# MODIS/Terra Sea Ice Extent 5-Min L2 Swath 1km, 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. Riggs. 2015. *MODIS/Terra Sea Ice Extent 5-Min L2 Swath 1km, 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/MOD29.006. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/MOD29

National Snow and Ice Data Center

# TABLE OF CONTENTS

# 1 DETAILED DATA DESCRIPTION

## 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

This section explains the file naming convention used for this MODIS data set with an example. Note that MODIS Terra data file names begin with MOD. MODIS Aqua file names being with MYD.

**Example File Name:**

```
MOD29.A2000055.0000.006.2015037192344.hdf
MOD[PID].A[YYYY][DDD].[HHMM].[VVV].[yyyy][ddd][hhmmss].hdf
```

Refer to Table 1 for the valid values for the file name variables listed above.

Table 1. Valid Values for MODIS File Name Variables

| 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 (00:00) 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 |

### 1.2.1 External Metadata File

Each HDF-EOS data file (.hdf) has a corresponding Extensible Markup Language external 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 Quality Assessment (QA). Note that post-production QA metadata will only be present if the granule was evaluated for QA.

## 1.3 File Size

Data files are typically between 0.9 - 6.0 MB using HDF compression. XML metadata files are between 5 - 10 KB.

## 1.4 Spatial Coverage

Coverage is global, however only ocean pixels are evaluated for sea ice.

### 1.4.1 Latitude Crossing Times

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.

### 1.4.2 Spatial Resolution

Resolution at nadir is approximately 1 km for data fields and 5 km for geolocation fields.

### 1.4.3 Projection and Grid Description

None (lat,lon referenced)

## 1.5 Temporal Coverage

MODIS Terra data extend from 24 February 2000 to present. Complete global coverage occurs every one to two days (more frequently near the poles). To view daily orbit tracks for the Terra satellite, visit the Space Science and Engineering Center | Terra Orbit Tracks Web page.

Over the course of the Terra mission a number of anomalies 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

MOD29/MYD29 data files contain five minutes of swath data (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 10 pixels in the 1 km bands, and as such

MOD29/MYD29 scenes typically contain 2030 pixels in the along-track direction (and occasionally 2040). The instrument's ±55° scanning pattern yields 1354 pixels per scene in the cross-track direction. In general, 144 five minute scenes are acquired during daylight.

## 1.6 Parameter or Variable

### 1.6.1 Parameter Description

The content of MODIS sea ice data files differs between day and night because visible data are not acquired when Earth's surface is dark. Thermal data are acquired during both day and nighttime. Users should be aware of the following:

- Swath data acquired during daylight, or during a mix of day and night mode, contain variables for both sea ice extent and ice surface temperature;
- Swath data acquired completely in night mode contain only the ice surface temperature variable;
- Daily sea ice data sets are split into separate files for day and night.

The DayNightFlag object, a metadata value stored with the CoreMetadata.0 global attribute, indicates whether the entire swath was acquired during daylight (day), darkness (night), or a mix of day and night (both).

Sea ice extent and ice surface temperature (IST) are the parameters of interest in this data set. These data are written to data files as Scientific Data Sets (SDSs) according to the HDF Scientific Data Set Data Model.

MOD29/MYD29 data files also contain important metadata, including HDF-EOS global attributes that are assigned to the file and pre-defined and user-defined local attributes assigned to the SDSs. For detailed information about HDF-EOS-specific metadata, see An HDF-EOS and Data Formatting Primer for the ECS Project.

The following table lists the SDSs in MOD29/MYD29 data files.

Table 2. MOD29/MYD29 Scientific Data Sets

| Scientific Data Set | Description |
|---|---|
| `Sea_Ice_by_Reflectance` | Sea ice extent map stored as coded integers[1]. Pixels are reported as sea ice, ocean, cloud, land, inland water, or other conditions (e.g. missing data). Daylight only. |
| `Sea_Ice_by_Reflectance_Pixel_QA` | General estimate of input data quality based on MODIS bands 31 and 32. Stored as coded integers[1]. Values are good, other, or a masked class (e.g. land). Daylight only. |

