MODIS/Terra Snow Cover 5-Min L2 Swath 500m, Version 6

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Hall, D. K. and G. A. Riggs. 2016. *MODIS/Terra Snow Cover 5-Min L2 Swath 500m, Version 6.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/MODIS/MOD10_L2.006. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/MOD10_L2

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

Snow covered land typically has a very high reflectance in visible bands and very low reflectance in the shortwave infrared. The Normalized Difference Snow Index (NDSI) reveals the magnitude of this difference. The snow cover algorithm in this data set calculates the NDSI for all land and inland water pixels in daylight using Terra MODIS band 4 (visible green) and band 6 (shortwave near-infrared) and then applies a series of data screens to alleviate errors and flag uncertain snow detections.

1.1 Format

Data files are provided in HDF-EOS2 (V2.17). JPEG browse images are also available.

HDF-EOS (Hierarchical Data Format - Earth Observing System) is a self-describing file format based on HDF that was developed specifically for distributing and archiving data collected by NASA EOS satellites. For more information, visit the HDF-EOS Tools and Information Center.

1.2 File Naming Convention

Example File Name:

```
MOD10_L2.A2000055.0005.006.2016058063010.hdf
```

```
MOD[PID].A[YYYY][DDD].[HHMM].[VVV].[yyyy][ddd][hhmmss].hdf
```

Refer to Table 1 for descriptions of the file name variables listed above.

Table 1. Variables in the MODIS File Naming Convention

Variable	Description
MOD	MODIS/Terra
PID	Product ID
A	Acquisition date follows
YYYY	Acquisition year
DDD	Acquisition day of year
HHMM	Acquisition hour and minute in Greenwich Mean Time (GMT)
VVV	Version (Collection) number
yyyy	Production year
ddd	Production day of year
hhmmss	Production hour/minute/second in GMT
.hdf	HDF-EOS formatted data file

Note: Data files contain important metadata including global attributes that are assigned to the file and local attributes like coded integer keys that provide details about the data fields. In addition, each HDF-EOS data file has a corresponding XML metadata file (.xml) which contains some of the same internal metadata as the HDF-EOS file plus additional information regarding user support, archiving, and granule-specific post-production. For detailed information about MODIS metadata fields and values, consult the *MODIS Snow Products Collection 6 User Guide*.

1.3 File Size

Data files are approximately 6.5 MB.

1.4 Spatial Coverage

Note: MOD10_L2 data files contain five minutes of swath data (a scene). Five minutes of MODIS swath data typically comprises 203 full scans of the MODIS instrument and occasionally 204. With an along-track viewing path of 10 km, each scan acquires 20 pixels in the 500 m bands, and thus a scene typically contains 4060 pixels in the along-track direction and occasionally 4080. The instrument's ±55 degree scanning pattern yields 2708 pixels per scene in the cross-track direction. In general, 144 5-minute scenes are acquired during daylight.

Coverage is global. Terra's sun-synchronous, near-polar circular orbit is timed to cross the equator from north to south (descending node) at approximately 10:30 A.M. local time. Complete global coverage occurs every one to two days (more frequently near the poles). The following sites offer tools that track and predict Terra's orbital path:

- Daily Terra Orbit Tracks, Space Science and Engineering Center, University of Wisconsin-Madison
- NASA LaRC Satellite Overpass Predictor (includes viewing zenith, solar zenith, and ground track distance to specified lat/lon)

1.4.1 Spatial Resolution

500 m (at nadir) for data fields

5 km for geolocation fields

1.4.2 Projection and Grid Description

None (latitude, longitude referenced)

1.5 Temporal Coverage

MODIS Terra data are available from 24 February 2000 to present. However, because the NDSI depends on visible light, data are not produced for the night phase of each orbital period or for those portions of fall and winter in polar regions when viewing conditions are too dark. In addition, anomalies over the course of the Terra mission have resulted in minor data outages. If you cannot locate data for a particular date or time, check the MODIS/Terra Data Outages Web page.

