover to generate a visually good representation of Antarctica in the global product. However, the snow algorithm is run for Antarctica without adjustment unique to Antarctica. The snow cover map may show areas of "no snow cover," which is a very obvious error. That error is related to the great difficulty in identifying clouds over Antarctica's ice/snow cover. The similarity in reflectance and lack of thermal contrast between clouds and ice/snow cover and thermal inversions are challenges to accurate snow/cloud discrimination. In situations where the cloud mask fails to identify "confident cloudy," the snow algorithm assumes a cloud-free view and either identifies the surface as "not snow covered" or identifies the cloud as snow. In either case the result is wrong. Scrolling through global browse imagery of M*D10_L2 reveals many instances of snow free patches in Antarctica.

6.0 M*D10GA

The daily Level 2-G gridded snow cover product M*D10GA has all the M*D10_L2 swath products from a day mapped into it and is then used as input for the M*D10A1 daily snow product. The M*D10GA is an intermediate product in the series of snow products that is not archived at the NSIDC DAAC thus is not available to order.

Algorithm Description

The MODAPS built a generic gridding algorithm for many of the MODIS data products to create the L2G daily gridded data products (Wolfe et al., 1999). The Earth is divided into an array of 36 x18, longitude by latitude tiles, about 10°x10° in size in the sinusoidal projection. The gridding algorithm maps MODIS Level-2 swath products into a tile of the grid and creates the relevant gridding projection data structures in the product. A snow product version of that gridding algorithm was built to generate the M*D10GA product in C6. During development of the algorithm it was realized that coding and production efficiency through the series of snow algorithms and products could be improved by moving the snow cover observation selection algorithm and snow albedo algorithm from the M*D10A1 product generation process to the M*D10GA product generation process, so they were integrated into M*D10GA product generation process.

The M*D10GA observation selection algorithm uses several criteria to select the 'best' observation of a day from the MODIS swaths that cover a location. The observation selection criteria used are: solar elevation, distance from nadir and observation coverage (pixel coverage in a grid cell of the projection), to map an observation into the first data layer. The 'best' observation for each product is based only on those criteria so that the observation selected is nearest local solar noon time, nearest the orbit nadir track and with most coverage in a grid cell, which is considered the best sensor view of the surface on a day relevant to snow cover detection. The 'best' observations are mapped into the product as the first layer of data. This strategy results in a contiguous mapping of swaths with a weave or checkerboard pattern along stitched-together swath edges within a tile. That weave pattern is sometimes apparent where cloud cover changed between acquisition times of overlapping swaths. Observations from other swaths that may be mapped into that same grid cell are stored in compact format as a one dimension array in run-length-encoded-format to reduce data volume.

The C6.1 includes pointers to the granule (swath) from which each observation was selected from. Those pointers stored as SDSs and can be linked to the names of input granules in the ArchiveMetadata to determine the date and time of acquisition of each observation.

Snow albedo is calculated for all NDSI snow cover observations in the range of 1-100 using the same snow albedo algorithm used in the M*D10A1 C6 algorithm and is mapped into first layer and compact layer SDSs. Snow albedo is calculated for the VNIR bands using the MODIS land-surface reflectance product MOD09GA as input. The MOD09GA observation corresponding to the selected observation in each grid cell is used. An anisotropic response function is used to correct for anisotropic scattering effects of snow in non-forested areas. Snow-covered forests are assumed to be Lambertian reflectors. Land cover type is read from the MODIS combined land cover product, MCDLCHKM. Slope and aspect data for the correction is derived from the Global 30 Arcsecond (GTOPO30) digital elevation model (DEM) stored for each tile as ancillary data files. The narrow band albedos are then converted to a broadband albedo for snow. A description of the snow albedo algorithm is given in Klein and Stroeve (2002).

The snow albedo algorithm was moved from the M*D10A1 algorithm to improve efficiency and simplify the M*D10A1 algorithm. At the L2G processing level the snow cover algorithm and the surface reflectance algorithm use different criteria and algorithms to determine what observation is the 'best' of the day, 24 hour period, to map into the first data layer of the lite products. It was more efficient to apply the snow 'best' observation to get the correct match of snow observation and surface reflectance observation for snow albedo calculation at this level than to have a complicated algorithm searching the MOD09GA data for the observation to match with the snow observation.

Scientific Data Sets

Data from M*D10_L2 swath products written into M*D10GA are the SDSs of NDSI_Snow_Cover, NDSI_Snow_Cover_Basic_QA, NDSI_Snow_Cover_Algorithm_Flags_QA and NDSI all in the first layer and compact data layers. Data on gridding of observations and selection of observations stored in data arrays are: 1) number of observations gridded to a cell and count of additional observations in the compact data layer both in first layer only, and 2) observation coverage in a cell, orbit and granule pointers to the swath from which that observation came in both first layer and compact SDSs. Data from those SDSs and from metadata can be used to unpack the compact arrays. Snow albedo calculated in the M*D10GA product generation process is stored in first layer and compact SDSs. Data from the M*D10GA algorithm stored in M*D10GA are: num_observations, NDSI_Snow_Cover_1, NDSI_Snow_Cover_Basic_QA_1, NDSI_Snow_Cover_Algorithm_Flags_QA_1, SnowAlbedo_1, obscov_1, orbit_pnt_1, granule_pnt_1, NDSI_Snow_Cover_c, , NDSI_Snow_Cover_Basic_QA_c, NDSI_Snow_Cover_Algorithm_Flags_QA_c, SnowAlbedo_c, obscov_c, orbit_pnt_c, granule_pnt_c, nadd_obs_row.

7.0 M*D10A1

The daily gridded snow cover product contains the 'best' NDSI_Snow_Cover, snow albedo and QA observation selected from all the M*D10_L2 swaths mapped into a grid cell on the sinusoidal projection in the M*D10GA. (The C6.1 product is unchanged from C6.) The product is a tile of approximately 1200x1200 km (10°x10°) area on the sinusoidal projection (http://modis-land.gsfc.nasa.gov/MODLAND_grid.html). Also included is a pointer to the swath granule from which an observation came that can be used to extract the time of acquisition. An example of the M*D10A1 NDSI_Snow_Cover map and algorithm QA bit flags is shown in Figure 6.

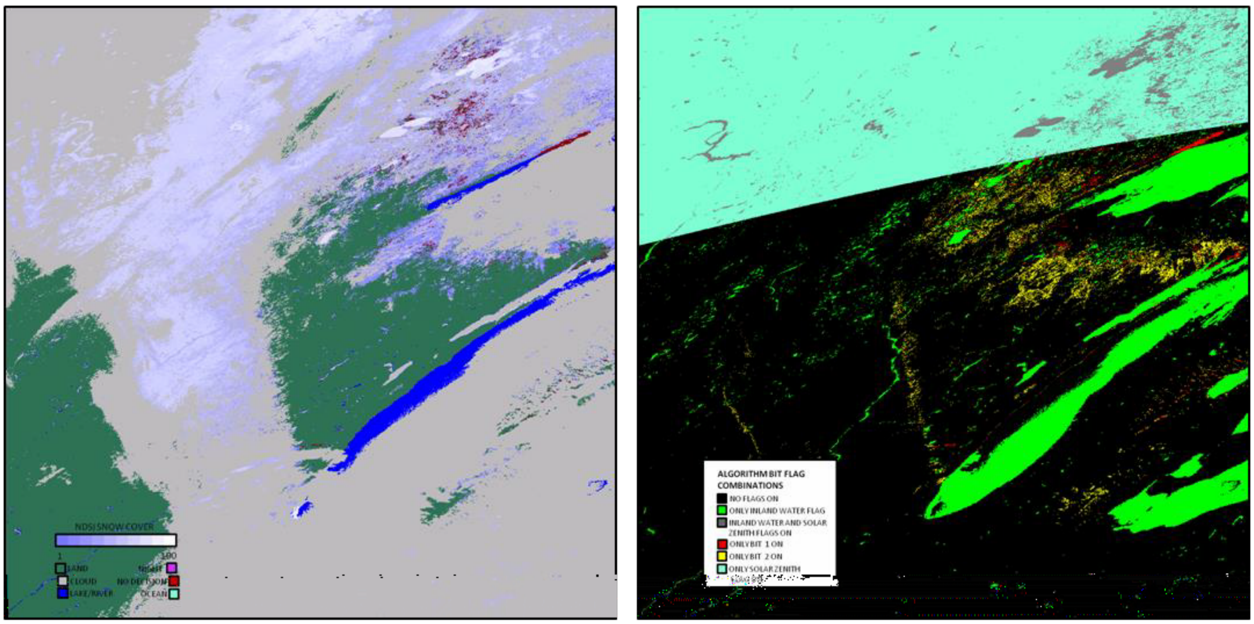

Figure 6. MOD10A1 C6 snow product. The daily NDSI_Snow_Cover product (left image) and NDSI_Snow_Cover_Algorithm_Flags_QA (right) for 2003014 tile h11v04 covering an area in the western Great Lakes region of North America.

Algorithm Description

The observation selection algorithm and snow albedo algorithm were moved to the M*D10GA product generation process (see section titled M*D10GA). The selection algorithm picks the 'best' observation based on nearness to solar noon and to nadir, from the one to many M*D10_L2 observations that were acquired of the surface from all swaths of a day. The snow albedo algorithm was also moved to production of M*D10GA and is described in Section M*D10GA. The M*D10A1 algorithm in reads the first layer SDSs from M*D10GA, calculates some descriptive QA statistics, and writes out those SDSs and descriptive metadata and also copies some metadata from M*D10GA into in the M*D10A1.

Scientific Data Sets

NDSI_Snow_Cover

This is the NDSI snow cover that was detected in the M*D10_L2 algorithm, then gridded by the M*D10GA algorithm and selected as the 'best' observation for a grid cell for the day, then subsequently written into this SDS. The list of local attributes and data content of the SDS are listed in Table 8.

