CCI Land Surface Temperature

Product User Guide

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Change log

Version	Date	Changes
1.0	3-Jun-2020	First version
2.0	10-Dec-2021	Version includes final datasets

List of Changes

Version	Section	Changes
2.0	Quick Start	Updated with new products
2.0	3.3	Updated with new / amended variable information and availability
2.0	4	Updated Fact Sheets for ATSRs, MODIS, SLSTR-A, SEVIRI, SSM/I – SSMIS, and new Fact Sheets for SLSTR-B, GOES, MTSAT, Merged GEO-LEO IR CDR, ATSR-SLSTR CDR
2.0	5	Updated with changes to metadata, filenames, and variable list
2.0	6.1	Added information on the single channel algorithm
2.0	7	New land cover information added

Quick Start Guide to ESA LST_cci Products

What products are available?

A principal strength of LST_cci products is the consistently processed long-term data records from multiple sensors. Their principal recommended application is in climate research, particularly those applications requiring long-term, stable, low bias records of LST.

Available CCI products are provided are given in below. For the remainder of this document the products are referred to by the Product Name given in the table. The product names follow the convention:

<Satellite>_<Sensor>-<Processing Level>[_<spatial resolution>]

Table 1: ESA LST_cci products.

Product Name	Version	Instrument	Satellite	Spatial resolution	Temporal resolution	Time period
ERS-2_ATSR__L3C_0.01	3.00	ATSR-2	ERS-2	0.01° global lon-lat grid	Daily and Monthly (day and night)	1995-2003
ENVISAT_ATSR__ L3C_0.01	3.00	AATSR	Envisat	0.01° global lon-lat grid	Daily and Monthly (day and night)	2002-2012
TERRA_MODIS_ L3C_0.01	3.00	MODIS	EOS Terra	0.01° global lon-lat grid	Daily and Monthly (day and night)	2000-2018
AQUA_MODIS_ L3C_0.01	3.00	MODIS	EOS Aqua	0.01° global lon-lat grid	Daily and Monthly (day and night)	2002-2018
SENTINEL3A_SLSTR_L3C_0.01	3.00	SLSTR	Sentinel 3A	0.01° global lon-lat grid	Daily and Monthly (day and night)	2016-2020
SENTINEL3B_SLSTR_L3C_0.01	3.00	SLSTR	Sentinel 3B	0.01° global lon-lat grid	Daily and Monthly (day and night)	2018-2020
MSG1_SEVIRI_L3U	3.00	SEVIRI	Meteosat-8	0.05° global lon-lat grid	Hourly	2004-2015
MSG2_SEVIRI_L3U	3.00	SEVIRI	Meteosat-9	0.05° global lon-lat grid	Hourly	2007-2020
MSG3_SEVIRI_L3U	3.00	SEVIRI	Meteosat-10	0.05° global lon-lat grid	Hourly	2013-2018
MSG4_SEVIRI_L3U	3.00	SEVIRI	Meteosat-11	0.05° global lon-lat grid	Hourly	2018-2020
GOES12_IMAGER_L3U	1.00	IMAGER	GOES-12	0.05° global lon-lat grid	3-hourly	2009-2010
GOES13_IMAGER_L3U	1.00	IMAGER	GOES-13	0.05° global lon-lat grid	3-hourly	2010-2017
GOES16_ABI_L3U	1.01	ABI	GOES-16	0.05° global lon-lat grid	Hourly	2018-2020

Product Name	Version	Instrument	Satellite	Spatial resolution	Temporal resolution	Time period
MTSAT1_JAMI_L3U	1.00	JAMI	MTSAT1	0.05° global lon-lat grid	3-hourly	2009-2010
MTSAT2_JAMI_L3U	1.00	JAMI	MTSAT2	0.05° global lon-lat grid	3-hourly	2010-2015
SSMI_SSMIS_L3C	2.23	SSM/I + SSMIS	DMSP	0.25° global lon-lat grid	Daily (descending and ascending)	1996 – 2020
MULTISENSOR_IRMGP_L3S_0.05	1.00	SEVIRI + IMAGER + ABI + JAMI+ ATSR-2 + AATSR + MODIS + SLSTR	MSGx + GOESx + MTSATx + ERS-2 + Envisat + EOS Terra + EOS Aqua + Sentinel-3x	0.05° global lon-lat grid	3-hourly	2009-2020
MULTISENSOR_IRCDR_L3S_0.01	2.00	ATSR-2 + AATSR + MODIS + SLSTR	ERS-2 + Envisat + EOS Terra + Sentinel-3A	0.01° global lon-lat grid	Daily and Monthly (day and night)	1995-2020

What tools are available for these products?

The CCI Toolbox (Cate) is a free, open source software environment for ingesting, processing and visualising ESA CCI data. All ESA CCI datasets which are published through the ESA CCI Open Data Portal, which includes LST_cci datasets, will be assessable to the Toolbox.

More information is available here: http://climatetoolbox.io/. Documentation for the CCI toolbox is provided online, including a Quick Start guide.

A new command-line re-gridding tool being developed will allow user customisation of the final output resolution to better serve the different types of climate users for LST. This will be made available in Q1 2022.

How to access the data

LST_cci datasets are available from the ESA CCI Open Data Portal (https://climate.esa.int/en/odp/#/dashboard).

How to read the ESA LST_cci data

The data are stored in NetCDF-4 format files. Information about the NetCDF format can be found at http://www.unidata.ucar.edu/software/netcdf/. Data arrays in NetCDF files are known as ‘variables’ and have associated metadata. The names of key variables, contained in the L3 (L3U, L3C and L3S) files, are given in the table below.

Please also read the notes below the table before using the data, particularly with regards to interpreting the quality/location type information. It is essential to check this information when using the data.

Table 2: Key variables in ESA LST_cci files.

Description of Key Variable	Name of Key Variable in Files	Comment
Reference time of the data points.	time	Reference time. The start time of the orbit, granule or disk in seconds since 1981-01-01 00:00:00 which the dtime is relative to.
Time difference from reference time for each LST retrieval.	dtime	Time difference in seconds of LST retrievals from the reference time in the "time" variable.
Latitudes of the data points	lat	
Longitudes of the data points	lon	
Per pixel Land Surface Temperature	lst	Good quality LSTs are those where the value in the LST data array is not -32768 (L3) or, for L2P from thermal infrared, where the second bit of the qual_flag is set.
Per pixel total uncertainty associated with the lst variable	lst_uncertainty	
Per pixel quality flags for each LST retrieval.	qual_flag	For L3C and L3S IR datasets the qual_flag are: observation_proximity_to_local_time-1_is_closest_observation.
		For MW datasets the qual_flag are: no_use no_use no_use snow_ice-1_is_snow_ice microwave_penetration_depth-1_is_ground_with_large_penetration_depth deep_convection_occurence-1_is_possibility_of_deep_convection coast-1_is_cost inundation_risk-1_is_possibility_of_inundated_land

Important:

- As noted by the _FillValue attribute, the number inserted into the data array where no LST was available is -32768. Some tools will identify these automatically. **It is essential to check for fill values as well as quality levels.**
- Check that the add_offset and scale_factor attributes are being applied if present when reading the variables. These must be used to convert the data stored in the file to the correct units. Some tools will do this automatically for NetCDF files.

Further information and how to contact us

For further help, first see the rest of this document. There is an extended introductory guide in Section 3 - "Getting started with the ESA LST_cci data" – and more detailed discussions of the data in other sections, plus references to documents that contain even more information.

If these do not help, email djg20@le.ac.uk (Darren Ghent, Scientific leader of LST_cci). We also welcome any feedback about the data to this address.

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1. Document Purpose and Scope

1.1. Purpose and Scope

This document is the user guide for the data products produced by the land surface temperature (LST) climate change initiative project (LST_cci), which is part of the European Space Agency (ESA) Climate Change Initiative (CCI).

The main aim of the document is to aid a user in both selecting a data product they require (including understanding its features and limitations) and in reading and using the data. A summary of how the data were produced is also included for interested users.

1.2. Document Structure

At the beginning of the document is a quick start guide to ESA LST_cci products. The remainder of this document provides more detailed information for users, summarised below:

- **Section 2**: An introduction to the ESA LST_cci project.
- **Section 3:** A guide to getting started with using the ESA LST_cci data.
- **Section 4:** Fact sheets describing the features of each of the ESA LST_cci products.
- **Section 5:** A detailed description of the ESA LST_cci data files.
- **Appendix 1:** A summary of how the ESA LST_cci data are processed.
- **Appendix 2:** A summary of land cover information used in ESA LST_cci data processing.
- **Appendix 3:** Examples of the structure of the ESA LST_cci data files.

1.3. Reference Documents

The following is a list of reference documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as RD-xx, where 'xx' is the number in the table below.

RD-1	Dodd, E., Veal, K., and Ghent, D. (2016) ESA DUE GlobTemperature Satellite LST User Handbook. GlobT-WP2-DEL-25. V1.0. http://www.globtemperature.info/index.php/public-documentation/deliverables-1/215-lst-handbook/file. Accessed 28th April 2020.
RD-2	Veal, K. L., G. K. Corlett, D. Ghent, D. T. Llewellyn-Jones, and J. J. Remedios (2013), A time series of mean global skin SST anomaly using data from ATSR-2 and AATSR, Remote Sensing of Environment, 135, 64-76.
RD-3	ESA Climate Office (2018) CCI data standards 2.2 (CCI-PRGM-EOPS-TN-13-0009), available from http://cci.esa.int/sites/default/files/CCIDataStandards_v2-2_CCI-PRGM-EOPS-TN-13-0009.pdf
RD-4	Prigent, C., Jimenez, C., and Aires, F., Towards all weather, long record, and real-time land surface temperature retrievals from microwave satellite observations, J. Geophys. Res., 121, 5699-5717, DOI: 10.1002/2015JD024402, 2016.
RD-5	Ghent, D.; Corlett, G.; Gottsche, F.; Remedios, J. Global land surface temperatures from the Along-Track Scanning Radiometers. J. Geophys. Res. Atmos. 2017, 122, 12167–12193.

RD-6	Ghent, D., Veal, K., Trent, T., Dodd, E., Sembhi, H. and Remedios, J., 2019. A new approach to defining uncertainties for MODIS land surface temperature. Remote Sensing, 11(9), p.1021.
RD-7	Trigo, I. F., I. T. Monteiro, F. Olesen, and E. Kabsch. (2008). An assessment of remotely sensed land surface temperature, J. Geophys. Res., 113, D17108.
RD-8	Perry, M., Ghent, D., Jimenez, C., Dodd, E., Ermida, S., Trigo, I. F., and Veal, K. (2020). Multi-Sensor thermal infrared and microwave land surface temperature algorithm intercomparison. Remote Sensing, 12(24), 4164
RD-9	Baret, F., Weiss, M., Lacaze, R., Camacho, F., Makhmara, H., Pacholcyzk, P. and Smets, B., 2013. GEOV1: LAI and FAPAR essential climate variables and FCOVER global time series capitalizing over existing products. Part1: Principles of development and production. Remote sensing of environment, 137, pp.299-309.
RD-10	Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate. Copernicus Climate Change Service Climate Data Store (CDS), 5th August 2019. https://cds.climate.copernicus.eu/cdsapp#!/home
RD-11	Combined ASTER and MODIS Emissivity database over Land (CAMEL) Emissivity Monthly Global 0.05Deg V001. NASA EOSDIS Land Processes DAAC. doi: 10.5067/MEaSUREs/LSTE/CAM5K30EM.001

1.4. Applicable Documents

The following is a list of applicable documents with a direct bearing on the content of this report. Where referenced in the text, these are identified as AD-xx, where 'xx' is the number in the table below.

AD-1	Dodd, E., Jimenez, C. and Ghent, D. (2021) Product Specification Document. V2.00
AD-2	Bulgin, C. and Ghent, D. (2021) End-To-End ECV Uncertainty Budget. V2.00
AD-3	Ghent, D., Perry, M., Veal, K., Jimenez, C., (2021) Algorithm Development Plan. V2.00
AD-4	Ghent, D., Dodd, E., Jimenez, C., and Ermida, S. (2021) Algorithm Theoretical Basis Document. V3.00
AD-5	Martin, M. and Ghent, D. (2021) Product Validation and Intercomparison Report (PVIR). V2.00
AD-6	Alfred, F., Good, E., Bulgin, C., Rayner, N., Ghent, D. (2021) User Requirements Document (URD). V2.10

1.5. Glossary

The following terms have been used in this document with the meanings shown.

Term	Definition
ATSR	Along Track Scanning Radiometer
ABI	Advanced Baseline Imager
CCI	Climate Change Initiative
CDR	Climate Data Records
DMI	Danish Meteorological Institute
DMSP	Defense Meteorological Satellite Program
ECV	Essential Climate Variable
ESA	European Space
GCOS	Global Climate Observing System
GOES	Geostationary Operational Environmental Satellite
IPMA	Instituto Português do Mar e da Atmosfera
IR	InfraRed
JAMI	Japanese Advanced Meteorological Imager
LST	Land Surface Temperature
MSG	Meteosat Second Generation
MTSAT	Multi-Functional Transport Satellite
MW	MicroWave
NCEO	National Centre for Earth Observation
NN	Neural Network Algorithms
OE	Optimal Estimation Algorithm
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SSM/I	Special Sensor Microwave / Imager
SSMIS	Special Sensor Microwave Imager / Sounder
SW	Split Window Algorithm
TES	Temperature and Emissivity Separation Algorithm
TIR	Thermal InfraRed

2. Introduction to the ESA LST_cci Project

2.1. Background

Land Surface Temperature (LST) is an important variable within the Earth climate system. It describes processes such as the exchange of energy and water between the land surface and atmosphere, and influences the rate and timing of plant growth. Knowledge of LST, which has been defined as a GCOS ECV, is increasingly being used in diverse applications such as drought monitoring and crop management, hydrological monitoring and water management, evapotranspiration and land-atmosphere feedbacks, landcover change, climate modelling and data assimilation, numerical weather prediction, forecasting and reanalysis, permafrost monitoring, and urban temperatures [RD-1].

LST information has been, and continues to be, provided from a variety of sources. These can be broadly grouped into in situ instruments (typically installed on flux towers or at meteorological sites) and satellite instruments (for example on platforms such as the ESA satellite Envisat). No observational record is perfect, and uncertainties are associated with both in situ and satellite records. These may stem from issues such as changing instrumentation over time, with different instruments having different bias characteristics, and gaps in their coverage. Satellite products provide far greater spatial coverage than in situ measurements, which are particularly sparse in certain geographical regions. Yet these sources of information provide complementary and provide independent records of surface temperature. In situ records can help validate and compare different satellite products, while satellite products provide information on spatial variations in LST which is not possible from the sparse network of LST in situ instruments.

Instruments that are sensitive to the temperature of the surface of the Earth's surface have been flown on board satellites over the past 30+ years in either sun-synchronous polar orbits or geostationary orbits. Polar orbiting satellites provide near global coverage from twice daily to once every few days depending on swath width and cloud clover, whilst geostationary satellites provide near-continent sized regional coverage every 15-60 minutes depending on observation cycling, cloud cover and spatial extent (latitude/longitude disk). Multi-decadal length records are available with existing datasets extending back to the mid-1990s and work is on-going to extend records back to the mid-1980s.

LST can be derived from both thermal infrared (TIR) and microwave (MW) data. The longest record of TIR data typically utilised for LST comes from a series of instruments provided by the Along Track Scanning Radiometer (ATSR) series of three instruments, which started in 1991 and ended in 2012. The Sea and Land Surface Temperature Radiometer (SLSTR) series of instruments on board Sentinel 3 satellites (2016 to present) continues the series, albeit with a gap. These sensors were designed explicitly for climate standard observations [RD-2], so provide more accurate data than some other sensors, but with less coverage (~500 km wide strips). Also commonly utilised for deriving LST are the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors flown on NASA Terra (1999 to present) and Aqua (2002 to present) satellites. The large swath width of these instruments, 2330km, enables these satellites to view almost the entire surface of the Earth every day. MODIS sensors also measure LST in the TIR on polar orbiting satellites. There are also TIR data from sensors on geostationary satellites – which perform one orbit per day and stay over the same spot on the Earth all the time providing data several times an hour – such as the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on Meteosat Second Generation (MSG). Finally, there are sensors such as the Special Sensor Microwave / Imager (SSM/I) or the Special Sensor Microwave Imager / Sounder (SSMIS) instruments which observe the Earth in the microwave part of the electromagnetic spectrum, allowing them to 'see' through the majority of clouds [RD-4]. These sensors have been launched on board the Defense Meteorological Satellite Program (DMSP) polar satellites since 1987 and there are up to 4 SSM/I instruments operating at the same time.

Although a large quantity of satellite data exists, working out the LST from those data is not simple. The signal emanating from the surface is altered – for example by absorption and scattering by the atmosphere – before it reaches the satellite and the magnitude of this effect must be estimated in order to 'retrieve' LST from the satellite measurements. Furthermore, unlike for surface temperature over the ocean, emissivity over the land is typically unknown and must be inferred from auxiliary data such as the biome, or can be retrieved simultaneously with LST through Temperature-Emissivity Separation methods using multiple thermal channels. There are also issues to deal with such as degradation of sensors over time and drift in the orbit of the satellites. Identifying and masking clouds is also a challenge. It is therefore very difficult to produce a satellite-based record of LST that meets the very stringent requirements of 'climate quality' data, such as having little artificial change in the LST data over time.