1.5.1 Temporal Resolution

Each data file contains five minutes of swath data (a scene). Complete global coverage occurs every one to two days.

1.6 Parameters

Note: Starting with Version 6, MODIS snow cover data sets no longer report Fractional Snow Cover (FSC) and binary snow-covered area (SCA). See "Section 3.4.1 | Processing Steps" for details.

NDSI snow cover, raw NDSI, screen results, and basic QA for each pixel are written to HDF-EOS formatted files as Scientific Data Sets (SDSs) according to the HDF Scientific Data Set Data Model. The SDSs for this data set are listed in Table 2:

Table 2. Scientific Data Sets and Descriptions

Scientific Data Set	Description
NDSI_Snow_Cover	NDSI snow cover plus other results. Possible values are: 0–100: NDSI snow cover 200: missing data 201: no decision 211: night 237: inland water 239: ocean 250: cloud 254: detector saturated 255: fill

Scientific Data Set	Description
NDSI_Snow_Cover_Basic_QA	A basic estimate of the quality of the algorithm result. Possible values are: 0: best 1: good 2: OK 3: poor (not currently in use) 211: night 239: ocean 255: unusable input or no data
NDSI_Snow_Cover_Algorithm_Flags_QA	Bit flags indicating screen results and the presence of inland water. Bits are set to on (1) as follows: Bit 0: Inland water Bit 1: Low visible screen failed. Snow detection reversed. Bit 2: Low NDSI screen failed. Snow detection reversed. Bit 3: Combined temperature/height screen failed. On means *either*: brightness temperature ≥ 281 K, pixel height < 1300 m, flag set, snow detection reversed to not snow, OR; brightness temperature ≥ 281 K, pixel height ≥ 1300 m, flag set, snow detection NOT reversed. Bit 4: Shortwave IR (SWIR) reflectance anomalously high. On means *either*: Snow pixel with SWIR > 0.45, flag set, snow detection reversed to not snow, OR; Snow pixel with 25% < SWIR <= 45%, flag set to indicate unusual snow conditon, snow detection NOT reversed. Bit 5: spare Bit 6: spare Bit 7: solar zenith screen failed, uncertainty increased.
NDSI	Raw NDSI (i.e. prior to screening) reported in the range 0–10,000. Values are scaled by 1 x 10^4.
Latitude	Coarse resolution (5 km) latitudes for geolocating the SDSs. Values correspond to the center pixel of 5 km x 5 km blocks in the data arrays.
Longitude	Coarse resolution (5 km) longitudes for geolocating the SDSs. Values correspond to the center pixel of 5 km x 5 km blocks in data arrays.

1.6.1 Geolocating MODIS 500 m Swath Data

The `StructMetadata.0` metadata object contains a dimension map that specifies how each dimension of each geolocation field relates to the corresponding dimension in each data field. When a data field and a geolocation field share a named dimension, no explicit map is needed. However, for MODIS data sets in which the resolution of the geolocation dimension (5 km) differs from the resolution of the data dimension (500 m), two additional metadata objects—`Offset` and `Increment`—are needed to fully define the mapping.

`Offset` specifies the location along the data dimension of the first data point with a corresponding entry along the geolocation dimension. `Increment` then specifies the number of steps between subsequent points with corresponding entries along the geolocation dimension. For MODIS 500 m data sets, `Offset` = 5 and `Increment` = 10.

Unfortunately, HDF-EOS specifications only allow integer offsets in dimension maps, and MODIS 500 m data sets require fractional offsets to be correctly geolocated. Two product-specific metadata attributes were created to accomodate this additional mapping requirement: `HDFEOS_FractionalOffset_Along_swath_lines_500m_MOD_Swath_Snow and` `HDFEOS_FractionalOffset_Cross_swath_pixels_500m_MOD_Swath_Snow`.

