MODIS Arctic Monthly Surface Temperature Dataset

1. Dataset Description

The MODIS Arctic Monthly Surface Temperature Dataset provides comprehensive surface temperature observations across the Arctic region from 2003 to 2024. This dataset integrates multiple MODIS-derived temperature products to create spatially and temporally consistent monthly composites covering land, sea ice, and ocean surfaces north of 60°N latitude. The dataset employs a systematic aggregation approach to combine observations from NASA's Terra and Aqua satellite platforms, synthesizing land surface temperature (LST), sea ice surface temperature (IST), and sea surface temperature (SST) retrievals into unified monthly products. Each monthly composite contains five scientific data layers: valid pixel count, maximum surface temperature, mean surface temperature, minimum surface temperature, and surface temperature standard deviation, providing both primary temperature measurements and associated statistical metrics for quality assessment and uncertainty quantification. The products are gridded to the NSIDC Sea Ice Polar Stereographic North projection at 1-kilometer spatial resolution, ensuring minimal distortion across high-latitude regions while maintaining compatibility with other Arctic monitoring datasets. The temporal span of 22 years with monthly temporal resolution enables robust analysis of seasonal cycles, interannual variability, and long-term trends in Arctic surface temperatures.

2. Parameters

2.1 Global Attributes

This dataset contains eight global attributes that define the essential metadata and spatial-temporal characteristics of the MODIS Arctic monthly surface temperature products. These attributes encompass the dataset title, data source information, spatial reference system, raster dimensions, and temporal identifiers. The detailed specifications of each global attribute are presented in Table 1.

Table 1. Global attributes of the MODIS Arctic monthly surface temperature dataset

Attribute	Description	Value/Format
Title	Dataset identifier string	MODIS Arctic Monthly Surface Temperature Dataset for YYYY-MM
Source	Data provenance and input products	Processed Data from MODIS LST (MOD11_L2/MYD11_L2), IST (MOD29/MYD29), and GHRSST L2P Products
Projection	Spatial reference system definition	WGS 84 / NSIDC Sea Ice Polar Stereographic North EPSG:3413
GeoTransform	Spatial transformation parameters	Array defining the affine transformation between pixel and projected coordinates
Rows	Number of rows in the raster grid	6647
Cols	Number of columns in the raster grid	6647

Year	Temporal identifier for year	Integer value representing the data acquisition year (YYYY)
Month	Temporal identifier for month	Integer value (01-12) representing the data acquisition month (MM)

2.2 Scientific Data Sets (SDSs)

The dataset comprises five Scientific Data Sets (SDSs) that contain the primary geophysical variables and associated statistical metrics derived from the monthly aggregation of MODIS surface temperature observations. Each SDS is stored as a two-dimensional array with dimensions of 6647 × 6647 pixels, maintaining spatial consistency across all data layers. The detailed specifications of each SDS are presented in Table 2.

Table 2. SDSs in the MODIS Arctic monthly surface temperature dataset

SDS Name	Description	Number Type	Units	Valid Range	Fill Value
PixelCount	MODIS Arctic Monthly Valid Pixel Count	float32	Count	Variable per SDS (minimum 1)	NaN
Temp_Max	MODIS Arctic Monthly Maximum Surface Temperature		Kelvin	Variable per SDS (195 K-355 K bounds)	
Temp_Mean	MODIS Arctic Monthly Mean Surface Temperature				
Temp_Min	MODIS Arctic Monthly Minimum Surface Temperature				
Temp_Std	MODIS Arctic Monthly Surface Temperature Standard Deviation			Variable per SDS (minimum 0 K)	

3. File Format

The dataset is distributed in Hierarchical Data Format version 5 (HDF5), which provides efficient storage and access for large multidimensional scientific arrays while maintaining comprehensive metadata documentation. Each file contains the complete set of SDSs and associated global attributes required for data interpretation and geospatial referencing. The file naming convention follows a standardized format that incorporates temporal identifiers:

File Name Structure:

MODIS_Arctic_Monthly_Surface_Temperature_Dataset_YYYYMM.h5

Where:

YYYY represents the four-digit year (2003-2024)

MM represents the two-digit month (01-12)

Example:

MODIS_Arctic_Monthly_Surface_Temperature_Dataset_202007.h5

4. Spatial Information

The dataset encompasses the entire Arctic region north of 60°N latitude, spanning from -180° to 180° longitude. The spatial domain is projected using the WGS 84 / NSIDC Sea Ice Polar Stereographic North coordinate system, which is specifically optimized for Arctic applications through its tangent plane at 70°N latitude, thereby minimizing geometric distortion across the high Arctic (Table 3). The grid configuration provides complete coverage of the Arctic Ocean and surrounding landmasses, with the 1-kilometer spatial resolution offering sufficient detail for regional climate studies while maintaining computational efficiency for large-scale analyses (Table 4). The consistent grid structure across all temporal instances facilitates direct pixel-to-pixel comparisons and time series extraction without additional resampling or reprojection requirements.