In 2009 ESA instigated their Climate Change Initiative (CCI). Its goal is:

"To realise the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV [essential climate variable] databases required by United Nations Framework Convention on Climate Change (UNFCCC)."

They established 13 projects in the first CCI that aimed to unlock the full potential for climate research of satellite based records of variables such as ocean colour and land use type. This was then followed up by 9 further projects in 2018, including the ESA LST_cci project.

The LST_cci project team has the University of Leicester (UK) as prime contractor, and the consortium is based on a close collaboration between the following partners: ACRI-ST (France), NCEO (UK), University of Reading (UK), UK Met Office (UK), Estellus (France), University of Valencia (Spain), Karlsruhe Institute of Technology (Germany), IPMA (Portugal), Ruhr University Bocham (Germany), DMI (Denmark), Max Planck Institute (Germany), Luxembourg Institute of Science and Technology (Luxembourg), and Meteo Romania (Romania).

2.2. The ESA LST_cci project

The LST_cci aims to provide an accurate view of temperatures across land surfaces globally over the past 20 to 25 years and meet the requirements of GCOS for climate applications by developing techniques to provide data from a variety of satellites, both as single sensor datasets and as combined long-term satellite records for climate. The project will provide a comprehensive suite of high quality IR LST ECV Products and MW LST ECV Products from geostationary (GEO) and low earth orbit (LEO) satellites covering a range of time periods from 1995 for the earliest sensor through to 2020 for many current and some future sensors. It will also provide a first Merged GEO-LEO IR Climate Data Record (CDR) from input bias corrected Level-1 GEO and LEO data at 0.05° and 3-hourly, and a consistent long-term LST CDR of over 20 years from 1995 to 2020 for ATSR-2 through to SLSTR by bridging and filling the gap between AATSR and SLSTR.

The project also includes:

- A strong validation component which aims to provide globally representative and consistent in-situ validation and intercomparison of LST products over all major land cover types.

- Sustained support to the surface temperature community through International LST and Emissivity Working Group (ILSTE), which is the principle forum of community expertise from data providers to users.
- Incorporating detailed climate user input into the specifications of the LST ECV products, and user assessment of these products to drive LST exploitation in climate science.
- Strong buy-in from the climate science community coordinated by the Climate Research Group, with key inputs from the CMUG and CSWG, and user interaction at two dedicated user workshops.
- Demonstration of a coherent and open pre-operational End-to-End processing system for delivering the LST ECV Products to the climate user community.

In the following subsections, some of the key components of the project are described in more detail.

2.2.1. User requirements gathering

LST user requirements for climate science were collated during the LST_cci project, building on work carried out within the precursor project ESA DUE GlobTemperature (http://www.globtemperature.info/). User requirements were obtained through two surveys open to both current and potential users of LST_cci data for climate applications and eight interviews with the LST_cci Climate Research Group. The surveys gathered information about user applications, current data use, user concerns surrounding satellite LST products, dataset specification (e.g. temporal and spatial resolution, stability, accuracy, etc.), data format, quality and uncertainty information, requirements for validation and intercomparison information, and issues concerning clouds. The interviews helped to gain an in-depth understanding of their user requirements and to provide context for the information gathered through the two surveys. A User Workshop was also held in June 2020 to understand where gaps may lie between the LST_cci products and the needs of the user community.

The information obtained through the surveys, interviews and workshops was synthesised, along with specifications for LST from the Global Climate Observing System (GCOS), and used to define LST user requirements for climate applications within the User Requirements Document provided [AD-6].

2.2.2. A multi-sensor matchup database

Validation of LST within CCI is undertaken in two different ways. The first approach is the validation of satellite LST data against in situ LST from station data, the second is an intercomparison of LST_cci products with external LST products. Validation within LST_cci follows protocols from the Committee on Earth Observation Satellites (CEOS), within its Working Group on Calibration and Validation (WGCV), as well as the guidelines for calibration and validation provided by CEOS-WGCV under the Quality Assurance Framework for Earth Observation (QA4EO) endorsed by CEOS, and existing LST Validation Protocols.

All data sets and software used for the validation are stored in a common, harmonised file format in a multi-sensor Matchup Database (MMDB). In situ data within the MMDB is partitioned into two sections, one is accessible for LST_cci data set producers to test their algorithms, and the second, larger part, are accessible only for the validation team to make sure the validations are performed independently. The results of all validations are discussed with the data set producers and are documented in the LST_cci Product Validation and Intercomparison Report (PVIR) [AD-5].

2.2.3. Algorithm development and intercomparison

Planned algorithm developments within LST_cci are detailed in the Algorithm Development Plan (ADP) [AD-3]. Developments are planned to the algorithms, auxiliary data, the calibration database for determining retrieval coefficients, radiative transfer models, and cloud masking schemes. Algorithms to be developed during LST_cci are those selected as the best algorithms for a future climate quality operational system during a Round Robin intercomparison exercise. Developments have continued throughout the project following feedback expected from validation and intercomparison using the Matchup Database (Section 2.2.2), and from the climate assessment of the LST_cci products.

2.2.4. The ESA LST_cci products

The ESA LST_cci project is developing two product families: LST Essential Climate Variable (ECV) products, and LST Climate Data Record (CDR) products. LST ECV products are data records formed from single satellite sensors. Separate products are produced from many satellite sensors including ATSR-2, ATSR-3 (AATSR), MODIS Terra, MODIS Aqua, SLSTR (A and B), SEVIRI, Imager and ABI, and JAMI. CDR products are climate records produced from combining data from different satellite sensors. Three CDRs are produced. A Merged GEO-LEO IR CDR, which is a merged IR CDR product produced from AATSR, SLSTR (Sentinel 3A and 3B), MODIS (Terra and Aqua), SEVIRI (MSG satellites 1-4), Imager / ABI (GOES satellites 12-16) and JAMI (MTSAT-1 and 2 satellites); an ATSR-SLSTR CDR, which is a merged IR CDR product produced from ATSR-2, AATSR, SLSTR and Terra-MODIS; and a merged MW CDR produced from SSM/I and SSMIS (DMSP F13 and F17).

These products are listed below in the format <Satellite>_<Sensor>_<processing level>*(_<resolution>)*.

- ERS-2_ATSR__L3C_0.01
- ENVISAT_ATSR__L3C_0.01
- TERRA_MODIS_L3C_0.01
- AQUA_MODIS_L3C_0.01
- SENTINEL3A_SLSTR_L3C_0.01
- SENTINEL3B_SLSTR_L3C_0.01
- MSG1_SEVIRI_L3U
- MSG2_SEVIRI_L3U
- MSG3_SEVIRI_L3U
- MSG4_SEVIRI_L3U
- GOES12_IMAGER_L3U
- GOES13_IMAGER_L3U
- GOES16_ABI_L3U
- MTSAT1_JAMI_L3U
- MTSAT2_JAMI_L3U
- SSMI_SSMIS_L3C
- MULTISENSOR_IRMGP_L3S_0.05
- MULTISENSOR_IRCDR_L3S_0.01

3. Getting Started with the ESA LST_cci Data

A very brief guide to getting started with the ESA LST_cci data is given in a Quick Start Guide at the beginning of this document. In this section, an extended introduction to the data is provided including a frequently asked questions section. This includes explanations for some of the terms that might be encountered throughout this document.

3.1. Which LST product do I need?

3.1.1. ESA LST_cci products

The ESA LST_cci project will deliver a comprehensive suite of high quality IR and MW LST ECV Products from geostationary (GEO) and low earth orbit (LEO) satellites containing information from single satellite instruments (or series of instrument). It will also provide a first Merged GEO-LEO IR Climate Data Record (CDR) from input bias corrected Level-1 GEO and LEO data at 0.05° and 3-hourly, and a consistent long-term LST CDR of over 20 years from 1995 to 2020 for ATSR-2 through to SLSTR by bridging and filling the gap between AATSR and SLSTR.

Currently, **LST single-sensor ECV Products and CDRs** are available from the following sensors and data levels:

- ATSR-2 (L3C)
- AATSR (L3C)
- MODIS Terra (L3C)
- MODIS Aqua (L3C)
- Sentinel-3x SLSTR (L3C)
- MSGx SEVIRI (L3U)
- GOESx Imager (L3U)
- GOES16 ABI (L3U)
- MTSATx JAMI (L3U)
- SSM/I and SSMIS CDR (L3C)
- Multisensor Merged IR Product CDR (L3S)
- Multisensor IR CDR (L3S)

Table 1 provides a succinct overview of each LST_cci products, with detailed descriptions of the products to be found in Section 4.

3.1.2. What are data levels?

When dealing with satellite data it is common to encounter references to 'data levels'. The level of the data describes the amount of processing that has been performed. The higher the level the more processing has occurred, from satellite instrument raw data into a geophysical product.

In the context of the ESA LST_cci data products the following data levels are relevant to users:

- L1B products, which are not disseminated by the LST_cci project, are radiometrically calibrated and geometrically corrected radiances or brightness temperatures presented on the orbit swath at native resolution and geolocated to latitude and longitude of centres (and/or corners) of pixels or to tie-points.

- L2P products contain LSTs on the instrument swath or disk. A single file will contain a single orbit in the case of narrow swath sensors (e.g. the ATSRs), part of an orbit track for wide swath sensors (e.g. MODIS), or a whole disk for geostationary instruments such as SEVIRI.
- L3U products, which are disseminated by the ESA LST_cci project for geostationary satellite products only, are L2 (swath) data from a single instrument that are mapped onto a space-time grid but do not combine data from different orbits.
- L3C products are collated products containing multiple L2P swaths from a single instrument that have been combined and mapped onto a space-time grid. Data are delivered in two separate files for each temporal resolution (either "day" and "night", "ascending" and "descending", or "daily" or "monthly" depending on the product).
- L3S products are L2 data from multiple instruments combined in a space-time grid. LST CDR products are generally L3S products.

The L2P data are stored on an irregular grid and require two-dimensional longitude and latitude data arrays to determine the locations of the LST data. L3C and L3S data combines multiple sets of observations from single or multiple sensors into a single data array and are stored on a regular latitude-longitude grid.

3.2. How do I get the data?

LST_cci datasets are available from the ESA CCI Open Data Portal (https://climate.esa.int/en/odp/#/dashboard).

3.3. How do I use the ESA LST_cci data?

3.3.1. The Data Files

The structure of the ESA LST_cci file names is described in detail in Section 5. Here we provide a summary restricted to the most useful information.

The most important parts of the LST_cci filenames are:

ESACCI-LST-<Processing Level>-LST-<Product String>[…]<Indicative Date>[<Indicative Time>]...

For example:

ESACCI-LST-L3S-LST-ATSR_3-0.01deg_1DAILY_DAY-20100101000000-fv2.00.nc

The first key part of the filename is the processing level of the data, which could be L3U (uncollated orbits of data, gridded), L3C (collated orbits of data, gridded), or L3S (super-collated orbits of data from multiple sensors, gridded). See Section 3.1.2 for more information on data levels. The second key part is the product string, which indicates the product or sensor data the file contains, for example ATSR_3 (AATSR). Then the indicative date, the date of the data in the form YYYY[MM[DD]] (the 1st of January 2010 in the example) is provided following by the indicative time if relevant, which is the time within that day in the form [HH[MM[SS]]] (which is the start of the day in the example).

The format of the data files is NetCDF-4. Within the files are data (known as variables) and metadata (known as attributes). A summary of the key variables within the ECV product files is provided in Table 3.

Table 3: Summary of the variables in the NetCDF files. Note, not every variable will be available in each of the LST_cci products. The variables marked with a * are

Description of Key Variable	Name of Key Variable in Files	Comment
Reference time of the data points.	*time	Reference time. The start time of the orbit, granule or disk in seconds since 1981-01-01 00:00:00 which the dtime is relative to.
Time difference from reference time for each LST retrieval.	*dtime	Time difference in seconds of LST retrievals from the reference time in the "time" variable.
Latitudes of the data points	*lat	
Longitudes of the data points	*lon	
Per pixel Land Surface Temperature	*lst	Good quality LSTs are those where the value in the LST data array is not -32768 (L3) or, for L2P from thermal infrared, where the second bit of the qual_flag is set.
Per pixel total uncertainty associated with the lst variable	*lst_uncertainty	
Per pixel uncertainty from uncorrelated errors	*lst_unc_ran	
Per pixel uncertainty from locally correlated errors on atmospheric scales	*lst_unc_loc_atm	
Per pixel uncertainty from locally correlated errors on surface scales	*lst_unc_loc_sfc	
Per pixel uncertainty from large-scale systematic errors	*lst_unc_sys	
Per pixel quality flags for each LST retrieval.	*qual_flag	For L3C and L3S IR datasets the qual_flag are: observation_proximity_to_local_time-1_is_closest_observation.
		For MW datasets the qual_flag are: no_use no_use no_use snow_ice-1_is_snow_ice microwave_penetration_depth-1_is_ground_with_large_penetration_depth deep_convection_occurence-1_is_possibility_of_deep_convection coast-1_is_cost inundation_risk-1_is_possibility_of_inundated_land
Satellite zenith angle	*satze	
Satellite azimuth angle	*sataz	
Solar zenith angle	*solze	

Solar azimuth angle	*solaz	
Number of pixels averaged in grid cell	*n	
Per pixel uncertainty from locally correlated errors on IR LST corrections	lst_unc_loc_cor	
Per pixel uncertainty from locally correlated errors on MW LST time corrections	lst_unc_time_correction	
Per pixel time correction for MW product	lst_time_correction	Offset to be added to the land surface temperature to adjust its value at the overpass local time to the value that would have been measured at 6PM local time
Land cover class	lcc	Full description of the different classes are provided in Appendix 2

Important:

- As noted by the _FillValue attribute, the number inserted into the data array where no LST was available is -32768. Some tools will identify these automatically. **It is essential to check for fill values as well as quality levels.**
- Check that the add_offset and scale_factor attributes are being applied if present when reading the variables. These must be used to convert the data stored in the file to the correct units. Some tools will do this automatically for NetCDF files.

3.3.2. Using the Uncertainty Estimates

Files contain uncertainties broken down into components from errors that correlate on different spatial and temporal scales:

- Random uncertainties, which are uncorrelated (or weakly correlated) on all spatial and temporal scales, for example random noise in the satellite sensor data.
- Locally correlated atmospheric uncertainties, which is uncertainty assumed to be correlated over distances of 5 km and 5 minutes (related to atmospheric conditions) [AD-2].
- Locally correlated biome or surface uncertainties, which is assumed to be correlated within each biome separately [AD-2].
- Large scale systematic uncertainties, which are assumed to be correlated on all spatial and temporal scales (for example related to calibration of the satellite sensor).
- Locally correlated LST correction uncertainties, such as for intercalibration or time corrections, which are assumed to be correlated on specific spatial and temporal scales (for example related to latitude, or land cover).

For each individual LST, the total uncertainty can be obtained by summing each uncertainty component noted above in quadrature (the square root of the sum of squares). The total uncertainty is provided in L3U, L3C and L3S files and is stored in the lst_uncertainty variables contained in the NetCDF files.

For applications combining multiple LSTs such as performing a regional average of the data it is essential that the correlations in the uncertainties are taken into account when combining the uncertainty components. This is why the uncertainty components have been provided.

3.3.3. Reading the data and tools that can be used on the data

The ESA LST_cci files use NetCDF format and so they are readable using many tools and programming languages including (but not limited to) Python, C, Fortran, IDL, and Matlab.

Another tool which is recommended for LST_cci data is the CCI Toolbox (Cate), which is a free, open source software environment for ingesting, processing and visualising ESA CCI data. All ESA CCI datasets which are published through the ESA CCI Open Data Portal, which includes LST_cci datasets, will be assessable to the Toolbox. More information is available here: http://climatetoolbox.io/.

Another tool which can be utilised is the Sentinel Application Platform (SNAP) which is a follow on from the BEAM software. More information on SNAP is available here: https://step.esa.int/main/toolboxes/snap/. This is a common architecture ideal for Earth Observation processing and analysis.

In addition, the CCI data portal provides interactive map services.

A new command-line re-gridding tool being developed will allow user customisation of the final output resolution to better serve the different types of climate users for LST. This will be made available in Q1 2022.

3.3.4. Dos and don'ts to be aware of when using the data

Do make sure the data read from the files are scaled to be in the correct units.

Do check for fill values in the data arrays and the quality information and/or data flags that say which locations contain usable LSTs.

Do make use of the uncertainty information.

Do make use of all the appropriate metadata and ancillary data (such as land cover and snow/ice information) available in the files.

Do tell us what you think of the data!

Don't forget to use the individual uncertainty components and propagate uncertainty as recommended if averaging the data.

Don't assume that because the grid spacing of the L3C products is 0.05° that LST features that fine are necessarily resolved.

