Moderate Resolution Imaging Spectroradiometer (MODIS)

Land Surface Temperature and Emissivity Product (MOD21) User Guide

Collection-6

Glynn Hulley[1], Robert Freepartner[1], Nabin Malakar[1], Sudipta Sarkar[2]

1. Jet Propulsion Laboratory, California Institute of Technology
2. Science Systems and Applications Inc., NASA GSFC

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Note:

The users' guide is supposed to be a living document that describes the new MODIS Land Surface Temperature and Emissivity (LST&E) product in Collection 6 (MOD21). The document describes the current state of the art, and is revised as progress is made in the development and assessment of the LST product. The primary purpose of the document is to present an overview of the MOD21 data product to the potential user. For a complete detail of the Algorithm Theoretical Basis Document (ATBD), please see Hulley et al (2015).

Change History Log

Revision	Effective Date	Prepared by	Description of Changes
Outline	02/28/2016	Glynn Hulley, Nabin Malakar	User Guide outline based on MOD11.
Draft	04/18/2016	Glynn Hulley, Robert Freepartner	User Guide first draft for MOD21 products.
Draft	04/19/2016	Sudipta Sarkar	Edits to MOD21A1/MOD21A2 production sections
Draft	07/18/2016	Glynn Hulley	Updates to remove MOD09/MOD10 dependence and include ASTER GEDv3 in the outputs. Updates to SDS in MOD21A1/A2 products.
Draft	08/29/2016	Glynn Hulley Robert Freepartner	Updates to include global attributes in MxD21A1 and MxD21A2

Contacts

Readers seeking additional information about this study may contact the following:

Glynn C. Hulley (PI)
MS 183-509
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
Email: *glynn.hulley@jpl.nasa.gov*
Office: (818) 354-2979

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1 Introduction

The new MODIS Land Surface Temperature and Emissivity (LST&E) product (MOD21) available in Collection 6 (C6) uses a physics-based algorithm to dynamically retrieve both the LST and Emissivity simultaneously for the three MODIS thermal infrared bands (29, 31 and 32) at a spatial resolution of 1 km at nadir. The MOD21 product address the documented cold bias of 3-5 K in the MOD11 heritage split-window products. The MOD21 algorithm is based on the ASTER Temperature Emissivity Separation (TES) algorithm, which uses full radiative transfer simulations for the atmospheric correction, and an emissivity model based on the variability in the surface radiance data to dynamically retrieve both LST and spectral emissivity. The TES algorithm is combined with an improved Water Vapor Scaling (WVS) atmospheric correction scheme to stabilize the retrieval during very warm and humid conditions. Simulations and validation results available in the ATBD have shown consistent accuracies at the 1 K level over all land surface types including vegetation, water, and deserts.

The MOD21 product will include a swath (scene) Level-2 product daily, and a Level 3 daily and eight-day gridded products in sinusoidal projections. The algorithms and data content of these LST products are briefly described in this guide, with the purpose of providing a user with sufficient information about the content and structure of the data files to enable the user to access and use the data, in addition to understanding the uncertainties involved with the product. Overviews of the file format and sequence of MOD21 products are given first. Descriptions of the algorithm and product content are presented in the following sections. Publications and documents related to the MOD21 LST products are listed in the final sections.

A description of the major components of the MOD21 algorithm implemented in the C6 daily LST Product Generation Executive (PGE) code are shown in Table 1 and described in depth in the ATBD available at https://modis.gsfc.nasa.gov/data/dataprod/mod21.php. The primary purpose of this document is to supply a user with sufficient information about the content and structure of the data files so that the users will be able to access and use the data with confidence.

1.1 File Format of the LST Products

The MODIS LST products are archived in Hierarchical Data Format V4 - Earth Observing System (HDF-EOS) format files. HDF, developed by the NSCA, is the standard archive format for EOS Data Information System (EOSDIS) products. The LST product files contain global attributes (metadata) and scientific data sets (SDSs) (arrays) with local attributes. Unique in HDF-EOS data files is the use of HDF features to create point, swath, and grid structures to support geolocation of data. These structures (Vgroups and Vdata) provide geolocation relationships between data in an SDS and geographic coordinates (latitude and longitude or map projections) to support mapping the data. Attributes (metadata), global and local, provide various information about the data. Users unfamiliar with HDF and HDF-EOS formats may wish to consult Web sites listed in the Related Web Sites section for more information.

Similar to the heritage MOD11 LST products, the MOD21 LST data product files contain three EOS Data Information System (EOSDIS) Core System (ECS) global attributes, which are also referred to as metadata by ECS. These ECS global attributes (CoreMetadata.0, ArchiveMetadata.0 and StructMetadata.0) contain information relevant to production, archiving, user services, geolocation and analysis of data. The ECS global attributes are written in parameter value language (PVL) and are stored as a character string. Metadata and values are stored as objects within the PVL string. Results of the LST algorithms are stored as SDSs with local attributes. Local attributes include summary statistics and other information about the data in an SDS or a key to data values. Detailed descriptions of each LST product are given in following sections.

Products may also contain product specific attributes (PSAs) defined by the product developers as part of the ECS CoreMetadata.0 attribute. Geolocation and gridding relationships between HDF-EOS point, swath, and grid structures and the data are contained in the ECS global attribute, StructuralMetadata.0.

A separate file containing metadata will accompany data products ordered from a DAAC. That metadata file will have a .met extension and is written in PVL. The .met file contains some of the same metadata as in the product file but also has other information regarding archiving and user support services as well as some post production quality assurance (QA) information relevant to the product file ordered. The post production QA metadata may or may not be present depending on whether or not the data file has been investigated. The .met file should be examined to determine if post production QA has been applied to the product file. (The Quality Assurance sections of this guide provide information on post production QA.) The data products were generated in the science data production system using the HDF-EOS toolkit, Science Data Processing (SDP) Toolkit, HDF API and the C programming language.