| Scientific Data Set | Description |
|---|---|
| `Ice_Surface_Temperature` | ISTs stored as calibrated data. To convert to kelvins, use `scale_factor` = 0.01 and `add_offset` = 0.0 in the following equation[2]: IST = `scale_factor` × (calibrated data - `add_offset`)<br><br>The valid range for ISTs is 210 K to 313.20 K. |
| `Ice_Surface_Temperature_Pixel_QA` | General estimate of input data quality based on MODIS bands 31 and 32. Stored as coded integers[1]. Values are good, other, or a masked class (e.g. land). |
| `Latitude` | Coarse resolution (5 km) latitudes for geolocating sea ice and IST data. Values correspond to the center pixel of 5 km x 5 km blocks in data arrays. See Geolocation. |
| `Longitude` | Coarse resolution (5 km) longitudes for geolocating sea ice and IST data. Values correspond to the center pixel of 5 km x 5 km blocks in data arrays. See Geolocation. |
| [1]Coded integer keys are stored as Local Attributes with each SDS.<br>[2]Values for `scale_factor` and `add_offset` are stored as Local Attributes with the IST SDS. | |

### 1.6.2 Geolocation

Data in the 5 km `Latitude` and `Longitude` SDSs correspond to the center pixel of 5 x 5 blocks of 1 km pixels in the sea ice SDSs. The following section describes how to map the 5 km geolocation SDSs to MODIS 1 km sea ice SDSs.

#### 1.6.2.1 Geolocating MODIS 1 km Swath Data

HDF-EOS formatted data files contain dimension maps that specify 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 data sets like MOD29/MYD29, in which the resolution of the geolocation dimension (5 km) differs from the resolution of the data dimension (1 km), two values—`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 data points with corresponding geolocation points. For MOD29/MYD29, `Offset` = 2 and `Increment` = 5, thus the first element (0,0) in the latitude and longitude fields corresponds to element (2,2) in the `Sea_Ice_by_Reflectance` field. Increments of five pixels in the cross track and along track direction correspond to subsequent elements in the geolocation fields.

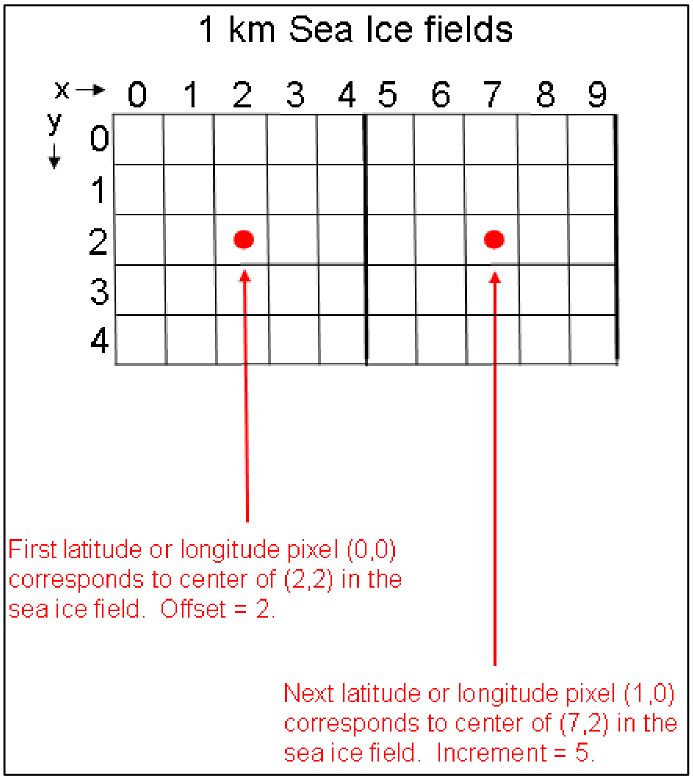


Figure 1. Offset and increment for MODIS 1 km swath data.

The dimension map including the offset and increment is stored in the StructMetadata.0 global attribute. For more information on dimension maps and geolocation offsets and increments, please consult Section 5.1.4: Dimension Maps in the HDF-EOS Library User's Guide, Volume 1 and Geolocating HDF-EOS Data.