Table 8. Structure and local attributes listing of NDSI_Snow_Cover

SDS name	NDSI_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover from best observation of the day
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 100
Missing_value	DFNT_UINT8	200
_FillValue	DFNT_UINT8	255
Key:	DFNT_CHAR8	0-100=NDSI snow, 200=missing data, 201=no decision, 211=night, 237=inland water, 239=ocean, 250=cloud, 254=detector saturated, 255=fill

NDSI_Snow_Cover_Basic_QA

A general estimate of the quality of the algorithm result for a pixel is reported in this SDS. This QA estimate that was made in the M*D10_L2 algorithm is then passed to the M*D10GA where the 'best' observation is selected and then written into this SDS. The structure and list of local attributes and data content are listed in Table 9.

Table 9. Structure and local attributes listing of NDSI_Snow_Cover_Basic_QA

SDS name	NDSI_Snow_Cover_Basic_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover general quality value
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 4
_FillValue	DFNT_UINT8	255

Key:	DFNT_CHAR8	0=best, 1=good, 2=ok, 3=poor-not used, 4=other-not used, 211=night, 239=ocean, 255=unusable L1B or no data

<u>NDSI_Snow_Cover_Algorithm_Flags_QA</u>
Bit flags are set for data screen results and for the inland water mask in the M*D10_L2 algorithm. This data corresponds to the 'best' observation selected in the M*D10GA algorithm which is then written into this SDS. The list of local attributes and data content of the SDS is provided in Table 10.

Table 10. Local attributes listing of NDSI_Snow_Cover_Algorithm_Flags_QA

SDS name	NDSI_Snow_Cover_Algorithm_Flags_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover algorithm bit flags
units	DFNT_CHAR8	none
format	DFNT_CHAR8	bit flag
valid_range	DFNT_UINT8	0, 254
_FillValue	DFNT_UINT8	255
Key:	DFNT_CHAR8	bit on means: bit 0: inland water flag bit 1: low visible screen failed, reversed snow detection bit 2: low NDSI screen failed, reversed snow detection bit 3: combined temperature and height screen failed, snow reversed because too warm and too low. This screen is also used to flag a high elevation too-warm snow detection, in this case the snow detection is not changed but this bit is set. Bit 4 : too high SWIR screen and applied at two thresholds: QA bit flag set if band 6 TOA > 25% & band 6 TOA <=45%, indicative of unusual snow condition, or snow commission error snow detection reversed if band 6 TOA > 45% bit 5 : MOD35_L2 probably cloudy bit 6 : MOD35_L2 probably clear bit 7 : solar zenith screen, indicates increased uncertainty in results

NDSI
This is the NDSI that was calculated in the M*D10_L2 algorithm, then gridded by the M*D10GA algorithm and selected as the 'best' observation for a grid cell for the day, then subsequently written into this SDS. The list of local attributes and data content of the SDS is provided in Table 11.

Table 11. Local attributes of NDSI.

SDS name	NDSI	
Data type	DFNT_INT16	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Raw NDSI
units	DFNT_CHAR8	none
valid_range	DFNT_INT16	-10000, 10000
_FillValue	DFNT_INT16	-32768
scale_factor	DFNT_FLOAT32	0.0001

Snow_Albedo_Daily_Tile
The snow albedo as calculated by the snow albedo algorithm is stored in this SDS. The snow albedo map corresponds to snow cover extent in the NDSI_Snow_Cover SDS. Snow albedo is reported in the 0 –100 range and non-snow features are mapped using unique data values. The list of local attributes and data content of the SDS is shown in Table 12.

Table 12. Structure and local attributes listing of Snow_Albedo_Daily_Tile

SDS name	Snow_Albedo_Daily_Tile	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Snow albedo of the corresponding snow cover observation
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Missing_value	DFNT_UINT8	250
Key:	DFNT_CHAR8	0-100=snow albedo, 101=no_decision, 111=night, 125=land, 137=inland water, 139=ocean, 150=cloud, 151=cloud detected as

		snow, 250=missing,, 251=self_shadowing, 252=landmask mismatch, 253=BRDF_failure, 254=non-production_mask

orbit_pnt
Pointer to the orbits of the swaths that were mapped into each grid cell is stored in this SDS. The pointers point by index to the listing of orbit numbers in the metadata object "ORBITNUMBERARRAY" written in ArchiveMetadata.0. The list of local attributes and data content of the SDS is shown in Table 13.

Table 13. Structure and local attributes listing of orbit_pnt

SDS name	orbit_pnt	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Orbit pointer for observation
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 15
_FillValue	DFNT_UINT8	255

granule_pnt
The pointer to the swaths that were mapped into each grid cell is stored in this SDS. The pointers correspond, by index, to the listing of granule pointers in the metadata object "GRANULEPOINTERARRAY" written in ArchiveMetadata.0. A positive granule pointer means that the swath was mapped into the tile. More granules (swaths) are staged for input then actually overlap with a tile. Only the granules that overlap the tile, identified by a positive pointer value, are mapped into the tile. To determine the swath origin of a cell observation, a user should link the pointers in GRANULEPOINTERARRAY to granule data and time in GRANULEBEGINNINGDATETIMEARRAY by index, then the date and beginning time string can be extracted. The list of local attributes and data content of the SDS is shown in Table 14.

Table 14. Structure and local attributes listing of granule_pnt

SDS name	granule_pnt
Data type	DFNT_UINT8
Number of dimensions	2
Dimensions--HDF order--	2400, 2400

Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Granule pointer for observation
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 254
_FillValue	DFNT_UINT8	255

Interpretation of Snow Cover and Snow Albedo Accuracy, Uncertainty and Errors

The NDSI snow cover originates from the M*D10_L2 algorithm with only a single observation (pixel) from the one to several that may have been acquired from satellite overpasses during a day selected and stored as the ‘best’ observation of the day. Discussion regarding the interpretation and uncertainty of the NDSI snow cover is the same as presented in the Interpretation of Snow Cover Accuracy, Uncertainty and Errors section under M*D10_L2.

Validation and evaluation of the snow albedo data is ongoing. Snow albedo is estimated to be within 10% of surface measured snow albedo based on studies in the literature (Klein and Stroeve, 2002; Tekeli et al., 2006) and unpublished evaluations. That estimate is based on best conditions, level surface and complete snow cover. However, in conditions such as steep mountain terrain the snow albedo error can be very large (Sorman et al., 2007). Snow-albedo-specific QA is not reported in C6 because ways of expressing the QA of the snow albedo result are still being investigated. Evaluation and validation of snow albedo will lead to the definition and setting of QA data. Updates to the snow albedo evaluation and validation will be posted on the snow project website. The MODIS BRDF/Albedo product MCD43 may also be of interest for the study of snow albedo http://www.umb.edu/spectralmass/terra_aqua_modis/modis_brdf_albedo_product_mcd43.

The granule pointer data points to the swath from which an observation came. The pointer data can be linked to metadata to determine the time of acquisition, start and end time of swath, of every observation. Acquisition time data is the swath beginning and ending times stored in metadata objects. Linking the pointers and metadata is described above in the granule_pnt description.

The selection algorithm for ‘best’ observation of the day results in a contiguous mapping of adjacent swaths with a weave or stitch pattern along swath edges as shown in Figure 7. The weave pattern is most apparent where cloud cover changed between acquisition times of overlapping swaths. There may be a weave of cloud and clear observations in images of the snow cover data. Viewing geometry differences between adjacent swaths may also cause discontinuity in overlap regions.

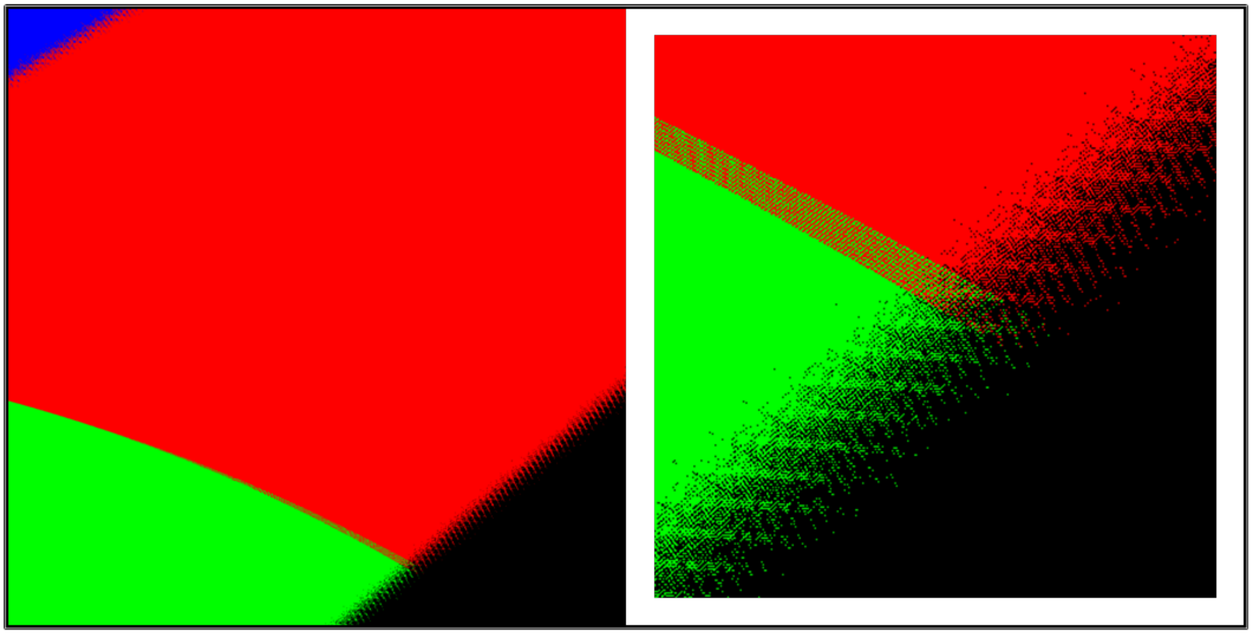

Figure 7. Example of stitching pattern along overlapping input swaths. The four overlapping input swaths to MOD10A1.A2003014.h11v04 (same tile as shown in Figure 10) each shown in a different color. The full tile is shown on the left, and a higher resolution image of the stitching pattern where three swaths overlap is shown on the right.