1.2 LST Products

The MOD21 LST data products are produced in swath, daily gridded, and 8-day gridded products. The swath (scene/granule) has a nadir resolution of 1 km with 2030 pixels along track and 1354 pixels per line for each five minutes of the MODIS scans. The MOD21 Level 2 swath products are aggregated to produce the global L3 daily and 8-day mean LST&E products. Table 1 shows a summary of products that will be available for MOD21 and their characteristics. Products in EOSDIS are labeled as Earth Science Data Type (ESDT). The ESDT label "shortname" is used to identify the LST data products. Each LST product in the sequence is built from the previous LST products. These LST products are identified, in part, by product levels in EOSDIS that indicate what spatial and temporal processing has been applied to the data.

Data product levels briefly described: Level 1B (L1B) is a swath (scene) of measured MODIS radiance data geolocated to latitude and longitude centers of 1 km resolution pixels. A level 2 (L2) product is a geophysical product retrieved from the L1B data that remains in latitude and longitude orientation; it has not been temporally or spatially manipulated. A level 3 (L3) product

is a geophysical product that has been temporally and or spatially manipulated, and is usually in a gridded map projection format referred to as tiles. Each tile is a piece, e.g., about 1113km by 1113km in 1200 rows by 1200 columns, of a map projection.

Table 1: Summary of the MOD21 LST&E product.

Earth Science Data Type (ESDT)	**Product Level**	**Data Dimension**	**Spatial Resolution**	**Temporal Resolution**	**Map Projection**
MOD21_L2	L2	2030 (2040) lines by 1354 pixels per line	1 km at nadir	Swath	None, (lat, lon tagged)
MOD21A1D/ MOD21A1N	L3	1200 rows by 1200 columns	1 km	Daily	Sinusoidal
MOD21A2	L3	1200 rows by 1200 columns	1 km	Eight day	Sinusoidal

The first product, MOD21_L2, is a LST product at 1 km spatial resolution for a swath. This product is generated from the Temperature and Emissivity Separation (TES) algorithm (Hulley et al. 2012a). Geolocation data (latitude and longitude) at a coarse resolution of ~5 km is also stored in the product. The second product, MOD21A1D/MOD21A1N, is a tile of daily LST Day/Night product at 1 km spatial resolution. It is generated by mapping the pixels in the MOD21_L2 products for a day to the Earth locations on the sinusoidal projection. The third product, MOD21A2, is an eight-day LST product by averaging from two to eight days of the MOD21A1D and MOD21A1N product.

2 MOD21_L2 LST Product

2.1 Algorithm Description

For a full detailed description of each module within the algorithm please see the MOD21 ATBD linked on the MODIS product page for MOD21 (Hulley et al. 2012a). The MOD21 product uses a physical-based Temperature and Emissivity Separation (TES) algorithm to retrieve the Land Surface Temperature and Emissivity (LST&E) products (Gillespie et al. 1998; Hulley and Hook 2011). The atmospheric correction of the MODIS thermal infrared (TIR) bands 29, 31, and 32 is performed using the RTTOV radiative transfer model (Matricardi 2008; Saunders et al. 1999) with input atmospheric profiles from the MERRA-2 numerical weather prediction model (Rienecker et al. 2011). However due to a data latency of 1 month, the PGE has an option to run with NCEP data to produce data in near real time in forward processing. As MERRA-2 data becomes available at MODAPS, all data will be reprocessed with this option. More detailed information on the two NWP data sources and their characteristics are available in the ATBD.

A Water Vapor Scaling (WVS) model is further employed to improve the atmospheric correction accuracy under conditions of heavy water vapor loadings on a pixel-by-pixel basis

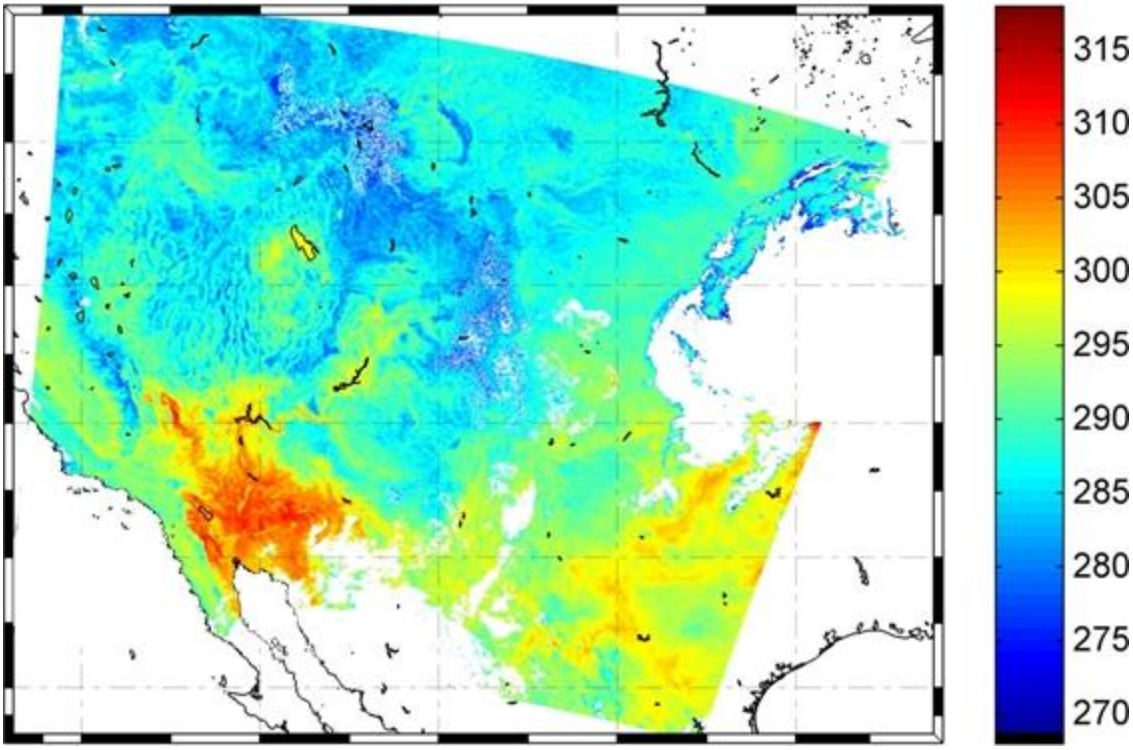

Figure 1. Example MOD21_L2 LST granule (2006195) over southwestern USA.