### 1.6.3 Sample Data Record

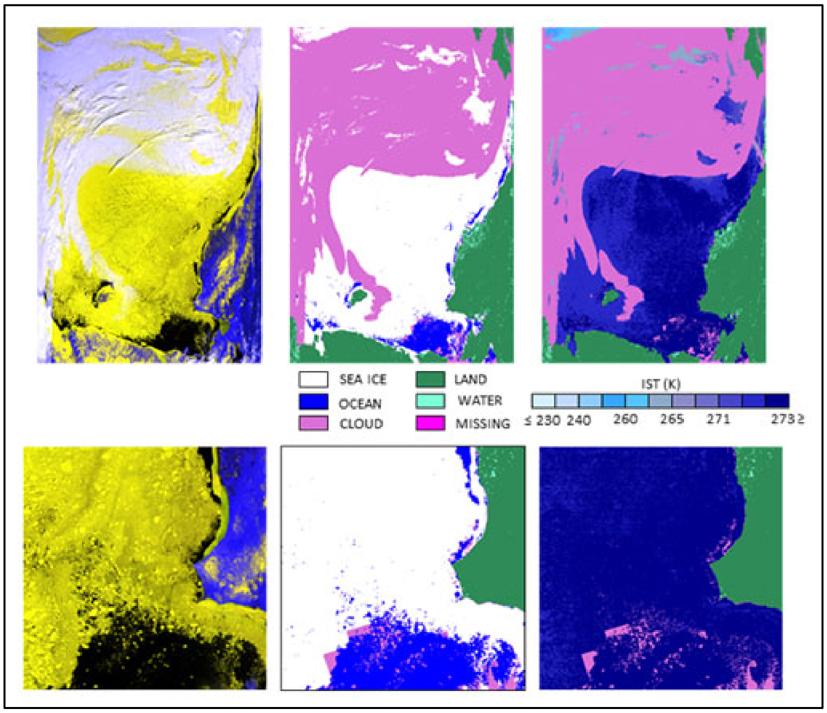


Figure 2. Typical MODIS swath data showing sea ice extent (top center) and IST (top right) from the Arctic Ocean along the Alaska and Russia coasts. IST scale has narrower intervals from 265–273 K to show detail in that temperature range. At 1km resolution, detail in data. Upper/lower left panels show corresponding false color image from MOD021KM to aid interpretation.

# 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/mosaicking 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

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 sea ice 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 Sea Ice Products User Guide to Collection 6
- 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)

The MODIS Version 6 (Collection 6) sea ice extent and ice surface temperature algorithms and products are the same as Version 5. However, Version 6 updates to algorithm inputs—in particular, the L1B calibrated radiances, land and water mask, and cloud mask products—have improved the sea ice outputs. Additional details are provided on the MODIS | Data Versions page and in section 3.4 | Quality Assessment of this user guide (below).

## 3.1 Theory of Measurements

Satellite-based remote sensing allows cryospheric scientists to better understand how the highly dynamic behavior of sea ice affects the climate system. The presence of sea ice influences atmospheric and oceanic temperature and circulation patterns and reduces the amount of solar radiation absorbed by the ocean. In addition, sea ice and its associated snow cover act as a strong insulator that restricts exchanges of heat, mass, momentum, and chemical constituents between the atmosphere and the ocean.

Multi-spectral radiometers such as MODIS can be used to determine sea ice extent, surface temperature, age, and other characteristics based on reflectance criteria and thermal data. For example, reflectance for snow-covered, opaque, white sea ice, thick first-year ice, and multiyear ice typically peaks between 0.4 µm and 0.8 µm and again at 1.9 µm. Young sea ice has a lower spectral albedo than older sea ice, when measured in this spectral range, by some 10-40 percent. Sea ice in the process of ablation and forming melt ponds exhibits decreasing reflectance between 0.6 µm and 0.8 µm, followed by a steady and uniformly low reflectance to approximately 1.6 µm (Riggs et al. 2015).

Ice surface temperature (IST) measurements offer scientists a useful tool that can be used to estimate radiative and turbulent heat fluxes for large-scale climate studies and as an additional discriminatory variable for identifying sea ice cover. For example, studies of MODIS Airborne Spectrometer (MAS) images in the Beaufort Sea, near St. Lawrence Island, Alaska, show that 271.4 K represents a typical threshold between the surface temperature of water and saline ice (Hall et al. 1998). In addition, because first-year ice has an emissivity of about 0.92 and multiyear ice has an emissivity of about 0.84—a difference that impacts recorded surface temperatures—researchers can use IST to distinguish the relative age of ice and infer relative ice thickness (Hall and Martinec 1985).

## 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 develops the algorithms used to detect snow cover and sea ice. The MODIS Data Processing System (MODAPS) generates the MODIS data sets and transfers them to NSIDC. The following sections outline the approach that the algorithm uses to generate the sea ice extent and ice surface temperature maps. Users seeking a fuller description should consult the MODIS Sea Ice Products User Guide to Collection 6.