Geolocation error may be apparent in the product due to uncertainty in L2 geolocation and gridding and projecting the swath data to the sinusoidal projection from day to day. That type of geolocation wobble is commonly observed in the location of freshwater bodies over time. In a composite of tile over the course of several consecutive days the position of a lake shoreline may shift by one or more cells in the horizontal or vertical directions each day resulting in a blurred outline of the lake composited over time. For example, a composite of the inland water mask, bit 0 in the NDSI_Snow_Cover_Algorithm_Flags_QA, from tile h11v04 for five days 7-11 January 2003 is shown in Figure 8. The southern shoreline of Lower Red Lake in Minnesota and smaller lakes to the south, shown in Figure 8, appear blurred in the composite due to day to day geolocation wobble.

Figure 8. Five-day composite of inland water mask in MOD10A1. The inland water mask, bit 0 of NDSI_Snow_Cover_Algorithm_Flags_QA, was extracted for 7-11 January 2003 and composited. In this composite image of the southern end of Lower Red Lake in Minnesota, black is land on all five days and white is lake on all five days, shades of gray are where the cell was 'not lake' on all five days. Shades of gray from light to dark show where lake was mapped to the cell on from 1 to 4 days in the period. Shades of gray represent the geolocation wobble of lakes.

8.0 M*D10C1

M*D10C1 is a daily global view of snow cover. All the daily M*D10A1 tiled products, approximately 320 tiles, are mapped on the MODIS climate modeling grid (CMG), a geographic projection at 0.05° (~ 5 km) resolution (http://modis-land.gsfc.nasa.gov/MODLAND_grid.html) to make this daily snow cover extent product. SCE is given as the percentage of snow cover, 500 m resolution observations, mapped into a 0.05° resolution cell of the CMG. A corresponding map of cloud cover percentage is also generated and stored. The snow and cloud percentage arrays can be combined to get a synoptic view of snow and cloud extents for a day. An example of the M*D10C1 snow cover and cloud cover maps is shown in Figures 9 and 10.

Figure 9. MOD10C1 9 January 2003 snow cover, 5 km resolution. Only snow is mapped; see Figure 10 for the corresponding daily cloud cover.

Figure 10. MOD10C1 9 January 2003 cloud cover, 5 km resolution. Only cloud is shown; see Figure 9 for the corresponding daily snow cover.

Algorithm Description

A binning algorithm is used to determine snow cover extent, cloud cover extent, and associated QA in a CMG grid cell. The input M*D10A1 NDSI_Snow_Cover data is translated to a ‘snow’ or ‘not snow’ flag that is counted in the binning algorithm to determine the percentage of snow observations in a cell. Inputs to the algorithm are listed in Table 15. The NDSI snow cover, from 0-100, is interpreted as a binary snow flag to tally observations of snow mapped in a grid cell. Cloud observations are interpreted and tallied using that method. The binning algorithm generates the snow and cloud cover maps based the total number of observations of a feature, e.g. snow, cloud, snow-free land, etc. and total number of land observations mapped into a cell of the CMG. Lake ice coverage is also included in the snow map. Inland water bodies are determined using the water flag bit in the NDSI_Snow_Cover_Algorithm_Flags_QA for counting the number of water body observations in a grid cell. Observations are tallied for lakes; if the water body has more lake ice observations than open water observations it is interpreted as lake ice with a value of 107 in the output. Lakes that are cloud obscured are output as cloud obscured with a value of 250.

Table 15. MODIS data product inputs to the M*D10C1 snow algorithm.

ESDT	Long Name	Data Used
M*D10A1	"MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid"	NDSI_Snow_Cover NDSI_Snow_Cover_Algorithm_Flags_QA NDSI_Snow_Cover_Basic_QA

A CMG-specific land base mask was made for use with the binning algorithm. The 0.05° land mask was derived from the University of Maryland 1km global land cover data set (http://glcf.umd.edu/data/landcover/index.shtml). If a CMG cell contains 12% or greater land then it is considered land and analyzed; if less than 12% it is considered ocean. That threshold was selected as a balance that minimized snow errors along coasts yet was sensitive to mapping snow along coasts.

The extent of clear views in a cell is presented as an index of the amount of surface observed in the grid cell. This index is called the clear index (CI) and is intended to provide users with an estimate of percentage of all observations mapped in a grid cell that were clear. The CI is essentially 100 minus the percentage of cloud in a cell, though it is calculated based on observation counts in the algorithm code. The CI values are stored in the Day_CMG_Clear_Index SDS. A high CI is indicative of clear conditions and a low CI is indicative of a lot of cloud cover and that snow percentage may not be a good estimate because of the cloud cover obscuring all or parts of a cell.

Polar darkness extent is determined based on the latitude of the CMG cell nearest the equator that is full of night observations. All CMG cells poleward from that latitude are filled as night. Polar darkness is determined this way so that a neat demarcation of night and day is shown in the CMG.

Antarctica has been masked as 100% snow covered. That masking was done to improve the visual quality of data display. This product is not recommended for study of snow cover in Antarctica. During the austral summer some coastal regions, mainly on parts of the Antarctic Peninsula, may be snow free for a brief period of time. Study of those or other areas of Antarctica should use the M*D10_L2 product that is of higher resolution and contains more data and information on accuracy and error.

A global mask showing where the occurrence of snow is extremely unlikely, e.g., the Amazon, the Sahara and the Great Sandy Desert, is applied at the end of the algorithm to eliminate probable erroneous snow cover detection. The source of erroneous snow in those regions is the M*D10_L2 product where erroneous snow detection occurs and is carried forward through the processing levels to the CMG. At the CMG level the use of this extremely unlikely snow mask eliminates erroneous snow from the masked regions but allows it in regions where snow may be a rare event.

Scientific Data Sets

Day_CMG_Snow_Cover
The percentage of snow-covered land mapped in the CMG cell is given in the Day_CMG_Snow_Cover SDS. Snow cover percentage is the fraction of snow covered land based on the entire amount of land mapped in the CMG grid cell. No attempt was made to interpret snow cover possibly obscured by cloud. Percentage of snow is reported in the range of 0-100%. The list of local attributes and data content of the SDS is shown in Table 16.

Table 16. Local attributes for Day_CMG_Snow_Cover

SDS name	Day_CMG_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Daily snow extent, global at 5km
units	DFNT_CHAR8	none
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Cell_resolution	DFNT_CHAR8	0.05 deg
Water_mask_land_threshold	DFNT_FLOAT32	12.0
Antarctica_snow_note	DFNT_CHAR8	Antarctica deliberately mapped as snow
Key:	DFNT_CHAR8	0-100=percent of snow in cell 107=lake ice 111=night 237=inland water 239=ocean 250=cloud obscured water 253=data not mapped 255=fill

Day_CMG_Cloud _Obscured
The percentage cloud obscuration for a cell is given in the Day_CMG_Cloud _Obscured SDS. The percentage of cloud is the extent of cloud cover in a cell based on the total extent of land in the grid cell. That is the same basis as used to calculate the percentage of snow. A cell may range from clear, 0% cloud, to completely cloud obscured, 100% cloud. Local attributes are listed in Table 17.

Table 17. Local attributes for Day_CMG_Cloud _Obscured

SDS name	Day_CMG_Cloud _Obscured	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Daily cloud obscuration percentage
units	DFNT_CHAR8	none
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Cell_resolution	DFNT_CHAR8	0.05 deg
Water_mask_land_threshold	DFNT_FLOAT32	12.0
Antarctica_cloud _note	DFNT_CHAR8	Antarctica deliberately mapped as snow. Cloud value set to 252
Key:	DFNT_CHAR8	0-100=percent of cloud in cell 107=lake ice 111=night 237=inland water 239=ocean 250=cloud obscured water 252=Antarctica mask 253=data not mapped 255=fill

Day_CMG_Clear_Index

An index of the snow cover being a good or poor estimate relative to cloud cover is stored in this SDS. The CI ranges from 0 -100%. Local attributes are listed in Table 18.

Table 18. Local attributes for Day_CMG_Clear _Index

SDS name	Day_CMG_Clear_Index	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Clear index for the daily snow map
units	DFNT_CHAR8	none
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Mask_value		254
Cell_resolution		0.05 deg
Water_mask_land_threshold(%)		12.00000
Antarctica_clear_index_note		Antarctica deliberately mapped as snow. Clear index set to 100
Key:	DFNT_CHAR8	0-100=clear index value, 107=lake

		ice, 111=night, 237=inland water, 239=ocean, 250=cloud obscured water, 253=data not mapped, 255=fill

Snow_Spatial_QA
The basic QA value for a grid cell is the most frequent basic QA value associated with the M*D10A1 observations mapped into a cell. The binning algorithm returns the most frequent QA value; if there is a tie in QA values then the highest QA value of the tied values is reported in the Snow_Spatial_QA SDS. Local attributes are listed in Table 19.

Table 19. Local attributes for Snow_Spatial_QA SDS

SDS name	Snow_Spatial_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	General QA of data in grid cell
units	DFNT_CHAR8	none
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 4
_FillValue	DFNT_UINT8	255
Cell_resolution		0.05 deg
Water_mask_land_threshold(%)		12.00000
Antarctica_QA _note		Antarctica deliberately maped as snow. QA value set to 252.
Key:	DFNT_CHAR8	0=best 1=good, 2=ok, 3=poor, 4=other 252=Antarctica mask 253=not mapped 254=no retrieval 255=fill

Interpretation of Snow Cover Accuracy, Uncertainty and Errors

The daily CMG gives a synoptic view of snow cover extent. The snow cover and cloud cover data and optionally the CI data array can be combined to make a synoptic view of snow cover with the cloud mask overlaid. Snow cover and cloud cover are produced in separate data arrays so that a user may interpret or combine the data relevant to their research or applications. Understanding the propagation of sources of possible snow and cloud errors in the M*D10_L2 products to the CMG is useful for determining how to interpret and possibly filter errors or uncertain conditions. Snow errors in M*D10C1 are propagated from the M*D10_L2 to the M*D10A1 product into the M*D10C1 (see the M*D10_L2 section for discussion of possible errors). Snow commission errors are typically associated with cloud cover thus snow errors on any day may appear to be associated with the cloud cover. A user should consider how to interpret and make best use the snow cover data or combine it with the cloud cover data for their specific needs.