These elements contain fractional offsets of 0.5 in the along-track direction and 0.0 in the cross-track direction that must be added to the integer offset stored with the dimension map. Thus, the combined along-track offset of 5.5 indicates that the first element (0,0) in the latitude and longitude fields maps to (5, 5.5) in any of the data fields. Subsequent elements in the geolocation arrays then map to locations in the data fields at 10-pixel increments in the both the along-track and cross-track directions.

2 SOFTWARE AND TOOLS

2.1 Get Data

Data are available via HTTPS.

2.2 Software and Tools

The following sites can help you identify the right MODIS data for your study:

- NASA's Earth Observing System Data and Information System | Near Real-Time Data
- NASA Goddard Space Flight Center | MODIS Land Global Browse Images

The following resources are available to help users work with MODIS data:

- The HDF-EOS to GeoTIFF Conversion Tool (HEG) can reformat, re-project, and perform stitching/mosaicing and subsetting operations on HDF-EOS objects.
- HDFView is a simple, visual interface for opening, inspecting, and editing HDF files. Users can view file hierarchy in a tree structure, modify the contents of a data set, add, delete and modify attributes, and create new files.
- The MODIS Conversion Toolkit (MCTK) plug-in for ENVI can ingest, process, and georeference every known MODIS data set, including products distributed with EASE-Grid projections. The toolkit includes support for swath projection and grid reprojection and comes with an API for large batch processing jobs.
- NSIDC's Hierarchical Data Format | Earth Observing System (HDF-EOS) Web page contains information about HDF-EOS, plus tools to extract binary and ASCII objects, instructions to uncompress and geolocate HDF-EOS data files, and links to obtain additional HDF-EOS resources.

3 DATA ACQUISITION AND PROCESSING

3.1 Mission Objectives

MODIS is a key instrument onboard NASA's Earth Observing System (EOS) Aqua and Terra satellites. The EOS includes satellites, a data collection system, and the world-wide community of scientists supporting a coordinated series of polar-orbiting and low inclination satellites that provide long-term, global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. As a whole, EOS is improving our understanding of the Earth as an integrated system. MODIS plays a vital role in developing validated, global, and interactive Earth system models that can predict global change accurately enough to assist policy makers in making sound decisions about how best to protect our environment. For more information, see:

- NASA's Earth Observing System
- NASA Terra | The EOS Flagship
- NASA MODIS | Moderate Resolution Imaging Spectroradiometer

3.2 Data Acquisition

The MODIS sensor contains a system whereby visible light from Earth passes through a scan aperture and into a scan cavity to a scan mirror. The double-sided scan mirror reflects incoming light onto an internal telescope, which in turn focuses the light onto four different detector assemblies. Before the light reaches the detector assemblies, it passes through beam splitters and spectral filters that divide the light into four broad wavelength ranges. Each time a photon strikes a detector assembly, an electron is generated. Electrons are collected in a capacitor where they are eventually transferred into the preamplifier. Electrons are converted from an analog signal to digital data, and downlinked to ground receiving stations. The EOS Ground System (EGS) consists of facilities, networks, and systems that archive, process, and distribute EOS and other NASA Earth science data to the science and user community.

3.3 Data Processing

The MODIS science team continually seeks to improve the algorithms used to generate MODIS data sets. Whenever new algorithms become available, the MODIS Adaptive Processing System (MODAPS) reprocesses the entire MODIS collection—atmosphere, land, cryosphere, and ocean data sets—and a new version is released. Version 6 (also known as Collection 6) is the most recent version of MODIS snow cover data available from NSIDC. NSIDC strongly encourages users to work with the most recent version.

Consult the following resources for more information about MODIS Version 6 data, including known problems, production schedules, and future plans:

- MODIS Snow Products Collection 6 User Guide
- The MODIS Snow and Sea Ice Global Mapping Project
- NASA Goddard Space Flight Center | MODIS Land Quality Assessment
- MODIS Land Team Validation | Status for Snow Cover/Sea Ice (MOD10/29)

3.4 Derivation Techniques and Algorithms

3.4.1 Processing Steps

3.4.1.1 Snow Cover

The MODIS snow cover algorithm detects snow by computing the Normalized Difference Snow Index (NDSI) (Hall and Riggs, 2011) from MODIS Level 1B calibrated radiances. Data screens are then applied to alleviate errors of commission and to flag uncertain snow detections. The final output consists of NDSI snow cover plus the location of clouds, water bodies, and other algorithm results of interest to data users. The following sections briefly describe the approach used to detect snow. For a detailed description, see the Algorithm Theoretical Basis Document (ATBD).