(Tonooka 2005). The MOD21 product is produced globally over all land cover types for all cloud-free pixels, and includes LST and emissivity for the three MODIS TIR bands 29, 31, and 32 at 1-km resolution at nadir. The product also includes a full set of uncertainty information, with estimated errors for LST and the emissivity fields generated from an uncertainty model (Hulley et al. 2012b). Figure 2 shows a schematic detailing the flow of the MOD21 PGE within the MODAPS Science Data System including the primary input datasets, and subprocesses.

Similar to the heritage MOD11 product, the MOD21 LST&E retrieval in a MODIS swath is constrained to pixels that:

(1) Have nominal Level 1B radiance data in bands 29, 31 and 32,

(2) Are on land or inland water,

(3) Are in clear-sky conditions at a confidence (defined in MOD35) of >= 66% over land

Data inputs to the MOD21 LST algorithm are listed in Table 2. Clouds are masked with the MODIS Cloud Mask data product (MOD35_L2) at >=66% confidence over land. The algorithm is only run over land pixels, so masking of oceans is accomplished with the 1 km resolution land/water mask contained in the MODIS geolocation product (MOD03).

The ASTER GED v3 emissivity product (Hulley et al. 2015) is used to assign the correct emissivity-dependent coefficients in the WVS model on a scene-by-scene basis. Details of this method are available in the MOD21 ATBD.

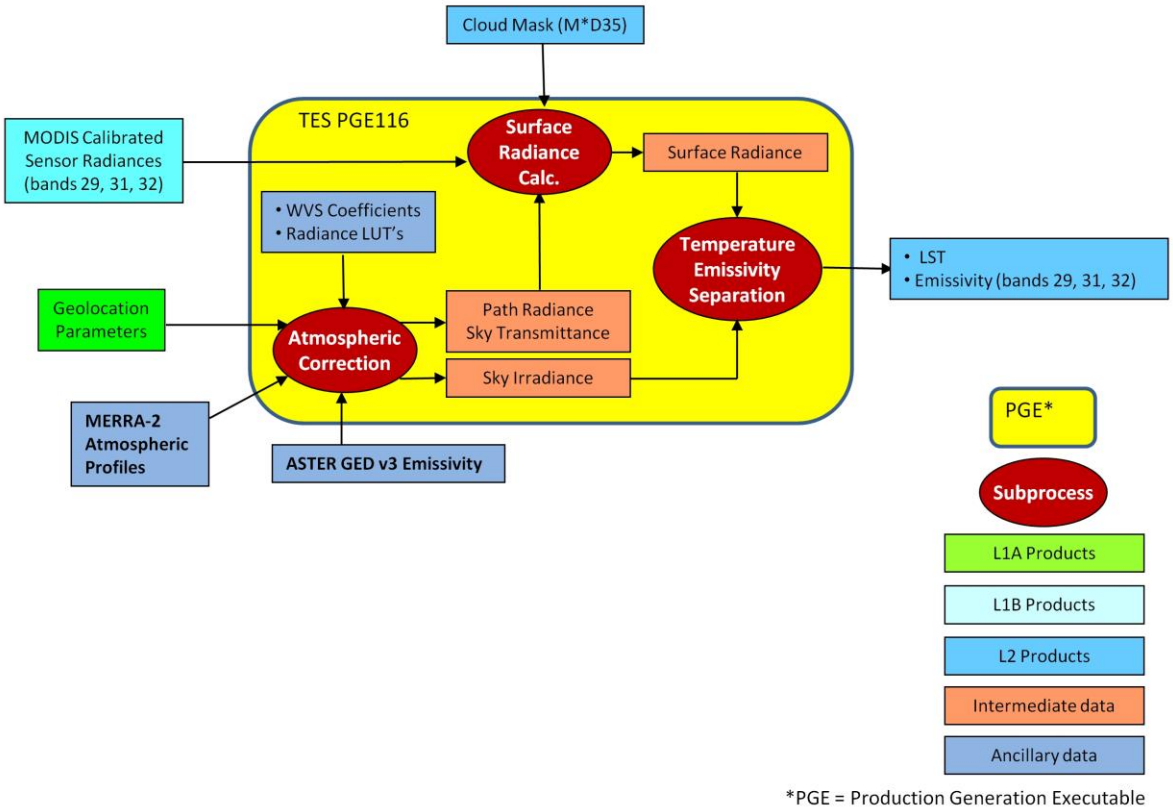

Figure 2. Schematic detailing the flow of the MOD21 PGE within the MODAPS Science Data System.

Table 2: This table describes the MODIS product and other ancillary input data required to produce the MOD21 product.

Ancillary Data Set	**Long Name**	**Data Used**
MOD021KM	MODIS Level 1B calibrated and geolocated radiances	EV_1KM_Emissive for bands: 29, 31, 32
MOD03	MODIS Geolocation	Land/Water mask Height Sensor and Solar Zenith Angles Latitude, Longitude
MOD35_L2	MODIS Cloud Mask	Cloud_Mask
ASTER GEDv3	ASTER Global Emissivity Database v3	Emis11 Emis13 Emis14 NDVI

MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2	Pressure Temperature Specific Humidity Surface Pressure

2.2 Scientific Data Sets (SDS)

The MODIS L2 LST product contains 15 scientific data sets (SDSs): LST, LST_err, QC, Emis_29, Emis_31, Emis_32, Emis_29_err, Emis_31_err, Emis_32_err, View_angle, Emis_ASTER, PWV, Oceanpix, Latitude, and Longitude. All SDS data are output at 1km pixels, except for the geolocation data which are output at coarse resolution (five lines by five samples) latitude and longitude data. Each set of them correspond to a center pixel of a 5 lines by 5 pixels in the LST SDS. A mapping relationship of geolocation data to the SDS's 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 SDS data with an offset = 2 and increment = 5. The first element (0,0) in the geolocation SDSs corresponds to element (2,2) in LST SDS, then increments by 5 in the cross-track or along-track direction to map geolocation data to the LST SDS element. Details are shown in Table 3.