Table 3. Projection parameters

Parameter	Value
Geographic Coordinate System	WGS 84
Projected Coordinate System	WGS 84 / NSIDC Sea Ice Polar Stereographic North
Longitude of True Origin	-45°
Latitude of True Scale	70°
Scale factor at longitude of true origin	1.0
Datum	WGS 1984
Ellipsoid/spheroid	WGS 84
Units	meter
False Easting	0.0
False Northing	0.0
PROJ4 String	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs +type=crs
EPSG Code	3413
Reference	http://epsg.io/3413

Table 4. Grid specifications

Parameter	Value
Grid Cell Size (X dimension)	1000 m
Grid Cell Size (Y dimension)	1000 m
Number of Rows	6647
Number of Columns	6647
Upper Left Corner (X, Y)	(-3323158.15, 3323158.15) m
Lower Right Corner (X, Y)	(3323841.85, -3323841.85) m
GeoTransform Array	[-3323158.1515, 1000.0, 0.0, 3323158.1515, 0.0, -1000.0]

5. Temporal Information

The dataset provides continuous monthly coverage spanning 22 years from January 2003 through December 2024, resulting in a comprehensive 264-month time series of Arctic surface temperature observations. The monthly temporal resolution represents an optimal balance between ensuring spatial coverage completeness and providing statistically robust aggregations of MODIS observations. Each monthly composite integrates all available high-quality temperature retrievals acquired during the calendar month from both Terra and Aqua platforms, leveraging the combined observational frequency to maximize spatial coverage and minimize data gaps caused by persistent cloud cover. The consistent temporal sampling interval enables direct month-to-month comparisons, seasonal cycle characterization, and robust trend analysis across the entire Arctic domain.

6. Data Acquisition and Processing

6.1 Acquisition

The MODIS, deployed on NASA's Terra (1999) and Aqua (2002) satellites, provides the primary observations for this Arctic surface temperature dataset. It features a 36-band imaging radiometer spanning 0.4–14.4 µm across visible, near-infrared, and thermal infrared wavelengths. The instrument delivers tiered spatial resolution tailored to different spectral regions: 250-meter for bands 1-2, 500-meter for bands 3-7, and 1-kilometer for bands 8-36. With its expansive 2330-kilometer swath width and ±55° scanning capability, MODIS achieves near-global coverage every 1-2 days. For Arctic applications, MODIS offers exceptional temporal resolution due to orbital convergence at high latitudes, where overlapping swaths provide multiple daily observations. The complementary Terra-Aqua constellation further enhances monitoring capabilities: Terra's descending orbit crosses the equator at 10:30 AM local time, while Aqua's ascending orbit crosses at 1:30 PM, effectively capturing the diurnal temperature cycle crucial for understanding Arctic surface processes.

6.2 Sources

The dataset is constructed through the integration of three complementary MODIS-derived temperature products, each optimized for specific surface types within the Arctic region. This multi-product synthesis approach ensures comprehensive spatial coverage across the heterogeneous Arctic environment, effectively capturing temperature variations across terrestrial, cryospheric, and oceanic domains. As presented in Table 5, the dataset draws on the following data sources: (1) MODIS LST products (MOD11_L2 from Terra and MYD11_L2 from Aqua), which provide high-accuracy temperature retrievals over terrestrial surfaces; (2) MODIS Level 2 IST products (MOD29 from Terra and MYD29 from Aqua), specifically designed for ice-covered regions with algorithms tailored for sea ice detection and temperature estimation; and (3) GHRSST (Group for High Resolution Sea Surface Temperature) Level 2P SST products, which deliver quality-controlled temperature measurements for ice-free ocean areas.

Table 5. Data sources for the MODIS Arctic monthly surface temperature dataset

Product ID	Long Name	SDSs Used
MOD11_L2	MODIS/Terra Land Surface Temperature/Emissivity 5-Min L2 Swath 1km V061	1) LST 2) QC 3) Latitude 4) Longitude
MYD11_L2	MODIS/Aqua Land Surface Temperature/Emissivity 5-Min L2 Swath 1km V061	
MOD29	MODIS/Terra Sea Ice Extent 5-Min L2 Swath 1km V061	1) Ice_Surface_Temperature 2) Ice_Surface_Temperature_Pixel_QA 3) Latitude 4) Longitude
MYD29	MODIS/Aqua Sea Ice Extent 5-Min L2 Swath 1km V061	

GHRSST L2P	GHRSST Level 2P Global Sea Surface Skin Temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the NASA Terra satellite (GDS2)	1) sea_surface_temperature 2) quality_level 3) l2p_flags 4) lat 5) lon
	GHRSST Level 2P Global Sea Surface Skin Temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the NASA Aqua satellite (GDS2)	