3.4.1.1.1 Input Products

Table 3 lists the MODIS products that are used as inputs to the snow detection algorithm:

Table 3. Inputs to the MODIS snow algorithm

Product ID	Long Name	Data Used
MOD02HKM	MODIS/Terra Calibrated Radiances 5-Min L1B Swath 500m	Band 1 (0.645 µm); Band 2 (0.865 µm); Band 4 (0.555 µm); Band 6 (1.640 µm)
MOD021KM	MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1km	Bands: 31 (11.03 µm)
MOD03	MODIS/Terra Geolocation Fields 5-Min L1A Swath 1km	Land/Water Mask (see the Note below); 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

Note: Version 6 utilizes a new land/water mask derived from the University of Maryland Global Land Cover Facility's *UMD 250m MODIS Water Mask*. To maintain continuity between Version 5 and Version 6, the UMD 250m MODIS Water Mask was converted from a 250 m, two-class map to 500 m and seven classes for use in all MODIS products. The conversion is detailed in *Development of an Operational Land Water Mask for MODIS Collection 6*.

The new land/water mask greatly improves the accuracy of lake and river locations compared with Version 5. Users will likely notice that many larger rivers are more continuous and that the number of mapped lakes has increased, especially in regions with small lakes such as northern Minnesota to the Northwest Territories.

The algorithm reads radiance data from MOD02HKM, geolocation data and the land/water mask from MOD03, and the cloud mask and day/night flag from MOD35_L2. The radiance data is checked for quality and converted to top of the atmosphere (TOA) reflectance. The NDSI is then computed for all land and inland water pixels in daylight using Band 4 (0.55 µm) and Band 6 (1.6 µm) reflectances as follows:

```
NDSI = (Band 4 - Band 6) / (Band 4 + Band 6)
```

Snow typically has a very high reflectance in visible bands and very low reflectance in the shortwave infrared, a characteristic which distinguishes snow cover from non snow-covered land and most cloud types. As such, pixels with NDSI > 0.0 are deemed to have some snow present. Pixels with NDSI ≤ 0.0 are classified as snow free land.

In the previous version of this data set (Version 5), fractional snow cover was computed from the NDSI using a regression technique. This approach has been abandoned for Version 6 because the NDSI is directly related to the presence of snow in a pixel and thus more accurately describes snow detection compared with FSC. The MODIS Science Team believes this change will offer users more flexibility to apply MODIS snow cover data sets to their research. Importantly, the change does not disrupt data continuity because the snow detection algorithm in Version 6 is essentially the same as Version 5 without the FSC calculation. Users who wish to estimate FSC can apply the FSC regression equation from Version 5 to Version 6 NDSI snow cover data.

In addition, the binary (snow/no snow) snow-covered area (SCA) map in Version 5 has been abandoned for Version 6. This SDS was computed by: a) setting a snow threshold of $0.4 \le \text{NDSI} \le 1$; and b) applying an additional test to pixels with $0.1 \le \text{NDSI} \le 0.4$ which used the Normalized Difference Vegetation Index (NDVI) to increase snow detection sensitivity in forested landscapes. However, this algorithm effectively prevented snow detections for NDSI < 0.4 on any landscape. Again, the MODIS Science Team believes this change offers the research community more flexibility. Users who wish to construct a binary SCA map can choose their own threshold for snow using the Version 6 NDSI Snow Cover, the raw NDSI data, or a combination of both.