### 3.3.1 Derivation Techniques and Algorithms

MOD29 is produced from the MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1km product (MOD021KM), the MOD03 geolocation product, and the MOD35_L2 MODIS Cloud Mask (see Figure 3 and Table 3). The output file contains sea ice extent, ice surface temperature (IST), quality assessment (QA) checks, and latitude and longitude SDSs. To ensure complete global coverage, data are generated for all swaths acquired during a 24-hour day. However, because the algorithm applies criteria tests based on visible and near-infrared wavelengths, swaths that were acquired completely in night mode contain only the temperature-based SDSs.

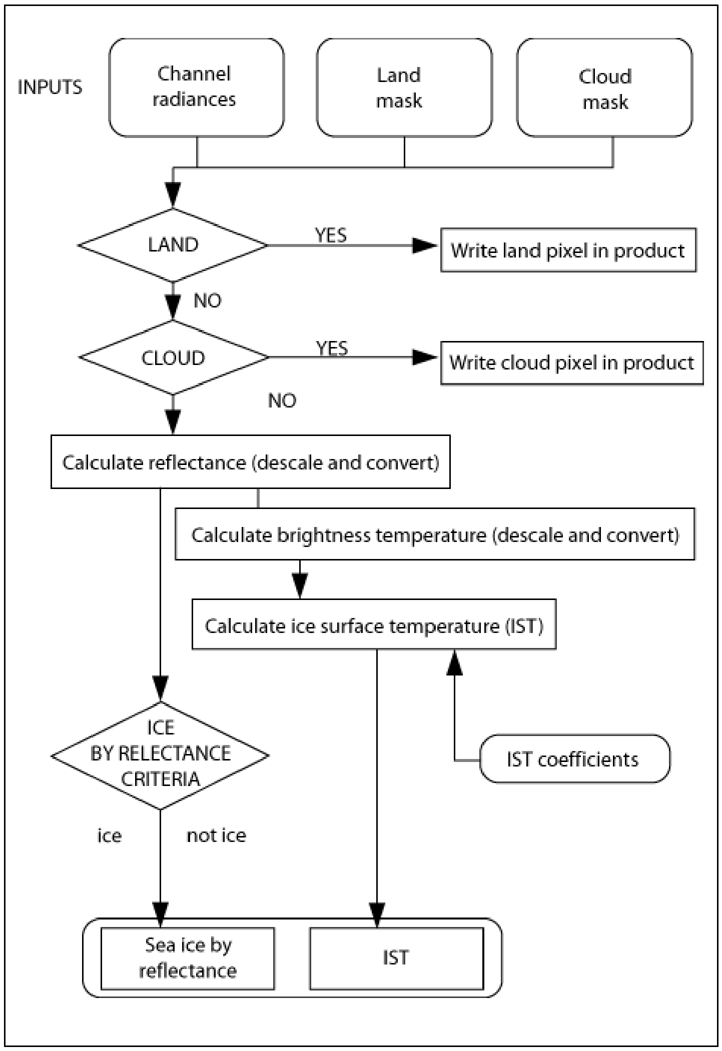


Figure 3. Flowchart showing the MOD29 and MYD29 sea ice algorithm

Table 3. Inputs to MOD29 Sea Ice Algorithm

| Short Name | Long Name | Data Used |
|---|---|---|
| MOD021KM[1] | MODIS/Terra Calibrated Radiances 5-Min L1B Swath 1km | Radiance for bands:<br>1 (0.645 µm)<br>2 (0.865 µm)<br>4 (0.555 µm)<br>6 (1.640 µm)<br>31 (11.03 µm)<br>32 (12.02 µm) |
| MOD03[1] | MODIS/Terra Geolocation Fields 5-Min L1A Swath 1km | Land/Water Mask<br>Solar Zenith Angle<br>Latitude<br>Longitude |
| MOD35_L2 | MODIS/Terra Cloud Mask and Spectral Test Results 5-Min L2 Swath 250m and 1km | Unobstructed Field of View Flag<br>Day/Night Flag |
| [1]Use link to view product documentation. | | |

### 3.3.1.1 Sea Ice

Sea ice analysis is constrained to daylight ocean pixels that have visible reflectance above 10 percent and are not obstructed by clouds. The new Version 6 land/water mask in MOD03 is used to guide processing on oceans. The mask's three ocean categories—deep, moderate and shallow—are all processed as ocean with no distinction between the categories.