6.3 Processing

The processing workflow implements a comprehensive multi-stage approach to transform the diverse input products into a unified, quality-controlled Arctic monthly surface temperature dataset. The methodology ensures both data quality and spatial-temporal consistency while addressing the unique challenges of integrating heterogeneous temperature observations across different surface types. The initial preprocessing stage focuses on data preparation and quality assurance. Raw digital numbers from each product undergo radiometric calibration to convert sensor measurements to physical temperature units in Kelvin. Concurrently, product-specific quality flags are examined to identify and retain only high-confidence, cloud-free observations. However, the MOD29 and MYD29 products require additional scrutiny, as their retrieval algorithms inadvertently include ocean pixels adjacent to sea ice. To address this issue, a temperature-based screening approach is applied, retaining only pixels within the physically constrained range of IST (243K to 273K), effectively filtering out erroneously classified open water areas. The GHRSST products undergo complementary processing whereby pixels coinciding with high-confidence sea ice detections from the MOD29/MYD29 products are masked, ensuring the retention of only genuine open-ocean temperature observations.

Following quality control, all surface temperature observations require geometric correction to ensure spatial consistency across the unprojected input products. A standardized 1-kilometer resolution grid is first established in the NSIDC Sea Ice Polar Stereographic North coordinate system, onto which all quality-controlled observations are sequentially projected and accumulated. For every 1km × 1km grid cell, the monthly aggregation algorithm compiles all available temperature observations within each calendar month and computes comprehensive statistics: the valid pixel count (PixelCount) provides a measure of data density and reliability; maximum (Temp_Max) and minimum (Temp_Min) temperatures capture the thermal extremes; mean temperature (Temp_Mean) represents the average conditions; and standard deviation (Temp_Std) quantifies the temporal variability within the month. This statistical approach leverages the high temporal sampling frequency of MODIS to create robust monthly characterizations of surface temperature patterns.

The final processing phase addresses data gaps and ensures spatial continuity while maintaining quality traceability. Grid cells containing zero values in any of the primary temperature layers (Temp_Max, Temp_Mean, Temp_Min) or exhibiting physically implausible temperatures outside the 195 K to 355 K range are identified as candidates for spatial interpolation. These gaps, which may result from persistent cloud cover or quality control filtering, are filled using Inverse Distance Weighting (IDW) interpolation with a search radius of 5 pixels. This approach generates spatially smooth temperature estimates that preserve local thermal gradients and patterns. Critically, while the temperature fields undergo gap filling to ensure spatial completeness, the PixelCount and Temp_Std layers deliberately retain null values at these interpolated locations. This design choice preserves the distinction between observed and interpolated data, enabling users to implement custom quality filtering strategies based on their specific requirements for observation density and acceptable uncertainty levels. The processing concludes by clipping all layers to the Arctic study domain north of 60°N latitude, producing the final MODIS Arctic monthly spatially seamless surface temperature dataset with five complementary layers. Fig. 1 illustrates an example of these five data layers from the July 2020 monthly composite, demonstrating the spatial patterns and data coverage achieved through this processing methodology.