3.4. Contact us

Our email address is djg20@le.ac.uk (Darren Ghent, Scientific leader of LST_cci) and our website is https://climate.esa.int/en/projects/land-surface-temperature.

For help related to polar orbiting TIR products specifically you can also contact klv3@le.ac.uk (Karen Veal, LST_cci scientist). For microwave products you can also contact carlos.jimenez@estellus.fr (Carlos Jimenez, LST_cci scientist). For geostationary TIR products you can also contact sofia.ermida@ipma.pt (Sofia Ermida, LST_cci scientist).

We are happy to answer queries about the data and also very much welcome any feedback on the data.

3.5. Frequently asked questions

Here we provide explanations for some of the questions that you may have asked when reading the preceding text.

3.5.1. What is Land Surface Temperature?

The Land Surface Temperature (LST) is a measure of how hot or cold the "surface" of the Earth would feel to the touch. It is the mean radiative temperature of all objects comprising the surface, as measured by ground-based, airborne, and spaceborne remote sensing instruments. LST is not the same as Land Surface Air Temperature or soil temperature.

3.5.2. What is a brightness temperature?

An instrument measures the number/energy of photons represented as counts on a detector. Raw counts are subsequently converted into calibrated radiances, which are transformed to calibrated Brightness Temperatures (BTs). A BT is therefore a measure of the calibrated radiance detected by the satellite from the top of the Earth's atmosphere, or by a ground-based instrument, expressed as an equivalent blackbody temperature. IR and MW radiances are often, but not always, given as BTs in Level 1 products.

3.5.3. What do we mean by LST retrieval?

The LST is estimated (retrieved) from radiances measured in different wavelength bands (channels) from satellite instruments which measure radiances at the top of the atmosphere. A retrieval method must account for both attenuation of surface emitted radiation by the atmosphere and radiation emitted by the atmosphere towards the instrument. The atmosphere component can be estimated by inputting information on the atmosphere from elsewhere, or by fitting statistical relationships to the well-known variation of brightness temperature with variations of water vapour and atmosphere temperature.

Even if the atmospheric state is known, the LST problem is under-determined because the surface radiance at a particular wavelength depends on both the surface emissivity at that wavelength and the LST so that there is always one more unknown than there are channel radiances: emissivity for each channel plus the LST.

Various algorithms can be used in the retrieval of LST including Split Window (SW), neural network (NN) algorithms, Temperature and Emissivity Separation (TES), and Optimal Estimation (OE). More information on these algorithms can be found in [AD-3].

3.5.4. Geostationary or polar orbiting platform?

Satellites in geostationary orbit circle the Earth above the equator at the same angular speed as the Earth. This means that they have a near fixed view of the Earth's surface, observing nearly the same area on the Earth's surface at all times and allowing resolution of the diurnal temperature cycle. For example, the SEVIRI instrument scans a wide field of view that includes Africa, South America and the Atlantic Ocean every 15 minutes. However, although the temporal resolution is high for geostationary platforms the spatial resolution is coarser (around 3-5 km compared with around 1 km for polar orbiters). Furthermore, each satellite only observes one region and there are high satellite zenith angles at the edge of the viewed disc which affect LST data quality at high latitudes.

Polar orbiting satellites pass around the Earth over or close to each pole in turn, alternating between day and night time. Most polar orbiting satellites are in sun-synchronous orbits, which are polar orbits where the orbit precesses at the same rate as the Earth revolves around the Sun and have the property that the satellite crosses a given latitude at the same local solar time on each orbit. Instruments on polar orbiting satellites view the whole of the Earth's surface from twice daily to a few days depending on instrument swath width. The majority of these instruments have spatial resolutions of approximately 1 km or higher. Each view of a location may occur with a different satellite zenith and azimuth angle than other views of the same location, which can result in varying LST data across the swath even for a homogeneous scene and is important for instruments with high swath such as MODIS and SLSTR.

3.5.5. Infrared or Microwave?

LST data derived from IR measurements usually use two wave bands: one at around 10.8 µm and one at around 12 µm. However, retrieval algorithms exist that use only one band or more than two bands (such as the TES algorithm). The bands used lie in so-called atmospheric windows – where water vapour absorption is low. Infrared soil penetration is of the order of a few microns and represents the surface skin temperature to a depth of around 50 µm. For densely vegetated regions the IR LST is the skin temperature of the vegetation canopy. LSTs cannot be retrieved through cloud from IR radiometers because IR radiation is absorbed by clouds. Aerosols also affect IR wavelengths and will prevent accurate LST retrieval. Aerosol impacted retrievals are often flagged in products or with associated auxiliary data. The spatial resolution of IR products is high, typically a few kilometres for geostationary satellite instruments, and 1 km or less for instruments on polar orbiting satellites.

MW surface data products are also based on observing at atmospheric windows in the MW spectrum. Frequencies in the Ka band (37 GHz) are typically used for LST estimation as this band balances and reduces sensitivity to soil characteristics with a high atmospheric transmissivity.

A few important things should be noticed when using MW LST, compared with the IR LST:

- MW land surface emission is minimally altered by the majority of clouds, allowing MW data products to provide all-sky retrievals (in both clear and cloudy conditions). An exception is the very optically thick clouds typically associated to convective and precipitating conditions, where emission from the liquid water or scattering from the ice phase can alter the surface emission.
- The spatial resolution of MW products tends to be in the order of tens of kilometres, being much coarser than the typical IR products. Therefore, it is more difficult in the MW to remove "no-land" areas, such a water bodies, and spatially averaged microwave LST is more subject to "no-land" contamination. A typical example are coastal areas, where IR LST can provide better spatial coverage for the coastline.

- The MW LST will represent the surface for a varying depth as the penetration depth depends both on MW frequency and moisture of the observed surface. Penetration can be up to tens of centimetres in very dry sand deserts at the frequencies used in this retrieval but is limited to a few centimetres at most for moist soils. MW can also penetrate snow and ice, depending on the frequency and snow/ice wetness. Therefore, the MW derived LST is not strictly the skin temperature measured in the IR.
- LST retrievals at MW wavelengths are more uncertain than the IR retrievals. This is due to the smaller variation of surface emissivity in the IR and their independence of measurements.

3.5.6. Why should I care about all those angles?

Satellite and solar, azimuth and zenith angles are provided with LST_cci satellite data. These angles give the user information about the angle from which the satellite views the surface and the relative position of the sun.

LST varies with satellite view angle (zenith angle) and local Sun position, by up to 2-4 K. The satellite zenith angle increases from the centre to the edge of the swath. Changing the satellite zenith angle changes what the instrument “sees”, and therefore measures, and the emissivities of bare soil and water decrease with increasing satellite zenith angle. Angular anisotropy due to emissivity is an issue for daytime and night-time LST. During the day incoming solar radiation, inhomogeneity of evaporation and shadowing cause angular dependency of LST. Confidence in the LST is greatest at low satellite and low solar zenith angles.

3.5.7. To which time do the observations correspond (view time)?

A measurement time is given for each pixel, usually in UTC. In LST_cci files a reference time (nominal start time of the file) and a time difference to the reference time for each pixel provide the measurement time in UTC. It should be noted that the Level 3 products may contain LSTs at different times depending on the time over which the data are collated. Polar orbiting, sun-synchronous satellite LSTs will contain temperatures with times ‘close’ to a common local solar time. The actual local time will depend on the position of the pixel on the original orbit swath: pixels that are closer to the equator will have observation times closer to the nominal overpass time, the local time of observations will also vary across the swath. For geostationary satellites, the pixel observation time will be close to a common UTC time but will also depend on the instrument scan duration and pattern.

3.5.8. Why is the land cover type (biome) important?

The surface of the Earth can be described by a set of discrete land cover types, one of which can be assigned to each location on the Earth. Locations do sometimes display dynamic change of biomes through the seasons or quite heterogeneous complexity. Nonetheless, land cover typing is improving rapidly as more visible and synthetic aperture radar sensors come on-stream.

There are two reasons why land cover type or biome is important for LST data sets. First of all, LST and emissivity both depend on land cover as well as other factors. Hence one would not expect two adjacent pixels with different land cover types to have the same LST. Secondly, LST uncertainties will vary with land cover type due to differing uncertainties in the retrieval coefficients per biome. There may also be uncertainties or errors in land cover type assignment which will result in corresponding effects in the LST data themselves from errors in retrieval coefficients or cloud masking, if this is dependent on land cover. Therefore consideration of the biome, which categorises the generic type of land cover, is relevant in any interpretation of the LST data.

Fractional vegetation cover (fraction of an area covered by green vegetation) is also relevant to LST science. For LST retrievals, this parameter is often used to infer emissivity given emissivities for the fully vegetated or low vegetation states. At the fine scale, in areas of mixed land use, mixed vegetation, or high topography the composition of the land cover affects the amount of sunlit / shadow area within a satellite pixel FOV. This consideration is related to the viewing geometry of the satellite instrument.

3.5.9. Why are there gaps in my data?

As mentioned above, cloud and aerosol will prevent accurate IR LST retrieval. There may be gaps in coverage due to the instrument not observing the whole grid in the time frame of the product (for example a narrow swath sensor such as ATSR-2 will not have complete global coverage in one day so grids of daily average data will have incomplete coverage). There are also times when the instrument may not be observing the Earth because of maintenance to the satellite and/or instrument anomalies.

3.5.10. Error or uncertainty?

Error is the result of a measurement minus a true value (often unknown) of the measurand, the “wrongness” of the measured value. For satellite derived LSTs the true value of LST cannot be determined and therefore we talk about uncertainty (the “doubt” given our knowledge of the measured value the effects causing the errors), rather than error, in these measurements. All LST observations will have an associated uncertainty estimate due to effects such as atmospheric attenuation and variability of surface emissivities that are not known to sufficient accuracy.

3.5.11. What constitutes a merged dataset?

Merged datasets in LST_cci are Level 3S products, where data from more than one instrument are combined after the removal of inter-instrument biases.

3.5.12. Why merge data?

Satellite data products have gaps in coverage – the major cause of gaps in the case of IR products is cloud. Merging data from two instruments, especially if MW is used, can increase spatial coverage. In addition, combining data from different satellites with different overpass times improves temporal resolution – a geostationary instrument that observes near-continuously can be used to remove inter-instrument biases between two polar orbiters. A final benefit is extension to the length of a dataset.

4. ESA LST_cci Product Fact Sheets

In this section, the key features of the ESA LST_cci data are listed. A table of features is provided for each instrument (or instrument series) used to produce ESA LST_cci single-sensor ECV products and CDRs. A summary of validation statistics is provided for some of the products. More detail can be found in the ESA LST_cci Product Validation and Intercomparison Report [AD-5].

4.1. ATSR LST ECV Products

ATSR LST ECV products from ESA LST_cci are climate records formed from single satellite sensors: ATSR_2 (internally represented as ATSR_2) and AATSR (internally represented as ATSR_3). Further information is given in the Tables below. Examples of the data are provided in plots below each table.

Table 4: Information evaluating the ERS-2_ATSR__L3C_0.01 product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci ATSR-2 ECV product version 3.0
Dataset notation	ERS-2_ATSR__L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed heritage data records spanning two ATSR sensors (ATSR-2 and AATSR), which have very high radiometric stability.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	August 1995 – June 2003
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	Full orbit files (~100 minutes) gridded to day and night composites
Timeliness of new data	Not currently being extended
Dataset volume	~140 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Along-Track Scanning Radiometer (ATSR) series of infrared sensors comprises three instruments. Two are included in the ESA LST_cci ATSR data products: ATSR-2 on ERS-2 (1995-2001) and AATSR on Envisat (2002-2012).
Dependence on other data	Dependant on ULeic / LandCover_cci (LCCS) hybrid biome classification data, Copernicus Global Land Service FCOVER dataset [RD-9], and ERA-5 TCWV [RD-10].
Traceability	Not yet established

Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	-1.79 K/decade < trend < -0.59 K/decade
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	[RD-5]
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

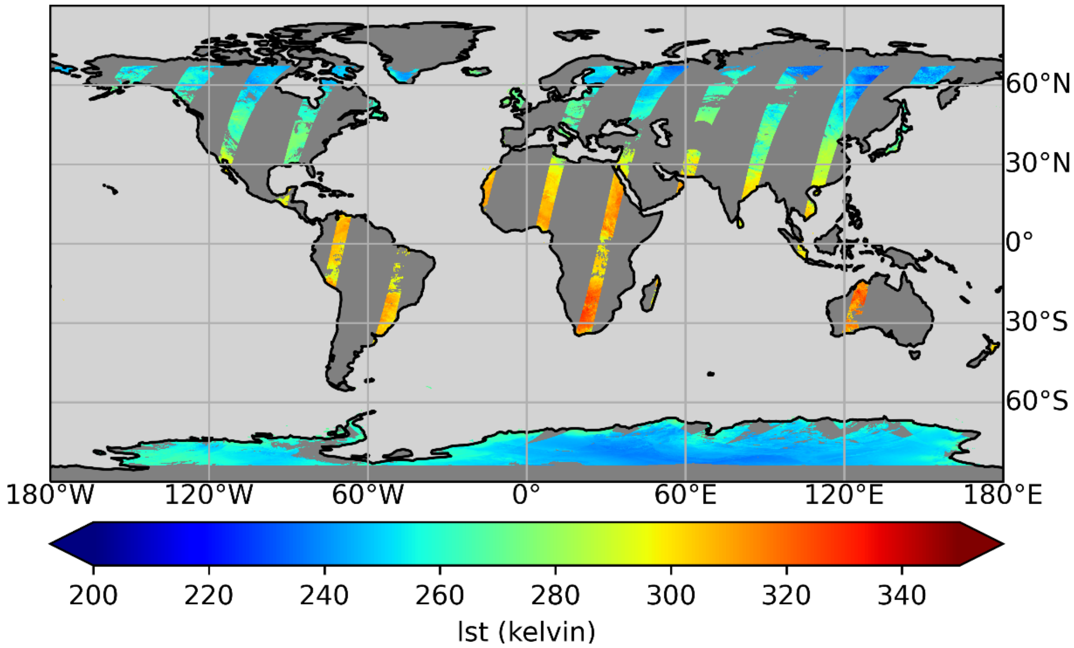

Figure 1: Example of ERS-2_ATSR__L3C_0.01 daily night-time data for 2nd January 2002. This data is provided as all night-time data for a day of orbits in each file. Cloud masking has been applied to this data.

Table 5: Information evaluating the ESA LST_cci AATSR ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci AATSR ECV product version 3.0
Dataset notation	ENVISAT_ATSR__L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed heritage data records spanning two ATSR sensors (ATSR-2 and AATSR), which have very high radiometric stability.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	July 2002 – April 2012
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	Full orbit files (~100 minutes) gridded to day and night composites
Timeliness of new data	Not currently being extended
Dataset volume	~200 GB
Valid data fraction	LST from clear-sky observations only

Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Along-Track Scanning Radiometer (ATSR) series of infrared sensors comprises three instruments. Two are included in the ESA LST_cci ATSR data products: ATSR-2 on ERS-2 (1995-2001) and AATSR on Envisat (2002-2012).
Dependence on other data	Dependant on ULeic / LandCover_cci (LCCS) hybrid biome classification data, Copernicus Global Land Service FCOVER dataset [RD-9], and ERA-5 TCWV [RD-10].
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	-0.05 K/decade < trend < 0.68 K/decade
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	[RD-5]
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

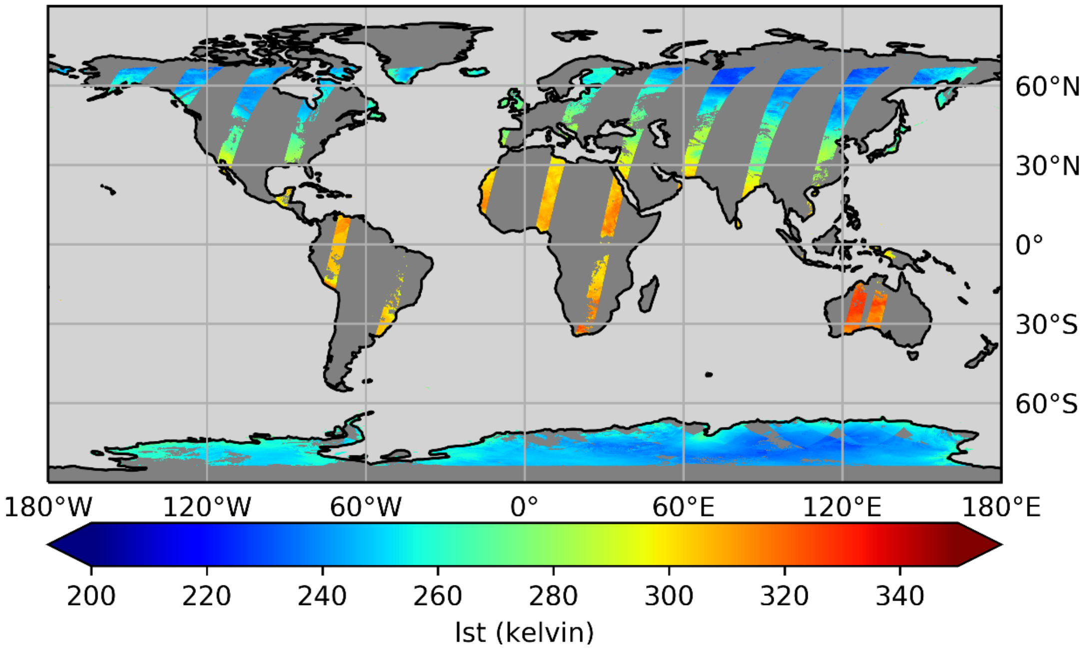

Figure 2: Example of ENVISAT_ATSR__L3C_0.01 daily daytime data for 1st January 2010. This product collates several orbits in each file. Cloud masking has been applied to this data.