The NDSI has proven effective at detecting snow cover on the landscape given clear skies and good viewing geometry and solar illumination. However, other illumination conditions can diminish the technique's effectiveness and induce errors of commission or omission. During the course of the MODIS mission, the Science Team and user community have identified several frequently occurring sources or error, for example, confusion between snow-covered land and certain cloud types or surface features with snow-like reflectances.

Examining the NDSI relationship more closely provides a means to circumvent many of these potential errors. For example, some bright surface features with snow-like NDSIs have MODIS Band 6 reflectances that exceed expected values for snow, while others have visible/near-infrared reflectance differences that are too low. As such, pixels determined to have some snow present are subjected to a series of screens that have been specifically developed to alleviate snow commission and omission associated with the most common error sources. In addition, snow-free pixels are screened for very low illumination conditions to prevent possible snow omission errors. The following sections describe these data screens.

3.4.1.1.2 Low Visible Reflectance Screen

This screen is applied to prevent errors from occurring when the reflectance is too low for the algorithm to perform well, such as in very low illumination or on surface features with very low reflectance. This screen is also applied to pixels that have no snow cover present (snow-free pixels) to prevent possible snow omission. If the MODIS Band 2 reflectance is ≤ 0.10 or the Band 4 reflectance is ≤ 0.11, the pixel fails the screen and is set to no decision in the NDSI snow cover SDS. The results of this screen are tracked in bit 1 of the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS.

3.4.1.1.3 Low NDSI screen

Pixels detected as having snow cover with 0.0 < NDSI < 0.10 are reversed to no snow and flagged by setting bit 2 in the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS. This flag can be used to find pixels where snow cover detections were reversed to not snow.

3.4.1.1.4 Estimated surface temperature and surface height screen

This screen serves a dual purpose by linking estimated surface temperature with surface height. It is used to alleviate errors of commission at low elevations that appear spectrally similar to snow but are too warm. It is also used to flag snow detections at high elevations that are warmer than expected. Using the estimated MODIS Band 31 brightness temperature (Tb), if snow is detected in a pixel with height < 1300 m and Tb ≥ 281 K, the pixel 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 with height ≥ 1300 m and Tb ≥ 281 K, the pixel is flagged as unusually warm by setting bit 3 in the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS.

3.4.1.1.5 High SWIR reflectance screen

This screen also serves a dual purpose by: a) preventing non-snow features that appear similar to snow from being detected as snow; b) allowing snow to be detected where snow-cover short-wave infrared reflectance (SWIR) is anomalously high. Snow typically has a SWIR reflectance of less than about 0.20; however, this value can be higher under certain conditions like a low sun angle. The SWIR reflectance screen thus utilizes two thresholds. Snow pixels with SWIR reflectance > 0.45 are reversed to not snow and bit 4 of `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS is set. Snow pixels with 0.25 < SWIR reflectance ≤ 0.45 are flagged as having an unusually high SWIR for snow by setting bit 4 in the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS.

3.4.1.1.6 Solar zenith screen

When solar zenith angles exceed 70°, the low illumination challenges snow cover detection. As such, pixels with solar zenith angles > 70° are flagged by setting bit 7 in the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS. This solar zenith mask is set across the entire swath. **Note**: night is defined as a solar zenith angle ≥ 85°. Night pixels are assigned a value 211.

3.4.1.2 Lake Ice

Ice/snow covered lake ice are detected by applying the snow algorithm specifically to inland water bodies. These data are provided so that the MODIS user community can evaluate the efficacy of this technique. Inland water bodies are flagged by setting bit 0 in the `NDSI_Snow_Cover_Algorithm_Flags_QA` SDS. Users can extract or mask inland water in the NDSI snow cover SDS using this flag. The algorithm relies on the basic assumption that a water body is deep and clear and therefore absorbs all of the solar radiation incident upon it. Water bodies with algal blooms, high turbidity, or other relatively high reflectance conditions may be erroneously detected as snow/ice covered.