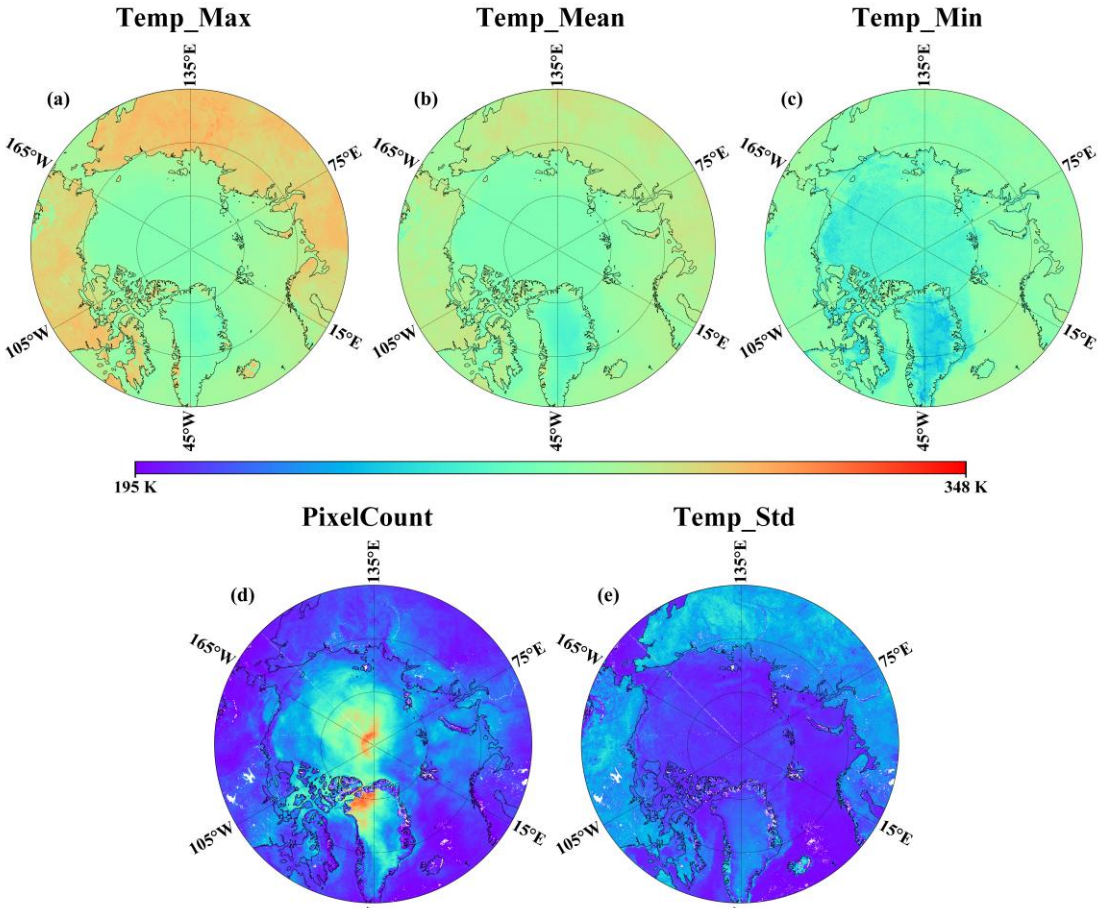

Fig. 1. The five scientific data layers of the MODIS Arctic Monthly Surface Temperature Dataset for July 2020: (a) Temp_Max, (b) Temp_Mean, (c) Temp_Min, (d) PixelCount, and (e) Temp_Std.

7. Errors and Uncertainties

As with any satellite-derived product, several sources of uncertainty may affect the accuracy and reliability of the temperature retrievals. Understanding these error sources enables appropriate interpretation and application of the dataset.

7.1 Geolocation Accuracy

Geometric uncertainties arise from orbital drift, attitude control variations, and terrain-induced distortions, particularly pronounced at high latitudes. Additional positioning errors may stem from the transformation of geographic coordinates to the NSIDC Sea Ice Polar Stereographic North projection employed in this dataset. While MODIS geolocation typically achieves sub-pixel accuracy, residual errors may approach 1 kilometer in extreme cases, potentially affecting temperature assignments at sharp thermal boundaries such as land-water interfaces or ice edges.

7.2 Cloud Contamination

Despite rigorous cloud screening procedures, undetected sub-pixel clouds or cloud edges may contaminate temperature retrievals, typically biasing observations toward cooler values. Thin cirrus clouds pose particular challenges in the Arctic, where their spectral signatures can be similar to ice surfaces. Persistent cloud cover during polar summer months may also result in reduced temporal sampling, affecting the representativeness of monthly statistics.

7.3 Observation Density Variations

The merging of multiple products with different quality control criteria can lead to heterogeneous observation densities across surface types. GHRSST products, which implement particularly stringent quality filters, may exhibit lower pixel counts compared to LST and IST products. Furthermore, as these three product suites were developed independently by different research teams, transition zones between surface types may receive inconsistent or incomplete coverage, resulting in reduced observation densities or data gaps in these critical interface regions. This variation in sampling density can affect the statistical robustness of monthly aggregates, particularly in areas where surface type classification ambiguities exist.

7.4 Swath Seam Artifacts

Discontinuities may occur where adjacent satellite swaths overlap or at interfaces between different product domains (land/ice/ocean). This mixing may produce visible seam artifacts manifesting as weave patterns in the data, particularly when adjacent swaths exhibit differences in cloud cover or surface characteristics. While the monthly aggregation process mitigates many of these artifacts through temporal averaging, residual effects may remain visible in regions with consistently different observation patterns between adjacent swaths.

7.5 Quality Assessment and Filtering

Users should carefully evaluate data quality through the auxiliary layers provided in the dataset. The PixelCount layer enables assessment of observation density, allowing users to establish minimum thresholds for statistical reliability based on their specific application requirements. The Temp_Std layer provides insights into temporal variability within each monthly composite, where elevated values may indicate mixed surface types, intermittent cloud contamination, or genuine physical variability. By combining these quality indicators, users can develop tailored filtering strategies that optimize the trade-off between spatial coverage and data reliability, ensuring that the retained observations meet the precision requirements of their particular research objectives while maintaining adequate spatial representation across the Arctic domain.

8. References

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