4.2. MODIS LST ECV Products

MODIS LST ECV products from ESA LST_cci are climate records formed from single satellite sensors: MODIS Terra (internally represented as MODIST) and MODIS Aqua (internally represented as MODISA). Further information is given in the Tables below. Examples of the data are provided in plots below each table.

Table 6: Information evaluating the ESA LST_cci MODIS Terra ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci MODIS Terra ECV product version 3.0
Dataset notation	TERRA_MODIS_L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed long-term data records spanning two MODIS sensors (Terra and Aqua).
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	February 2000 – December 2018
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	5 minute granules gridded to day and night composites
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~1.2 Tb

Valid data fraction	LST from clear-sky observations only
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Moderate Resolution Imaging Spectroradiometer (MODIS) series of infrared sensors comprises two instruments, both of which are included in the ESA LST_cci MODIS data products: MODIS on Terra (2000-2018) and MODIS on Aqua (2002-2018).
Dependence on other data	Dependant on the CAMEL V2 Global Infrared Land Surface Emissivity Database [RD-11]
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	0.01 K/decade < trend < 0.43 K/decade
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	[RD-6]
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

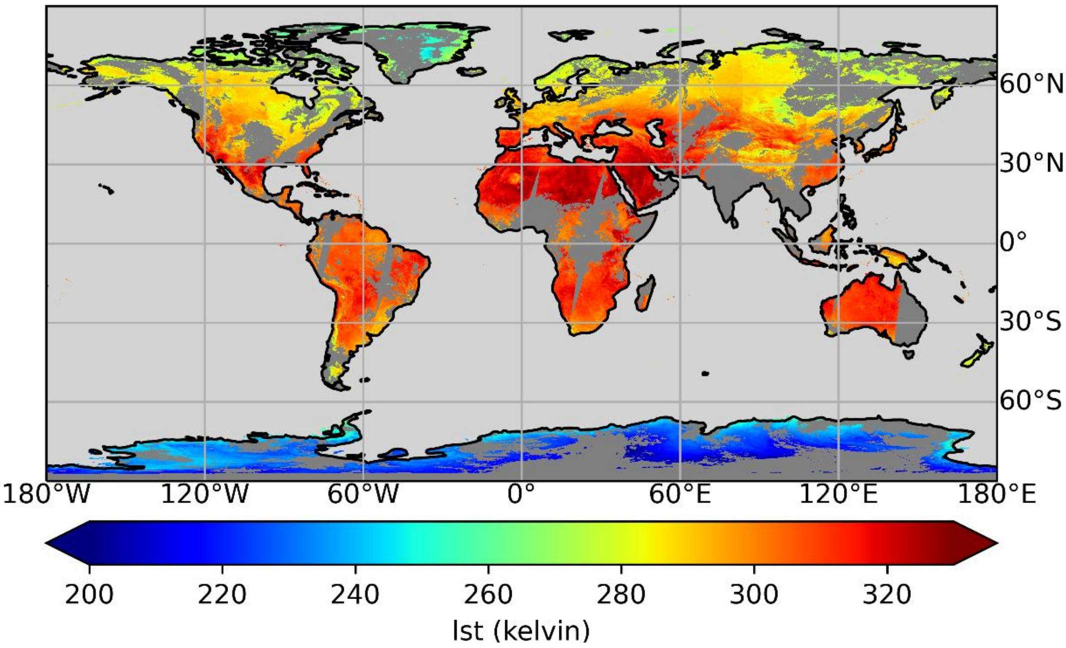

Figure 3: Example of TERRA_MODIS_L3C_0.01 daily daytime data for 15th September 2011. This product collates several orbits in each file. Cloud masking has been applied to this data.

Table 7: Information evaluating the ESA LST_cci MODIS Aqua ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci MODIS Aqua ECV product version 3.0
Dataset notation	AQUA_MODIS_L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed long-term data records spanning two MODIS sensors (Terra and Aqua).
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	July 2002 – December 2018
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	5 minute granules gridded to day and night composites
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~1.1 Tb
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Moderate Resolution Imaging Spectroradiometer (MODIS) series of infrared sensors comprises two

	instruments, both of which are included in the ESA LST_cci MODIS data products: MODIS on Terra (2000-2018) and MODIS on Aqua (2002-2018).
Dependence on other data	Dependant on the CAMEL V2 Global Infrared Land Surface Emissivity Database [RD-11]
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	-0.21 K/decade < trend < 0.26 K/decade
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	[RD-6]
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

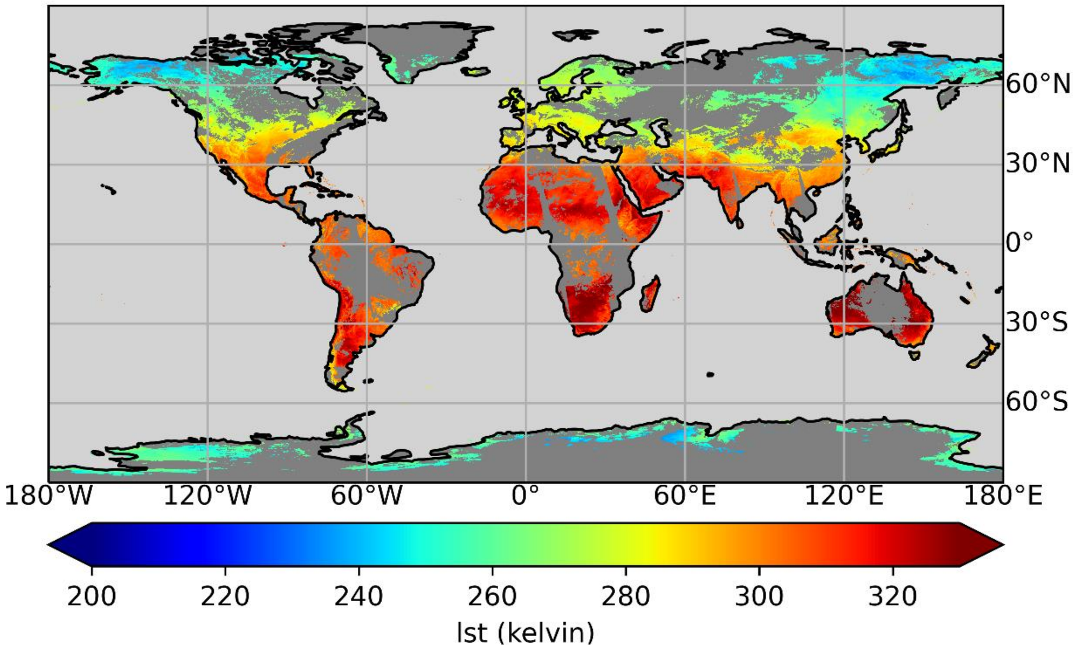

Figure 4: Example of AQUA_MODIS_L3C_0.01 daily daytime data for 15th September 2011. This product collates several orbits in each file. Cloud masking has been applied to this data.

4.3. SLSTR LST ECV Product

SLSTR LST ECV products from ESA LST_cci are climate records formed from single satellite sensors, currently comprising SLSTR on Sentinel-3A (internally represented as SLSTRA) and Sentinel-3B (internally represented as SLSTRB). Further information is given in the Tables below. Examples of the data are provided in plots below each table.

Table 8: Information evaluating the ESA LST_cci SLSTR 3A ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci SLSTR 3A ECV product version 1.0
Dataset notation	SENTINEL3A_SLSTR_L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed data from the SLSTR sensor on the Sentinel 3A platform, which has very high radiometric stability.
Principal recommended applications	Local to global climate applications requiring recent data; particularly applications requiring stable, low bias records of LST
Key Descriptive Features	
Period covered	May 2016 – December 2020
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	3 minute granules gridded to day and night composites

Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~180 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Sea and Land Surface Temperature Radiometer (SLSTR) series of infrared sensors currently comprises two instruments both of which are included in the ESA LST_cci SLSTR data products: SLSTR on Sentinel-3A (2016-2020) and SLSTR on Sentinel-3B (2018-2020).
Dependence on other data	Dependant on ULeic / LandCover_cci (LCCS) hybrid biome classification data, Copernicus Global Land Service FCOVER dataset [RD-9], and ERA-5 TCWV [RD-10].
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

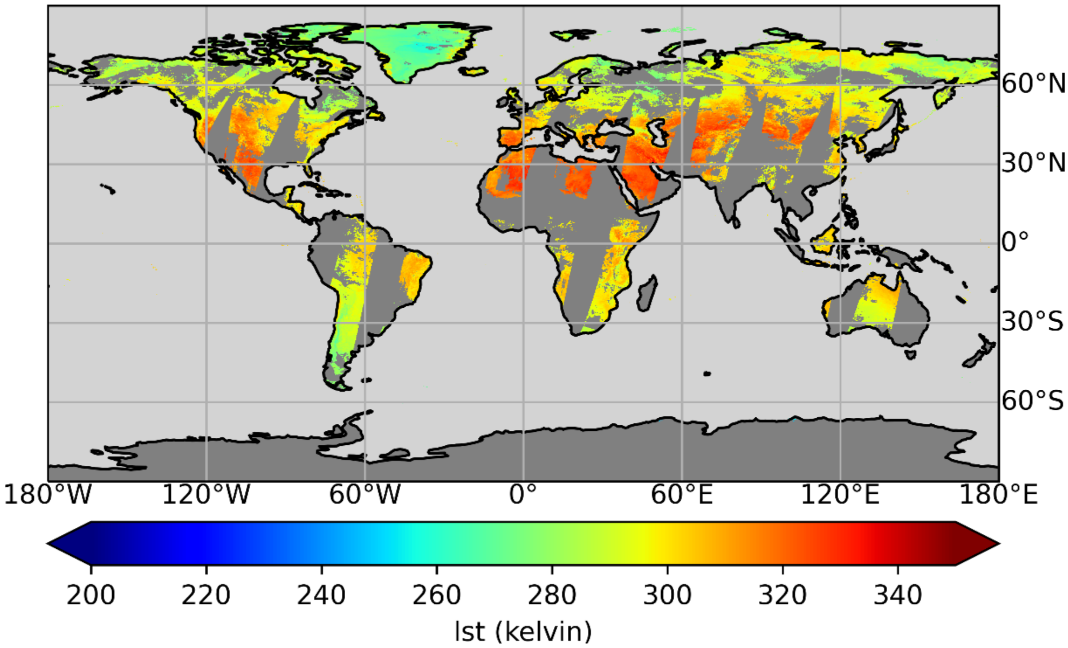

Figure 5: Example of SENTINEL3A_SLSTR_L3C_0.01 daily daytime data for 3rd August 2019. This product collates several orbits in each file. Cloud masking has been applied to this data.

Table 9: Information evaluating the ESA LST_cci SLSTR 3B ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci SLSTR 3B ECV product version 1.0
Dataset notation	SENTINEL3B_SLSTR_L3C_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed data from the SLSTR sensor on the Sentinel 3B platform, which has very high radiometric stability.
Principal recommended applications	Local to global climate applications requiring recent data; particularly applications requiring stable, low bias records of LST
Key Descriptive Features	
Period covered	November 2018 – December 2020
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	3 minute granules gridded to day and night composites
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~80 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The Sea and Land Surface Temperature Radiometer

	(SLSTR) series of infrared sensors currently comprises two instruments both of which are included in the ESA LST_cci SLSTR data products: SLSTR on Sentinel-3A (2016-2020) and SLSTR on Sentinel-3B (2018-2020).
Dependence on other data	Dependant on ULeic / LandCover_cci (LCCS) hybrid biome classification data, Copernicus Global Land Service FCOVER dataset [RD-9], and ERA-5 TCWV [RD-10].
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

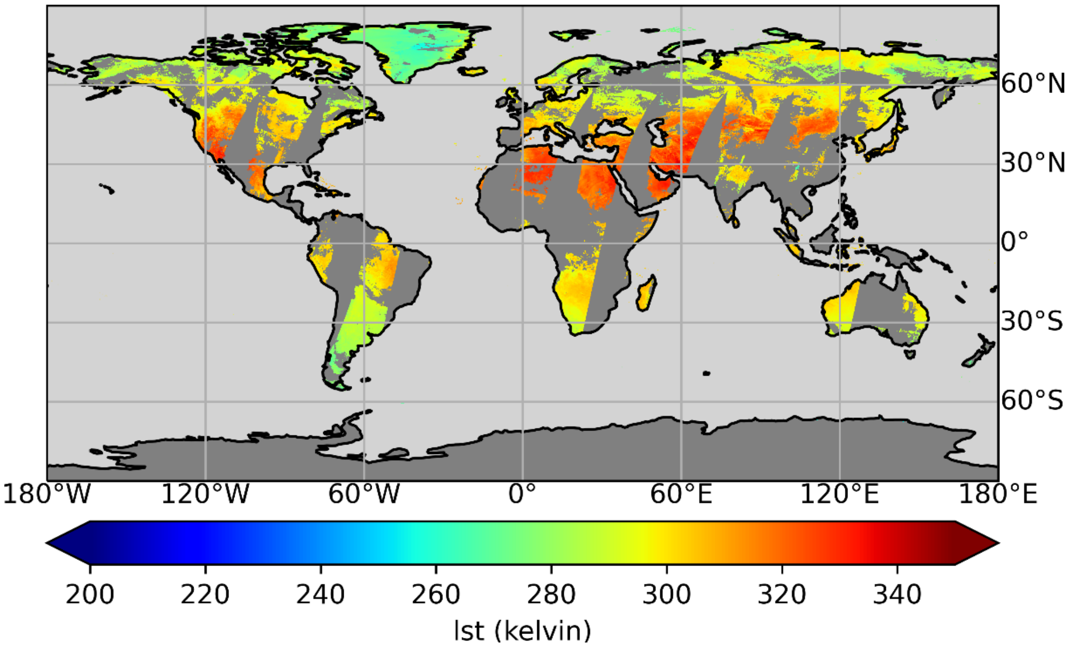

Figure 6: Example of SENTINEL3B_SLSTR_L3C_0.01 daily daytime data for 3rd August 2019. This product collates several orbits in each file. Cloud masking has been applied to this data.

4.4. SEVIRI LST ECV Product

SEVIRI LST ECV products from ESA LST_cci are climate records formed from single satellite sensors: MSG SEVIRI (internally represented as SEVIRI). Further information is given in the Table below.

Table 10: Information evaluating the ESA LST_cci SEVIRI ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci SEVIRI ECV product version 3.0
Dataset notation	MSGx_SEVIRI_L3U (where x is 1-4)
Lead Investigator and/or Agency	Isabel Trigo, IPMA
Principal strengths of data set	Consistently processed high temporal resolution data spanning all MSG platforms. Each dataset is a separate LST ECV product.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	January 2004 – December 2020
Geographic range	Europe, Africa and part of South America
Satellite orbit	Geostationary (GEO)
Spatial resolution	0.05°
Temporal resolution	Hourly
Timeliness of new data	To be extended in Phase-2 of LST_cci project.