3.4.1.3 Cloud Masking

Clouds are masked using the Unobstructed Field of View (UFOV) cloud mask flag from MOD35_L2. Values in the 1 km mask value are applied to the four corresponding 500 m pixels. If the cloud mask flags “certain cloud,” the pixels are masked as cloud. Values of “confident clear," “probably clear,” or “uncertain clear” are interpreted as clear in the snow cover algorithm.

3.4.1.4 Abnormal Condition Rules

If radiance data are missing in any of the MODIS bands used by the algorithm, the pixel is set to "missing data" and is not processed for snow cover. Unusable radiance data are set to "no decision."

3.4.2 Version History

See the MODIS | Data Versions page for the history of MODIS snow and sea ice product versions.

3.4.3 Error Sources

Anomalies in the input data can propagate to the output. Table 3 lists the MODIS products that are used as input to the snow cover algorithm. Although developing a global snow cover detection algorithm presents a variety of challenges, the NDSI technique has proven to be a robust indicator. Numerous investigators have utilized MODIS snow cover data sets and reported accuracy in the range of 88% to 93%. Consult the MODIS Snow Products Collection 6 User Guide for more details about potential sources of error in the MODIS snow cover data sets.

3.5 Quality Assessment

Quality Assessment (QA) in Version 6 consists of:

- Basic QA values stored in `NDSI_Snow_Cover_Basic_QA`
- Bit flags stored in `NDSI_Snow_Cover_Algorithm_Flags_QA` that report data screen results

Basic QA values provide a qualitative estimate of the algorithm result for a pixel based on the input data and solar zenith data. The basic QA value is initialized to "best" and then adjusted as needed based on the quality of the MOD02HKM input radiance data and the solar zenith angle screen. If the MOD02HKM data (TOA reflectance) lie outside the range of 5% to 100% but are still usable, the QA value is set to good. If the solar zenith angle is in range of 70° ≤ solar zenith angle < 85°, the QA is set to okay to indicate the increased uncertainty stemming from low illumination. If the input data are unusable, the QA value is set to "other." The conditions for a poor result are not defined (i.e. this value is not currently used). Features that are masked, like night and ocean, use the same values as the snow cover SDS.

Bit flags can be used to investigate results for all pixels which have been processed for snow. By examining the bit flags, users can determine if any of the data screens: a) changed a pixel's initial result from "snow" to "not snow"; or b) flagged snow cover in a pixel as uncertain. The Processing Steps section above describes each data screen and the location of its bit flag. Consult the Interpretation of Snow Cover Detection Accuracy, Uncertainty, and Errors section of the MODIS Snow Products Collection 6 User Guide to see how each screen should be interpreted.

3.6 Instrument Description

The MODIS instrument provides 12-bit radiometric sensitivity in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Two bands are imaged at a nominal resolution of 250 m at nadir, five bands at 500 m, and the remaining bands at 1000 m. A ±55 degree scanning pattern at an altitude of 705 km achieves a 2330 km swath with global coverage every one to two days.

The scan mirror assembly uses a continuously rotating, double-sided scan mirror to scan ±55 degrees, and is driven by a motor encoder built to operate 100 percent of the time throughout the six year instrument design life. The optical system consists of a two-mirror, off-axis afocal telescope which directs energy to four refractive objective assemblies, one each for the visible, near-infrared, short- and mid-wavelength infrared, and long wavelength infrared spectral regions.

The MODIS instruments on the Terra and Aqua space vehicles were built to NASA specifications by Santa Barbara Remote Sensing, a division of Raytheon Electronics Systems. Table 4 contains the instruments' technical specifications:

Table 4. MODIS Technical Specifications

Variable	Description
Orbit	705 km altitude, 10:30 A.M. descending node (Terra), sun-synchronous, near-polar, circular
Scan Rate	20.3 rpm, cross track
Swath Dimensions	2330 km (cross track) by 10 km (along track at nadir)
Telescope	17.78 cm diameter off-axis, afocal (collimated) with intermediate field stop
Size	1.0 m x 1.6 m x 1.0 m
Weight	228.7 kg
Power	162.5 W (single orbit average)
Data Rate	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization	12 bits
Spatial Resolution	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands (8-36)
Design Life	6 years