Table 3. The SDSs in the MOD21_L2 product.

SDS	**Long Name**	**Data type**	**Units**	**Valid Range**	**Fill Value**	**Scale Factor**	**Offset**
LST	Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC	Quality control for LST and emissivity	uint16	n/a	0-65535	0	n/a	n/a
Emis_29	Band 29 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_31	Band 31 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_32	Band 32 emissivity	uint8	n/a	1-255	0	0.002	0.49
LST_err	Land Surface Temperature error	uint8	K	1-255	0	0.04	0.0
Emis_29_err	Band 29 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis_31_err	Band 31 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0
Emis_32_err	Band 32 emissivity error	uint16	n/a	0-65535	0	0.0001	0.0

View_angle	MODIS view angle for current pixel	uint8	Deg	0-180	0	0.5	0.0
Emis_ASTER	ASTER GED Emissivity (min of 5 bands)	uint8	n/a	1-255	0	0.002	0.49
PWV	Precipitable Water Vapor	uint16	cm	0-65535	0	0.001	0.0
oceanpix	Ocean-land mask	uint8	n/a	1-255	0	n/a	n/a
Latitude	Pixel Latitude	float32	Deg	-90 to 90	999.99	n/a	n/a
Longitude	Pixel Longitude	float32	Deg	-180 to 180	999.99	n/a	n/a

2.3 Local Attributes

Archived with the "LST" SDS are local attributes including the coefficients of the calibration which converts the SDS value to real LST value in K. HDF predefined local attributes (Table 5) describe characteristics of the data.

2.4 Global Attributes

There are three global ECS attributes, i.e., *CoreMetadata.0*, *ArchiveMetadata.0*, and *StructMetadata.0*, in the MOD21_L2 data product. Contents of these global attributes were determined and written during generation of the product and are used in archiving and populating the EOSDIS database to support user services. They are stored as very long character strings in parameter value language (PVL) format. Descriptions of the global attributes are given here to assist the user in understanding them.

CoreMetadata.0 is the global attribute in which information compiled about the product during product generation is archived and is used to populate the EOSDIS database to support user services. The content of the global attributes with sample values and comment of definition are listed in Table 4, Table 5, and Table 6, respectively. The user wanting detailed explanations of the global attributes and related information should query the EOSDIS related web sites.

Table 4. Listing of objects in the global attribute *CoreMetadata.0* in MOD21_L2.

Object Name	**Sample Value**	**Comment**
ShortName	"MOD21"	ESDT name of product
VersionID	6	ECS Version
ReprocessingActual	"reprocessed"	
ReprocessingPlanned	"further update is anticipated"	Expect that products will be reprocessed one or more times.
LocalGranuleID	"MOD21.A2004216.1100.006.2016090230901.hdf"	
DayNightFlag	"Day"	Day , Night or Both.

ProductionDateTime	"2006-07-27T23:10:07.000Z"	
LocalVersionID	"SCF V6.0.21"	Version of algorithm delivered from the SCF.
PGEVersion	"6.0.40"	Version of production generation executable.
InputPointer	"MOD03.A2004216.1100.006.2012277025215.hdf","..."	Location of input files in the production system.
RangeBeginningDate	"2000-04-04"	Beginning and ending times of the first and last scan linein the swath.
RangeBeginningTime	"19:15:00.000000"	
RangeEndingDate	"2000-04-04"	
RangeEndingTime	"19:20:00.000000"	
ExclusionGRingFlag	"N"	Geographic bounds of swath coverage.
GRingPointLatitude	[54.085346, 49.240036, 32.346612, 35.789540]	
GRingPointLongitude	[-134.529204, -100.841011, -110.349156, -135.759611]	
GRingPointSequenceNo	[1,2,3,4]	
OrbitNumber	1579	
EquatorCrossingLongitude	-131.114787	
EquatorCrossingDate	"2000-04-04"	
EquatorCrossingTime	"19:29:39.345204"	
ParameterName	" 1km LST, 3band Emissivity"	
AutomaticQualityFlag	"Passed"	Result of automated checks during the run of the algorithm that screen for significant amounts of anomalous data.
AutomaticQualityFlagExplanation	“No automatic quality assessment is performed in the PGE.”	Explanation of result of automated QA checks made during execution.
ScienceQualityFlag	"Not Investigated"	Set by LST investigator after post-production investigation
SciencelQualityFlagExplanation	"See http://landweb.nascom/nasa.gov/cgi-bin/QA_WWW/qaFlagPage.cgi?sat=terra the product Science Quality status."	Explanation of Science Flag
QAPercentMissingData	0	0-100
QAPercentCloudCover	60	0-100

AncillaryInputPointer	"MOD03.A2000095.1915.005.2006188045128.hdf"	Location of geolocation input product in production system.
AncillaryInputType	"Geolocation"	Type of ancillary data referenced by pointer.
AssociatedSensorShortName	"MODIS"	
AssociatedPlatformShortName	"Terra"	
AssociatedInstrumentShortName	"MODIS"	
Product Specific Attributes (PSA)		
QAPercentGoodQuality	29	Summary quality assurance statistic for data product. Range is from 0-100.
QAPercentOtherQuality	8	
QAPercentNotProducedCloud	33	
QAPercentNotProducedOther	29	
GranuleNumber	233	Unique granule identifier
QAFractionGoodQuality	0.2947352	Summary fraction of the LST product. Range is from 0.0 to 1.0.
QAFractionOtherQuality	0.0831999	
QAFractionNotProducedCloud	0.3331286	
QAFractionNotProducedOther	0.2889363	

The four QAFraction PSAs are specially useful to granules in ocean regions where only a small number of island pixels exist. Because the total number of land and coastal pixels is highly variable in granules covering both land and ocean, the values of QAPercent and QAFraction PSAs are calculated on the base of the total number of all pixels in a granule. Therefore, we can always calculate how many pixels with LST in good quality and other quality from these PSA values, even for island pixels.