Top-of-the-atmosphere (TOA) reflectance is read from MOD021KM and screened for missing and unusable data. Unusable data results from processing at L1B when the sensor radiance data fails to meet acceptable criteria. The algorithm maps missing MOD021KM data as missing in the output. No action is taken in the algorithm to analyze missing data. If other anomalous conditions are encountered in the input data, the algorithm makes no decision for that pixel, except for a few cases where a value indicating the source of the anomaly is written.

Land and inland water bodies are masked using the land/water mask in MOD03. Clouds are masked using the MODIS Cloud Mask (MOD35_L2) unobstructed field-of-view flag. If the flag is set to certain cloud then the pixel is set to cloud. If the cloud flag is set to clear, or any level of possible cloud, the pixel is interpreted as clear. This logic aims to increase the number of retrievals and balance the cloud conservative nature of the cloud mask, given the potential ice/cloud confusion and cloud contamination in IST.

Sea ice detection is achieved by using grouped criteria tests for sea ice reflectance characteristics in the visible and near-infrared regions. The algorithm assumes that sea ice is snow-covered and that the normalized difference snow index (NDSI) can be used to detect sea ice. The NDSI is computed from MODIS band 4 (0.55 µm) and band 6 (1.6 µm) as follows:

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

Pixels that pass all of the following criteria tests are identified as sea ice and passed through for additional tests:

- NDSI > 0.4
- Band 2 (visible) reflectance > 0.11
- Band 1 reflectance > 0.10

The algorithm also conducts intermediate checks based on theoretical bounds of 0 to 100 percent for reflectance and -1.0 to +1.0 for the NDSI. However, the sea ice test is performed regardless of violations of these limits and the QA data is set to indicate an unusual condition with low quality result.

#### 3.3.1.2 Sea Ice QA

The QA SDS provides an indication of the quality of the sea ice by reflectance algorithm output for each pixel. QA performed within the algorithm checks that the input data and calculated intermediate values lie within theoretical or expected ranges. The default QA value is good (0); if any of the data checks fail, the value set to "other" (1). If the algorithm was not applied, for example to a land pixel, then the mask value is output. Unless the input data is unusable or missing, the data quality will usually be set to good.

#### 3.3.1.3 Ice Surface Temperature (IST)

Radiance data for bands 31 and 32 are read from MOD021KM and converted to brightness temperatures using a version of the Plank function:

$$T = c_2 v / \ln[1 + (e c_1 v^3)/E]$$

where:

T = brightness temperature (K)
$c_1 = 1.1910659 \times 10^{-5}$ mW·m$^{-2}$·sr·cm$^{-4}$
$c_2 = 1.438833$ cm·°·K
v = central wavelength in cm$^{-1}$

E = radiance from sensor in $mW \cdot m^{-2} \cdot sr \cdot cm^{-4}$

e = emissivity

ISTs are estimated using a split-window technique and a version of Key's equation for the Advanced Very High Resolution Radiometer (AVHRR) that was adapted for use with MODIS Channels 31 and 32 (Key et al., 1997):

$$IST = a + bT_{31} + c(T_{31} - T_{32}) + d[(T_{31} - T_{32})(\sec(q) - 1)]$$

where:

$T_{31}$ = brightness temperature of MODIS channel 31 (11 µm)

$T_{32}$ = brightness temperature of MODIS channel 32 (12 µm)

q = sensor scan angle from nadir

a,b,c, and d are coefficients determined by a multilinear regression of brightness temperatures to estimated surface temperatures.

Coefficients for the IST equation were derived using MODIS spectral response functions and radiative transfer calculations. Different coefficients sets are used for each of three temperature ranges in the Northern and Southern hemispheres as shown in Table 4:

Table 4. N. and S. Hemisphere IST Coefficient Sets

| T (K) | Coef. | N. Hemisphere | S. Hemisphere |
|---|---|---|---|
| < 240 | a | -1.5711228087 | -0.1594802497 |
| | b | 1.0054774067 | 0.9999256454 |
| | c | 1.8532794923 | 1.3903881106 |
| | d | -0.7905176303 | -0.4135749071 |
| 240 to 260 | a | -2.3726968515 | -3.3294560023 |
| | b | 1.0086040702 | 0.9999256454 |
| | c | 1.6948238801 | 1.2145725772 |
| | d | -0.2052523236 | 0.1310171301 |
| > 260 | a | -4.2953046345 | -5.207360416 |
| | b | 1.0150179031 | 1.0194285947 |
| | c | 1.9495254583 | 1.5102495616 |
| | d | 0.197132579 | 0.2603553496 |

The IST algorithm is constrained to ocean pixels that are not obstructed by clouds and is run for daytime and nighttime data. The new Version 6 land/water mask is used to guide processing on oceans. The mask's three ocean categories—deep, moderate, and shallow—are all processed as ocean with no distinction between the categories.