3.6.1 Calibration

MODIS has a series of on-board calibrators that provide radiometric, spectral, and spatial calibration of the MODIS instrument. The blackbody calibrator is the primary calibration source for thermal bands between 3.5 µm and 14.4 µm, while the Solar Diffuser (SD) provides a diffuse, solar-illuminated calibration source for visible, near-infrared, and short wave infrared bands. The Solar Diffuser Stability Monitor tracks changes in the reflectance of the SD with reference to the sun so that potential instrument changes are not incorrectly attributed to changes in this calibration source. The Spectroradiometric Calibration Assembly provides additional spectral, radiometric, and spatial calibration.

MODIS uses the moon as an additional calibration technique and for tracking degradation of the SD by referencing the illumination of the moon since the moon's brightness is approximately the same as that of the Earth. Finally, MODIS deep space views provide a photon input signal of zero, which is used as a point of reference for calibration.

For additional details about the MODIS instruments, see NASA's MODIS | About Web page.

4 REFERENCES AND RELATED PUBLICATIONS

Hall, D.K., and G.A. Riggs. 2011. Normalized-difference snow index (NDSI). Encyclopedia of Snow, Ice and Glaciers, Encyclopedia of Earth Sciences Series. 779-780. doi: http://dx.doi.org/10.1007/978-90-481-2642-2_376.

Derksen, C. and R. Brown. 2012. Spring snow cover extent reductions in the 2008-2012 period exceeding climate model projections. *Geophysical Research Letters* (39). Art. #L19504. doi: http://dx.doi.org/10.1029/2012GL053387.

Gladkova, I., M., Bonev G. Grossberg, 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. doi: http://dx.doi.org/10.1109/LGRS.2011.2180505.

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. doi: http://dx.doi.org/10.3189/172756402781817662.

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.

Riggs, George A. and Dorothy K. Hall. 2016. *MODIS Snow Products Collection 6 User Guide*. https://nsidc.org/sites/nsidc.org/files/files/MODIS-snow-user-guide-C6.pdf.

Salomonson, V.V. and I. Appel. 2004. Estimating the fractional snow covering using the normalized difference snow index. *Remote Sensing of Environment* 89(3):351-360. doi: http://dx.doi.org/10.1016/j.rse.2003.10.016.

Salomonson, V.V. and I. Appel, 2006: Development of the Aqua MODIS NDSI fractional snow cover algorithm and validation results, *IEEE Transactions on Geoscience and Remote Sensing* 44(7):1747-1756. doi: http://dx.doi.org/10.1109/TGRS.2006.876029.

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. *Hydrological Processes* 20:705–721. doi: http://dx.doi.org/10.1002/hyp.6114.

Wolfe, R.E., D.P. Roy, and E. Vermote. 1999. MODIS land data storage, gridding and compositing methodology: level 2 grid. *IEEE Transactions on Geoscience and Remote Sensing* 36(4):1324-1338.

Wolfe, R.E. 2006. MODIS Geolocation. Earth Science Satellite Remote Sensing, Eds. Qu J.J, Wei, G, Menas, K, Murphy, R.E. and Salomonson, VV. Springer Berlin Heidelberg. 50-73. doi: http://dx.doi.org/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: http://dx.doi.org/10.1117/12.826598.

4.1 Published Research

See MODIS | Published Research for a list of studies that used MODIS data from NSIDC.

4.2 Related Data Collections

- MODIS/Aqua Snow Cover 5-Min L2 Swath 500m, Version 6 (MYD10_L2)
- MODIS Data Sets @ NSIDC

4.3 Related Websites

- MODIS @ NASA Goddard Space Flight Center
- The MODIS Snow and Sea Ice Global Mapping Project

5 CONTACTS AND ACKNOWLEDGMENTS

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6 DOCUMENT INFORMATION

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