Dataset volume	~2.5 Tb
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3U / regular latitude-longitude grid
Observational technology	The Spinning Enhanced Visible and Infrared Imager (SEVIRI) infrared sensor is available in four platforms. All are included in the ESA LST_cci SEVIRI data products: Meteosat-8 (2004-2007), Meteosat-9 (2007-2013), Meteosat-10 (2013-2018), Meteosat-11 (2018-2020)
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	Not yet evaluated
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	sofia.ermida@ipma.pt
Other Documentation	[RD-7]

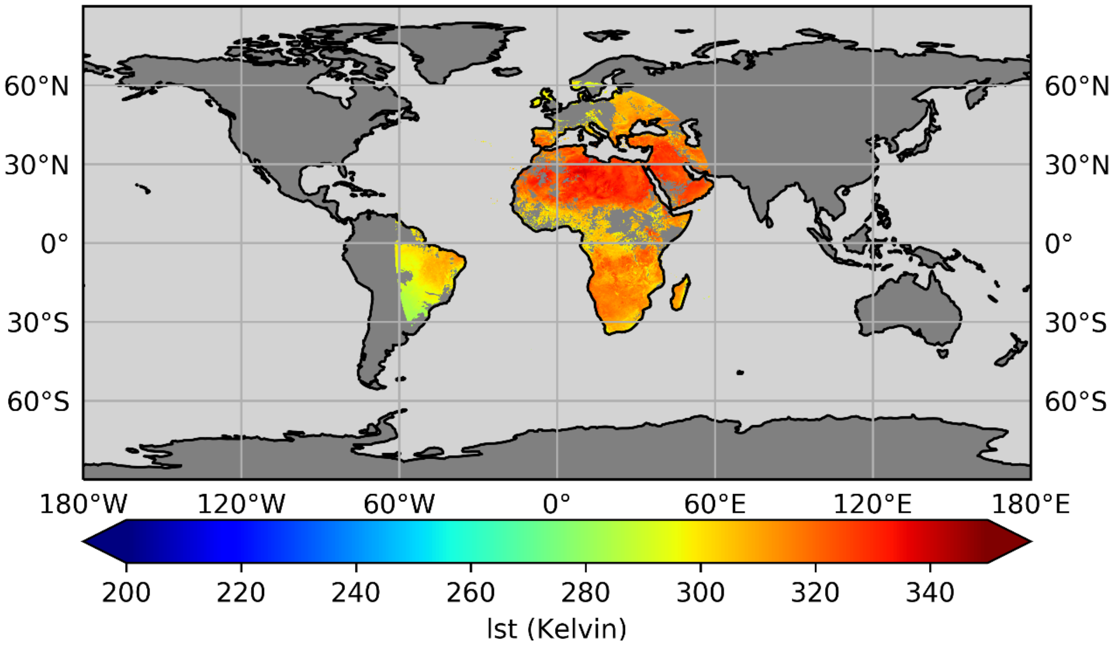

Figure 7: Example of MSG_SEVIRI_L3U data for 15th August 2010 at 12:00. This product contains one orbit in each file. Cloud masking has been applied to this data.

4.5. GOES LST ECV Product

GOES LST ECV products from ESA LST_cci are climate records formed from single satellite sensors: the IMAGER onboard GEOS12 and GOES13 (internally represented by GOES12 and GOES13, respectively), and the ABI onboard GOES16 (internally represented by GOES16). Further information is given in the Table below.

Table 11: Information evaluating the ESA LST_cci GOES ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci GOES ECV product version 1.0
Dataset notation	GOESx_IMAGER_L3U (where x is 12-13) GOES16_ABI_L3U
Lead Investigator and/or Agency	Isabel Trigo, IPMA
Principal strengths of data set	Consistently processed high temporal resolution data spanning all GOES platforms. Each dataset is a separate LST ECV product.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	August 2009 – December 2020

Geographic range	North and South America
Satellite orbit	Geostationary (GEO)
Spatial resolution	0.05°
Temporal resolution	3-Hourly (GOES12-13) / Hourly (GOES16)
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~550 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3U / regular latitude-longitude grid
Observational technology	The Imager / Advanced Baseline Imager (ABI) infrared sensors are available on three platforms; all are included in the ESA LST_cci GOES data products: GOES-12 (2009-2010), GOES-12 (2010-2017), GOES-16 (2018-2020).
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	Not yet evaluated
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	sofia.ermida@ipma.pt
Other Documentation	[RD-7]

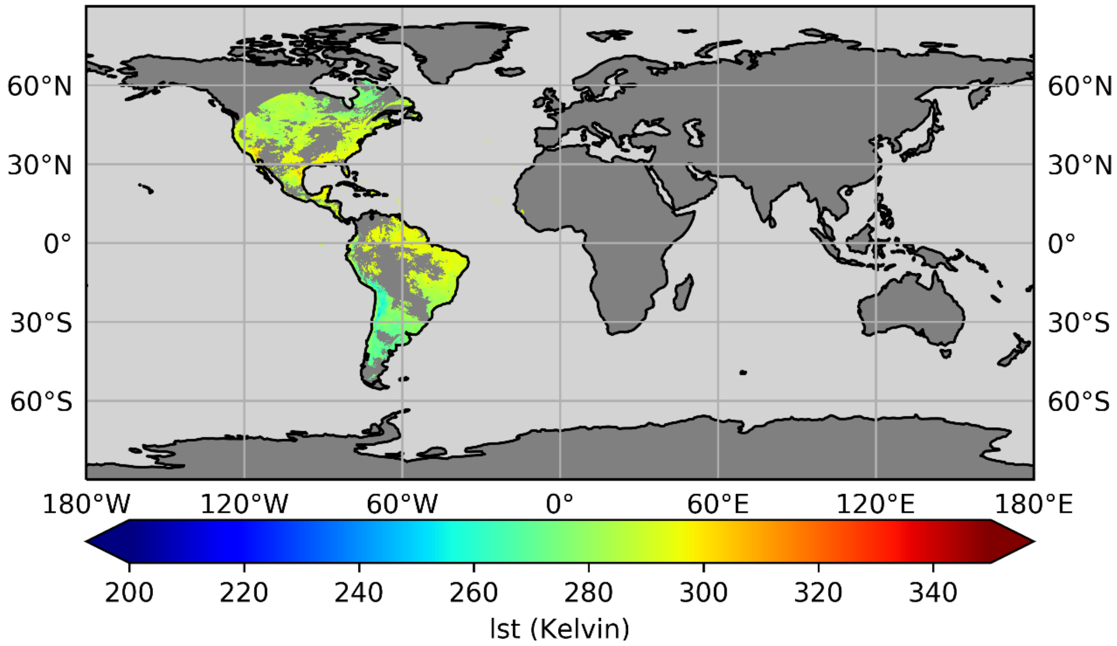

Figure 8: Example of GOES16_ABI_L3U data for 15th August 2018 at 09:00. This product contains one orbit in each file. Cloud masking has been applied to this data.

4.6. MTSAT LST ECV Product

MTSAT LST ECV products from ESA LST_cci are climate records formed from single satellite sensors: the JAMI onboard MTSAT1 and MTSAT2 (internally represented by MTSAT1 and MTSAT2, respectively). Further information is given in the Table below.

Table 12: Information evaluating the ESA LST_cci MTSAT ECV product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci MTSAT ECV product version 1.0
Dataset notation	MTSATx_JAMI_L3U (where x is 1-2)
Lead Investigator and/or Agency	Isabel Trigo, IPMA
Principal strengths of data set	Consistently processed high temporal resolution data spanning all MTSAT platforms. Each dataset is a separate LST ECV product.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	August 2009 – December 2015
Geographic range	Australia and part of Asia
Satellite orbit	Geostationary (GEO)

Spatial resolution	0.05°
Temporal resolution	3-Hourly
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~210 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3U / regular latitude-longitude grid
Observational technology	The Japanese Advanced Meteorological Imager (JAMI) infrared sensor is available on two platforms; both are included in the ESA LST_cci MTSAT data products: MTSAT-1 (2009-2010), MTSAT-2 (2010-2015).
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Night-time biases are generally within ± 2.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	Not yet evaluated
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	sofia.ermida@ipma.pt
Other Documentation	[RD-7]

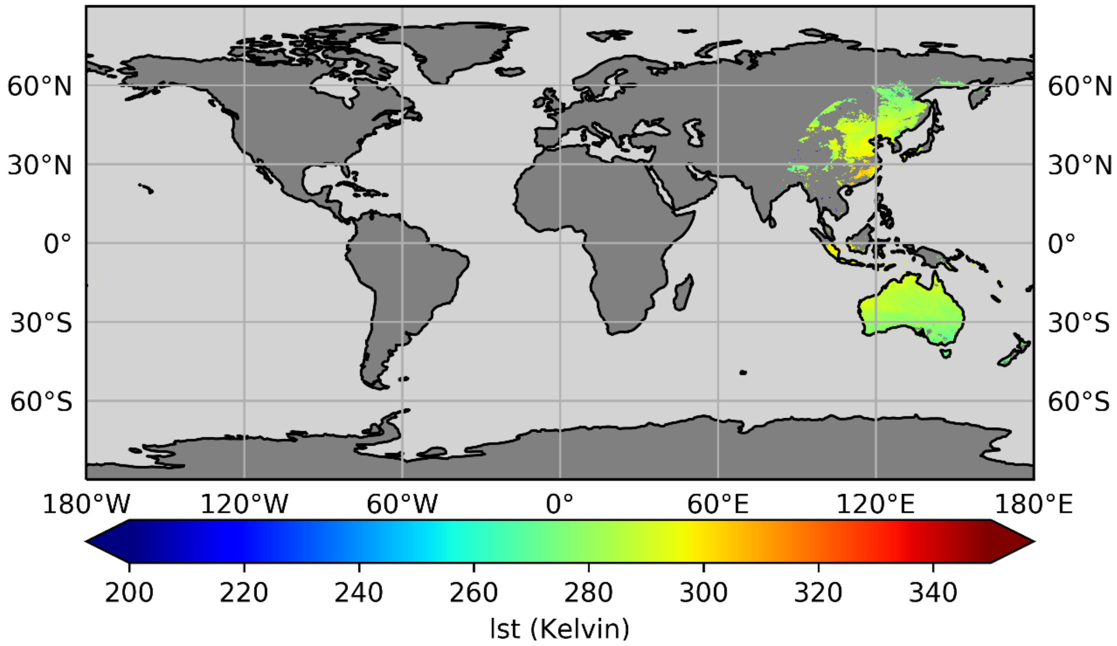

Figure 9: Example of MTSAT1_JAMI_L3U data for 15th August 2012 at 15:00. This product contains one orbit in each file. Cloud masking has been applied to this data.

4.7. SSM/I and SSMIS LST CDR Product

The SSM/I-SSMIS LST CDR product from ESA LST_cci is a climate record formed from single satellite sensors, currently comprising the SSM/I instrument onboard the DMSP satellite F13 (1996-2008) (internally represented as SSMI13), and the SSMIS onboard the F17 (2009-2020) (internally represented as SSMI17). The use of F13 and F17 inter-calibrated radiances as inputs to a common retrieval algorithm for both instruments assume some consistency in the SSM/I and SSMIS LST time series, but studies using the full 1996-2020 time period should be aware of possible stability issues due to potentially unresolved inter-calibration issues. Independent of the quality of the inter-calibration, the stability of the SSM/I and SSMIS time series is also compromised by the change in the observing local times due to orbital drift of the DMSP satellites. The impact of this local time drift is visible in the observed LST time series, especially at places with a strong diurnal cycle due to the significant changes in LST with time. If the SSM/I and SSMIS LSTs are considered together, there is an abrupt change of around one hour in local time when switching instruments at the beginning of 2009, which produces a noticeable discontinuity of a few kelvins in the LST time series. To mitigate this issue, an optional LST offset that adjusts the time series to a fixed 6 AM/PM local time is also provided in the SSM/I and SSMIS climate records. Notice that this time adjustment increases the stability of the data record, but it adds uncertainty to the final LST estimate. Further information is given in the Table below.

Table 13: Information evaluating the ESA LST_cci SSM/I-SSMIS CDR product as a climate record.

Summary	
Status of assessment	Assessed in the PVIR [AD-5].
Dataset name and version	ESA LST_cci SSM/I-SSMIS CDR version 2.23
Dataset notation	SSMI_SSMIS_L3C
Lead Investigator and/or Agency	Carlos Jimenez, Estellus
Principal strengths of data set	Consistently processed all-sky data currently spanning two sensors on DMSP satellite platforms to form a 25-year long climate data record.
Principal recommended applications	Climate research; particularly applications requiring all-sky records of LST
Key Descriptive Features	
Period covered	January 1996 – December 2020
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.25°
Temporal resolution	Twice per day at 6 AM/PM local times
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~50 GB
Valid data fraction	LST from clear-sky and cloudy observations
Data level / grid	L3C / regular latitude-longitude grid
Observational technology	The MW instruments SSM/I and SSMIS are operated onboard the Defense Meteorological Satellite Program (DMSP) satellites. Two DMSP platforms are used to complete the full time series: F13, carrying the SSM/I instrument (1996-2008), and F17 (2008-2020), carrying the SSMIS instrument.
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty. Components of uncertainty from effects with different spatiotemporal correlation scales will be provided in next versions.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Daytime and night-time biases are generally within ± 4.0 K of in situ stations [AD-5].
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	0.10 K/decade < trend < 0.25 K/decade (with the time adjustment applied).
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in*	Not yet evaluated

the dataset, the difference from 100% representing the weight of prior information in the LSTs	
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	carlos.jimenez@estellus.fr
Other Documentation	None currently available

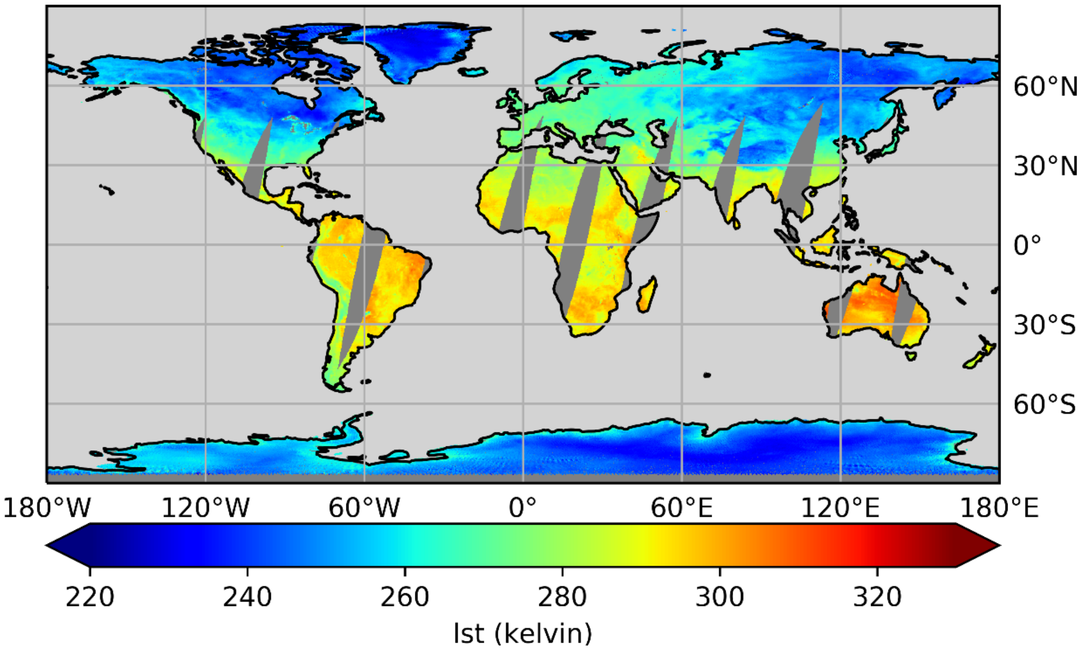

Figure 10: Example of SSMI_SSMIS_L3C daily ascending data. This product collates several orbits in each file.

4.8. ATSR-SLSTR LST CDR Product

Climate records produced from combining data from different satellite sensors that have been harmonised through intercalibration. The ATSR-SLSTR CDR product combines ATSR-2 and AATSR (internally represented as ATSR_2 or ATSR_3), Terra MODIS (internally represented as MODIST), and SLSTR on Sentinel-3A (internally represented as SLSTRA). The climate record is produced by first intercalibrating between sensors using IASI as a reference sensor in accordance with GSICS methodology, and then adding the temporal correction detailed in [AD-4] to any sensor not nominally at the LECT of the chosen reference sensor. In this climate record Terra MODIS is the reference sensor.

Table 14: Information evaluating the ESA LST_cci ATSR-SLSTR LST CDR product as a climate record.