The ECS global attribute *ArchiveMetadata.0* contains information relevant to production of the data product. It also contains an alternate bounding of geographic coverage of the swath. These data may be useful in determining what version of the algorithm was used to generate the product. Contents are described in Table 5.

Table 5. Listing of objects in the global attribute *ArchiveMetadata.0* in MOD21_L2.

Object Name	**Typical Value**	**Comment**
EastBoundingCoordinate	-100.843259	Extent of swath coverage, in latitude and longitude.
WestBoundingCoordinate	-135.743222	
NorthBoundingCoordinate	54.070671	
SouthBoundingCoordinate	32.460855	

AlgorithmPackageAcceptanceDate	"12-2011"	Algorithm Descriptors
AlgorithmPackageMaturityCode	"Normal"	
AlgorithmPackageName	"MOD_PRLST"	
AlgorithmPackageVersion	"6"	
InstrumentName	"Moderate-Resolution Imaging SpectroRadiometer"	
ProcessingDateTime	"2006-07-27T23:10:07.000Z"	
LongName	"MODIS/Terra Land Surface Temperature/Emissivity 5-Min L2 Swath 1km"	
ProcessingCenter	"MODAPS"	
SPSOParameters	"2484 and 3323"	
LocalInputGranuleID	"MOD021KM.A2000095.1915..."	input L1B HDF file.
ProcessingEnvironment	"Linux moddev-c64 2.6.18-406.el5 #1 SMP Tue Jun 2 17:25:57 EDT 2015 x86_64 x86_64 x86_64 GNU/Linux"	

The *StructMetadata.0* global attribute is used by the HDF-EOS toolkit to specify the mapping relationships between the geolocation data and the LST data (SDSs) as listed in Table 6. Mapping relationships are unique in HDF-EOS and are stored in the product using HDF structures. Description of the mapping relationships is not given here. Use of HDF-EOS toolkit, other EOSDIS supplied toolkits may be used to geolocate the data.

Table 6. Listing of objects in the global attribute *StructMetadata.0* in MOD21_L2.

Object	**Definition**
DIMENSION_1	swath_lines_5km (2*nscans)
DIMENSION_2	swath_pixels_5km
DIMENSION_3	swath_lines_1km (10*nscans)
DIMENSION_4	swath_pixels_1km
DIMENSION_5	number1km
GEOFIELD_1	GeoFieldName=Latitude
GEOFIELD_2	GeoFieldName=Longitude
DATAFIELD_1	DataFieldName=LST
DATAFIELD_2	DataFieldName=QC
DATAFIELD_3	DataFieldName=”Emis_29”
DATAFIELD_4	DataFieldName=”Emis_31”
DATAFIELD_5	DataFieldName=”Emis_32”
DATAFIELD_6	DataFieldName=”LST_err”

DATAFIELD_7	DataFieldName=”Emis_29_err”
DATAFIELD_8	DataFieldName=”Emis_31_err”
DATAFIELD_9	DataFieldName=”Emis_32_err”
DATAFIELD_10	DataFieldName=”PWV”
DATAFIELD_11	DataFieldName=”Emis_ASTER”
DATAFIELD_12	DataFieldName=”oceanpix”
DATAFIELD_13	DataFieldName=”View_angle”

2.5 Quality Assurance (QA)

Indicators of quality are given in metadata objects in the *CoreMetadata.0* global attribute QA and in a quality control (QC) SDS, generated during production, or in post-product scientific and quality checks of the data product. QA metadata objects in the *CoreMetadata.0* global attribute are the AutomaticQualityFlag and the ScienceQualityFlag and their corresponding explanations. The AutomaticQualityFlag is set according to rules based on data conditions encountered during a run of the LST algorithm. Setting of this QA flag is fully automated. The rules used to set it are liberal; nearly all of the data or intermediate calculations would have to be anomalous for it to be set to "Failed". Typically, it will be set to "Passed". The ScienceQualityFlag is set post production either after an automated QA program is run on the data product or after the data product is inspected by a qualified LST investigator. Content and explanation of this flag are dynamic so it should always be examined if present. A sampling of products will be inspected. Sampling may be random, in support of field campaigns, or event driven.

The QC SDS in the data product provides additional information on algorithm results for each pixel. The QC SDS unsigned 16-bit data are stored as bit flags in the SDS. This QC information can be extracted by reading the bits in the 16-bit unsigned integer. The purpose of the QC SDS is to give the user information on algorithm results for each pixel that can be viewed in a spatial context. The QC information tells if algorithm results were nominal, abnormal, or if other defined conditions were encountered for a pixel. The QC information should be used to help determine the usefulness of the LST and Emissivity data for a user's needs. The bit flags in the QC SDS are listed in Table 7 and consist of flags related to data quality, cloud, TES algorithm diagnostics, and error estimates.

A value of 0 in the QC bit flags means good, cloud free data quality and no further analysis of the QC bits is necessary. Users may use data of 'unreliable quality' (bits 1&0 = 01), but caution should be taken since either the retrieved emissivity is suspect (emissivity in both longwave bands 31 and 32 < 0.95), the pixel is nearby cloud, there was low transmissivity in the atmospheric correction implying a very opaque and likely moist atmosphere which results in large uncertainty in the TES retrieval.

Table 7. Bit flags defined in the QC SDS in the MOD21_L2 product. (Note: Bit 0 is the least significant bit).