The MOD021KM data are screened for missing data and for unusable data. Unusable data result from the processing at L1B when the sensor radiance data fails to meet acceptable criteria. MODIS data may be unusable for several reasons. Specifics of L1B processing and criteria can be found at the MODIS Calibration Support Team (MCST) web page and in supporting documentation. In the case of missing data, the algorithm maps the data as missing in the output product. No action is taken in the algorithm to make an analysis for missing data. If other anomalous conditions occur with the input data, the algorithm makes no decision for that pixel, except for a few anomalous conditions where a value indicating the source of the anomaly is written. Quality checks are applied to the input data and at intermediate processing steps, quality value is lowered if checks are failed, and the final quality value associated with a pixel is output. Clouds are masked using the MODIS Cloud Mask data product (MOD35_L2) unobstructed field-of-view flag for both daytime and nighttime data. If the cloud flag is set to clear or any level of possible cloud the pixel is interpreted as clear. That logic is used to increase the number of retrievals balanced against the cloud conservative nature of the cloud mask, and accepts potential ice/cloud confusion and cloud contamination in IST.

ISTs are stored in the SDSs as calibrated data. To convert these values to kelvins, use scale_factor = 0.01 and add_offset = 0.0 in the following equation:

IST = `scale_factor` × (calibrated data - `add_offset`)

The values for `scale_factor` and `add_offset` are also stored as Local Attributes with the IST SDSs. The valid range for ISTs is 210 K to 313.20 K.

#### 3.3.1.4 Ice Surface Temperature (IST) QA

The IST QA data provides an indication of the quality of the output data. The algorithm checks that the input data from MODIS bands 31 and 32 and calculated intermediate values lie within theoretical or expected ranges. The default QA value is good (0); if any of the data checks fail, the value set to "other" (1). If the algorithm was not applied, for example to a land pixel, then the mask value is output. Unless the input data is unusable or missing, the data quality will usually be set to good.

### 3.3.2 Error Sources

Anomalies in the input data can propagate to the output. Refer to Table 3 for a list of MODIS products that are input to the MOD29 algorithm.

## 3.4 Quality Assessment

Sea ice extent has been evaluated by visual comparison with MODIS radiance imagery and comparative analysis with sea ice products and maps from other sources. Although the MODIS Science Team is not aware of any definitive quantitative evaluations, qualitative comparisons suggest that the sea ice extent maps can be very accurate under clear sky conditions, showing ice details at 1 km resolution. However, the extensive and frequent cloud cover in the Arctic factors against the use of MODIS data for monitoring sea ice conditions.

For the IST product, the algorithm is applied to all ocean pixels without pre-screening for the possible occurrence of sea ice. The IST algorithm is not a sea surface temperature algorithm and should not be used as one. ISTs in this data set are only relevant in the context of oceans and seas where sea ice occurs.

Water vapor and the presence of any clouds potentially degrades the accuracy of the ISTs. Under ideal conditions (clear skies and low water vapor), IST accuracy is estimated at 1-3 K (Hall et al., 2004, Scambos et al., 2006, Shuman et al., 2014, and Hall et al., 2015). IST accuracy has been evaluated in the daytime only; no nighttime IST evaluation has been performed.

For Version 6, the MODIS Calibration Support Team revised the calibration of thermal bands 31 and 32 in the MOD021KM product, which decreased calculated brightness temperatures by about -0.01 K and improved accuracy for low temperature scenes. Science tests of the MOD29/MYD29 IST algorithm using MOD021KM Version 6 found IST differences in the range of ±0.1 K across all conditions compared with Version 5, with 97% of all differences lying in that range. See MODIS Land Quality Assessment | Final C6 L1B Changes for details.

The IST algorithm utilizes the MODIS scan angle range of 55 degrees in the IST calculation. The science team has compared this convention with using the MODIS sensor zenith angle, which includes the surface curvature effect, and found that both geometries yield accurate ISTs—in general within 1 K of each other. The science team continues to evaluate the practice of using the fixed sensor scan angle to calculate ISTs.