Summary	
Status of assessment	Not yet evaluated
Dataset name and version	ESA LST_cci ATSR LST CDR product version 2.0
Dataset notation	MULTISENSOR_IRCDR_L3S_0.01
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed data spanning two ATSR sensors (ATSR-2 and AATSR), one MODIS sensor (on Terra), and one SLSTR sensor on Sentinel-3A). The data is harmonised across sensors and corrected to a common local equatorial crossing time.
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	August 1995 – December 2020
Geographic range	Global
Satellite orbit	Low Earth (LEO) sun synchronous
Spatial resolution	0.01°
Temporal resolution	Daily (daytime and night-time)
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~500 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3S / regular latitude-longitude grid
Observational technology	The Along-Track Scanning Radiometer (ATSR) series of infrared sensors comprises three instruments; two are included in the ESA LST_cci ATSR-SLSTR CDR: ATSR-2 on ERS-2 (1995-2002) and AATSR on Envisat (2002-2012). The Moderate Resolution Imaging Spectroradiometer (MODIS) series of infrared sensors comprises two instruments; one of which is included in the ESA LST_cci ATSR-SLSTR CDR: MODIS on Terra (2012-2016). The Sea and Land Surface Temperature Radiometer (SLSTR) series of infrared sensors currently comprises two instruments; one of which is included in the ESA LST_cci ATSR-SLSTR CDR: SLSTR on Sentinel-3A (2016-2020).
Dependence on other data	Dependant on ULeic / LandCover_cci (LCCS) hybrid biome classification data, Copernicus Global Land Service FCOVER dataset [RD-9], and ERA-5 TCWV [RD-10].
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference	Not yet evaluated

Global median difference of satellite minus reference across the full dataset.	
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and mean near-surface air temperature from the homogenized EUSTACE dataset*	-0.41 K/decade < trend < 0.25 K/decade for ATSR2-AATSR period
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

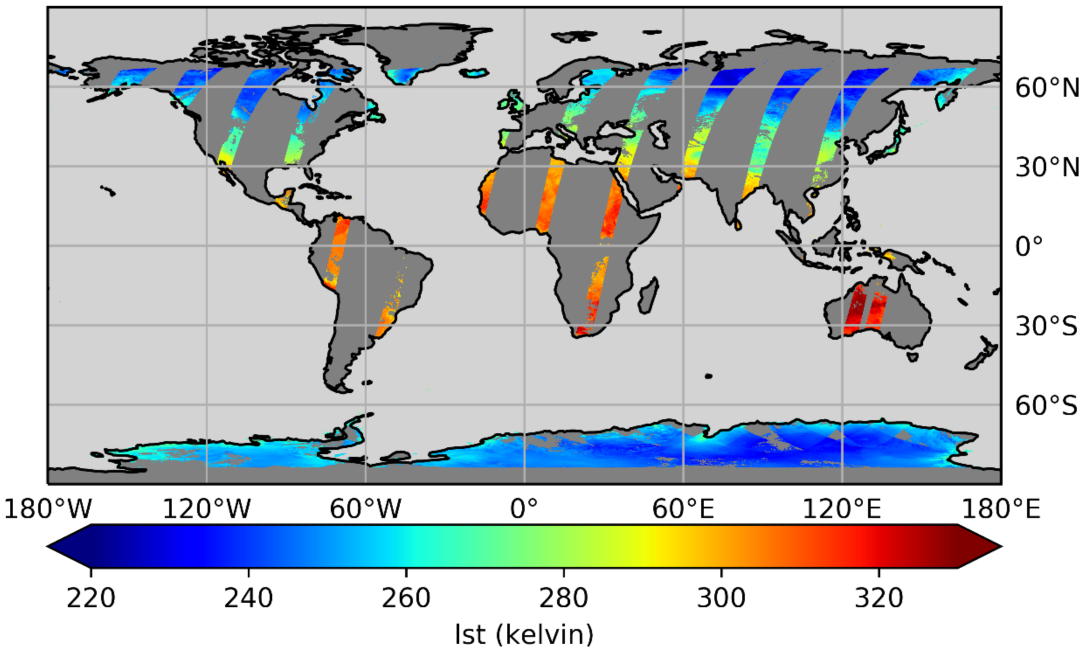

Figure 11: Example of MULTISENSOR_IRCDR_L3S_0.01 daily daytime data for 1st January 2010. This product collates several orbits in each file.

4.9. Merged GEO-LEO IR LST CDR Product

Climate records produced from combining data from different satellite geostationary and polar-orbiting sensors to resolve the global diurnal cycle. The Merged IR CDR product combines SEVIRI on MSG 1-4 (internally represented as SEVIR1, SEVIR2, SEVIR3 and SEVIR4), Imager / ABI on GOES 12, 13 and 16 (internally represented as GOES12, GOES13 and GOES16), JAMI on MTSAT 1-2 (internally represented as MTSAT1 and MTSAT2), ATSR-2 and AATSR (internally represented as ATSR_2 or ATSR_3), Terra and Aqua MODIS (internally represented as MODIST and MODISA), and SLSTR on Sentinel-3A and Sentinel-3B (internally represented as SLSTRA and SLSTRB).

Table 15: Information evaluating the ESA LST_cci Merged IR LST CDR product as a climate record.

Summary	
Status of assessment	Not yet evaluated
Dataset name and version	ESA LST_cci Merged IR LST CDR product version 1.0
Dataset notation	MULTISENSOR_IRMGP_L3S_0.05
Lead Investigator and/or Agency	Darren Ghent, University of Leicester
Principal strengths of data set	Consistently processed data with higher frequency to resolve the global diurnal cycle. This merges four SEVIRI sensors on MSG 1-4, three Imager / ABI sensors on GOES 12, 13 and 16; two JAMI sensors on MTSAT 1-2; two ATSR sensors (ATSR-2 and AATSR); two MODIS sensors (on Terra and Aqua); and two SLSTR sensors on Sentinel-3A and Sentinel-3B).
Principal recommended applications	Climate research; particularly applications requiring long-term, stable, low bias records of LST
Key Descriptive Features	
Period covered	January 2009 – December 2020
Geographic range	Global
Satellite orbit	Geostationary (GEO) + Low Earth (LEO) sun synchronous
Spatial resolution	0.05°
Temporal resolution	3-hourly
Timeliness of new data	To be extended in Phase-2 of LST_cci project.
Dataset volume	~110 GB
Valid data fraction	LST from clear-sky observations only
Data level / grid	L3S / regular latitude-longitude grid
Observational technology	The Spinning Enhanced Visible and Infrared Imager (SEVIRI) infrared sensor is available on four platforms. Three are included in the ESA LST_cci Merged IR CDR: Meteosat-9 (2007-2013), Meteosat-10 (2013-2018), Meteosat-11 (2018-2020). The Imager / Advanced Baseline Imager (ABI) infrared sensors are available on three platforms; all are included in the ESA LST_cci Merged IR CDR: GOES-12 (2009-2010), GOES-12 (2010-2017), GOES-16 (2018-2020). The Japanese Advanced Meteorological Imager (JAMI) infrared sensor is available on two platforms; both are included in the ESA LST_cci

	Merged IR CDR: MTSAT-1 (2009-2010), MTSAT-2 (2010-2015). The Along-Track Scanning Radiometer (ATSR) series of infrared sensors comprises three instruments; one is included in the ESA LST_cci Merged IR CDR: AATSR on Envisat (2002-2012). The Moderate Resolution Imaging Spectroradiometer (MODIS) series of infrared sensors comprises two instruments; both are included in the ESA LST_cci Merged IR CDR: MODIS on Terra (2009-2018) and MODIS on Aqua (2009-2018). The Sea and Land Surface Temperature Radiometer (SLSTR) series of infrared sensors currently comprises two instruments; both are included in the ESA LST_cci Merged IR CDR: SLSTR on Sentinel-3A (2016-2020) and SLSTR on Sentinel-3B (2018-2020).
Dependence on other data	Dependant on the CAMEL V2 Global Infrared Land Surface Emissivity Database [RD-11]
Traceability	Not yet established
Uncertainty information in product	Provided for each LST is total uncertainty and components of uncertainty from effects with different spatiotemporal correlation scales.
Quantitative Metrics	
Systematic difference *Global median difference of satellite minus reference across the full dataset.*	Not yet evaluated
Stability *95% confidence interval for the relative multi-year trend between satellite LSTs and some reference data*	Not yet evaluated
Sensitivity to true LST *Average weight of the satellite observations in determining LSTs in the dataset, the difference from 100% representing the weight of prior information in the LSTs*	~100%
Availability, Documentation and Feedback	
Data URL / ftp / DOI	https://climate.esa.int/en/odp/#/dashboard
Primary peer reviewed reference	Not yet available
Source of technical documents	https://climate.esa.int/en/projects/land-surface-temperature/
Dataset restrictions	None, free and open access
Facility for user feedback	djg20@le.ac.uk
Other Documentation	[RD-8]

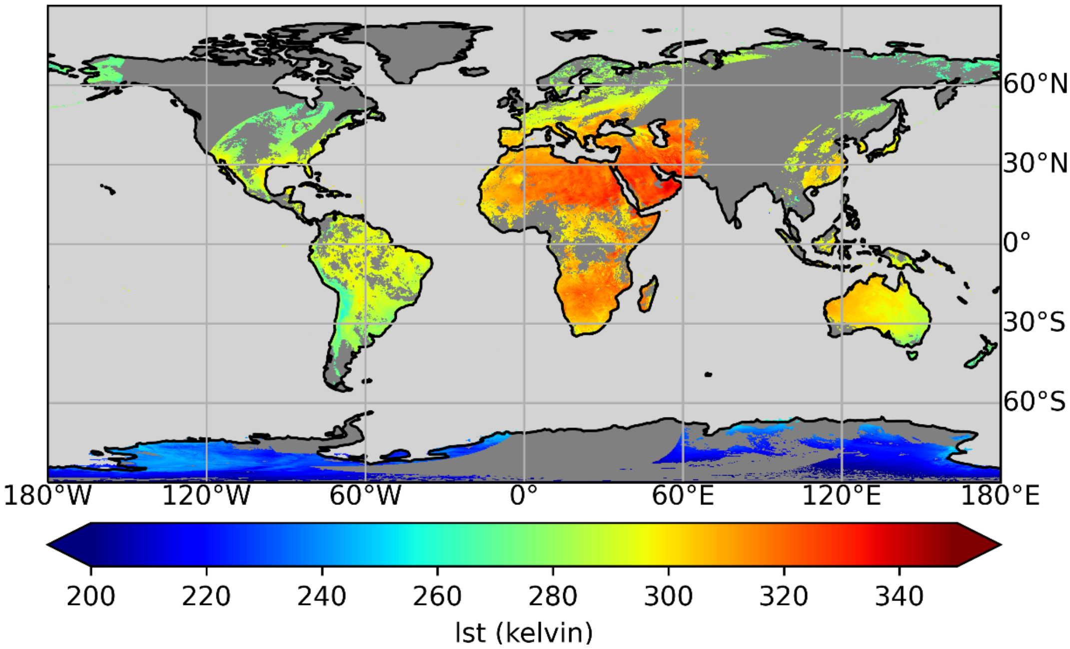

Figure 12: Example of MULTISENSOR_IRMGP_L3S_0.05 daily daytime data for 09:00 UTC on 15th September 2011. This product collates several orbits in each file.

5. Using the Data Files

The data files for the ESA LST_cci products are described in this section. The file naming convention is discussed in Section 5.1. The format of the files is described in Section 5.2 and the structure of the data within the files is given in Section 5.4.

5.1. File names

The format of the ESA LST_cci filenames is [AD-1]:

ESACCI-<CCI Project>-<Processing Level>-<Data Type>-<Product String>[-<Additional Segregator>]-<Indicative Date><Indicative Time>-fv<FileVersion>.nc

For example:

ESACCI-LST-L3C-LST-ATSR_3-0.01deg_1DAILY_DAY-20040101000000-fv3.00.nc

The components of the file names denoted in <> are described in the sections below.

5.1.1. CCI Project

This is the standard project name as stated on Page 15 of the CCI data standards 2.2 [RD-3]. Here the CCI project is “LST”.

5.1.2. Processing Level

The data processing level code, defined on Pages 13-14 of the CCI data standards 2.2 [RD-3]. The data processing level for currently available LST ECVs is “L3U”, “L3C” or “L3S”.

5.1.3. Data Type

This is a short term describing the main data type in the dataset. The data type is “LST”.

5.1.4. Product String

Each ECV team defines the Product String they will use for their data and make this information available in their documentation. The product strings for currently available LST ECVs and CDRs are “ATSR_2”, “ATSR_3”, “MODISA”, “MODIST”, “SLSTRA”, “SLSTRB”, “SEVIR1”, “SEVIR2”, “SEVIR3”, “SEVIR4”, “GOES12”, “GOES13”, “GOES16”, “MTSAT1”, “MTSAT2”, “SSMI13”, “SSMI17”, ”IRCDR_”, ”IRMGP_” .

5.1.5. [-<Additional Segregator>]

An additional segregator with further relevant information about the product if relevant. For LST_cci, these additional segregators provide additional information about the spatio-temporal resolution and whether the product is day or night, or descending or ascending. This is used for L3C and L3S data, for example in SSMI files (“0.25deg_1DAILY_ASC”) and MODIS files (“0.01deg_1DAILY_DAY”, “0.01deg_1MONTHLY_DAY”). The number before “DAILY” or “MONTHLY” gives the number of days or months this file relates to (so 1DAILY is data across 1 day).

5.1.6. Indicative Date

The identifying date for this data set. The format used is YYYY[MM[DD]], where YYYY is the four digit year, MM is the two digit month from 01 to 12 and DD is the two digit day of the month from 01 to 31. The date used should best represent the observation date for the data set. It can be a year, a year and a month or a year and a month and a day.

5.1.7. Indicative Time

The identifying time for this data set in UTC. Format is [HH[MM[SS]]] where HH is the two digit hour from 00 to 23, MM is the two digit minute from 00 to 59 and SS is the two digit second from 00 to 59.

5.1.8. File Version

File version number in the form n{1,}[.n{1,}] with a maximum of 2 digits after the decimal point. Each full reprocessing will increment main digit by 1. Internal processing for significant bug fixes will increment first digit after decimal point to 5. Each minor release will increment by second digit after decimal point.

5.2. Format of the data files

All data are contained in Network Common Data Format (NetCDF) files. This format allows multiple data arrays and metadata to be stored together in one file.

More specifically, the data format of the files is NetCDF-4. This means that the files cannot be read by versions of the NetCDF software library earlier than version 4. Data within the files are internally compressed. The NetCDF software automatically handles decompression of the data.

The ESA LST_cci data files use the 'classic' NetCDF-4 data model.

For more information about NetCDF, see http://www.unidata.ucar.edu/software/netcdf/.

5.3. Tools that can be used to work with the data files

As NetCDF is a commonly used format, there are many tools available to view and work on the data within the files. For example see http://www.unidata.ucar.edu/software/netcdf/software.html and the tools listed in Section 3.3.3.

5.4. Contents of the data files

Each ESA LST_cci data file contains metadata describing the file and its contents (for NetCDF files, these are referred to as global attributes), multiple data arrays (which are referred to as variables) and metadata specific to each variable (variable attributes). The names and form of the variables and attributes follow Climate and Forecasting (CF) conventions, recommendations from [RD-3] and are similar to those used for ESA DUE GlobTemperature harmonised format to support the existing GlobTemperature LST community. The files meet the CCI Data Standards V2.2 [RD-3].

In the sections below the file formats are described. First, the global attributes that are common to all the files are listed. Then, attributes that apply to variables are given. Finally, the variables that are contained in the files are listed. A sample listing of the structure of each type of file is given in Appendix 3.

For a complete, technical description of the file format see the ESA LST_cci Product Specification Document [AD-1], which can be downloaded from https://climate.esa.int/en/projects/land-surface-temperature.

5.4.1. Global Attributes

The global attributes common to all the ESA LST_cci product files are described in Table 16. Most of the contents were adapted from the definitions in [RD-3]. Global attributes which are optional for L2P, but mandatory for L3C, ESA LST_cci product files are described in Table 17.

Table 16: Global attributes that are included in all LST_cci format data files, from [AD-1].

Global Attribute Name	Format	Description	Source	LST_cci definition
title	string	A text string containing a succinct description of the dataset.	CF, ACDD	See examples in Appendix A.
institution	string	A text string detailing where the data was produced using names from the CCI common vocabulary.	CCI	See examples in Appendix A.
source	string	A text string containing the original data source(s). If multiple sources and ancillary data are used this source be a comma-separated list.	CF	See examples in Appendix A.
history	string	Processing history of the dataset.	CF, ACDD	See examples in Appendix A.
references	string	References to ATBD, product specification document, technical note or other document describing the data.	CF	Include any relevant publications or webpages.
Conventions	string	A text string identifying the netCDF conventions followed. This attribute should be set to the version of CF used and should also include the ACDD. For example: “CF-1.4, Unidata Observation Dataset v1.0”.	CF	CF-1.7, Unidata Observation Dataset v1.0
product_version	string	A text string containing the product version of the dataset.		See examples in Appendix A.

Global Attribute Name	Format	Description	Source	LST_cci definition
format_version	string	A text string containing the CCI data used for the dataset.		The CCI data format used, for example “CCI Data Standards v2.1”.
summary	string	A paragraph describing the dataset.	ACDD	See examples in Appendix A.
keywords	string	A comma-separated list of key words and phrases. Typical keywords include: Earth Science, Land Surface, Land Temperature and Land Surface Temperature	ACDD	As stated in Description column.
id	string	The filename of the file.	ACDD	As stated in Description column.
naming_authority	string	The naming authority. Fixed as le.ac.uk following ACDD convention.	ACDD	As stated in Description column.
keywords_vocabulary	string	The guideline being followed for the words/phrases in the “keywords” attribute. For LST_cci this is “NASA Global change Master Directory (GCMD) Science Keywords”.	ACDD	As stated in Description column.
cdm_data_type	string	The THREDDS data type appropriate for this dataset. “swath” or “grid”.	ACDD	“swath” if L2P file, otherwise “grid”
comment	string	Miscellaneous information about the data or methods used to produce it.	CF, ACDD	Should include the text "These data were produced as part of the ESA LST_cci project." as well as information on dataset length and coverage.
date_created	string	The date on which the data were produced in the form “yyyymmddThhmmssZ”. This time format is ISO 8601 compliant.	ACDD	As stated in Description column.
creator_name creator_url creator_email	string	Provide a name and email address for the most relevant point of contact, as well as a URL relevant to this data set.	ACDD	See examples in Appendix A.