Bits	**Long Name**	**Description**
1&0	Mandatory QA flags	00 = Pixel produced, good quality, no further QA info necessary

		01 = Pixel produced but unreliable quality. Either one or more of the following conditions are met: emissivity in both bands 31 and 32 < 0.95, retrieval affected by nearby cloud, low transmissivity due to high water vapor loading (<0.4). Recommend more detailed analysis of other QC information 10 = Pixel not produced due to cloud 11 = Pixel not produced due to reasons other than cloud (e.g. ocean pixel, poorly calibrated input radiance, TES algorithm divergence flag)
3 & 2	Data quality flag	00 = Good data quality of L1B bands 29, 31, 32 01 = Missing pixel 10 = Fairly calibrated 11 = Poorly calibrated, TES processing skipped
5 & 4	Cloud flag	00 = Cloud free pixel 01 = Thin cirrus 10 = Pixel within 2 pixels of nearest cloud (~2km) 11 = Cloud pixel
7 & 6	TES Iterations (k)	00 = ≥7 (Slow convergence) 01 = 6 (Nominal) 10 = 5 (Nominal) 11 = <5 (Fast)
9 & 8	Atmospheric Opacity $L_{\lambda}^{\downarrow}/L^{'}$	00 = ≥0.3 (Warm, humid air; or cold land) 01 = 0.2 - 0.3 (Nominal value) 10 = 0.1 - 0.2 (Nominal value) 11 = <0.1 (Dry, or high altitude pixel)
11 & 10	Min-Max Difference (MMD). Difference between minimum and maximum emissivity for bands 29, 31, 32	00 = >0.15 (Most silicate rocks) 01 = 0.1 - 0.15 (Rocks, sand, some soils) 10 = 0.03 - 0.1 (Mostly soils, mixed pixel) 11 = <0.03 (Vegetation, snow, water, ice)
13 & 12	Emissivity accuracy	00 = >0.017 (Poor performance) 01 = 0.015 - 0.017 (Marginal performance) 10 = 0.013 - 0.015 (Good performance) 11 = <0.013 (Excellent performance)
15 & 14	LST accuracy	00 = >2.5 K (Poor performance) 01 = 1.5 - 2.5 K (Marginal performance)

		10 = 1 - 1.5 K (Good performance) 11 = <1 K (Excellent performance)

3 MOD21A1 Daily LST Product

The daily level 3 LST&E day and night product at 1km spatial resolution is a tile of daily LST&E product gridded in the Sinusoidal projection. A tile contains 1200 x 1200 grids in 1200 rows and 1200 columns. The exact grid size at 1km spatial resolution is 0.928km by 0.928km.

3.1 Algorithm Description

The daily MOD21A1D/MOD21A1N LST products are compiled from daily gridded L2G intermediate products (MOD21GD/MOD21GN). The L2G process maps the daily MOD21_L2 granules onto a sinusoidal MODIS grid and stores all observations falling over a gridded cell for a given day. The total number of observations for a day are determined not only by the number of orbits passing over that cell but also by the spread of observations from off-nadir coverage.

The MOD21A1 algorithm sorts through all these observations for each cell and for a given day and estimates the final LST value as a weighted average over all observations that are cloud free and have good LST and emissivity accuracies, weighted by the observation coverage for that cell. Only observations having observation coverage more than a certain threshold (15%) are considered for this averaging. This process is repeated for all day and night granules separately to create separate MOD21A1D (day) and MOD21A1N (night) products. The final quality byte for the output product reflects the lowest quality values from all observations that went into the final averaging.

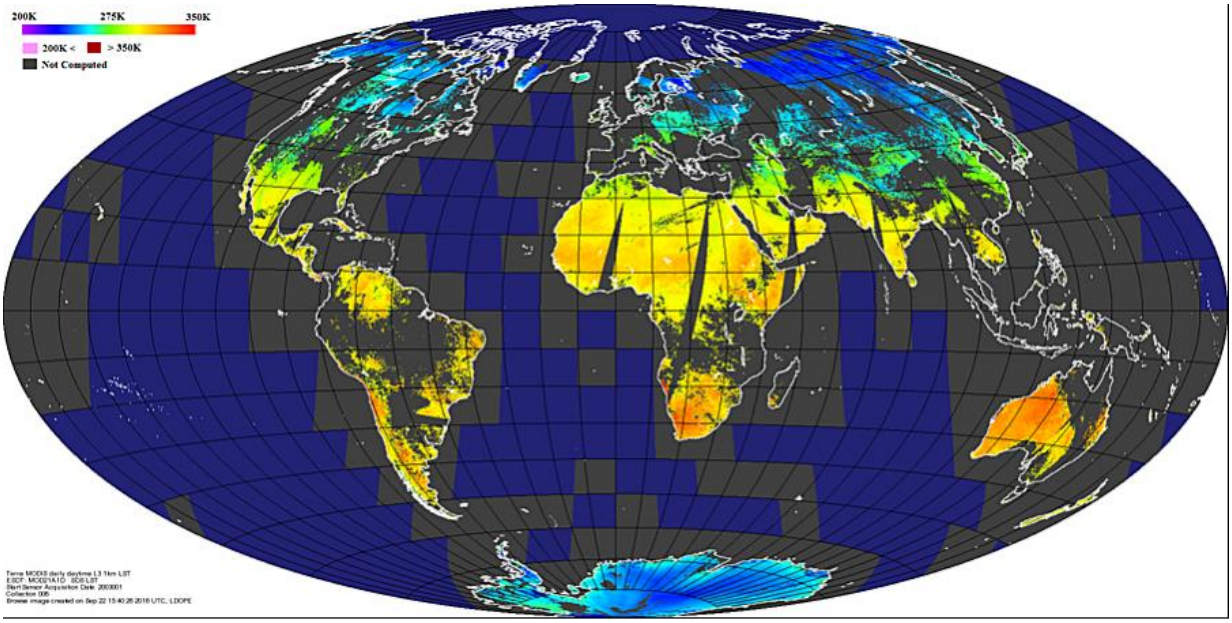

Figure 3. Example MOD21A1D LST product for 2003001 produced by MODAPS.

3.2 Scientific Data Sets (SDS)

The SDSs in the MOD21A1D/MOD21A1N product include:

- LST_1KM: Daily 1km Land Surface temperature
- QC: Daily QA bytes for LST and emissivity.
- View_Angle: View zenith angle of LST
- View_Time: Time of LST observations
- Emis_29: Daily Band 29 emissivity
- Emis_31: Daily Band 31 emissivity
- Emis_32: Daily Band 32 emissivity

Table 8. The SDSs in the MOD21A1D/MOD21A1N product.

SDS	Long Name	Data type	Units	Valid Range	Fill Value	Scale Factor	Offset
LST_1KM	Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC	Quality control	uint16	n/a	0-65535	0	n/a	n/a
Emis_29	Band 29 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_31	Band 31 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_32	Band 32 emissivity	uint8	n/a	1-255	0	0.002	0.49
View_Angle	MODIS view angle	uint8	deg	0-130	255	1	-65
View_Time	Time of MODIS observation	uint8	hrs	0-240	255	0.1	0

3.3 Local Attributes

The local attributes for SDS, LST_1KM is similar to those in Table 5.