Because of the great difficulty in discriminating between clouds and snow over Antarctica in the level-2 snow detection and cloud mask algorithms (see earlier discussion in M*D10_L2 section) the quality of the data product is low and therefore Antarctica is masked as 100% snow cover. Though masking improves the visual quality of the image, it excludes scientific study of Antarctica.

To reduce erroneous snow mapping in regions of the world that climatologically should never have snow, a “snow impossible” mask was created and applied in the algorithm. The purpose of this mask is to improve the visual quality of the product. A drawback of application of the mask is that highly unusual snowfall events can be masked. The M*D10_L2 and M*D10A1 products should be used to investigate unusual snowfall events because they do not include a “snow impossible” mask.

9.0 M*D10A2

This product provides the maximum extent of snow cover, and the cloud free days on which snow cover was observed over an eight day period. The maximum snow extent represents snow that was observed on at least one day during the period. Days in the period on which snow was observed are mapped as a bit flag chronology of observed snow cover. Cloud cover is not included but if there was persistent cloud cover on all eight days then cloud cover is reported for a grid cell. An example of the eight-day snow cover map is shown in Figure 11. An eight day compositing period was chosen because that is the ground track repeat period of the Terra and Aqua satellites (Masuoka et al., 1998).

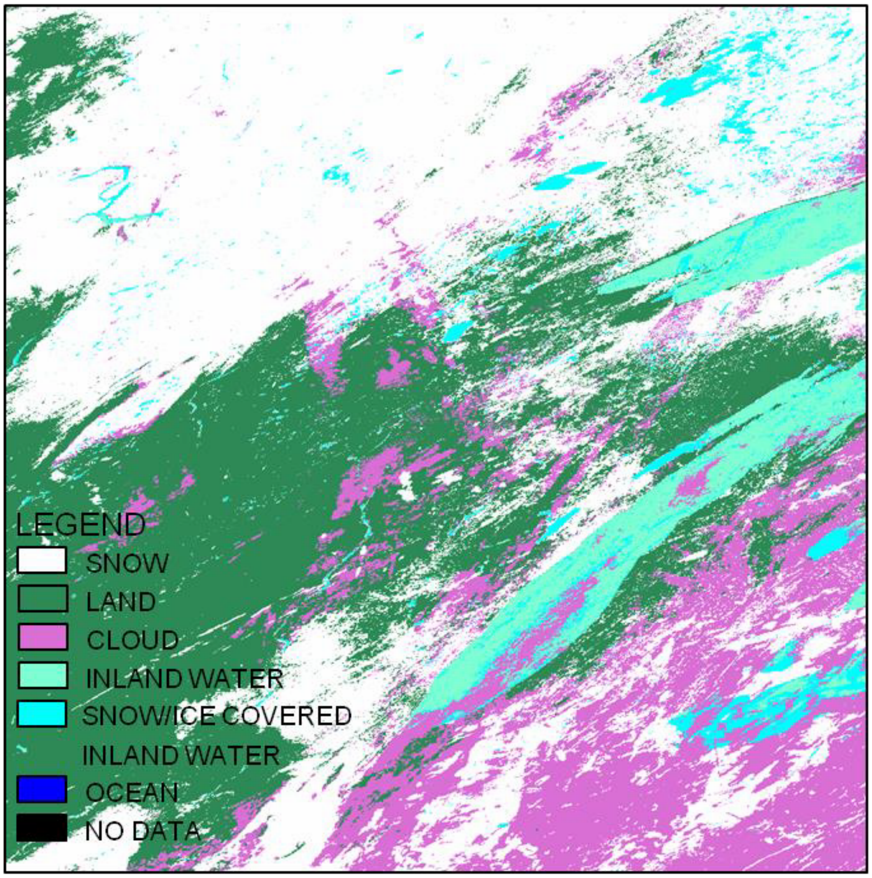

Figure 11. MOD10A2.A2003001.h11v04 8-day snow extent.

Eight day periods begin on the first day of the calendar year with the last eight day period of the year extending into the next year (Table 20). The date given in the product name is the first day of the period. The product can be produced with two to eight days of input. There may not always be eight days of input, so the user should check the global attributes to determine on which day observations were obtained or were missing in a period.

Table 20. Eight-Day Periods

Period No.	Year Days	Period No.	Year Days
1	1-8	24	185-192
2	9-16	25	193-200
3	17-24	26	201-208
4	25-32	27	209-216
5	33-40	28	217-224
6	41-48	29	225-232
7	49-56	30	233-240
8	57-64	31	241-248
9	65-72	32	249-256
10	73-80	33	257-264
11	81-88	34	265-272
12	89-96	35	273-280
13	97-104	36	281-288

14	105-112	37	289-296
15	113-120	38	297-304
16	121-128	39	305-312
17	129-136	40	313-320
18	137-144	41	321-328
19	145-152	42	329-336
20	153-160	43	337-344
21	161-168	44	345-352
22	169-176	45	353-360
23	177-184	46	361-368*
			*Includes 2 or 3 days from next year, depending on leap year

Algorithm Description

The algorithm composites eight days of M*D10A1 tiles to map the maximum snow extent for the period and tracks the days on which snow was observed chronologically across a bit field. Inputs to the algorithm are listed in Table 21. The eight days of observations for a cell are read and if snow was found for any day in the period then that cell is mapped as snow in the Maximum_Snow_Extent data array. The M*D10A1 NDSI_Snow_Cover input is filtered for the purpose of reducing possible snow commission errors and giving a more spatially consistent snow extent map by interpreting NDSI_Snow_Cover in the 1-10 range as “uncertain snow” and not counting it for maximum snow cover. If no snow is found in the period then the type of observation that occurred most often is mapped as the observation for the period. For example, if there were five snow free land, and three cloud observations, the cell will be reported as snow free land. The algorithm is biased to selecting clear views for the period using only the clear views to determine the composite observation. An exception to that logic is made if all eight days are observed with cloud, however if all eight days are cloud then the result is cloud. The logic minimizes cloud cover extent in that a cell must to be cloud obscured for all eight days of observation to be labeled as cloud. If a composite observation is not determined then the output is a “no decision,” to catch unexpected conditions. Lake ice is also composited using the same algorithm.

A chronology of observed snow is tracked as a bit field in the Eight_Day_Snow_Cover data array. The bit corresponding to a day on which snow is observed, eight days across the byte from right to left (least significant bit order), is set. The input days are ordered from first to last day including placing any missing days in the order.

Table 21. MODIS data product inputs to the M*D10A2 snow algorithm.

ESDT	Long Name	Data Used
M*D10A1	“MODIS/Terra Snow Cover Daily L3 Global 500m SIN Grid"	NDSI_Snow_Cover_

The algorithm will generate a product if there are two to eight days of input available. If there is only a single day of input (i.e., only one non-cloudy day), the product will not be produced. All eight days of input may sometimes not be available due to data acquisition or data product production problems. The algorithm was designed to run with fewer than eight days of input so that the data acquired could be processed even if one to six days of data is unavailable. Days used as input are identified in the global attributes.

Scientific Data Sets

Maximum_Snow_Extent
The maximum snow extent for the period depicts where snow was observed on one or more days in the period. Maximum snow extent and other features observed are mapped in this SDS. Local attributes are listed in Table 22.

Table 22. Local Attributes for the Maximum_Snow_Extent SDS

SDS name	Maximum_Snow_Extent	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Maximum snow extent over the 8-day period
units	DFNT_CHAR8	none
valid_range	DFNT_UINT8	0, 254
_FillValue	DFNT_UINT8	255
Cell_area (km^2)	DFNT_FLOAT32	0.2146587
Max_snow_area (km^2)	DFNT_FLOAT32	443282.0
Key:	DFNT_CHAR8	0=missing data, 1=no decision, 11=night, 25=no snow, 37=lake, 39=ocean, 50=cloud, 100=lake ice, 200=snow, 254=detector saturated, 255=fill

Eight_Day_Snow_Cover
Input files are ordered chronologically in the algorithm and if snow was observed the corresponding day bit is set. Across a byte the days are ordered from right to left: bit 0 corresponds to day 1 of the eight-day period; bit 1 corresponds to day 2 of the eight-day period, etc. Local attributes are listed in Table 23.

Table 23. Local Attributes for the "Eight_Day _Snow_Cover" SDS

SDS name	Eight_Day _Snow_Cover
Data type	DFNT_UINT8
Number of dimensions	2

Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Eight day snow cover chronobyte
units	DFNT_CHAR8	bit
valid_range	DFNT_UINT8	0, 255
_FillValue	DFNT_UINT8	0
Key:	DFNT_CHAR8	Snow occurrence in chronological order. Day in period ordered as 87654321 corresponds to bit order of 76543210. Bit value of 1 means snow was observed. Bit value of 0 means snow was not observed.

Interpretation of Snow Cover Accuracy, Uncertainty and Errors

The eight day snow cover extent is intended to provide a map of maximum snow cover extent during that time period and to show on which days snow cover was observed. Typically the accuracy is similar to the M*D10A1 product but may be lower because compositing of the daily snow commission errors over eight days can increase the error spatially and temporally despite the filter to reduce errors.

Accuracy and errors from the M*D10A1 inputs, which originated in the M*D10_L2, are propagated into the eight-day snow cover maps. Errors associated with cloud/snow confusion from the M*D10_L2 product can be seen in the eight-day snow maps. Snow errors of commission are typically manifest as snow in locations and seasons where snow is impossible or very unlikely. Errors accumulate from each day and the errors probably occur in different locations on different days which increase the spatial extent of error in the eight-day snow map.