Global Attribute Name	Format	Description	Source	LST_cci definition
project	string	The scientific project that produced the data. Set to "Climate Change Initiative - European Space Agency".	ACDD	As stated in Description column.
geospatial_lat_min	float	Southernmost latitude in decimal degrees north, range -90 to +90.	CCI, ACDD	As stated in Description column.
geospatial_lat_max	float	Northernmost latitude in decimal degrees north, range -180 to +180.	CCI, ACDD	As stated in Description column.
geospatial_lon_min	float	Westernmost longitude in decimal degrees north, range -180 to +180.	CCI, ACDD	As stated in Description column.
geospatial_lon_max	float	Easternmost longitude in decimal degrees north, range -180 to +180.	CCI, ACDD	As stated in Description column.
geospatial_vertical_min	float	Assumed to be in metres above ground unless geospatial_vertical_units attribute defined otherwise.	CCI, ACDD	Set to 0 for LST products.
geospatial_vertical_max	float	Assumed to be in metres above ground unless geospatial_vertical_units attribute defined otherwise.	CCI, ACDD	Set to 0 for LST products.
time_coverage_start	string	The time of the earliest observation contained in the data file in the form "yyyymmddThhmmssZ".	ACDD	As stated in Description column.
time_coverage_end	string	The time of the latest observation contained in the data file in the form "yyyymmddThhmmssZ".	ACDD	As stated in Description column.
time_coverage_duration	string	An ISO8601 string of the difference between time_coverage_start and time_coverage_end.	ACDD	In the form PdDThHmMsS where d is the number of days, h is the number of hours, m is the number of minutes, s is the number of seconds, omitting dD etc. if the number is zero.

Global Attribute Name	Format	Description	Source	LST_cci definition
time_coverage_resolution	string	An ISO8601 string of the time coverage resolution for the data in the file. For L2 data on the original satellite sampling frequency it is acceptable to use 'satellite_orbit_frequency'.	CCI, ACDD	'satellite_orbit_frequency' for L2P data and ISO8601 strings for L3 data.
standard_name_vocabulary	string	The name of the controlled vocabulary from which variable standard names are taken.	CF	Set to "NetCDF Climate and Forecast (CF) Metadata Convention version 1.7".
license	string	Description of the data access and distribution restrictions.	ACDD	Set to "ESA CCI Data Policy: free and open access".
platform	string	Satellite names from the CCI common vocabulary list. Comma-separated if more than one and angled brackets for a platform series.	CCI	See examples in Appendix A.
sensor	string	Sensor names from the CCI common vocabulary list. Comma-separated if more than one.	CCI	See examples in Appendix A.
spatial_resolution	string	String describing the approximate resolution of the product For example, "1.1km at nadir".	CCI	Value depends on the product. See examples in Appendix A.
key_variables	string	A comma-separated list of the key primary variables in the file i.e. those that have been scientifically validated and are appropriated for display in the CCI Open Data Portal and CCI Toolbox.	CCI	Set as "land_surface_temperature".

Table 17: Global attributes that are optional for L2P LST_cci format data files but mandatory for L3C files, from [AD-1].

Global Attribute Name	Format	Description	Source	LST_cci definition
geospatial_lat_units	string	Units of the latitudinal resolution. Typically "degrees_north"		Mandatory for gridded files on a regular lat/lon grid (L3C, L3U, and L3S).
geospatial_lon_units	string	Units of the longitudinal resolution. Typically "degrees_east"		Mandatory for gridded files on a regular lat/lon grid (L3C, L3U, and L3S).
geospatial_lat_resolution	float	Latitude Resolution in units matching geospatial_lat_units.		Mandatory for gridded files on a regular lat/lon grid (L3C, L3U, and L3S).
geospatial_lon_resolution	float	Latitude Resolution in units matching geospatial_lat_units.		Mandatory for gridded files on a regular lat/lon grid (L3C, L3U, and L3S).
doi	string	Digital Object Identifier assigned by CEDA	CCI	Mandatory for dissemination via ESA CCI Open data Portal

5.4.2. Variable Attributes

The attributes that contain the metadata associated with particular variables are listed in Table 18. Note that each variable may only have a subset of these attributes. These attributes are based on [RD-3], CF conventions and variable attributes used for the GlobTemperature Harmonised Format. These attributes are compliant with CCI Data Standards V2.2 [RD-3].

Table 18: Global attributes that are included in all LST_cci format data files.

Variable Attribute Name	Description
long_name	A free-text descriptive variable name.
standard_name	Where defined, a standard and unique description of a physical quantity. Do not include this attribute if no standard_name exists.
units	Text description of the units, preferably S.I., compatible with the Unidata UDUNITS package. For a given variable (e.g. LST), these must be the same for each dataset.
_FillValue	A value used to indicate array elements containing no valid data. This value must be of the same type as the storage (packed) type. This should be set for all variables except for time. For LST_cci this is set to -32768.
calendar	A string giving the calendar used for the time variable. For LST_cci is set to "gregorian".
valid_min	Minimum valid value for this variable once they are packed (in storage type). The fill value should be outside this valid range. This should be set for all variables except for time.

Variable Attribute Name	Description
valid_max	Maximum valid value for this variable once they are packed (in storage type). The fill value should be outside this valid range. This should be set for all variables except for time.
actual_range	Gives the actual range of the range within the file, within the limits of the valid range.
coordinates	Identifies auxiliary coordinate variables, label variables, and alternative coordinate variables. For LST_cci this is set as "lat lon" for L3C and L3S gridded variables that are not dimension variables.
scale_factor	To be multiplied by the variable to recover the original value. Defined by the producer. Valid values within valid_min and valid_max should be transformed by scale_factor and add_offset, otherwise skipped to avoid floating point errors.
add_offset	To be added to the variable after multiplying by the scale factor to recover the original value. If only one of scale_factor or add_offset is needed, then both should be included anyway to avoid ambiguity, with scale_factor defaulting to 1.0 and add_offset defaulting to 0.0.
flag_meanings	Space-separated list of text descriptions. Words within a phrase should be connected with underscores. This is used only for flags.
flag_masks	Array of valid variable masks (required when the bit field contains independent Boolean conditions). This is used only for flags.
ancillary_variables	Ancillary variables such as uncertainty or quality flags should be identified by the ancillary_variables attribute of the related primary variable. This metadata is provided for the "lst" variable only.

5.4.3. Level-3 Data Format

Level 3 collated (L3C) data files are collated products containing L2P (swath) from a single instrument that have been combined and mapped onto a space-time grid. Level 3 super-collated (L3S) data files combines the data from these L3C data files into a multi-sensor climate data records. Data are delivered in two separate files for each temporal resolution (either "day" and "night", or "ascending" and "descending" depending on product).

The dimensions of the data in the file are described in Table 19. The data are stored in variables in the NetCDF file with the names given in Table 20.

Table 19: The dimensions of the data in a L3U / L3C / L3S file.

Dimension Name	Description
lat	These are the dimensions of the regular latitude-longitude grid on which the data are stored.
lon	
time	This is always 1 for L3C data because there is only one orbit of data per file.
channel	Channel dimension for the channel variable, which gives the channel wavelengths used to derive LST data.
Length_scale	Uncertainty correlation length scale

Table 20: Data arrays stored in L3U / L3C / L3S data files. The dimensions of the arrays are given in parenthesis after the name of the variable in the NetCDF file. The dimensions are defined in Table 19.

Category	Name of data (size of array)	Description
Coordinates	time (time)	Coordinate variable; time of each temporal point of the data arrays; the start time of the orbit, granule or disk.
	dtime (time x lat x lon)	Time differences of LST retrievals from the base time in the “time” coordinate variable
	lat (time x lat x lon)	Coordinate variable; central latitude of each spatial point of the data arrays
	lon (time x lat x lon)	Coordinate variable; central latitude of each spatial point of the data arrays
	channel (channel)	Coordinate variable; sensor channel information
Geophysical variables	lst (time x lat x lon)	Best available LST retrievals; fill values to be provided where there is ocean (ice free or ice covered) or cloud.
	lcc (time x lat x lon)	Land cover classification of the pixel (biome).
	lst_time_correction (time x lat x lon)	Time correction offset for MW CDR.
Uncertainty information – total uncertainty	lst_uncertainty (time x lat x lon)	Per pixel total uncertainty of the LST retrieval. Calculated by adding the individual uncertainty components (“lst_unc_ran”, “lst_unc_loc_atm”, “lst_unc_loc_sfc”, “lst_unc_sys”) in quadrature.
Uncertainty information – individual components	lst_unc_ran (time x lat x lon)	Random uncertainties, which are uncorrelated (or weakly correlated) on all spatial and temporal scales.
	lst_unc_loc_atm (time x lat x lon)	Locally correlated atmospheric uncertainties.
	lst_unc_loc_sfc (time x lat x lon)	Locally correlated biome or surface uncertainties.
	lst_unc_loc_cor (time x lat x lon)	Locally correlated intercalibration / time correction uncertainties for IR CDRs
	lst_unc_time_correction (time x lat x lon)	Time correction uncertainties for MW CDR
	lst_unc_sys (length_scale)	Large scale systematic uncertainties, which are correlated on all spatial and temporal scales.
Retrieval information	satze (time x lat x lon)	The per pixel satellite zenith angle of the observation.
	sataz (time x lat x lon)	The per pixel satellite azimuth angle of the observation.
	solze (time x lat x lon)	The per pixel solar zenith angle of the observation.
	solaz (time x lat x lon)	The per pixel solar azimuth angle of the observation.
	n (time x lat x lon)	Number of L2P pixels flagged as clear-sky which have contributed to the L3 pixel for IR products, or number of L2P pixels which have contributed to the L3 pixel for MW products.
Quality information	qual_flag (time x lat x lon)	Per pixel quality flags for each LST retrieval.

6. Appendix 1: Summary of how the data were produced

6.1. Retrieval of LST from satellite measurements

The best algorithms for a future climate quality operational system were identified during LST_cci in an open algorithm intercomparison round-robin [RD-5]. The algorithms selected for use in deriving LST from Thermal Infrared and Microwave sensors are described in detail in the Algorithm Theoretical Basis Document (ATBD) [AD-4]. The algorithms selected were the University of Leicester (UOL) algorithm and Generalised Split Window (GSW) algorithm for thermal infrared data, and the Neural-Network-Emissivity-All-channels (NNEA) algorithm for microwave data. For single-channel instruments the Single-channel (SMW) Algorithm is used. A summary of these algorithms used to retrieve LST in LST_cci is provided here.

6.1.1. The University of Leicester (UOL) Algorithm

The University of Leicester (UOL) Algorithm for thermal infrared data is used for the ATSR LST ECV products and the ATSR-SLSTR-MODIS CDR. The UOL algorithm is a nadir only Split-Window (SW) with classes of coefficients for each combination of land cover-diurnal (day/night) condition. The full form of the algorithm is presented as follows:

$$LST = d(\sec(\theta) - 1)pw + \left(f a_{v,i} + (1-f)a_{s,i}\right) + (f b_{v,i} + (1-f)b_{s,i})(T_{11} - T_{12})^{1\,/\,(\cos(\theta\,/\,m))} + \left((f b_{v,i} + (1-f)b_{s,i}) + (f c_{v,i} + (1-f)c_{s,i})\right)T_{12}$$

where the six retrieval coefficients $a_{s,i}$, $a_{v,i}$, $b_{s,i}$, $b_{v,i}$, $c_{s,i}$ and $c_{v,i}$ are dependent on the land cover (i), fractional vegetation cover (f) - the retrieval coefficients $a_{s,i}$, $b_{s,i}$ and $c_{s,i}$ relate to bare soil (f = 0) conditions, and $a_{v,i}$, $b_{v,i}$ and $c_{v,i}$ relate to fully vegetated (f = 1) conditions. The fractional vegetation cover (f) and precipitable water (pw) are seasonally dependent whereas the land cover (i) is invariant.

The retrieval parameters d and m are empirically determined from validation and control the behaviour of the algorithm for each zenith viewing angle (θ) across the nadir swath. The parameter d resolves increases in atmospheric attenuation as water vapour increases, an effect accentuated with increasing zenith viewing angle. The parameter m is a non-linear dependence term on the BT difference T11 - T12 as BT difference increases with increasing atmospheric water vapour. Attenuation due to water vapour is greater at 12 µm than at 11 µm.

For the generation of the retrieval coefficients for each land cover–diurnal (day/night) combination vertical atmospheric profiles of temperature, ozone, and water vapour, surface and near-surface conditions and the surface emissivities are required. These are input, in addition to specifying the spectral response functions of the instrument, into a radiative transfer model in order to simulate TOA BTs. Retrieval coefficients are determined by minimizing the l2-norm. This means that land surface emissivity is implicitly dealt with through the regression of retrieval coefficients to land cover and bare soil / fully vegetated states. LSE knowledge is passed to the algorithm through the chosen land cover and fractional vegetation states (derived from auxiliary data), which themselves are regressed to emissivity states within coefficient generation.

6.1.2. The Generalised Split Window (GSW) Algorithm

The Generalised Split Window (GSW) Algorithm for thermal infrared data is used for the MODIS and SEVIRI LST ECV products, SEVIRI LST ECV products, GOES-16 LST ECV product and for the Merged GEO-LEO IR CDR. The generalised split window algorithm is a view-angle dependent split-window algorithm.

The generalized split-window LST algorithm depends on knowledge of the band emissivities for real land surfaces. In the LST_cci GSW method, emissivity information is used explicitly rather than incorporating this information implicitly through land cover coefficients as for the UOL algorithm. Emissivity for the GSW algorithm in LST_cci, ε_{mean}, is derived as:

$$\varepsilon_{mean} = 0.5\,(\varepsilon_{11} + \varepsilon_{12})$$

Where ε_{mean} is the mean emissivity of the two thermal channels used in the GSW algorithm. $\Delta\varepsilon$ is the difference between the two thermal channels, calculated as:

$$\Delta\varepsilon = \varepsilon_{11} - \varepsilon_{12}$$

Having determined the emissivity of the pixel coefficients these can be applied to derive an LST estimate similar to that given below:

$$T_s = C + \left(A_1 + A_2\frac{1-\varepsilon_{mean}}{\varepsilon_{mean}} + A_3\frac{\Delta\varepsilon}{\varepsilon_{mean}^2}\right)\frac{T_1+T_2}{2} + \left(B_1 + B_2\frac{1-\varepsilon_{mean}}{\varepsilon_{mean}} + B_3\frac{\Delta\varepsilon}{\varepsilon_{mean}^2}\right)\frac{T_1-T_2}{2}$$

Where C, A and B are coefficients derived from linear regression using simulated data as done for the UOL algorithm, but are adapted for the GSW. T1 and T2 are the 11 and 12 µm brightness temperatures. The coefficients for GSW are dependent on satellite viewing angle and water vapour. Viewing angle and atmospheric column water vapour are considered in the retrieval to achieve highest accuracy over the wide atmospheric and surface conditions. The bands for water vapour are of width 15 $kg{\cdot}m^{-2}$ so that the first water vapour band is from [0,15) $kg{\cdot}m^{-2}$. The bands for satellite zenith angle are of width 5°. The retrieval coefficients are linearly interpolated between viewing angle and water vapour bands to minimise step changes.

6.1.3. The NNEA Algorithm

Comparable to the TIR, the MW retrieval algorithm needs to deal with emissivity and atmospheric variations. Pre-calculated microwave monthly mean emissivity estimates from the Tool to Estimate Land Surface Emissivity in the Microwave (TELSEM) are used as inputs to the NNEA algorithm, together with MW brightness temperatures. No atmospheric temperature or water vapour information is used as input, but the information is introduced into the retrieval by including the 22 GHz channel, which is close to a water vapour line and therefore sensitive to changes in atmospheric conditions.

For the NNEA algorithm a non-linear regression, describing the relationship between LST and the combination of the brightness temperatures and emissivity values, with coefficients of regression determined with a calibration database is built by a standard multi-layer perceptron (MLP). MLPs are a type of neural network commonly used to reproduce transfer functions between observations and related geophysical parameters.

A MLP of one input layer of 14 nodes (the inputs of function F, i.e., the brightness temperatures and emissivities for the 7 MW channels), one hidden layer with a number of nodes, and one output node (the LST), are used here. If the input vector of the MLP is called *i* and the output of the MLP *u*, the way the input signal propagates through the MLP is given by:

$$u = f_o(W^o i^o + b^o) = f_o\left(W^o f_h\left(W^h i + b^h\right) + b^o\right)$$

where f_i is the activation function, W^j the weighting matrix, b^j the bias, and i^j the input at layer j, in this case *o* is for the output layer and *h* for the hidden layer. Hyperbolic tangent and linear activation functions are used for the hidden and output neurons, respectively.

The weight and biases can be considered as the regression coefficients of the non-linear model provided by the MLP. These are determined during a training phase where the weights and biases that minimize a cost function, determined by a set of input-output examples, are determined. For NNEA the examples are provided by a calibration database, while the cost function can be expressed as:

$$C = \sum_{l=1}^{Z} \left\| t^l - u(y^l) \right\|$$

where Z is the number of samples in the calibration database, ⟦ ⟧is the standard 2-norm, and $u(y^l)$ is the output vector of the MLP for the corresponding input vector. The mean sum of squares of the difference between targets (the training LSTs of the calibration database) and current outputs of the MLP to the corresponding input vectors (the training brightness temperatures and emissivities) is minimised. The initial weights of the neural network are randomly initialized by the Nguyen-Widrow algorithm, and the final weights are assigned by a Marquardt-Levenberg back-propagation algorithm. To prevent over-fitting to the training data set, a cross-validation technique is used to monitor the evolution of the training error function.