3.4 Global Attributes

Three ECS global attributes and 12 product-specific global attributes are stored as metadata. The ECS global attributes, *CoreMetadata.0*, *ArchiveMetadata.0* and *StructMetadata.0* are stored as very long character strings in PVL format.

CoreMetadata.0 contains information about the product during production and is used to populate the EOSDIS data base for user support. A listing of objects along with sample values is given in Table 4.

Table 9. Listing of objects in the global attribute *CoreMetadata.0* in the MOD21A1D/MOD21A1N products.

Object Name	Sample Value	Comment
ReprocessingPlanned	"further update is anticipated"	Expect that products will be reprocessed one or more times.
ReprocessingActual	"reprocessed"	
LocalGranuleID	" MOD21A1D.A2003001.h06v14.006.2016229184116.hdf"	
DayNightFlag	"Day"	Day , Night or Both.
ProductionDateTime	"2006-07-27T23:10:07.000Z"	
LocalVersionID	“6.0.3”	Version of algorithm delivered from the SCF.
ParameterName	“MOD21A1”	
AutomaticQualityFlag	"Passed"	Result of automated checks during the run of the algorithm that screen for significant amounts of anomalous data.
AutomaticQualityFlagExplanation	“No automatic quality assessment is performed in the PGE.”	Explanation of result of automated QA checks made during execution.
ScienceQualityFlag	"Not Investigated"	Set by LST investigator after post-production investigation
SciencelQualityFlagExplanation	"See http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/qaFlagPage.cgi?sat=terra&ver=C6 for the product Science Quality status."	Explanation of Science Flag
QAPercentInterpolatedData	0	0-100
QAPercentMissingData	0	0-100
QAPercentOutOfBoundsData	0	0-100
QAPercentCloudCover	60	0-100
ShortName	"MOD21A1D"	ESDT name of product
VersionID	6	ECS Version
InputPointer	["MODPT1KD.A2003001.h06v14.006.2016229184000.hdf", "MODMGGAD.A2003001.h06v14.006.2016229184008.hdf", "MOD21GD.A2003001.h06v14.006.2016229184037.hdf", "MOD03.A2003001.2005.006.2012260054944.hdf",	Location of input files in the production system.

	"MOD03.A2003001.2140.006.2012260053401.hdf", " MOD03.A2003001.2145.006.2012260055003.hdf"]	
ExclusionGRingFlag	"N"	Geographic bounds of swath coverage.
GRingPointLongitude	[-134.529204, -100.841011, -110.349156, -135.759611]	
GRingPointLatitude	[54.085346, 49.240036, 32.346612, 35.789540]	
GRingPointSequenceNo	[1,2,3,4]	
RangeBeginningDate	"2000-04-04"	Beginning and ending times of the first and last scan line in the swath.
RangeBeginningTime	"19:15:00.000000"	
RangeEndingDate	"2000-04-04"	
RangeEndingTime	"19:20:00.000000"	
PGEVersion	"6.0.4"	Version of production generation executable.
AssociatedSensorShortName	"MODIS"	
AssociatedPlatformShortName	"Terra"	
AssociatedInstrumentShortName	"MODIS"	
QAPercentGoodQuality	29	Summary quality assurance statistic for data product. Range is from 0-100.
QAPercentOtherQuality	8	
QAPercentNotProducedCloud	33	
QAPercentNotProducedOther	29	
HorizontalTileNumber	6	
VerticalTileNumber	14	
TileID	51006014	
ProcessVersion	6.0.3	
identifier_product_doi	10.5067/MODIS/MOD21A1D.006	
identifier_product_doi_authority	http://dx.doi.org	

3.5 Quality Assurance

The bit flags defined for the quality assurance SDS QC are listed in Table 10.

Table 10. Bit flags defined in the QC SDS in the MOD21A1D/MOD21A1N product. (Note: Bit 0 is the least significant bit).

Bits	Long Name	Description
1&0	Mandatory QA flags	00 = Pixel produced, good quality, no further QA info necessary 01 = Pixel produced but unreliable quality. Either one or more of the following conditions are met: emissivity in both bands 31 and 32 < 0.95, retrieval affected by nearby cloud, low transmissivity due to high water vapor loading (<0.4), Recommend more detailed analysis of other QC information 10 = Pixel not produced due to cloud 11 = Pixel not produced due to reasons other than cloud
3 & 2	Data quality flag	00 = Good data quality of L1B bands 29, 31, 32 01 = Missing pixel 10 = Fairly calibrated 11 = Poorly calibrated, TES processing skipped
5 & 4	Cloud Flag	00 = Cloud free 01 = Thin cirrus 10 = Pixel within 2 pixels of nearest cloud 11 = Cloudy pixels
7 & 6	Iterations	00 = Slow convergence 01 = Nominal 10 = Nominal 11 = Fast
9 & 8	Atmospheric Opacity	00 = >=3 (Warm, humid air; or cold land) 01 = 0.2 - 0.3 (Nominal value) 10 = 0.1 - 0.2 (Nominal value) 11 = <0.1 (Dry, or high altitude pixel)
11 & 10	MMD	00 = > 0.15 (Most silicate rocks) 01 = 0.1 - 0.15 (Rocks, sand, some soils) 10 = 0.03 - 0.1 (Mostly soils, mixed pixel)

		11 = <0.03 (Vegetation, snow, water, ice)
13 & 12	Emissivity accuracy	00 = >0.02 (Poor performance) 01 = 0.015 - 0.02 (Marginal performance) 10 = 0.01 - 0.015 (Good performance) 11 = <0.01 (Excellent performance)
15 & 14	LST accuracy	00 = >2 K (Poor performance) 01 = 1.5 - 2 K (Marginal performance) 10 = 1 - 1.5 K (Good performance) 11 = <1 K (Excellent performance)

4 MOD21A2 Eight-day LST Product

An eight-day compositing period was chosen because double that period is the exact ground track repeat period of the Terra/Aqua platform. LST over eight days is the averaged LSTs of the MOD21A1 product over eight days.