For both the sea ice and IST data sets, discriminating between clouds and sea ice is challenging. Clouds are masked using the MOD35_L2 cloud mask, and thus the accuracy and error of that product's algorithm propagates into MOD29/MYD29. Furthermore, the cloud conservative nature of MOD35_L2 tends to report sea ice as cloud under certain conditions. Although a detailed discussion of MOD35_L2 is not given here, users should also be aware that an artifact from the cloud mask product appears in MODIS sea ice data sets. In order to initialize the sea ice background flag, the cloud mask algorithm uses ancillary data with a relatively coarse spatial resolution: 25 km compared with the 1 km cloud mask resolution. This difference in the resolution of the background map sometimes creates artifacts in which cloud edges in the cloud mask have straight lines or 90 degree corners.

Revisions to the MODIS cloud mask algorithm for Version 6 generally increased the accuracy of cloud detection. The MODIS Science Team has observed improved cloud detection in some situations relative to sea ice (usually very localized in daytime scenes). Differences in total cloud amount usually lie in the range of 1-3 percent but may range up to 10 percent. The cloud mask now uses a new nighttime ocean test that enhances detection of low level and cirrus clouds (Baum et.al., 2012) which may decrease cloud and sea ice confusion in the IST nighttime maps.

The Version 6 land/water mask is derived from the 250 m MODIS Water Mask produced by the Global Land Cover Facility at the University of Maryland (UMD). The location of coastlines and rivers in polar regions is greatly improved compared with the land/water mask used in Version 5; users will likely notice improved coastline mapping in all regions and all product levels.

The UMD 250 m Water Mask was converted to a 500 m, seven class land/water mask for use with MODIS Version 6. This was done to maintain the continuity of the land/water mask across all land products from Version 5 to Version 6 and yet exploit the enhanced accuracy in the location of water bodies in the UMD mask. For details about how the UMD mask was adapted for MODIS, see Development of an Operational Land Water Mask for MODIS, Collection 6 (PDF).

Geolocation accuracy remains constant from Version 5. Although users may notice some geolocation "wobble"—slight changes in the location of certain land/water mask features from day to day and product to product—it lies within the expected range.

MODIS sea ice data sets are considered validated at stage 2, meaning that accuracy has been assessed via comparisons with in situ data and other satellite sensors. See the MODIS Land Team: Validation Web page for details. In addition, the NASA Goddard Space Flight Center: MODIS Land Quality Assessment Web site provides updated quality information for all MODIS land products.

## 3.5 Sensor or 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 5 contains the instruments' technical specifications:

Table 5. 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)<br>500 m (bands 3-7)<br>1000 m (bands (8-36) |
| Design Life | 6 years |

### 3.5.1 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

Baum, B. A., P. W. Menzel, R. A. Frey, D. C. Tobin, R. E. Holz, S. A. Ackerman, A. K. Heidinger, and P. Yang. 2012. MODIS cloud-top property refinements for Collection 6. Journal of Applied Meteorology and Climatology 51:1145-1163. doi: http://dx.doi.org/10.1175/JAMC-D-11-0203.1

Earth Science Data and Information System (ESDIS). 1996. EOS Ground System (EGS) Systems and Operations Concept. Greenbelt, MD: Goddard Space Flight Center.

Hall, Dorothy K., J. L. Foster, D. L. Verbyla, A. G. Klein, and C. S. Benson. 1998. Assessment of Snow Cover Mapping Accuracy in a Variety of Vegetation Cover Densities in Central Alaska. Remote Sensing of the Environment 66:129-137.

Hall, D. K., A.B. Tait, G.A. Riggs, V.V. Salomonson, with contributions from J.Y.L. Chien and A.G. Klein. October 7, 1998. Algorithm Theoretical Basis Document (ATBD) for the MODIS Snow-, Lake Ice-, and Sea Ice-Mapping Algorithms, Version 4.0.

Hall, Dorothy K., Jeffrey R. Key, Kimberly A. Casey, George A. Riggs, and Donald Cavalieri. 2004. Sea Ice Surface Temperature Product From MODIS. IEEE Transactions on Geoscience and Remote Sensing 42:5.

Hall, Dorothy K. and J. Martinec. 1985. Remote Sensing of Ice and Snow. London: Chapman and Hall.

Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. 1995. Development of Methods for Mapping Global Snow Cover Using Moderate Resolution Imaging Spectroradiometer (MODIS). Remote Sensing of the Environment 54(2):127-140.