10.0 M*D10C2

This product gives a global view of maximum snow cover extent for an eight day period. All the eight-day M*D10A2 tiled products, approximately 320 tiles, are mapped and binned on the MODIS climate modeling grid (CMG), a geographic projection 0.05° resolution (http://modis-land.gsfc.nasa.gov/MODLAND_grid.html) to make the maximum snow cover extent map (Figure 12). Maximum snow cover extent with corresponding persistent cloud cover, CI and QA data arrays are in the product.

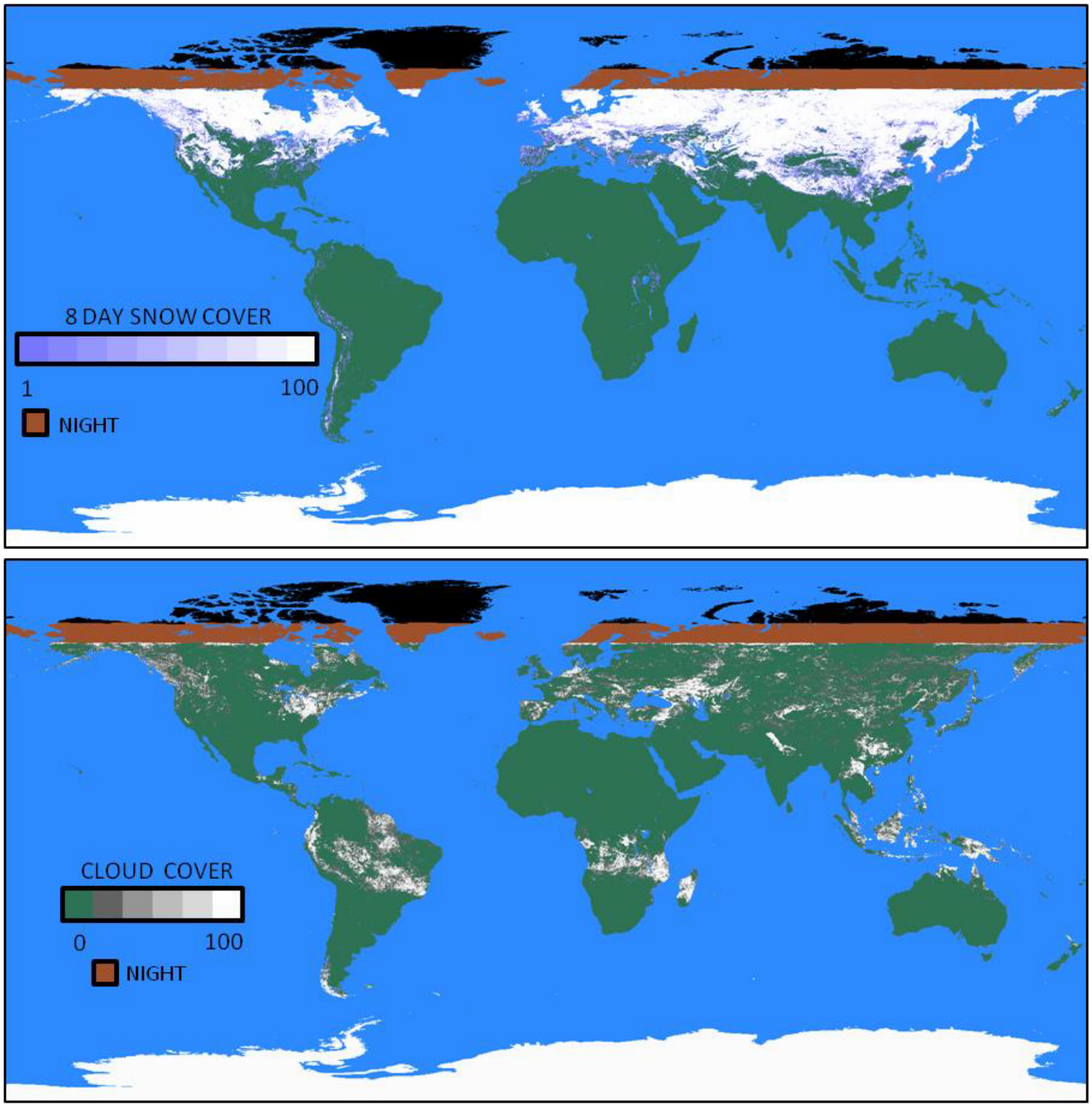

Figure 12. MOD10C2 for 1-8 January 2003. Maximum snow cover extent (top) for the eight-day period and corresponding map of persistent cloud cover (bottom). The eight-day snow cover is the fraction of observations mapped into the CMG grid cell that were snow on any one of the eight days.

Algorithm Description

The M*D10C2 algorithm is a revised version of the M*D10C1 algorithm running with the M*D10A2 eight day products as inputs. The M*D10A2 data inputs are mapped, binned and tallied for a grid cell. Results for a cell are determined by the percentage of counts of observations, maximum snow cover or persistent cloud, mapped in the cell based on total land extent in the grid cell. Inputs to the algorithm are listed in Table 24. A binning algorithm is employed to count the data by category, e.g. maximum snow, persistent cloud, night, etc. mapped to a grid cell. As with the M*D10C1 algorithm a clear index of the amount of surface observed in the grid cell is calculated. The index in M*D10C2 measures that amount of persistent cloud that was present in a grid cell (eight consecutive days). Any value > 0 means that some fraction of the cell was cloud obscured for eight days. The CI values are stored in the Eight_Day_CMG_Clear_Index SDS.

The QA value is determined by a count of valid and invalid values tallied in a grid cell. This simple method of estimating QA is used because there is no QA data generated or stored in the M*D10A2 product. Default QA value is good, A poor QA value is set if the count of invalid data is the majority tally of observations in a grid cell.

Antarctica is arbitrarily mapped as permanent snow cover because Antarctica is 99% or greater snow covered. During the summer up to 1% may be snow-free mostly on the Antarctic Peninsula. Mapping Antarctica as always snow-covered was done for aesthetic purposes for producing and viewing a global map.

Table 24. MODIS data product inputs to the M*D10C2 snow algorithm.

ESDT	Long Name	Data Used
M*D10A2	“MODIS/Terra Snow Cover 8-day L3 Global 500m SIN Grid"	Maximum_Snow_Extent

Scientific Data Sets

Eight_Day_CMG_Snow_Cover

This SDS is the global map of maximum snow cover extent for the eight-day period. Extent of snow cover observed is expressed as a percentage of maximum snow observations mapped in to the CMG cell. The valid range of snow cover extent is 0-100%. Local attributes are listed in Table 25.

Table 25 Local attributes for Eight_Day_CMG_Snow_Cover

SDS name	Eight_Day_CMG_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Eight day snow extent, 5km
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Mask_value	DFNT_UINT8	254
Night_value	DFNT_UINT8	111
Water_mask_land_threshold	DFNT_FLOAT32	12.0
Antarctica_snow_note	DFNT_CHAR8	Antarctica deliberately mapped as snow
Key:	DFNT_CHAR8	0-100=percent of snow in cell 107=lake ice 111=night

		237=inland water 250=cloud obscured water 253=data not mapped 254=water mask 255=fill

Eight_Day_CMG_Cloud_Obscured
This SDS is the global map of persistent cloud cover extent for the eight-day period. Extent of cloud cover observed, expressed as a percentage of persistent, i.e. eight days of cloud cover mapped is into a grid cell. The valid range of cloud cover extent is 0-100%. Local attributes are listed in Table 26.

Table 26. Local attributes for Eight_Day_CMG_Cloud _Obscured

SDS name	Day_CMG_Cloud _Obscured	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Cloud obscuration percentage for the eight day snow map
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Mask_value	DFNT_UINT8	254
Not_processed_value	DFNT_UINT8	252
Night_value	DFNT_UINT8	111
Cell_resolution	DFNT_CHAR8	0.05 deg
Water_mask_land_threshold	DFNT_FLOAT32	12.0
Antarctica_cloud _note	DFNT_CHAR8	Antarctica deliberately mapped as snow. Cloud value set to 252
Key:	DFNT_CHAR8	0-100=percent of snow in cell 107=lake ice 111=night 237=inland water 250=cloud obscured water 253=data not mapped 254=water mask 255=fill

Eight_Day_CMG_Clear_Index
This index indicates the fraction of persistent cloud cover observed in the period. The lower the value the greater the fraction of persistent cloud cover. Local attributes are listed in Table 27.

Table 27. Local attributes for Eight_Day_CMG_Clear _Index

SDS name	Eight_Day_CMG_Clear_Index
Data type	DFNT_UINT8

Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Clear index for the eight day snow map
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Mask_value		254
Water_mask_land_threshold(%)		12.00000
Antarctica_clear_index_note		Antarctica deliberately mapped as snow. Clear index set to 100
Key:	DFNT_CHAR8	0-100=clear index value, 107=lake ice, 237=inland water, , 250=cloud obscured water, 253=data not mapped, 254=water mask 255=fill

Snow_Spatial_QA

The QA value is determined based on count of valid or invalid data values mapped into a grid cell. Local attributes are listed in Table 28.

Table 28 Local attributes for Snow_Spatial_QA SDS

SDS name	Snow_Spatial_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Snow cover per cell QA
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 1
_FillValue	DFNT_UINT8	255
Mask_value	DFNT_UINT8	254
Water_mask_land_threshold (%)		12.00000
Antarctica_QA _note		Antarctica deliberately mapped as snow. QA value set to 252.
Key:	DFNT_CHAR8	0=good quality, 1=other quality, 252=Antarctica mask, 253=data not mapped 254=ocean mask

		255=fill

Interpretation of Snow Cover Accuracy, Uncertainty and Errors

A synoptic view of maximum snow extent is provided in this product. The maximum snow extent in each grid cell is the fraction of all observations mapped, and binned into a cell that had snow cover on at least one day in the eight-day period. Persistent cloud cover, i.e., eight consecutive days of cloud cover, is mapped in the "cloud obscured" data array, in which the fraction of all observations binned in that cell had persistent cloud cover in the period. Because single day cloud cover is not tracked in this product the "clear" index should be interpreted as the extent of persistent cloud cover. A clear index of 0 does not mean that there was no obscuring cloud cover in the period; it means that there were not eight consecutive days of cloud cover. This index indicates how much of the surface in a cell was persistently cloud covered.