4.1 Algorithm Description

A simple average method is used in the current algorithm for the MOD21A2 product. The averaging is done for day and night separately for LST, QC, View angle and Viewing time, while for the Band 29, 31 and 32 emissivities the averaging is done over both day and night. The averaging process includes only daily values that are cloud free.

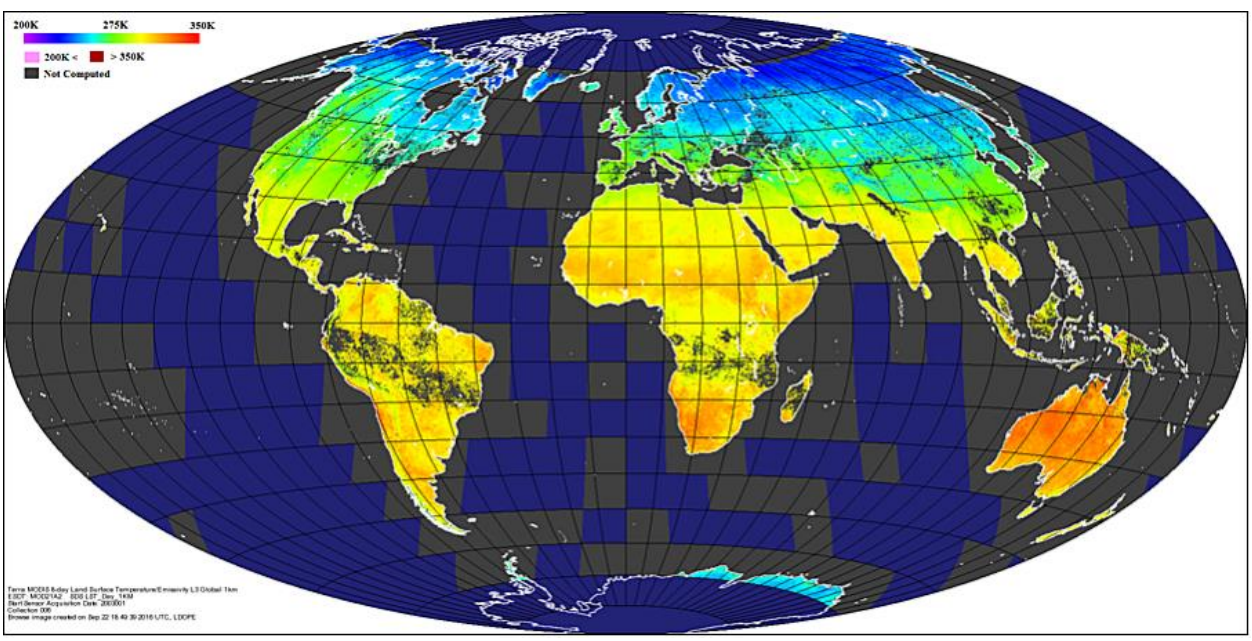

Figure 4. Example MOD21A2 8-day LST product for 2003001 produced by MODAPS.

4.2 Scientific Data Sets (SDS)

In the MOD21A2 product, the day and night daily MOD21A1 products are combined into single product but it has different SDS for LST, QC, View angle and View time for day and night respectively. The day and night specific SDS in MOD21A2 are listed below and summarized in Table 11.

- LST_Day_1KM
- QC_Day
- View_Angle_Day
- View_Time_Day
- LST_Night_1KM
- QC_Night
- View_Angle_Night
- View_Time_Night
- Emis_29
- Emis_31
- Emis_32

Table 11. The SDSs in the MOD21A2 product.

SDS	Long Name	Data type	Units	Valid Range	Fill Value	Scale Factor	Offset

LST_Day_1KM	Day Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC_Day	Day Quality control	uint8	n/a	0-255	0	n/a	n/a
View_Angle_Day	Day view angle	uint8	deg	0-130	255	1	-65
View_Time_Day	Day time of observation	uint8	hrs	0-240	255	0.1	0
LST_Night_1KM	Night Land Surface Temperature	uint16	K	7500-65535	0	0.02	0.0
QC_Night	Night Quality control	uint8	n/a	0-255	0	n/a	n/a
View_Angle_Night	Night view angle	uint8	deg	0-130	255	1	-65
View_Time_Night	Night time of observation	uint8	hrs	0-240	255	0.1	0
Emis_29	Average Day/Night Band 29 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_31	Average Day/Night Band 31 emissivity	uint8	n/a	1-255	0	0.002	0.49
Emis_32	Average Day/Night Band 32 emissivity	uint8	n/a	1-255	0	0.002	0.49

4.3 Local Attributes

Similar to MOD21A1.

4.4 Global Attributes

Similar to MOD21A1.

4.5 Quality Assurance

The bit flags defined for the quality assurance SDSs QC_Day and QC_Night are listed in Table 12.

Table 12. Bit flags defined in the QC_Day and QC_Night SDS in the MOD21A2 product. (Note: Bit 0 is the least significant bit).

Bits	**Long Name**	**Description**
1&0	Mandatory QA flags	00 = Pixel produced, good quality, no further QA info necessary 01 = Pixel produced but unreliable quality. Recommend more detailed analysis of other QC information 10 = Pixel not produced due to cloud

		11 = Pixel not produced due to reasons other than cloud
3 & 2	Data quality flag	00 = Good data quality of L1B bands 29, 31, 32 01 = Missing pixel 10 = Fairly calibrated 11 = Poorly calibrated, TES processing skipped
5 & 4	Emissivity accuracy	00 = >0.02 (Poor performance) 01 = 0.015 - 0.02 (Marginal performance) 10 = 0.01 - 0.015 (Good performance) 11 = <0.01 (Excellent performance)
7 & 6	LST accuracy	00 = >2 K (Poor performance) 01 = 1.5 - 2 K (Marginal performance) 10 = 1 - 1.5 K (Good performance) 11 = <1 K (Excellent performance)

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