In practice, the NNEA algorithm is slightly modified to simultaneously predict the LST value and its total uncertainty. The MLP architecture, functions, and calibration methods remain unchanged, apart from the addition of a second output node to the MLP to provide the uncertainty estimate, and the modification of the calibration database to also include representative samples of the estimated LST error.

The MW retrieval algorithm is applied to the brightness temperatures at sensor swath acquisitions. Given the different channel footprints, the retrieval combines information at different spatial resolutions. As the 19.35 GHz channels have a resolution of ~60 km, information from up to ~ 60 km affects the LST retrievals. However, retrieval tests show that the 37.0 GHz channels are the ones having more weight in the retrieval and as such the effective spatial resolution may be considered to be of the order of ~25 km, corresponding to the resolution of those channels.

6.1.4. Single-channel (SMW) Algorithm

For some single-sensor products (GOES-12 and -13 and MTSAT) only one thermal infrared channel can be used. The specific algorithm chosen is that used by the CM SAF for MVIRI retrievals:

$$LST = A + \frac{T_x}{\varepsilon_x} + B\frac{1}{\varepsilon_x} + C$$

Where A, B and C are coefficients derived from linear regression using simulated data as done for the split window algorithms but adapted for the SMW. T_x is the single channel brightness temperature and ε_x is the spectral emissivity for this channel.

The coefficients for SMW are dependent on satellite viewing angle and water vapour. The bands for water vapour are of width 15 $kg \cdot m^{-2}$ so that the first water vapour band is from [0,15) $kg \cdot m^{-2}$. The bands for satellite zenith angle are of width 5°.

6.2. Processing of L2 and L3 data to obtain L3C and L3S products

To produce L3C and L3S data, which are comprised of data from multiple orbits/disks/granules and/or multiple sensors, LST_cci products are processed from L2P to intermediate L3 products (L3U) through to L3C and L3S.

L3U products, are produced from L2P products by mapping the Level-2 pixels onto equal-angle grids and averaging the LST values. A L3U file is produced for each L2P file, containing one orbit/disk/granule from a single satellite sensor. L3U data contain, for each pixel, a single clear sky observation (if available). At higher latitudes, there may be multiple observations in clear-sky conditions. If multiple clear sky observations exist the L2P data closest to local time is selected for inclusion in the L3U product.

L3C products, which combine orbits but not satellite sensors, are then produced from the L3U data. L3C products are provided at both daily and monthly temporal resolution. For each grid cell you simply average the LST values in the input L3U datafile(s) across the defined time window (daily or monthly).

Then L3S products, which combine several satellite sensors to produce a CDR product, are produced from L3C data. To get L3S you first intercalibrate between sensors using IASI as a reference sensor in accordance with GSICS methodology, and then add the temporal correction detailed in ATBD to any sensor not nominally at the LECT of the chosen reference sensor.

7. Appendix 2: Land Cover information for the LST data

Table 21: ULeic / LandCover_cci (LCCS) hybrid biome definition.

Biome number	Definition
0	No data
10	cropland rainfed
11	cropland rainfed herbaceous cover
12	cropland rainfed tree or shrub cover
20	cropland irrigated
30	mosaic cropland
40	mosaic natural vegetation
50	tree broadleaved evergreen closed to open
60	tree broadleaved deciduous closed to open
61	tree broadleaved deciduous closed
62	tree broadleaved deciduous open
70	tree needleleaved evergreen closed to open
71	tree needleleaved evergreen closed
72	tree needleleaved evergreen open
80	tree needleleaved deciduous closed to open
81	tree needleleaved deciduous closed
82	tree needleleaved deciduous open
90	tree mixed
100	mosaic tree and shrub
110	mosaic herbaceous
120	shrubland
121	shrubland evergreen
122	shrubland deciduous
130	grassland
140	lichens and mosses
150	sparse vegetation
151	sparse tree
152	sparse shrub
153	sparse herbaceous
160	tree cover flooded fresh or brakish water
170	tree cover flooded saline water
180	shrub or herbaceous cover flooded
190	Urban
200	bare areas of soil types not contained in biomes 203 to 207
201	unconsolidated bare areas of soil types not contained in biomes 203 to 207
202	consolidated bare areas of soil types not contained in biomes 203 to 207
203	bare areas of soil type Entisols Orthents
204	bare areas of soil type Shifting sand
205	bare areas of soil type Aridisols Calcids
206	bare areas of soil type Aridisols Cambids
207	bare areas of soil type Gelisols Orthels
210	Water
220	Snow and ice

8. Appendix 3: Sample Listings of File Contents

8.1. Header from an example IR L3C file

```
netcdf ESACCI-LST-L3C-LST-ATSR_3-0.01deg_1DAILY_DAY-20040101000000-fv3.00 {
dimensions:
	time = 1 ;
	length_scale = 1 ;
	channel = 2 ;
	lat = 18000 ;
	lon = 36000 ;
variables:
	double time(time) ;
		time:long_name = "reference time of file" ;
		time:standard_name = "time" ;
		time:units = "seconds since 1981-01-01 00:00:00" ;
		time:_FillValue = -32768. ;
		time:calendar = "gregorian" ;
	float dtime(time, lat, lon) ;
		dtime:long_name = "time difference from reference time" ;
		dtime:units = "seconds" ;
		dtime:_FillValue = -32768.f ;
		dtime:valid_min = 0.f ;
		dtime:valid_max = 86400.f ;
		dtime:coordinates = "lon lat" ;
		dtime:actual_range = 394.f, 84365.f ;
```

```
float lat(lat) ;
        lat:long_name = "latitude_coordinates" ;
        lat:standard_name = "latitude" ;
        lat:units = "degrees_north" ;
        lat:_FillValue = -32768.f ;
        lat:valid_min = -90.f ;
        lat:valid_max = 90.f ;
        lat:reference_datum = "geographical coordinates, WGS84 projection" ;
float lon(lon) ;
        lon:long_name = "longitude_coordinates" ;
        lon:standard_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:_FillValue = -32768.f ;
        lon:valid_min = -180.f ;
        lon:valid_max = 180.f ;
        lon:reference_datum = "geographical coordinates, WGS84 projection" ;
short satze(time, lat, lon) ;
        satze:long_name = "satellite zenith angle" ;
        satze:units = "degrees" ;
        satze:_FillValue = -32768s ;
        satze:add_offset = 0.f ;
        satze:scale_factor = 0.01f ;
        satze:valid_min = 0s ;
        satze:valid_max = 18000s ;
        satze:coordinates = "lon lat" ;
```

```
        satze:actual_range = 0.09999999f, 21.29f ;
short sataz(time, lat, lon) ;
        sataz:long_name = "satellite azimuth angle" ;
        sataz:units = "degrees" ;
        sataz:_FillValue = -32768s ;
        sataz:add_offset = 0.f ;
        sataz:scale_factor = 0.01f ;
        sataz:valid_min = -18000s ;
        sataz:valid_max = 18000s ;
        sataz:coordinates = "lon lat" ;
        sataz:actual_range = -179.4f, 179.7f ;
short solze(time, lat, lon) ;
        solze:long_name = "solar zenith angle" ;
        solze:units = "degrees" ;
        solze:_FillValue = -32768s ;
        solze:add_offset = 0.f ;
        solze:scale_factor = 0.01f ;
        solze:valid_min = 0s ;
        solze:valid_max = 18000s ;
        solze:coordinates = "lon lat" ;
        solze:actual_range = 1.54f, 89.99f ;
short solaz(time, lat, lon) ;
        solaz:long_name = "solar azimuth angle" ;
        solaz:units = "degrees" ;
        solaz:_FillValue = -32768s ;
```

```
        solaz:add_offset = 0.f ;
        solaz:scale_factor = 0.01f ;
        solaz:valid_min = -18000s ;
        solaz:valid_max = 18000s ;
        solaz:coordinates = "lon lat" ;
        solaz:actual_range = -179.96f, 179.85f ;
short qual_flag(time, lat, lon) ;
        qual_flag:long_name = "Quality Flags" ;
        qual_flag:flag_meanings = "local_solar_time_quality-1_is_nearest_to_local_solar_time" ;
        qual_flag:flag_masks = 1s ;
        qual_flag:_FillValue = -32768s ;
        qual_flag:valid_min = 0s ;
        qual_flag:valid_max = 1s ;
        qual_flag:coordinates = "lon lat" ;
short lst(time, lat, lon) ;
        lst:long_name = "land surface temperature" ;
        lst:units = "kelvin" ;
        lst:_FillValue = -32768s ;
        lst:add_offset = 273.15f ;
        lst:scale_factor = 0.01f ;
        lst:valid_min = -8315s ;
        lst:valid_max = 7685s ;
        lst:coordinates = "lon lat" ;
        lst:actual_range = 217.21f, 334.79f ;
short lst_uncertainty(time, lat, lon) ;
```

lst_uncertainty:long_name = "land surface temperature total uncertainty" ;

lst_uncertainty:units = "kelvin" ;

lst_uncertainty:_FillValue = -32768s ;

lst_uncertainty:add_offset = 0.f ;

lst_uncertainty:scale_factor = 0.001f ;

lst_uncertainty:valid_min = 0s ;

lst_uncertainty:valid_max = 10000s ;

lst_uncertainty:coordinates = "lon lat" ;

lst_uncertainty:actual_range = 0.135f, 10.f ;

short lst_unc_ran(time, lat, lon) ;

lst_unc_ran:long_name = "uncertainty from uncorrelated errors" ;

lst_unc_ran:units = "kelvin" ;

lst_unc_ran:_FillValue = -32768s ;

lst_unc_ran:add_offset = 0.f ;

lst_unc_ran:scale_factor = 0.001f ;

lst_unc_ran:valid_min = 0s ;

lst_unc_ran:valid_max = 10000s ;

lst_unc_ran:coordinates = "lon lat" ;

lst_unc_ran:actual_range = 0.031f, 10.f ;

short lst_unc_loc_atm(time, lat, lon) ;

lst_unc_loc_atm:long_name = "uncertainty from locally correlated errors on atmospheric scales" ;

lst_unc_loc_atm:units = "kelvin" ;

lst_unc_loc_atm:_FillValue = -32768s ;

lst_unc_loc_atm:add_offset = 0.f ;

lst_unc_loc_atm:scale_factor = 0.001f ;

lst_unc_loc_atm:valid_min = 0s ;

lst_unc_loc_atm:valid_max = 10000s ;

lst_unc_loc_atm:coordinates = "lon lat" ;

lst_unc_loc_atm:actual_range = 0.127f, 1.15f ;

short lst_unc_loc_sfc(time, lat, lon) ;

lst_unc_loc_sfc:long_name = "uncertainty from locally correlated errors on surface scales" ;

lst_unc_loc_sfc:units = "kelvin" ;

lst_unc_loc_sfc:_FillValue = -32768s ;

lst_unc_loc_sfc:add_offset = 0.f ;

lst_unc_loc_sfc:scale_factor = 0.001f ;

lst_unc_loc_sfc:valid_min = 0s ;

lst_unc_loc_sfc:valid_max = 10000s ;

lst_unc_loc_sfc:coordinates = "lon lat" ;

lst_unc_loc_sfc:actual_range = 0.f, 9.929001f ;

short lst_unc_sys(length_scale) ;

lst_unc_sys:long_name = "uncertainty from large-scale systematic errors" ;

lst_unc_sys:units = "kelvin" ;

lst_unc_sys:_FillValue = -32768s ;

lst_unc_sys:add_offset = 0.f ;

lst_unc_sys:scale_factor = 0.001f ;

lst_unc_sys:valid_min = 0s ;

lst_unc_sys:valid_max = 10000s ;

short lcc(time, lat, lon) ;

lcc:long_name = "land cover class" ;

lcc:units = "1" ;

lcc:flag_meanings = "cropland_rainfed cropland_rainfed_herbaceous_cover cropland_rainfed_tree_or_shrub_cover cropland_irrigated mosaic_cropland mosaic_natural_vegetation tree_broadleaved_evergreen_closed_to_open tree_broadleaved_deciduous_closed_to_open tree_broadleaved_deciduous_closed tree_broadleaved_deciduous_open tree_needleleaved_evergreen_closed_to_open tree_needleleaved_evergreen_closed tree_needleleaved_evergreen_open tree_needleleaved_deciduous_closed_to_open tree_needleleaved_deciduous_closed tree_needleleaved_deciduous_open tree_mixed mosaic_tree_and_shrub mosaic_herbaceous shrubland shrubland_evergreen shrubland_deciduous grassland lichens_and_mosses sparse_vegetation sparse_tree sparse_shrub sparse_herbaceous tree_cover_flooded_fresh_or_brakish_water tree_cover_flooded_saline_water shrub_or_herbaceous_cover_flooded urban Bare_areas_of_soil_types_not_contained_in_biomes_203_to_207 Unconsolidated_bare_areas_of_soil_types_not_contained_in_biomes_203_to_207 Consolidated_bare_areas_of_soil_types_not_contained_in_biomes_203_to_207 Bare_areas_of_soil_type_Entisols_Orthents Bare_areas_of_soil_type_Shifting_sand Bare_areas_of_soil_type_Aridisols_Calcids Bare_areas_of_soil_type_Aridisols_Cambids Bare_areas_of_soil_type_Gelisols_Orthels water snow_and_ice Sea_ice" ;

lcc:flag_values = 10s, 11s, 12s, 20s, 30s, 40s, 50s, 60s, 61s, 62s, 70s, 71s, 72s, 80s, 81s, 82s, 90s, 100s, 110s, 120s, 121s, 122s, 130s, 140s, 150s, 151s, 152s, 153s, 160s, 170s, 180s, 190s, 200s, 201s, 202s, 203s, 204s, 205s, 206s, 207s, 210s, 220s, 230s ;

lcc:_FillValue = -32768s ;

lcc:valid_min = 10 ;

lcc:valid_max = 230 ;

lcc:coordinates = "lon lat" ;

lcc:actual_range = 10s, 220s ;

short channel(channel) ;

channel:long_name = "channel wavelength in microns" ;

channel:units = "microns" ;

channel:_FillValue = -32768s ;

channel:add_offset = 0.f ;

channel:scale_factor = 0.001f ;

channel:valid_min = 0s ;

channel:valid_max = 15000s ;

// global attributes:

:title = "ESA LST CCI land surface temperature data at product level L3C from Advanced Along-Track Scanning Radiometer." ;

:institution = "University of Leicester" ;

:source = "ESA LST CCI ATSR_3 L3U V3.00" ;

:history = "Created using software developed at University of Leicester" ;

:references = "https://climate.esa.int/en/projects/land-surface-temperature" ;

:Conventions = "CF-1.8" ;

:product_version = "3.00" ;

:summary = "This file contains level L3C global land surface temperatures from AATSR. L3C data are derived from multiple orbits of single sensor L3U data combined onto a space and/or time grid." ;

:keywords = "Earth Science; Land Surface; Land Temperature; Land Surface Temperature" ;

:id = "ESACCI-LST-L3C-LST-ATSR_3-0.01deg_1DAILY_DAY-20040101000000-fv3.00.nc" ;

:naming_authority = "le.ac.uk" ;

:keywords_vocabulary = "NASA Global change Master Directory (GCMD) Science Keywords" ;

:cdm_data_type = "grid" ;

:comment = "These data were produced as part of the ESA LST CCI project." ;

:date_created = "20211123T152030Z" ;

:creator_name = "University of Leicester Surface Temperature Group" ;

:creator_url = "https://climate.esa.int/en/projects/land-surface-temperature" ;

:creator_email = "djg20@le.ac.uk" ;

```
        :project = "Climate Change Initiative - European Space Agency" ;
        :geospatial_lat_min = -83.78402f ;
        :geospatial_lat_max = 83.78394f ;
        :geospatial_lon_min = -180.f ;
        :geospatial_lon_max = 180.f ;
        :geospatial_vertical_min = 0.f ;
        :geospatial_vertical_max = 0.f ;
        :time_coverage_start = "20040101T101845" ;
        :time_coverage_end = "20040101T120733" ;
        :time_coverage_duration = "PT01H48M47S" ;
        :time_coverage_resolution = "P1D" ;
        :standard_name_vocabulary = "CF Standard Name Table v71" ;
        :license = "ESA CCI Data Policy: free and open access" ;
        :platform = "Envisat" ;
        :sensor = "AATSR" ;
        :geospatial_lat_units = "degrees_north" ;
        :geospatial_lon_units = "degrees_east" ;
        :geospatial_lon_resolution = 0.01f ;
        :geospatial_lat_resolution = 0.01f ;
        :key_variables = "land_surface_temperature" ;
        :svn_version = 4940 ;
        :format_version = "CCI Data Standards v2.2" ;
        :spatial_resolution = "0.01 degree" ;
        :doi = "" ;
}
```

End of document