Accuracy and error are similar to the M*D10A2 product with snow detection errors occurring in M*D10_L2 being propagated into the eight-day snow cover product. Snow commission errors are typically the most apparent type of error seen. Probable snow commission errors over eight days may spread in spatial extent and manifest as low percentages of maximum snow fractions in a grid cell. Snow commission errors in the southeastern U.S. in Figure 12 (zoom to 300+% to see them) show the spread of snow commission errors. A majority of most probable snow commission errors can be filtered by interpreting snow cover values < 20 to be "not snow." However, screening at that level *may* block actual snow along the periphery of snow covered regions. No screening for errors is done in the algorithm so a user should analyze the snow cover and interpret it in a way that minimizes probable errors yet makes reasonable use of the product to track maximum snow cover extent.

The QA data indicates if the input data are valid or invalid or if a special condition like polar darkness existed. The QA value should be interpreted as whether the input data value was good or poor.

11.0 M*D10CM

This is a global, 0.05° resolution monthly mean snow cover extent derived from the MODIS daily snow cover extent product M*D10C1, an example of which is shown in Figure 13.

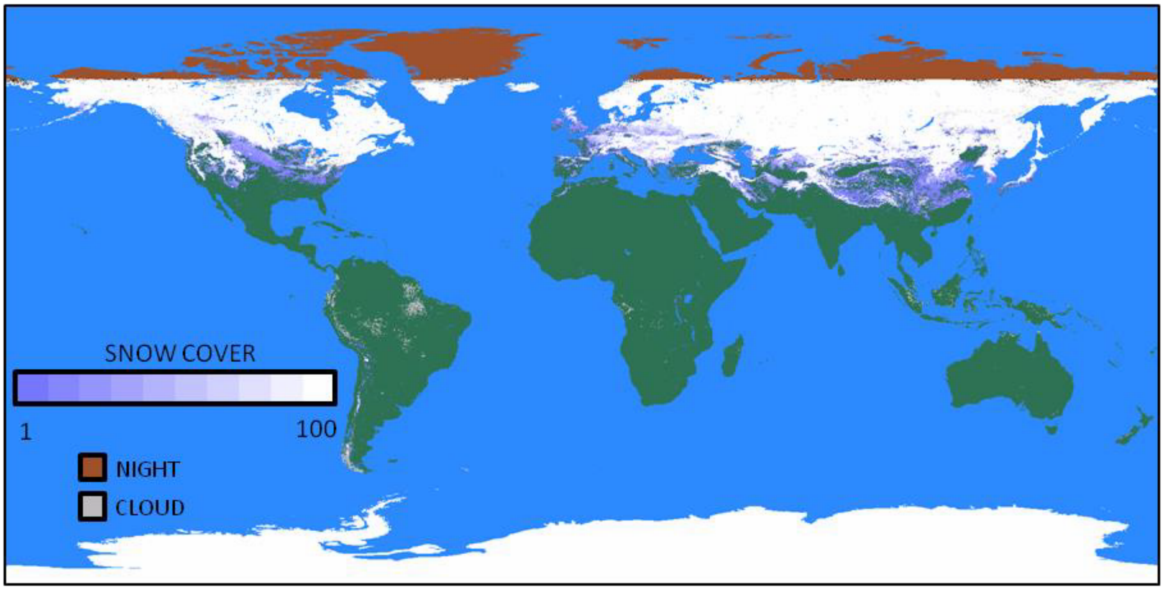

Figure 13. MOD10CM monthly mean snow cover for January 2003.

Algorithm Description

Average snow cover is calculated for each cell in the CMG using the 28 – 31 days of M*D10C1 for the month (Table 29). Data is filtered so that the most relevant days of snow cover are used to calculate the average and to filter out data that is of low magnitude, i.e. low occurrence of snow during the month. The latter filter works to remove some occurrences of erroneous snow from the monthly snow average. The daily snow data is used to compute the monthly average snow cover. A daily cell must have a CI of > 70% to be included in the average. That filter is applied so that only the clearest of the daily observations are included in the average. (See the M*D10C1 section for a description of the CI.) A daily observation contributes to the monthly average for a cell as follows:

Daily contribution to monthly mean = 100 * snow% / CI

For daily observations that are cloud free the snow contribution to the mean is the observed snow fraction in a grid cell. For daily observations of mixed snow and cloud fractions with a high CI it is assumed that there is some fraction of snow cover obscured by cloud. In that case the daily snow observation is increased in that equation so that the contribution to the monthly mean will be greater than the daily snow observation. For example, a cell has 25% snow cover and the CI = 75 then the cell is determined to have (25% / 75 * 100) = 33% fractional snow cover. Daily observations with a CI ≤ 70 are assigned either as 100% cloudy, night, missing or no decision. There must be at least one day in the month for each cell with the CI > 70 for the mean snow cover to be computed for that cell of the monthly CMG. If that restriction is not met then the cell is reported as “no decision.”

A second filter is applied to the calculated mean fractional snow cover of each cell to filter out those cells in which the magnitude of snow cover is less than 10%. Cells failing the filter are assigned 0% snow for the month. Cells with a low magnitude are considered suspect and may be erroneous snow originating in the M*D10_L2 algorithm and that has been propagated through the sequence of snow products. The magnitude of snow is calculated as an average snow for all days with snow passing the first filter of CI > 70. For example, cell A has 20 days with CI = 100, 10 days with 100% snow and 10 days with 0% snow, thus the mean monthly snow = (10 * 100 + 10 * 0) / 20 = 50%. The second filter would be calculated as (days of snow * CI) / days of snow, (10 * 100) / 10 = 100%. That average is retained because the average snow magnitude was > 10. Cell B also has 20 days with CI = 100 however, the 10 days of snow are all 5%. In this case the snow magnitude is (5 * 10) / 10 = 5 thus the cell is filtered out and the monthly snow average is set to 0%. Minimal QA is applied. By default the QA is set to “good quality” and is changed only if all the input data are bad.

Table 29. MODIS data product inputs to the M*D10CM snow algorithm.

ESDT	Long Name	Data Used
M*D10CM	MODIS/Terra Snow Cover Daily L3 Global 0.05 Deg CMG	Day_CMG_Snow_Cover Day_CMG_Cloud _Obscured Day_CMG_Clear_Index

Scientific Data Sets

Snow_Cover_Monthly_CMG

Mean monthly snow cover data is stored in this SDS. Mean monthly snow is reported in the range 0-100%. Other features are mapped with specific values, e.g. water feature = 254. Local attributes are listed in Table 30.

Table 30. Local attributes for Day_CMG_Snow_Cover

SDS name	Snow_Cover_Monthly_CMG	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Monthly snow cover extent, 5km
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Mask_value	DFNT_UINT8	254
Night_value	DFNT_UINT8	211
Cell_resolution	DFNT_CHAR8	0.05 deg
Antarctica_snow_note	DFNT_CHAR8	Antarctica deliberately mapped as snow
Key:	DFNT_CHAR8	0-100=percent of snow in cell 211=night 250=cloud 253=no decision 254=water mask 255=fill

Snow_Spatial_QA
The quality determined for data in a grid cell is written in this SDS. Local attributes are listed in Table 31.

Table 31. Local attributes for Snow_Spatial_QA.

SDS name	Snow_Spatial_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	3600, 7200	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	Thematic QA of the monthly snow
units	DFNT_CHAR8	none
format	DFNT_CHAR8	I3
coordsys	DFNT_CHAR8	latitude, longitude
valid_range	DFNT_UINT8	0, 1
_FillValue	DFNT_UINT8	255
Cell_resolution	DFNT_CHAR8	0.05 deg
Antarctica_snow_note	DFNT_CHAR8	Antarctica deliberately mapped as snow
Key:	DFNT_CHAR8	0=good quality 1=other quality 252=Antarctica mask 254=water mask 255=fill

Interpretation of Snow Cover Accuracy, Uncertainty and Errors

Analysis of the quality of the M*D10CM has been limited to visual and qualitative comparative analysis of the monthly snow maps. Overall the M*D10CM appears to be a reasonable representation of mean monthly snow cover when compared to other sources of global or regional snow maps. However there are notable amounts of spurious snow cover which is the result of compounding of daily snow commission errors over the month. Such snow commission errors can be seen in the monthly snow cover in Figure13. In some situations the snow commission errors may be indicative of anomalous surface conditions, or frequent snow/cloud confusion. Users may choose to screen out low to moderate value snow cover values to reduce probable snow commission errors or interpret the data in other ways relevant to their interest. The validation status of this product is Stage 1 (http://landval.gsfc.nasa.gov/background.html) but may change as more evaluation and validation analysis is done.

Monthly lake ice is not included in the product. All inland water bodies are masked (value =254).

12.0 M*D10A1F

M*D10A1F is a new daily ‘cloud-gap-filled’ gridded snow cover product produced in C6.1. The purpose of this product is to provide a daily ‘cloud-gap-filled’ (CGF) map of snow cover extent. A CGF daily map is generated by retaining a previous day non-cloud observation when the current day has a cloud observation. The data product includes the CGF snow cover map, a cloud persistence map, the basic QA and algorithm QA flags for observations, and the NDSI snow cover map from the corresponding daily M*D10A1 product. The snow cover map from M*D10A1 is included to facilitate comparison with the CGF snow cover map. An example of MOD10A1F is shown in Figure 14.