Hall, Dorothy K., George A. Riggs, and Vincent V. Salomonson. September 2001. Algorithm Theoretical Basis Document (ATBD) for the MODIS Snow and Sea Ice-Mapping Algorithms. Greenbelt, MD: Goddard Space Flight Center. http://modis-snow-ice.gsfc.nasa.gov/?c=atbd&t=atbd (accessed March 30, 2015).

Hall, Dorothy K. and George A. Riggs. 2007. Accuracy assessment of the MODIS snow-cover products. Hydrological Processes 21(12):1534-1547. doi: http://dx.doi.org/10.1002/hyp.6715

Hall, D.K., S.V. Nghiem, I.G. Rigor, and J.A. Miller. 2015. Uncertainties of temperature measurements on snow-covered land and sea ice from in-situ and MODIS data during

BROMEX. Journal of Applied Meteorology and Climatology. doi: http://dx.doi.org/10.1175/JAMC-D-14-0175.1

Hapke, B. 1993. Theory of Reflectance and Emittance Spectroscopy. Cambridge: Cambridge University Press.

Key, J. R., J. B. Collins, Chuck Fowler, and R. S. Stone. 1997.High Latitude Surface Temperature Estimates From Thermal Satellite Data. Remote Sensing of the Environment 61:302-309.

Key, J. R., J. A. Maslanik, T. Papakyriakou, Mark C. Serreze, and A. J. Schweiger. 1994. On the Validation of Satellite-Derived Sea Ice Surface Temperature. Arctic 47:280-287.

Markham, B. L. and J. L. Barker. 1986. Landsat MSS and TM Post-Calibration Dynamic Ranges, Exoatmospheric Reflectances and At-Satellite Temperatures. EOSAT Technical Notes 1:3-8.

MODIS Characterization and Support Team (MCST). 2000. MODIS Level-1B Product User's Guide for Level-1B Version 2.3.x Release 2. MCST Document #MCM-PUG-01-U-DNCN.

MODIS Science and Instrument Team. MODIS Web. July 2003. <https://modis.gsfc.nasa.gov/> Accessed October 2000.

Pearson II, F. 1990. Map Projections: Theory and Applications. Boca Raton, FL: CRC Press, Inc.

Riggs, George A., Dorothy K. Hall, and S. A. Ackerman. 1999. Sea Ice Extent and Classification Mapping With the Moderate Resolution Imaging Spectroradiometer Airborne Simulator. Remote Sensing of the Environment 68:152-163.

Riggs, George A, Dorothy K. Hall, and Steven A. Ackerman. "Sea Ice Extent and Classification Mapping with the Moderate Resolution Imaging Spectroradiometer Airborne Simulator." http://modis-snow-ice.gsfc.nasa.gov/?c=pap_seaice. [accessed 2015]

Scambos, T.A., T.M. Haran, and R. Massom. 2006. Validation of AVHRR and MODIS Ice Surface Temperature Products Using In Situ Radiometers. Annals of Glaciology, 44:345-351.

Shuman, C.A., D.K. Hall, N.E. DiGirolamo, T.K. Mefford, and M.J. Schnaubelt. 2014. Comparison of near-surface air temperatures and MODIS ice-surface temperatures at Summit, Greenland (2008-2013). Journal of Applied Meteorology and Climatology 53(9):2171-2180. doi: http://dx.doi.org/10.1175/JAMC-D-14-0023.1

Wiscombe, W. J. and S. G. Warren. 1980. A Model for the Spectral Albedo of Snow I: Pure Snow. Journal of the Atmospheric Sciences 37:2712-2733.

## 4.1 Published Research

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

## 4.2 Related Data Collections

See MODIS | Data Sets for all the MODIS snow cover and sea ice data sets available from NSIDC.

## 4.3 Related Websites

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

# 5 CONTACTS AND ACKNOWLEDGMENTS

## 5.1 Principal Investigators

**Miguel O. Román**

NASA Goddard Space Flight Center

Mail Code: 619

Greenbelt , MD 20771

**Dorothy K. Hall**

National Aeronautics and Space Administration (NASA)

Goddard Space Flight Center (GSFC)

Mail Code 615

Greenbelt, MD 20771

**George A. Riggs**

NASA GSFC

Science Systems and Applications, Inc.

Mail stop 615

Greenbelt, MD 20771

# 6 DOCUMENT INFORMATION

## 6.1 Publication Date

April 2015

## 6.2 Date Last Updated

April 2015