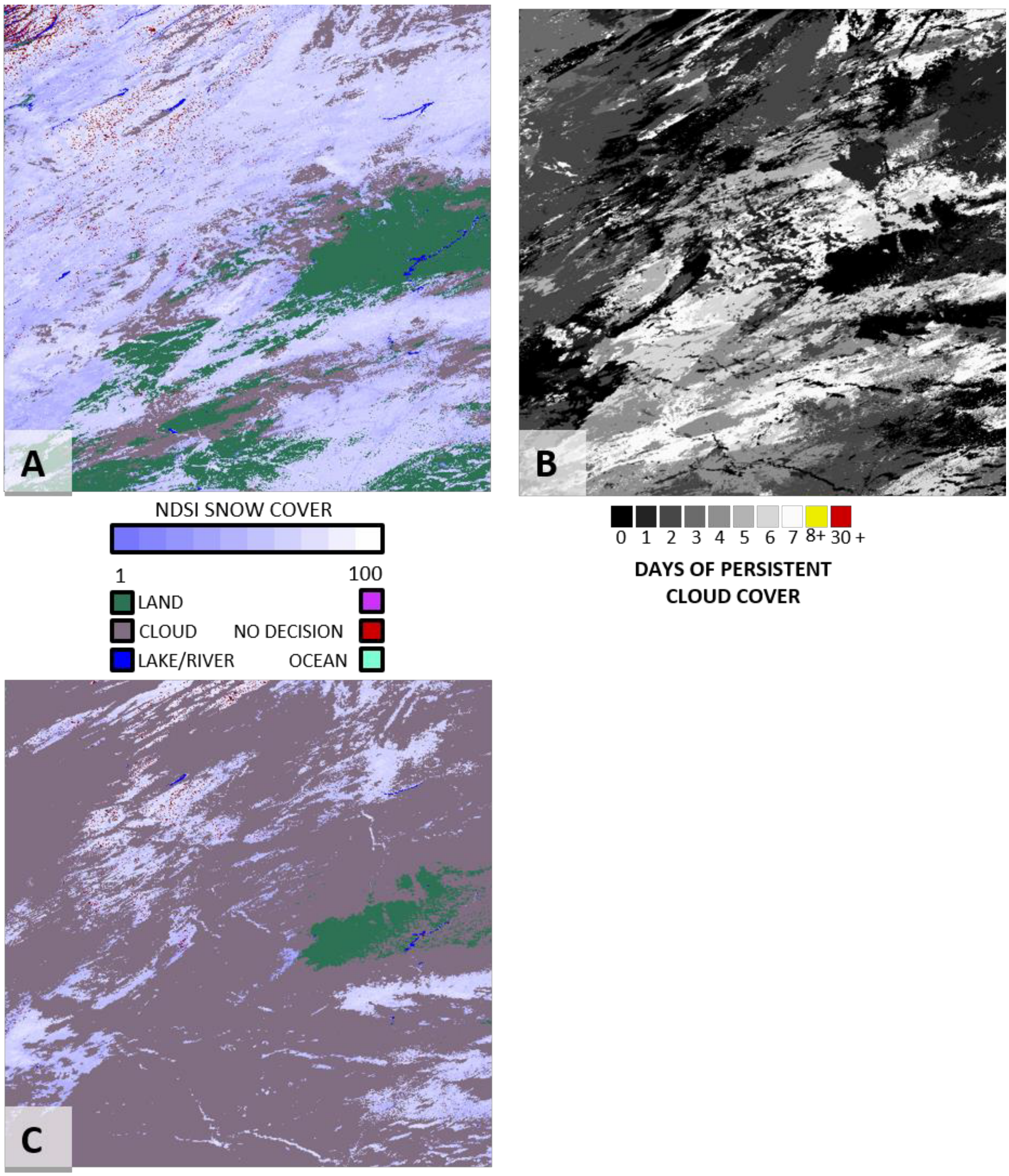

Figure 14. The MOD10A1F.A2017360.h10v04 (26 December 2017), tile covering the region from southern Nebraska to northern Montana, with the CGF_NDSI_Snow_Cover (A), the cloud persistence dataset (B), and the corresponding NDSI_Snow_Cover map (C) from the MOD10A1 product.

Algorithm Description

The CGF algorithm that was developed for the daily global M*10CMG and evaluated in a data assimilation experiment with the Noah land surface model in the NASA Land Information System (LIS) (Hall et al., 2010) was adapted for use with the M*D10A1 daily snow cover product. Since the M*D10A1 product is the most often used snow cover product the CGF product was developed at this level to provide the opportunity for maximum usage of the product.

Inputs to the CGF algorithm are the current day M*D10A1 and the previous day M*D10A1F. The CGF current day snow cover map is generated by replacing current day cloud observations in M*D10A1 with a non-cloud observation from yesterday's CGF snow cover map. Cloud persistence is tracked by incrementing or resetting the count of consecutive days of cloud observed for a cell in the Cloud_Persistence dataset. Cloud tracking is done by incrementing the count of consecutive cloud days in M*D10A1F. If the current day is a cloud observation, then the count is incremented by one day. If the current day is a non-cloud observation then the cloud persistence count is reset to 0. The basic QA and the algorithm flags QA datasets in M*D10A1F are also set to the current day non-cloud observation corresponding QA data or replaced with previous day values if current day observation is cloud. The current day M*D10A1F contains the above datasets and summary statistics as metadata. The M*D10A1F also contains a copy of the current day M*D10A1 NDSI_Snow_Cover data set to facilitate comparison with the CGF snow cover.

The CGF product will be produced as a 12 month sequence corresponding to the United States Geological Service (USGS) "water year" beginning on 1 October and ending on 30 September of each year. The exceptions are for the first year of Terra which begins in February 2000 and for the first year of Aqua which begins in July 2002, when temporal coverage began for those missions. On the first day of the "water year" (or first day of temporal coverage) the M*D10A1 datasets are copied into the M*D10A1F product and the cloud persistence is set to one for cells that are cloudy.

In situations where there is fill data in orbit gaps or missing parts of swaths, the fill data is replaced with a non-fill data value from the previous day CGF and the cloud persistence count is incremented by one.

There are some missing days of M*D10A1 tiles in the data record. When a missing tile is encountered, yesterday's CGF becomes the current day CGF and the cloud persistence data is incremented by one for all the cells. In this situation the missing data is treated as a cloud observation and the cloud persistence count of days is incremented by one. The global attribute "Missing days MODIS 10A1 tile count" reports the number of missing day(s). There are some gaps in the data record that are longer than a single day.

Scientific Data Sets

CGF_NDSI_Snow_Cover

This is the CGF NDSI snow cover that has current day cloud observations replaced with a previous day non-cloud observation. The list of local attributes and data content of the SDS are listed in Table 32.

Table 32. Structure and local attributes listing of NDSI_Snow_Cover

SDS name	CGF_NDSI_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	cloud-gap-filled NDSI snow cover
valid_range	DFNT_UINT8	0, 100
FillValue	DFNT_UINT8	255
Key	DFNT_CHAR8	0-100=NDSI snow, 200=missing data, 201=no decision, 211=night, 237=inland water, 239=ocean, 250=cloud, 254=detector saturated, 255=fill

Cloud_Persistence

This is the count of the number of preceding, including current day, days of cloud for a cell. Cloud persistence count is also incremented by one for fill data. The list of local attributes and data content of the SDS is shown in Table 33.

Table 33. Structure and local attributes listing of Cloud_Persistence

SDS name	Cloud_Persistence	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	cloud persistence for preceding days
valid_range	DFNT_UINT8	0, 254
_FillValue	DFNT_UINT8	255
Key	DFNT_CHAR8	count of consecutive preceding days of cloud cover

Basic_QA

A general estimate of the quality of the algorithm result for a pixel is reported in this dataset. This QA estimate was made in the M*D10_L2 algorithm and passed to the M*D10A1 product. The structure and list of local attributes and data content are listed in Table 34.

Table 34. Structure and local attributes listing of the Basic_QA

SDS name	Basic_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	CGF snow cover general quality value
valid_range	DFNT_UINT8	0, 4
_FillValue	DFNT_UINT8	255
Key	DFNT_CHAR8	0=best, 1=good, 2=ok, 3=poor-not used, 4=other-not used, 211=night, 239=ocean, 255=unusable L1B or no data

Algorithm_Flags_QA

Bit flags are set for data screen results and for the inland water mask in the M*D10_L2 algorithm and passed to the M*D10A1 product. The list of local attributes and data content of the SDS is provided in Table 35.

Table 35. Local attributes listing of the Algorithm_Flags_QA

SDS name	Algorithm_Flags_QA	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	CGF algorithm bit flags
format	DFNT_CHAR8	bit flag
Key	DFNT_CHAR8	bit on means: bit 0: inland water flag bit 1: low visible screen failed, reversed snow detection bit 2: low NDSI screen failed, reversed snow detection bit 3: combined temperature and height screen failed, snow reversed because too warm and too low. This screen is also used to flag a high elevation too-warm snow detection, in this case the snow detection is not changed but this bit is set. Bit 4 : too high SWIR screen and applied at two thresholds: QA bit flag set if band 6 TOA > 25% & band 6 TOA <=45%, indicative of unusual snow condition, or snow commission error

		snow detection reversed if band 6 TOA > 45% bit 5 : MOD35_L2 probably cloudy bit 6 : MOD35_L2 probably clear bit 7 : solar zenith screen, indicates increased uncertainty in results

*M*D10A1_NDSI_Snow_Cover*

This is the NDSI snow cover from the corresponding current day M*D10A1 data product. This dataset is included to facilitate comparison of current day view of snow cover to the current day cloud-gap-filled snow cover. The list of local attributes and data content of the SDS are listed in Table 36.

Table 36. Structure and local attributes listing of M*D10A1_NDSI_Snow_Cover

SDS name	M*D10A1_NDSI_Snow_Cover	
Data type	DFNT_UINT8	
Number of dimensions	2	
Dimensions--HDF order--	2400, 2400	
Local Attributes		
Attribute name	DATA TYPE	Data
long_name	DFNT_CHAR8	NDSI snow cover from current day M*D10A1
valid_range	DFNT_UINT8	0, 100
_FillValue	DFNT_UINT8	255
Key	DFNT_CHAR8	0-100=NDSI snow, 200=missing data, 201=no decision, 211=night, 237=inland water, 239=ocean, 250=cloud, 254=detector saturated, 255=fill

Interpretation of Snow Cover Accuracy, Uncertainty and Errors

The CGF snow cover map is an estimate of the snow cover that might exist under current cloud cover. The CGF snow cover map (Figure 14 A) is made by using all the cloud-free observations from the current day and by replacing the current day cloud observations with the non-cloud (clear view) observation from a previous day in yesterday's M*D10A1F. The persistence of cloud cover is tracked by incrementing the count of days of cloud cover for each consecutive day that cloud is observed in a cell. The number of days since the last non-cloud observation in a cell is tracked in the Cloud_Persistence dataset (Figure 14 B). When a cloud-free observation is made the cloud persistence day count is reset to 0. If the cloud persistence is 0 for a grid cell that means that a cloud-free observation was made on the current day. A cloud persistence value of 1 means that current day was "cloud". A cloud persistence value greater than 1 is the count of previous consecutive days of cloud cover observed for a cell; it is the number of days since a non-cloud observation was observed. The Cloud_Persistence dataset should be used as quality assessment (QA) data when using the CGF_NDSI_Snow_Cover dataset to determine the age of an observation. The basic and algorithm bit flag QA datasets are copied from the M*D10A1 for non-cloud observations and from previous day M*D10A1F, for cloudy observations. The snow cover algorithm was applied in the L2 processing so the user is referred to Section 5.0 for description of the algorithm and information on the basic QA, the algorithm bit flags QA, and interpretation of the snow cover datasets in this product.

Interpretation/evaluation of the CGF relative to the current day M*D10A1 snow cover can done by comparing the CGF to the M*D10A1 NDSI_Snow_Cover dataset which is copied from the M*D10A1 product to facilitate this comparison. Interpretation and use of the M*D10A1 should be done independent of the M*D10A1F product. The discussion of interpretation, accuracy and errors for M*D10A1 (Section 7.0) applies to the M*D10A1F observations.

Cloud/snow confusion (confusing snow cover as cloud in the cloud mask product that occurs in the M*D10_L2 algorithm) can be passed through to the M*D10A1F and appear as persistent cloud cover over more days than would seem reasonable for cloud cover to persist in a location at a time when snow cover is expected. Some of the cloud cover in MOD10A1F CGF snow cover, in the central area of image A of Figure 14, could be attributable to the cloud/snow confusion that had persisted for seven days. Analysis/evaluation of that cloud/snow confusion relies on comparison with either the MOD09GA daily surface reflectance product or the L2 swath products MOD10_L2 and MOD02HKM. Cloud/snow confusion is being investigated in the MOD10_L2 algorithm and if that confusion can be decreased, the quality of the sequence of snow products would be enhanced.

On the first day of M*D10A1F production the CGF snow map will be the same as the M*D10A1; on successive days the cloud cover in the CGF will decline, eventually to zero, as non-cloud observations replace cloud observations over time. A reasonable estimate of the number of days to reach a nearly cloud free CGF is five to seven days, but is dependent on the season and location imaged. The production plan is to produce M*D10A1F for each day of a USGS "water year" beginning on 1 October and ending on 30 September, except for the first year of Terra and Aqua acquisitions which begin in February 2000 and July 2002, respectively. A user can determine if the M*D10A1F is the initial day of a time series or a day in the series by reading the global attribute "First Day of series." "First Day of series" is set to "Y" for the first day in a time series and is to "N" for all other days in the time series. The global attribute "Time Series Day" is the count of days in the series since the first day.

There are some missing M*D10A1 products (tiles), single day or multiple days in the data record. The CGF algorithm processes a missing day as a completely cloudy day and the cloud persistence count is incremented by one and the previous day M*D10A1F becomes the current day M*D10A1F. A single day of missing data has minimal impact on the continuity of snow cover, however the impact can vary temporally and by region. The effect of multiple consecutive days of missing M*D10A1 tile inputs has not been assessed but would probably be significant, especially during periods when snow cover could be reasonably expected to occur. The global attribute “Missing days MODIS 10A1 tile count” reports the number of missing day(s). MODIS data outages are listed at https://modaps.modaps.eosdis.nasa.gov/services/production/outages_terra.html

Orbit gaps and missing swaths that appear in the M*D10A1 product are filled with fill data. In the CGF algorithm fill data is processed in a manner similar to how a cloud observation is processed. A fill data value is replaced with a non-fill data value from yesterday’s M*D10A1F and the cloud persistence count is incremented by one. If the observation from yesterday’s M*D10A1F is fill data then fill data is written for the cell and the cloud persistence count is incremented by one. The objective of processing fill data in this way is to provide a CGF snow map without fill data disrupting the continuity of the CGF snow cover map over time. However, situations of persistent fill data will be retained as fill data until non-fill data is available.

13.0 Acronyms

ATBD	Algorithm Theoretical Basis Document
BRDF	Bidirectional Reflectance Distribution Function
BT	brightness temperature
C5	Collection 5
C6	Collection 6
C6.1	Collection 6.1
CGF	cloud-gap-filled
CI	Clear Index
CMG	climate modeling grid
DAAC	Distributed Active Archive Center
DEM	Digital elevation model
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
ESDT	Earth Science Data Type
FSC	Fractional snow cover
HDF	Hierarchical Data Format
LDOPE	Land Data Operational Product Evaluation
MCST	MODIS Calibration Support Team
MOD	Terra MODIS
MODAPS	MODIS Adaptive Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MYD	Aqua MODIS
NASA	National Aeronautics and Space Administration
NDSI	Normalized Difference Snow Index
NSIDC	National Snow and Ice Data Center
PGE	Production Generation Executive
QA	quality assessment

QIR	Quantitative Image Restoration
RGB	red, green, blue
SCE	Snow cover extent
SDPTK	Scientific Data Processing ToolKit
SDS	Scientific Data Set
SWIR	Shortwave infrared
SZA	Solar zenith angle
TOA	top-of-atmosphere
UMD	University of Maryland
UTC	Universal Time Coordinate
VIIRS	Visible Infrared Imager Radiometer Suite
VIS	Visible

14.0 Related Web Sites

All site links checked on 12 September 2018.

Data Ordering
National Snow and Ice Data Center: http://nsidc.org/daac
Earthdata: https://earthdata.nasa.gov

Imagery and Data Product Viewing
Worldview: https://worldview.earthdata.nasa.gov
MODIS Land Global Browse: http://landweb.nascom.nasa.gov/cgi-bin/browse/browseMODIS.cgi

EOS
Terra Website: http://terra.nasa.gov
Aqua Website: http://aqua.nasa.gov
National Snow and Ice Data Center: http://nsidc.org/daac

MODIS
MODIS Snow/Ice Global Mapping Project: http://modis-snow-ice.gsfc.nasa.gov
MODIS Project: http://modis.gsfc.nasa.gov
MODIS Land Discipline: http://modis-land.gsfc.nasa.gov
Cloud Mask (M*D35): https://modis-atmos.gsfc.nasa.gov/products/cloud-mask
MODIS Characterization Support Team: http://mcst.gsfc.nasa.gov
MODIS Atmosphere Discipline: http://modis-atmos.gsfc.nasa.gov/

HDF-EOS Information and Tools
EOSDIS: https://earthdata.nasa.gov
HDF-EOS: https://hdfeos.org
MODIS Swath Reprojection Tool (MRT Swath): https://lpdaac.usgs.gov/tools
HDF-EOS to GeoTIFF Conversion Tool (HEG)
http://newsroom.gsfc.nasa.gov/sdptoolkit/HEG/HEGHome.html
NDSI: https://nsidc.org/data/hdfeos /index.html

15.0 References

Gladkova, I., M. Grossberg, G. Bonev, P. Romanov and F. Shahriar, 2012: Increasing the accuracy of MODIS/Aqua snow product using quantitative image restoration technique, *IEEE Geoscience and Remote Sensing Letters,* 9(4):740-743.

Hall, D.K., G.A. Riggs, J.L. Foster and S.V. Kumar, 2010: Development and evaluation of a cloud-gap-filled MODIS daily snow-cover product, *Remote Sensing of Environment,* 114:496-503, doi:10.1016/j.rse.2009.10.007, doi:10.1016/j.rse.2009.10.007.

Hall, D.K., and G.A. Riggs, 2011: Normalized-difference snow index (NDSI), Encyclopedia of Earth Sciences Series, Encyclopedia of Snow, Ice and Glaciers, doi:10.1007/978-90-481-2642-2_376.

Klein, A.G. and J. Stroeve, 2002: Development and validation of a snow albedo algorithm for the MODIS instrument, *Annals of Glaciology*, 34:45-52.

Masuoka, E., A. Fleig, R.E. Wolfe and F. Patt, 1998: Key characteristics of MODIS data products, *IEEE Transactions on Geoscience and Remote Sensing*, 36(4):1313-1323.

MCST, 2014: MODIS Characterization Support Team, Website: http://mcst.gsfc.nasa.gov.

Riggs, G.A., D.K. Hall, and M.O. Román, 2016: VIIRS Snow Cover Algorithm Theoretical Basis Document (ATBD), NASA VIIRS project document.

Sorman, A.Ü., Z. Akyurek, A. Sensoy, A.A. Sorman and A.E. Tekeli, 2007: Commentary on comparison of MODIS snow cover and albedo products with ground observations over the mountainous terrain of Turkey, *Hydrology and Earth System Sciences,* 11(4):1353-1360.

Tekeli, A.E., A. Sensoy, A. Sorman, Z. Akyürek and Ü. Sorman, , 2006: Accuracy assessment of MODIS daily snow albedo retrievals with *in situ* measurements in Karasu basin, Turkey, *Hydrol. Process*., 20, 705–721.

Wolfe, R.E., D.P. Roy and E. Vermote, 1999: MODIS land data storage, gridding and compositing methodology: Level 2 grid, *IEEE TGARS*, July 1999, 36(4):1324-1338.

Wolfe, R.E., 2006: MODIS Geolocation, *In* Earth Science Satellite Remote Sensing, Eds., Qu J.J, Wei, G, Menas, K, Murphy, R.E. and Salomonson, VV. Springer Berlin Heidelberg, pp 50-73, doi: 10.1007/978-3-540-37293-6_4.

Wolfe, R.E. and M. Nishihama, 2009: Trends in MODIS geolocation error analysis, *Proc. SPIE 7452*, Earth Observing Systems XIV, 74520L (August 24, 2009), doi:10.1117/12.826598.